

Aquaculture in desert and arid lands

Development constraints and opportunities

FAO Technical Workshop
6–9 July 2010
Hermosillo, Mexico



Cover photo: Harvesting of Nile tilapia (*Oreochromis niloticus*) in a small-scale desert fish pond in Ouargla District, Algeria (courtesy of Valerio Crespi).

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Preparation of this document

This document contains the proceedings of the technical workshop entitled “Aquaculture in desert and arid lands: development constraints and opportunities” held from 6 to 9 July 2010, in Hermosillo, Mexico, and organized by the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) and the Centro de Investigación en Alimentación y Desarrollo (CIAD).

The workshop was a direct result of the growing interest by FAO Member countries with vast desert territories within their national boundaries and the desire to make better use of the limited water resources in these areas characterized by harsh climatic conditions. The production of additional animal proteins would contribute to the dietary needs of rural households, as well as generate additional employment opportunities and revenues. This document contains a summary of the workshop, including major opportunities and constraints in the development of desert aquaculture and a series of follow-up and recommended actions for the sector to grow. It also includes a brief global overview on the status and trend of aquaculture development in desert and arid lands and seven reviews from different countries and regions of the world. These reviews provide interesting information on past and recent experiences, as well as ongoing activities on desert aquaculture. The document is written for national authorities (e.g. governments, ministries and research institutions) that are interested in promoting and supporting the development of desert aquaculture, and it attempts to provide a comprehensive review on the main issues specific to this subsector.

This document was prepared under the supervision of Valerio Crespi and Alessandro Lovatelli, Aquaculture Officers, Aquaculture Service (FIRA), FAO Fisheries and Aquaculture Department.

Abstract

Aquaculture in desert and arid lands has been growing steadily over the last decade thanks to the modern technologies and alternative energy sources that have allowed water in these places of extremes to be exploited more effectively and more efficiently, using it for both crop irrigation and production of fish.

This publication presents the evolution of desert and arid lands aquaculture in the past few decades in seven countries and regions (Australia, Egypt, Israel, Mexico, Southern Africa, the United States of America and Central Asia) describing the achievements of a number of farming operations, which demonstrate the significant potential for farming commercial aquatic organisms using geothermal, fresh and brackish waters. The global overview on desert aquaculture development shows, through the use of maps and tables, those countries with vast extensions of arid territories that should be better investigated for potential aquaculture development.

Limiting factors were extensively discussed during the workshop, and several measures were identified and proposed. Desert conditions are characterized by high day temperatures, cold winter nights, high solar radiation, scarce precipitation and very low relative humidity. The experts reached consensus on the definition of aquaculture in the desert and arid lands, which was defined as follows: “Aquaculture activities practised in desert and arid lands characterized by low precipitation (<250 mm/year), high solar radiation, high rate of evaporation, using subsurface and surface water”.

At the end of the workshop, a series of recommendations were elaborated by the experts to assist FAO Member countries wishing to generate a favourable national environment to promote sustainable aquaculture development.

Limited water supply remains the single largest constraint for aquaculture development in arid and semi-arid regions; however, where the resource is available, the development of integrated aqua-agriculture systems may certainly provide economic output opportunities from such resource-limited regions. Such farming systems may also enable the production of highly priced fish, vegetables and fruits all year round.

Crespi, V.; Lovatelli, A.

Aquaculture in desert and arid lands: development constraints and opportunities.

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Abbreviations and acronyms

AASA	Aquaculture Association for Southern Africa
ADU	Aquaculture Development Unit
AI	Aridity index
AISA	Aquaculture Institute of South Africa
AMA	Arizona Mariculture Associates
ASDB	Aral Sea Drainage Basin
AUD	Australian dollar
CA	Central Asia
CBS	Central Bureau of Statistics
CFGC	California Department of Fish and Game
CIAD	Centro de Investigación en Alimentación y Desarrollo
CIBNOR	Centro de Investigaciones Biológicas del Noroeste
CICESE	Centro de Investigación Científica y de Educación Superior de Ensenada
CONAPESCA	National Aquaculture and Fishing Commission
CPISARC	Cooke Plains Inland Saline Aquaculture Research Centre
CSAP	Camdeboo Satellite Aquaculture Project
DAFF	Department of Agriculture, Forestry and Fisheries
DoFWA	Department of Fisheries – Western Australia
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCDC	Uzbek Research Centre of Fish Culture Development
FCR	Feed conversion ratio
FDA	Federal Drug Administration
FRDC	Fisheries Research and Development Corporation
FTS	Flow-through system
GAFRD	General Authority for Fish Resources Development
GDP	Gross domestic product
GMO	Genetically modified organism
GoB	Government of Botswana
HACCP	Hazard Analysis and Critical Control Point (system)
HE	Haemocytic enteritis
IAAS	Integrated agri-aquaculture systems
IFREMER	Institute français de recherche pour l'exploration de la mer
IISBA	International Initiative for Sustainable and Biosecure Aquafarming
INAPESCA	Instituto Nacional de Pesca
INFOSA	Marketing Information and Technical Advisory Services for the Fisheries Industry in Southern Africa
INWEH	Institute for Water, Environment & Health
ISAARG	Inland Saline Aquaculture Applied Research Group
ISARC	Inland Saline Aquaculture Research Centre
KIFI	Kamutjonga Inland Fisheries Institute
MAWR	Ministry of Agriculture and Water Resources
MDB	Murray-Darling Basin
MFCF	Muynak Fish Canning Factory
MFMR	Ministry of Fisheries and Marine Resources
MIL	Murray Irrigation Limited

MoAG	Ministry of Agriculture and Rural Development
NSW	New South Wales
OAI	Organic Aquaculture Institute
PL	Post-larva
PRONAR	National Programme for the Support of Rural Aquaculture
R&D	Research and development
RAS	Recirculation aquaculture system
SA	South Australia
SADC	Southern Africa Development Community
SAGARPA	Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación
SARDI	South Australia Research and Development Institute
SARS	Severe acute respiratory syndrome
SENASICA	Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria
SGR	Specific growth rate
SIFTS	Semi-intensive floating tank system
SIS	Salt Interception Schemes
SPADA	Special Programme for Aquaculture Development in Africa (FAO)
TAFE	Technical and Further Education, Tertiary Education Institute
TSV	Taura syndrome virus
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNU	United Nations University
USD	United States dollar
USDA	United States Department of Agriculture
USSR	Union of Soviet Socialist Republics
UzAS	Uzbekistan Academy of Sciences
UZS	Uzbekistani sum
WA	Western Australia
WISAC	Waikerie Inland Saline Aquaculture Centre
WMO	World Meteorological Organization
WSSV	White spot syndrome virus
YHV	Yellowhead virus

Workshop summary

WORKSHOP BACKGROUND

An increasing number of countries, with extensive arid and semi-arid areas, have approached the Food and Agriculture Organization of the United Nations (FAO) in recent years for technical advice in support of desert aquaculture development. Rural communities living in dry and arid regions are often among the poorest as the rigid climatic conditions dramatically reduce the variety and quantities of crops that can be adequately produced. Furthermore, the development of aquaculture as an economic activity may have positive socio-economic impacts on rural communities living in these climatically challenging regions in terms of improving the economic viability of farming activities in general while generating additional income and providing a healthy source of food to the local diet. Business and employment opportunities that may be generated may also help to avoid emigration from such areas. Additional research and the proposition of technical solutions are nevertheless required, particularly in terms of suitable feed and farming technologies that can be utilized in such areas.

Therefore, the Aquaculture Service of FAO's Fisheries and Aquaculture Department took the initiative to organize a technical workshop to discuss salient issues related to aquaculture development in desert and arid lands and to identify actions to assist in strengthening this economic sector. During the three-day workshop, the experts identified key trends and issues affecting desert aquaculture growth and discussed ways to strengthen national and regional collaboration for future responsible development of the sector. The workshop participants proposed a series of recommendations to be followed by those investors of the public and private sectors willing to start up aquaculture activities in arid lands.

WORKSHOP OBJECTIVES AND APPROACH

The main objective of the workshop was to assess the current situation and future prospects of desert and arid land aquaculture development around the globe through the seven reviews commissioned to the experts. The main output of this technical brainstorming was the identification of activities and intervention areas (covering biological, technical, policy/governance, economic and other issues) to be included as components of an FAO action programme in support of desert and arid lands aquaculture development. The workshop was organized in three main sessions focusing on the following themes:

- presentation and discussion of the country and region reviews commissioned on the status and trends of desert and arid lands aquaculture development;
- drafting of a series of recommendations based on the workshop discussions and outcomes;
- proposal, discussion and drafting of a series of priority mini and targeted project concept notes in support of desert and arid lands aquaculture development for possible funding through FAO or the donor community. The elaborated project proposal concept notes have not been included in this publication.

WORKSHOP RECOMMENDATIONS

A number of basic requirements associated with the development of aquaculture in desert and arid lands have been identified by the experts and need careful consideration. These are:

1. Education, training and communication

Education and training are the key foundations for building up the necessary skills for production, management and environment-friendly practices for desert and arid lands aquaculture. This can be achieved through:

Needs:

- Enhance education institutions with specific aquaculture programmes in their curricula covering the following subjects:
 - biology of cultured species;
 - hydrology in desert and arid lands aquaculture;
 - technology implied;
 - business management;
 - water management; and
 - integrated/organic aquaculture.
- Promote refresher courses and mentorship programmes as means of maintaining a continuous “knowledge” stream of desert and arid lands aquaculture education among stakeholders.
- Disseminate the “how to” information for starting desert and arid lands aquaculture to potential investors as an encouragement of a sustainable practice associated with a positive income.
- Facilitate networking arrangements to support exchange of specialists and sharing of technical know-how.

Actions:

- Institute demonstration and/or extension farms for training and information dissemination to local farmers (short courses, fieldwork, manuals, Web-based information sheets, etc.).
- Establish “information centres” (physical and/or online Web sites) that can supply information on desert and arid lands aquaculture.
- Promote regional and interregional cooperation and networking in the development of curricula, exchange of experience and development of educational material and training workshops.
- Establish standard schemes for training and educational components of desert aquaculture.
- Develop effective mechanisms for access to relevant and reliable information for all stakeholders.

2. Research and development

The need for new and/or adapted technologies able to withstand the aquaculture conditions in desert and arid lands is important, especially in developing countries and countries that are in a transition stage of development. The research and development (R&D) for sustainable desert and arid lands aquaculture should focus on:

Needs:

- Identify advanced technologies and infrastructures designed for new or existing aquaculture facilities adapted to local desert and arid lands conditions.
- Develop protocols to manage health-related issues of aquatic organisms on the domestic and regional level.
- Characterize water quality from aquaculture effluents in an attempt to maintain the surrounding ecosystem as pristine as possible.
- Select and introduce new aquatic species (most suitable for local conditions) with high production values.
- Produce feed using locally available feed ingredients.

- Integrate desert and arid lands aquaculture with other productive sectors such as agriculture (aquaponics, production of fodder and technical crops, etc.).

Actions:

- Establish regional desert and arid lands aquaculture research centres and aquaculture parks, ensuring stakeholder participation in research identification and implementation including demonstrations on how to diversify and/or integrate farmers' activities with aquaculture.
- Develop funding mechanisms at the national, regional and international level in R&D in desert and arid lands aquaculture involving public- and private-sector organizations.
- Implement species introduction programmes to diversify and intensify aquaculture production in desert and arid lands.
- Develop policy and technical guidelines on improved feeding and feed management in desert and arid lands aquaculture.
- Conduct training needs assessment to improve technical capacities of national aquaculture researchers and technicians.

3. Smart water use in desert and arid lands aquaculture

Aquaculture integration refers to the physical linkage of various activities (e.g. agriculture, hydroponics, recreation and tourism) by using the same volume of water each time for obtaining its final product. The strategy implied is to reduce the use of water, and reuse the water for different activities. Ultimately, the water is being maximized to produce several crops with the same amount of water. This scheme minimizes its waste and can be achieved by:

Needs:

- Set up a recommended list of water conservation technologies for all desert and arid lands aquaculture and subsidiary activities deriving from it.
- Develop water-saving strategies and/or guidelines for aquaculture stakeholders to follow, ensuring the best water use and exploitation to maximize the profit from it.

Actions:

- Implement efficient vertical and/or horizontal integration of water effluents with secondary (or more) activities that efficiently use the nutrient passage from one activity to the other, in an attempt to increase production and release water in the environment in compliance with governmental standards.

4. Clear policy and regulations

Desert and arid lands aquaculture is a relatively new industry and, in several cases and in many countries, existing policies and regulations dealing with arid land and available water resources use for aquaculture purposes are not yet developed or do not exist.

Very often, licences for desert and arid lands aquaculture activities are spread among several agencies (e.g. land use, water use, environment). This situation may significantly limit and/or even arrest the development of this sector.

Needs:

- Adopt specific policies for water use for desert and arid lands aquaculture.
- Adopt regulations for desert and arid lands aquaculture.
- Streamline licence-approval processes.
- Facilitate information access for the public.
- Promote investment in desert and arid lands aquaculture.

Actions:

- Develop comprehensive regulations and administrative procedures that encourage desert and arid lands aquaculture development (in line with existing local laws and regulations).
- Develop national policies for optimizing water use and disposal (e.g. water reuse and integrated aquaculture-agriculture systems).
- Develop a reference agency (information centre) with adequate organizational stature to assist potential investors to comply with the local regulations. The agency can be within one of the aquaculture managing agencies or coordinate collaboration between the agencies involved.
- Establish economic incentives for private investors willing to start desert aquaculture activities.

5. Environmental sustainability

Desert and arid lands aquaculture should be developed by adopting policies and practices that ensure environmental sustainability, especially through the use of environmentally sound technologies and appropriate water management. The establishment of efficient farming systems that are integrated into environmental management plans will enable more efficient use of water, land, seed and feed inputs. Countries are recommended to consider the following needs and actions:

Needs:

- Promote awareness for both small-scale and commercial activities on the codes of good practice for aquaculture (e.g. codes of conduct for sustainable aquaculture).
- Use renewable energy sources (solar, wind, etc.).
- Promote efficient use of locally made feed ingredients – small and/or rural activities.
- Ensure efficient use of water resources and effluent management.
- Develop environmental policies and regulations of a high standard at the national and regional level for desert and arid lands aquaculture.

Actions:

- Develop water-use, effluent discharge and waste-disposal regulations for aquaculture/agriculture purposes.
- Develop a code of conduct specifically for the region in question based on rural and commercial farms, and publicize the existence of codes of conduct to regulatory agencies and producers involved in desert and arid lands aquaculture.
- Increase renewable energy sources availability in an effort to promote a “green” desert and arid lands aquaculture.
- Encourage the utilization of available agriculture and by-products in fish feed formulation, especially for small-scale farms.

6. Socio-economic aspects

The purpose of increasing desert and arid lands aquaculture is to secure food supply and protein sources, provide jobs, create business opportunities and improve livelihoods in desert and arid lands locations through the development of aquaculture activities.

Needs:

- Offer both genders equal employment opportunities.
- Evaluate the economical sustainability of aquaculture production individually or integrated with secondary activities (i.e. agriculture).
- Implement credit schemes for the support of desert and arid lands aquaculture development.

- Promote the nutritional advantages of consuming aquatic organisms at the local and national level.

Actions:

- Develop strategic action plans addressing aquaculture needs and potential.
- Conduct socio-economic impact studies for pre- and post-implementation of desert and arid land aquaculture in an attempt to quantify changes over time.
- Develop credit schemes as incentives to facilitate investment in aquaculture development (e.g. microcredit programmes, especially for small-scale aquaculture development).
- Establish cooperatives and farmers associations for small-scale aquaculture.
- Implement awareness programmes aimed at highlighting benefits from agriculture integration.

7. Market development and trade

Commercial aquaculture in desert and arid lands in general should be market-oriented for its sustainability and well linked with the trends and dynamics of world seafood markets.

Needs:

- Develop market strategies to establish a continuous demand for desert aquaculture products.
- Ensure that the processing and handling of aquaculture products in harsh environments is compliant with the protocol of the Hazard Analysis and Critical Control Point (HACCP) system.
- Develop the infrastructure to enable the storage, processing and transportation of aquaculture products in remote areas.
- Facilitate transport and access to and from markets for the local communities.
- Increase consumption of aquaculture products by diversifying traditional diets.

Actions:

- Market product qualities that highlight its environmental sustainability in order to target niche markets.
- Develop and establish alternative processing protocols for extending shelf-life.
- Establishing cooperatives and/or centralized entities (facilities) for processing and trading purposes.
- Make available basic infrastructure for storage, processing and transportation of aquaculture products (e.g. cold rooms, small-scale processing plants, and roads) to ensure adequate access to the market even for the aquaculture farms located in rural areas.
- Create programmes that promote the benefits of consuming aquaculture products in order to attract local consumption.

8. Regional and interregional cooperation

Over the years, regional and interregional cooperation has brought considerable benefits to aquaculture development through dissemination of knowledge and expertise. Further strengthening of this cooperation at all levels will ensure increased benefits for the development and sustainability of desert and arid lands aquaculture. Although desert and arid land aquaculture is a relatively new sector, some countries and regions are more advanced than others in this field. Therefore, the most advanced countries should share their expertise with less advanced ones in order to facilitate the development of the sector.

Needs:

- Foster information and technical knowledge transfer between more advanced regions and/or countries and less developed ones.
- Improve interregional collaboration and networking of regional and/or national institutions specialized in desert and arid lands aquaculture to ensure synergies and exchange of expertise.
- Encourage the establishment of regional organizations for the development of desert and arid lands aquaculture in regions where they are lacking.

Actions:

- Establish regional “desert aquaculture” associations that will link States, regions and/or nearby countries.
- Establish Web-based regional information systems focusing on desert and arid lands aquaculture as a first entry point and source of information.
- Establish bilateral and/or multilateral exchange networks between regions to allow information and technical flow through regional courses, workshops, and exchange of technicians and scientists.
- Establish links with international donors and agencies to support the development of regional desert and arid lands aquaculture through the above-mentioned actions.

Annex 1 – Agenda

FAO EXPERT WORKSHOP ON “AQUACULTURE DEVELOPMENT IN THE DESERT AND ARID LANDS: DEVELOPMENT CONSTRAINTS AND OPPORTUNITIES”

Hermosillo, Mexico
6–9 July 2010

Monday, 5 July 2010	
Arrival of participants and transfer to hotel	
Tuesday, 6 July 2010	
09:00–09:30	Welcome note from Centro de Investigación Alimentación y Desarrollo (CIAD) representative Opening remarks
09:30–13:00	Workshop introduction <ul style="list-style-type: none"> • <i>Introduction note and adoption of the agenda</i> Scope and main objectives to be achieved by the workshop Review presentations <ul style="list-style-type: none"> • <i>Australia</i> • <i>Central Asia (Aral Sea Drainage Basin)</i> • <i>Israel</i> • <i>Southern Africa</i>
13:00–14:00	<i>Lunch break</i>
14:00–17:30	Review presentations (cont'd) <ul style="list-style-type: none"> • <i>Egypt</i> • <i>United States of America</i> • <i>Mexico</i> • <i>Additional presentations (delivered by national experts and/or observers)</i> Open debate Feedback and comments on the reviews presented. Summary of major issues and salient aspects identified
Wednesday, 7 July 2010	
09:00–12:30	Working Session I <ul style="list-style-type: none"> • <i>Elements for a targeted developmental programme</i> Drafting the “Desert and arid lands aquaculture development: the way forward” document
12:30–14:00	<i>Lunch break</i>
14:00–17:30	Working Session I (cont'd)
Thursday, 8 July 2010	
09:00–12:30	Working Session II <ul style="list-style-type: none"> • <i>Priority and targeted project proposals</i> Preparation of selected and targeted project proposal concept notes. Each expert is invited to prepare two or three (or more) project proposals concept notes for presentation and discussion at the workshop (see below recommended concept note template)
12:30–14:00	<i>Lunch break</i>
14:00–17:30	Finalization of the first draft of the “The way forward” document Workshop follow-up actions Closing remarks
Friday, 9 July 2010	
09:00–17:30	Field trip <ul style="list-style-type: none"> • <i>Visit to aquaculture facilities and the desert of Sonora</i> Departure

Annex 2 – List of participants

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Annex 3 – Expert profiles

APPELBAUM, Samuel – Professor Samuel Appelbaum obtained his B.Sc. at the Hebrew University, Jerusalem, Israel, and his M.Sc. and Ph.D. at the University of Hamburg, Germany. He has been the head of the Bengis Center for Desert Aquaculture at Ben-Gurion University of the Negev for the last 16 years. He is an eminent leader in the field of brackish water aquaculture and desert aquaculture research and development. Working closely with local collectives (Kibbutzim) and Negev fish farmers, he is responsible for the introduction and expansion of brackish water fish farming in the Negev Desert in southern Israel and is currently researching the efficient and economical aquacultural use of this desert brackish water and its application to the “Integrated aqua/agricultural” farming model. This research includes the introduction of two suitable species (Barramundi, *Lates calcarifer* and gilthead seabream, *Sparus aurata*) for desert aquaculture and the studying of the suitability of the brackish water at different locations in the Negev Desert for the cultivation of gilthead seabream. His current research also includes utilization of brine from desalination plants for aquaculture and the reproduction of marine and freshwater species for cultivation in the desert. Evaluating the potential use of decapsulated *Artemia salina* cysts and the use of various enrichments for *Artemia* nauplii as a nutrient in aquaculture is another aspect of his research. His activities include training and instruction of foreign visitors, teaching students and post-doctorate researchers, and participation in courses and seminars. He has published numerous articles in international scientific journals and chapters in related books.

CRESPI, Valerio – Valerio Crespi graduated from the “La Sapienza” University of Rome, Italy, in biological sciences with a specialization in fisheries and aquaculture. He has undertaken a three-year advanced post-graduate course (Master equivalent) at IFREMER (French Research Institute for Exploitation of the Sea) at the laboratory of Sète (France), funded by the European Union (EU). Up to 1999, he was actively involved in research activities related to inland fisheries and aquaculture in Africa, Guinea and Uganda within the framework of EU cooperation projects. In 2000, he joined the FAO Fisheries and Aquaculture Department in Rome, working as a consultant for two years and collaborating on the development, support and management of the Fisheries Global Information System (FIGIS) and for the FAO-COPEMED project on the analysis of the inventory of the artisanal fisheries in the Western and Central Mediterranean Sea. In 2002, he was appointed Aquaculture Officer (Information) in the Aquaculture Service of FAO, and he has conducted extensive normative work dealing with aquaculture information dissemination through the Internet and other information technology (IT) tools. The main activities he is currently focused on are: technical assistance to field projects on freshwater aquaculture in a number of countries; and technical assistance to FAO regional fishery bodies through the establishment of Web-based regional aquaculture information systems. He is directly responsible for the management and maintenance of the FAO aquaculture gateway page (www.fao.org/fishery/aquaculture).

KARIMOV, Bakhtiyor – Dr Bakhtiyor Karimov is Head of the Laboratory of “Problems of intensive aquaculture and fisheries” of the Institute of Zoology of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan. He has a Candidate of Sciences (Ph.D.) degree in biology from the State Scientific Research Institute for River

and Lake Fisheries of the Fisheries Ministry of the Russian Federation, Saint Petersburg (1985) and holds a Doctor of Sciences degree in biology from Tashkent State University (1995). He has been working in the field of ichthyology, ecotoxicology, aquatic ecology, aquaculture and fisheries development on arid and desert areas of the Aral Sea Basin for the past 25 years. In particular, he has studied artificial desert lakes of irrigational origin, such as the Aydar-Arnasay Lake System, Lakes Sarikamysh, Kamishlibash and Shorkol, and the deltaic lakes of the Amudarya River. His scientific publications (more than 100) have been published in well-recognized journals of the former Soviet Union and of the Commonwealth of Independent States (CIS), as well as in peer-reviewed journals. He has edited international conference proceedings, an FAO aquaculture and fisheries review and a special issue of the scientific popular journal *Ecological bulletin* devoted to aquaculture and fisheries issues. He has research experience from Europe and Central Asia through a series of short- and longer-term joint research projects. In the period 1995–97, he worked at the Zoological Institute of the University of Hamburg as a fellow of the Alexander von Humboldt Foundation (Germany) on the project “The impact of water pollution on fisheries”. He has coordinated two FAO technical cooperation projects on aquaculture and fisheries (in 2007–2008 and in 2009–2010) and a German-Uzbek project on sustainable aquaculture development in the Aral Sea Basin (2006–2007). He was a team leader of the EU–INTAS-funded Aral Sea project (2002–2004), and has participated in several other UNESCO and national projects on aquaculture, fisheries and sustainable use of water resources. He has been a member of the Committee on Coordination of Science and Technologies Development under the Cabinet of Ministers of the Republic of Uzbekistan: Section 4: Agriculture, Biology and Ecology since 2002, and he is also an active member of the Zoological Society and President of the Humboldt Society of Uzbekistan.

KOLKOVSKI, Sagiv – Mr Sagiv Kolkovski is Principal Research Scientist of the Aquaculture and Aquatic Health Unit at the Department of Fisheries, Western Australia, Australia. He is also Research and Development (R&D) Director at Nutrakol Pty. Ltd., a company specialized in nutrition and health solutions for the aquaculture industry. He has been working in the field of aquaculture for the past 25 years, undertaking R&D and consultancy work around the world including: Australia, Chile, Ecuador, France, Indonesia, Israel, Japan, Malaysia, Mexico, New Zealand, Portugal, Singapore, Spain, Thailand and the United States of America. In the past ten years, he has led the marine aquaculture research programme at the Department of Fisheries, Western Australia. Prior to this role, he was invited professor at Ohio University, the United States of America. He has diverse interests and expertise in marine aquaculture including marine organisms’ nutrition and physiology and aquaculture engineering. He has developed techniques, systems and diets for a wide range of marine organisms, including finfish (groupers, seabream, seabass, mahi mahi, *Seriola* sp. ornamental fish and others), crustaceans (lobsters, shrimps), octopus and live food (rotifers, *Artemia*). His R&D projects, linked with industry, and his applied approach resulted in the establishment of the first large-scale commercial production of *Artemia* in closed-system, commercial (patented) feeding systems, maturation diets for crustaceans and many other “tailor-made” nutritional and health solutions. He is also specialized in site and species selection and “desert” aquaculture. He has published more than numerous papers in international science journals, several book chapters, and many scientific and professional reports to several government agencies around the world and commercial clients. He is on the editorial board of the journals *Aquaculture* and *Aquaculture Nutrition*.

LOVATELLI, Alessandro – A trained marine biologist and aquaculturist, he obtained his B.Sc. and M.Sc. degrees at the universities of Southampton and Plymouth (the United Kingdom of Great Britain and Northern Ireland), respectively. His first

experience with FAO dates back to 1987, working as the bivalve expert attached to an FAO/UNDP (United Nations Development Programme) regional project. His subsequent FAO assignment was in Mexico, working on a regional aquaculture development project (AQUILA) funded by the Italian Government. From 1993 to 1997, he worked in Viet Nam, Somalia and then again in Southeast Asia. In Viet Nam, he headed the aquaculture and fisheries component of a large EU project developing, among other activities, ten regional aquaculture demonstration, training and extension centres. In Somalia, he acted as the lead aquaculture and fisheries consultant for the European Commission. Following an additional year in Viet Nam as one of the team leaders under the Danish-funded Fisheries Master Plan Project, he was recruited by FAO as the Aquaculture Advisor attached to the FAO-EASTFISH project based in Denmark. In 2001, he once again joined the FAO Fisheries and Aquaculture Department in Rome. The main activities he is currently focusing on are marine/offshore aquaculture development, transfer of farming technologies and resources management. Mr Lovatelli has coordinated and co-authored a number of FAO technical reviews and papers, mainly focused on marine aquaculture development.

MAPFUMO, Blessing – A national of Zimbabwe, he is the Regional Aquaculture Advisor at INFOSA (the intergovernmental organization for marketing information and technical advisory services for the fisheries industry in Southern Africa), responsible for all technical matters pertaining to aquaculture development in Southern Africa (a regional block of 15 countries). He has nearly eight years of direct experience in fish farming, having worked as Production Administrator at Lake Harvest Aquaculture based in Zimbabwe (the largest freshwater aquaculture farm in Africa). He has been consulted by the Governments of Angola (Socio-Economic Study for Small-Scale Fisheries), Mozambique (Small-Scale Aquaculture Development Plan), Namibia (Study on Assessment of Markets for Namibian Aquaculture Products) and Zimbabwe (National Training Needs Assessment on Aquaculture). Furthermore, he has undertaken several consultancy projects on freshwater aquaculture development and trade aspects and has so far trained more than 100 aquaculturists in the region under INFOSA's capacity-building programme on aquaculture. On desert and arid land aquaculture, he has conducted two feasibility studies on the potential for freshwater aquaculture in dry eastern regions of Namibia. He is also an advisor to two large-scale pilot projects in desert/arid lands: CAMDEBOO Satellite Aquaculture Project (Eastern Cape, South Africa) and Tahal (Botswana) on both production and marketing issues. He also administers the regional Technical Information Centre (TIC), including INFOSA's Web site (www.infosa.org.na) for all inland fisheries and aquaculture activities in Southern Africa. This centre is also a regional dissemination hub for FAO technical information. He is also a guest lecturer at the University of Namibia and inland fisheries colleges in Zimbabwe on aquaculture and fish-trade-related subjects. He has written two case studies for the SARNISSA Web site (www.sarnissa.org) on both freshwater and mariculture in the region, some articles for the EUROFISH Africa Pages Magazine and several training manuals on freshwater aquaculture. He sits on the board of directors as a technical advisor for the Zimbabwe Aquaculture Trust and is also a key advisor to the Ministry of Fisheries and Marine Resources on aquaculture-related matters. He holds an MBA (Management College of South Africa), an Higher National Diploma (United Kingdom) in agricultural management (Zimbabwe), a diploma in fish farming (South Africa), a diploma in information technology (University of Zimbabwe) and several certificates on aquaculture, inland fisheries, project development and related fields.

SADEK, Sherif – An aquaculture specialist. In 1984, he obtained his Ph.D. (Doctor Engineer) from the Institut National Polytechnique (INP), Toulouse, France. He has evaluated the expected problems and solutions in earthen brackish water ponds in

Egypt, related to gilthead seabream, European seabass and mullet species. In the period 1986–1987, he undertook post-doctoral study and research at the Department of Fisheries and Allied Aquaculture at Auburn University, the United States of America. His topic was: development possibilities of freshwater prawn and marine shrimp culture in Egypt. In 1998, he obtained the degree of Docteur de l'INP from the Institut National Polytechnique, Toulouse, France. His research subject was: the different techniques of giant river prawn (*Macrobrachium rosenbergii*) during the last ten years in Egypt. In the period 1980–1991, he participated as a research assistant in the General Authority for Fish Resources Development (GAFRD), Egypt. Since 1991, he has been the creator and general manager of the firm Aquaculture Consultant Office. Dr Sadek has been nominated as a consultant for different projects in North African and Arab countries. His career history contains a long series of successful management of large projects: programming, budgeting, planning, supervision and monitoring of implementation, coordination and control of outside consulting experts and suppliers of specific equipment, elaboration of process schedules and execution rules and check-lists, recruitment, training and management of personnel. In the past five years, he has been involved in numerous efforts by the International Union for Conservation of Nature (IUCN) and FAO to apply the ecosystem approach to aquaculture and to establish guidelines to make aquaculture a more sustainable industry. He has published about 30 complete scientific papers in different international journals and also presented 35 short papers at various international aquaculture conferences. Dr Sadek's field expertise is more related to freshwater prawn breeding and culture, in addition to the culture of finfish (gilthead seabream, European seabass, mullet and meagre) and shrimp (*Penaeus semisulcatus*) in arid land, desert areas and coastal zones.

SEGOVIA QUINTERO, Manuel – A researcher at the Center for Scientific Research and Higher Education at Ensenada (CICESE), Ensenada, Baja California, Mexico. He has a Ph.D. in aquaculture from Louisiana State University, the United States of America, and has been doing research in the field of aquaculture for the last eight years. His research expertise is in the design and development of modular recirculating aquaculture technology and the economic feasibility of such systems for commercial aquaculture in Mexico and Latin America. In arid lands, his ongoing research is focused in the study of mass transfer between high-density recirculating systems and aquaponics and the design of low-cost recirculating systems with commercial applications. He has been involved in research, consulting and transferring technology in Mexico and other countries such as Argentina, Bolivia, Chile, Costa Rica and Peru. As a result, he has developed recirculating technology for abalone production, oyster broodstock conditioning and maturation and spiny lobster larvae systems. He has published scientific publications in peer-reviewed journals on diverse aquaculture topics.

TREECE, Granvil – An aquaculture specialist at the Texas A&M University and the Sea Grant College Program since 1983, he received an M.Sc. from Texas A&M University, the United States of America, in 1977, and worked in the commercial aquaculture industry as a shrimp hatchery manager 32 years ago. He has worked in 44 countries over the years on various aquaculture projects, working with the United States Department of Agriculture's Foreign Agriculture Services, USAID and as a private consultant to build shrimp farms and hatcheries, as well as providing training. He has conducted marine shrimp culture courses throughout the world in the last 27 years and has conducted the Texas Shrimp Farming and Marine Finfish Farming Course at Texas A&M University for 24 years. He has been an Adjunct Associate Professor at the TAMU Wildlife and Fisheries Sciences Department since 1999. He has worked with most of the shrimp farms in the United States of America, including the desert farms in Arizona and West Texas. He has served for 21 years on the board

of directors of the Texas Aquaculture Association, and helps them maintain their Web site (www.texasaquaculture.org). He has numerous scientific publications on various aspects of aquaculture and related topics in peer-reviewed journals and books. He has also developed computer software to assist in aquaculture planning, feasibility and design. He has assisted Texas Parks and Wildlife with the rules and regulations for offshore aquaculture and assisted the Gulf of Mexico Fisheries Management Council in preparing their fisheries management plan to regulate offshore aquaculture in the Gulf of Mexico Exclusive Economic Zone.

Annex 4 – Selected photographs

Small-scale aquaculture in the desert and arid lands of Ouargla, Algeria

PHOTO 1
Pump station for pumping underground water



COURTESY OF V. CRESPI

PHOTO 2
Fish pond in the desert



COURTESY OF V. CRESPI

PHOTO 3
Stocking fingerlings



COURTESY OF V. CRESPI

PHOTO 4
Farm-made feed



COURTESY OF V. CRESPI

PHOTO 5
Feeding fish



COURTESY OF V. CRESPI

PHOTO 6
Discharge canals



COURTESY OF V. CRESPI

Small-scale aquaculture in the desert and arid lands of Ouargla, Algeria (continued)

PHOTO 7
Integration with agriculture (salad)



COURTESY OF V. CRESPI

PHOTO 8
Integration with agriculture (greenhouses)



COURTESY OF V. CRESPI

PHOTO 9
Fingerlings production in hapas



COURTESY OF V. CRESPI

PHOTO 10
Palm leaves used to protect hapas from the sun



COURTESY OF V. CRESPI

PHOTO 11
Harvesting a fish pond



COURTESY OF V. CRESPI

PHOTO 12
Farmed Nile tilapia (*Oreochromis niloticus*)



COURTESY OF V. CRESPI

Commercial aquaculture farms in the desert and arid lands of Ouargla, Algeria

PHOTO 13
Bottom of earthen pond lined with PVC sheet



COURTESY OF V. CRESPI

PHOTO 14
Fish pond in a medium-sized commercial farm



COURTESY OF V. CRESPI

PHOTO 15
Concrete ponds used as hatchery



COURTESY OF V. CRESPI

PHOTO 16
Commercial fish farm "Pescado de la Duna"



COURTESY OF V. CRESPI

PHOTO 17
Ongrowing raceways



COURTESY OF V. CRESPI

PHOTO 18
Indoor nursery raceways



COURTESY OF V. CRESPI

Commercial aquaculture farms in the desert and arid lands of Ouargla, Algeria (continued)

PHOTO 19
Broodstock of red tilapia



COURTESY OF V. CRESPI

PHOTO 20
Feed processing plant on the farm



COURTESY OF V. CRESPI

PHOTO 21
Farmed red tilapia



COURTESY OF S. SADEK

PHOTO 22
Fish processing plant



COURTESY OF V. CRESPI

PHOTO 23
Fillets of red tilapia



COURTESY OF S. SADEK

PHOTO 24
Value-added products



COURTESY OF V. CRESPI

Commercial aquaculture farms in the desert of Sonora, Mexico

**PHOTO 25
Shrimp farm**



COURTESY OF V. CRESPI

**PHOTO 26
Seawater inlet pumps**



COURTESY OF V. CRESPI

**PHOTO 27
Bottom PVC lining in an earthen pond**



COURTESY OF V. CRESPI

**PHOTO 28
Earthen ponds for shrimp culture**



COURTESY OF V. CRESPI

**PHOTO 29
Manual feeding of shrimp**



COURTESY OF V. CRESPI

**PHOTO 30
Manual feeding of shrimp**



COURTESY OF V. CRESPI

Commercial aquaculture farms in Mexico

PHOTO 31
Circular earthen ponds in Sonora



COURTESY OF M. SEGOVIA

PHOTO 32
Rectangular stonemasonry tanks in Sonora



COURTESY OF M. SEGOVIA

PHOTO 33
Hatchery and tanks covered with liners to avoid sand contamination in Baja California



COURTESY OF R. MALONE

PHOTO 34
Rectangular tanks covered with PVC in Baja California



COURTESY OF R. MALONE

PHOTO 35
Concrete tanks covered with PVC against solar radiations



COURTESY OF M. SEGOVIA

PHOTO 36
Nursery tanks



COURTESY OF M. SEGOVIA

Contributed papers

Global desert aquaculture at a glance

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SUMMARY

The present paper is a brief introduction to desert and arid land aquaculture where the main developmental constraints and opportunities are highlighted. The information provided on the surface extension of such harsh territories throughout all continents is an indication of land availability for developing fish farming, as well as other food production activities where surface and/or underground water resources are available. In terms of farming systems, the paper introduces those that are in use while others which are more innovative and require a certain degree of technical know-how and skills. The description of the advantages and disadvantages of desert and arid land aquaculture along with the selection of suitable farming species, provides additional information on the challenges faced in the development of this aquaculture subsector. The final part of this chapter recommends key elements to be included in national strategies by those countries interested in supporting the establishment of aquaculture activities in such territories.

RÉSUMÉ

Le présent document est une brève introduction à l'aquaculture dans des environnements arides ou désertiques. Il met en avant les principaux problèmes relatifs au développement de cette activité et ses possibilités. Les informations concernant les milieux arides et désertiques sur tous les continents indiquent l'étendue des terres susceptibles de permettre le développement de la pisciculture et la production d'autres activités de production de denrées alimentaires là où des ressources hydriques de surface et/ou souterraines sont disponibles. Les systèmes d'élevage adoptés sont aussi présentés, ainsi que des techniques innovantes qui nécessitent un certain degré de savoir-faire et de compétences techniques. La description des avantages et des inconvénients de l'aquaculture dans les zones arides ou désertiques, ainsi que celle des espèces élevées les plus appropriées, fournissent des informations supplémentaires sur les difficultés rencontrées dans le développement de ce sous-secteur de l'aquaculture. On trouvera dans la dernière partie de ce chapitre des

recommandations au sujet des principaux éléments qui doivent être pris en compte dans les stratégies nationales mises en place par les pays qui entendent soutenir la création d'activités aquacoles dans des zones arides ou désertiques.

ملخص

ان الورقة الحاليه تعطي نبذه مختصره حول تربية الاحياء المائية في المناطق الصحراوية والجافة حيث تم التركيز على عوائق التنميه والفرص الموجوده. و المعلومات المتوفرة حول المسح السطحي لمثل هذه الأراضي القاحلة الممتده عبر جميع القارات تعتبر مؤشرا لتوافر الأراضي المناسبه لتطوير تربيته الأسماك، بالإضافة الى الانشطه الأخرى لانتاج الغذاء حيث تتوفر المياه السطحيه و/أو الجوفيه. وفيما يخص أنظمة التربيته فإن الورقة تستعرض تلك الأنظمه المستخدمه حاليا و الأنظمه الابتكاريه التي تتطلب درجه معينه من الخبره والمهارات الفنيه. كما تتضمن وصفا لمميزات وسلبيات تربية الاحياء المائية في المناطق الصحراوية الجافة جنبا الى جنب مع اختيار الأنواع المناسبه للاستزراع. كما توفر الورقة معلومات اضافيه حول العوائق التي تواجه تنميه هذا القطاع الفرعي من تربية الاحياء المائية. والجزء الاخير من هذا الفصل يوفر مقترحات حول العناصر الرئيسيه التي يجب ادراجها في الاستراتيجيات الوطنيه من طرف البلدان التي ترغب في دعم انشاء انشطه تربية الاحياء المائية في مثل هذه الاراضي.

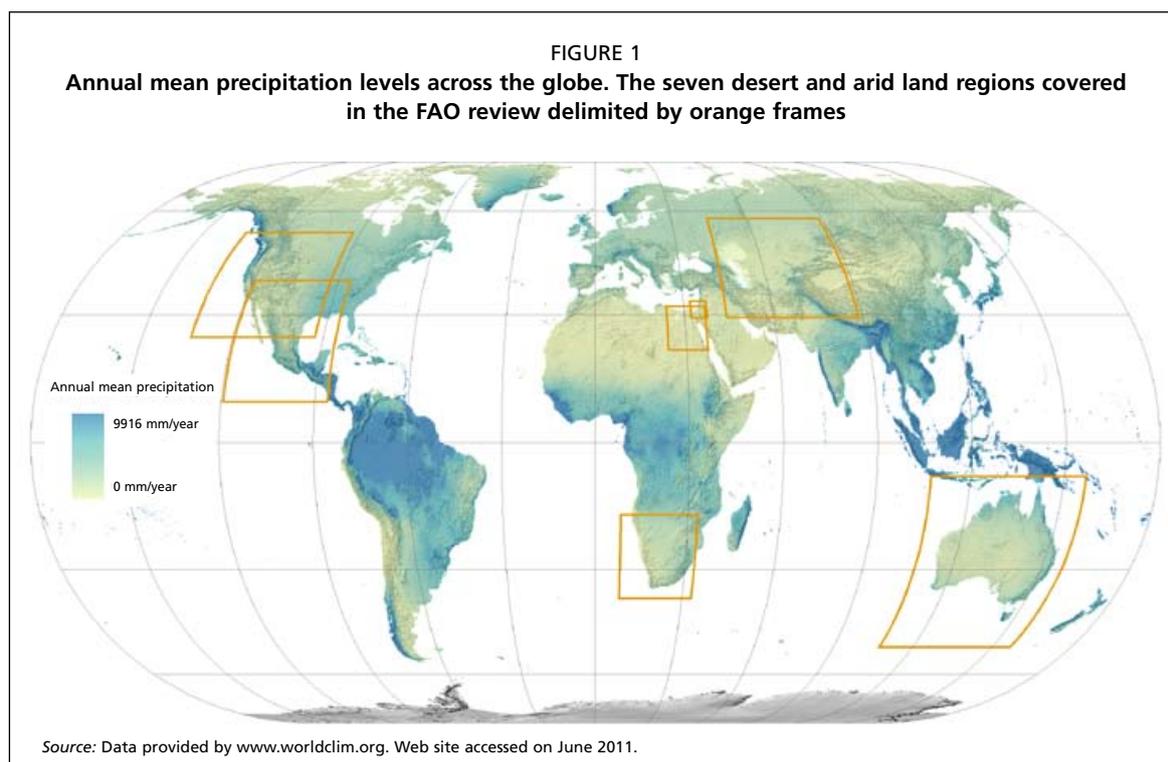
INTRODUCTION

This paper provides a brief introduction on desert and arid land aquaculture highlighting the main physical characteristics of this environment and identifying the foremost limiting factors hampering the development of this industry subsector. Furthermore, this chapter is an introduction to the review papers incorporated in this publication summarizing and taking into account the key issues reported by the reviewers along with the outcomes and recommendations of the FAO Technical Workshop held in Mexico (see Workshop summary).

The above mentioned reviews cover seven geographical regions characterized by extensive arid lands and limited surface water resources where different strategies have been adopted to allow commercial fish production with or without the integration of secondary farming activities. Several examples of commercial aquaculture systems are provided indicating the technical feasibility of growing aquatic organisms in such a harsh environment. Furthermore, the reviews cover a geographical area which spreads out globally and includes countries and regions that have gained considerable and valuable experience in farming fish in these water-poor environments over the past twenty years, as well as those regions that are considered to have a significant potential in the development of this aquaculture subsector. Figure 1 indicates the seven regions covered in this study promoted by FAO along with the annual mean precipitation levels across the globe.

The importance of aquaculture in supplying fish protein to the growing human population is escalating (FAO Fisheries Department, 2011) particularly in regions where other types of intensive animal husbandry are expensive or even simply not possible. Arid and semi-arid zones are among such regions where conventional agriculture and intensive livestock practices are severely hindered by the habitat and climate, and particularly the reduced annual rainfall levels.

The idea of desert fish farming was formulated in 1963–1965 and tested experimentally, showing that it was possible to use desert salt or brackish waters to rear fish successfully (Fishelson and Loya, 1969). The high mineral content of these waters, along with high ambient temperatures and solar radiation in fact support high primary productivity forming a suitable and favourable food-base for the fish (Pruginin, Fishelson and Koren, 1988). Furthermore, the increasing competition for land and particularly water use for a wide range of economic activities is driving the expansion of aquaculture operations towards new frontiers such as in exposed and offshore sea areas or inhospitable regions such as desert and arid lands which can now be better exploited through the use of modern and responsible aquaculture practices.



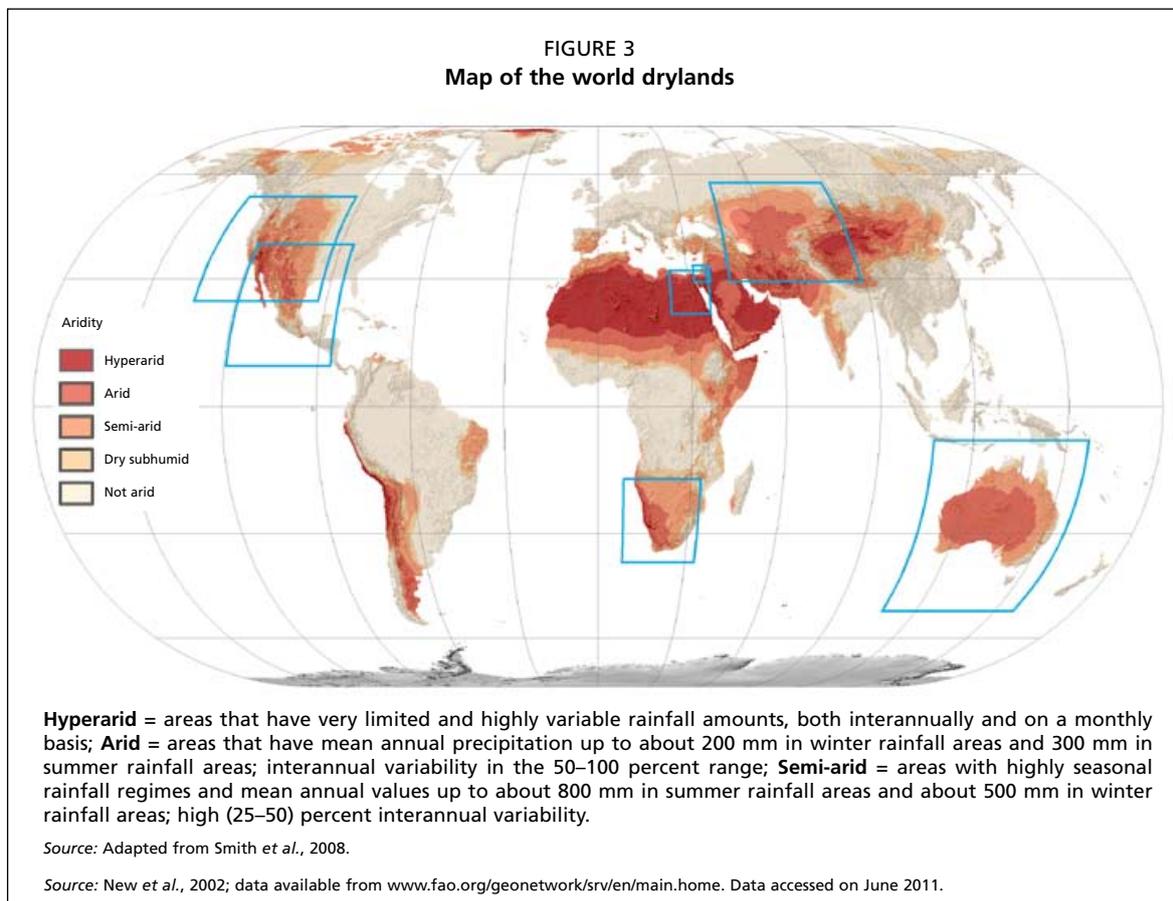
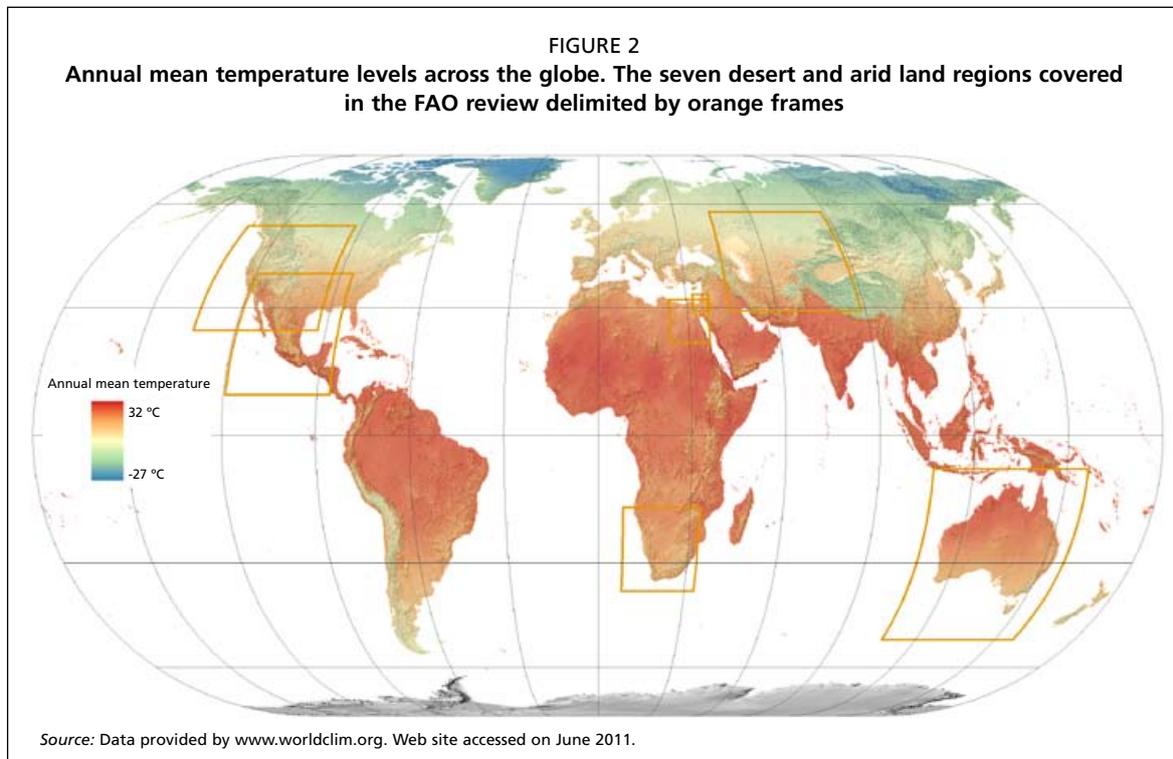
The global population growth and increase in food demand is driving the rapid expansion and intensification of cultivated lands. This, along with increasing evapotranspiration and the decrease in rainfall, possibly also as a result of global climate changes, are certainly contributing to the desertification process as recognized by the United Nations Convention to Combat Desertification and the United Nations University, Institute for Water, Environment & Health (UNU-INWEH) (UNCCD, 2007). Furthermore, according to the World Meteorological Organization (WMO), climate change and desertification are expected to lead to increasing levels of salinization and desertification of agricultural lands. Despite the grave problems of drylands, it is generally recognized that such areas have a great potential for development. They already provide many resources and are home to 50 percent of the world's livestock (UNCCD, 2007). Current statistics from the United Nations Development Programme/United Nations Office to Combat Desertification (UNDP/UNSO) indicate that about 13 percent of the total world population (approximately 313 million) live in arid zones with 92 million alone residing in hyperarid deserts (Smith *et al.*, 2008).

GEOGRAPHY

Deserts cover more than one fifth of the Earth's land, and they are found on every continent. Deserts cover around 25 500 000 km² or approximately 20 percent of the world land mass (Smith *et al.*, 2008). These harsh environments are characterized by high day temperatures and solar radiations, cold winter nights, scarce precipitations and very low relative humidity (Hochman and Brill, 1994). The map in Figure 1 shows the annual mean precipitation across the globe, while Figures 2 and 3 illustrate the annual mean temperatures and land aridity distribution from hyperarid to not-arid based on the aridity index (AI) of the United Nations Environment Programme (FAO, 2011).

Current and future developments of inland aquaculture in such areas will rely greatly on the appropriate use of subsurface waters using farming technologies which ensure the conservative use of this limited resource. The constant growth of the human population and the continuous exploitation for land and water resources

for food production, as well as other economic activities, will undoubtedly increase the extraction of groundwater in arid regions to meet the growing needs. It appears, therefore, obvious that the expansion of monitoring programmes and activities of



subsurface water extraction and utilization particularly from arid regions will become increasingly important and should be carefully addressed as adequate replenishment of groundwater resources may occur over long periods of time.

Table 1 shows the estimated surface area in square kilometres of the main world deserts by continent/region and country. The figures provide an idea on the magnitude of the various deserts and arid areas, which in some cases cover a large portion of national territories. Although there is scattered information on the presence of groundwater and less so on the amount of such resources, these arid lands represent areas with a potential for aquaculture development.

TABLE 1
Main world deserts and their estimated surface area

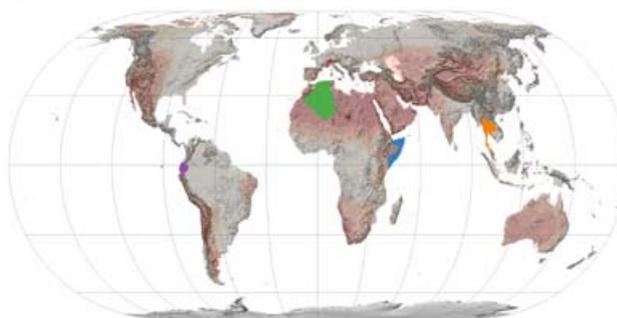
Continent/ World region	Desert name	Surface (in km ²) ¹	Geographical references	Hyper arid/arid lands (in km ² by country) ²	
North and Central America	Great Basin	492 000	USA – Nevada, California, Oregon, Idaho	1 348 000	
	Mojave	38 000	USA – California, Nevada, Utah, Arizona	–	
	Sonoran	310 800	USA – Arizona, California Mexico – Baja California, Sonora, Baja California Sur	– 777 000	
	Chihuahuan	509 500	USA – Arizona, New Mexico, Texas Mexico – Chihuahua	–	
South America	Sechura	189 000	Peru – Piura region	–	
	Atacama	105 200	Peru – South border Chile	– 255 000	
	Patagonian	670 000	Chile	–	
			Argentina	878 000	
Africa	Sahara	9 100 000	Algeria	2 101 000	
			Chad	713 000	
			Egypt	1 000 000	
			Eritrea	48 000	
			Libya	1 698 000	
			Mali	755 000	
			Mauritania	882 000	
			Morocco	163 000	
			Niger	853 000	
			Sudan	1 191 000	
	Tunisia	113 000			
	Namib	80 900	Namibia	30 900	
			Angola	50 000	
	Kalahari	900 000	Botswana	404 000	
Namibia			501 100		
South Africa			559 000		
Arabian	2 330 000	Yemen	460 000		
		Oman	272 000		
		Jordan	71 000		
		Iraq	303 000		
		Rub' al Khali	650 000	Saudi Arabia	2 400 000
				Oman	–
				United Arab Emirates	75 000
Syrian	520 000	Saudi Arabia	–		
		Jordan	–		
		Iraq	–		
		Syria	59 000		
		An-Nafud	103 000	Saudi Arabia	–
Ad-Dahna	80 000	Saudi Arabia	–		

TABLE 1 (CONTINUED)

Central Asia	Karakum	350 000	Uzbekistan	–
			Turkmenistan	–
	Kyzyl Kum	300 000	Uzbekistan	280 000
			Turkmenistan	253 000
			Kazakhstan	–
	Markansu	60	Tajikistan	51 000
	Moyunqum	–	Kazakhstan	–
	Ryn	–	Kazakhstan	–
	Saryesik Atyrau	–	Kazakhstan	–
	Taklamakan	270 000	Kyrgyzstan	27 000
Aral Karakum	40 000	Kazakhstan	–	
Aralkum	–	Kazakhstan	1 516 000	
Asia	Gobi	1 300 000	China – Gansu Province	3 477 000
			Mongolia – Southern	868 000
	Taklamakan	270 000	China – Xinjiang Uygur	–
	Thar	200 000	Pakistan – Sindh, Punjab	648 000
			India – Rajasthan, Haryana, Punjab, Gujarat	133 000
	Ordos	90 650	China – Ningxia Hui, Gansu Province	–
	Gurbantüנגgüt	50 000	China – Xinjiang Uygur	–
	Badain Jaran	49 000	China – Gansu Province	–
	Tengger	36 700	China – Gansu Province	–
			Mongolia	–
Cholistan	26 300	Pakistan – Punjab	–	
Hami	Part of Gobi	China – Gobi Desert	–	
Kumtagh	22 800	China – Xinjiang Uygur	–	
Lop	100 000	China – Xinjiang Uygur	–	
Oceania	Great Sandy	360 000	Australia – Northern Territories, Western Australia	357 3000
	Great Victoria	424 400	Australia – Western Australia, South Australia	–
	Gibson	156 000	Australia – Western Australia	–
	Tanami	184 500	Australia – Northern Territories	–
	Simpson	176 500	Australia – Queensland	–

For comparison, below is the surface area in km² of selected countries:

■ Switzerland		= 41 293 km ²
■ Ecuador		= 272 045 km ²
■ Thailand		= 513 115 km ²
■ Somalia		= 637 657 km ²
■ Algeria		= 2 381 741 km ²



¹ Source: From different Internet sources.

² Source: FAO. www.fao.org/nr/land/information-resources/terrestat/en

AQUACULTURE SYSTEMS IN THE DESERT AND ARID LANDS

The availability of water for farming fish and other commercially valuable aquatic organisms limits the extent to which this food production sector can develop in these water-poor territories. However, it is also quite true that water is not exclusively available from underground sources. Other water bodies do exist including natural ponds and rivers that may either be perennial or seasonal, as well as man-made water retention dams mainly constructed for irrigation purpose and for livestock, and small lakes from abandoned open mines.

Developing aquaculture in harsh environmental physical conditions, typical of deserts and arid lands, therefore dictates the adoption of production strategies focused

on good water management which includes the use of water saving and recycle practices, but also protection against strong solar radiations and the introduction of modern aquaculture technologies such as recirculation systems particularly if high density fish farming is technically and economically possible. These latter systems usually occupy a relatively small area and are extremely efficient with water usage with fish productions of up to 50 kg/m³ of water (Kolkovski *et al.*, 2011).

The long exploitation and utilization of arid lands in many parts of the world has brought about the buildup of artificial water reservoirs of different typology and dimensions, many of which harness a great potential for aquaculture activities. The use of such water bodies is well documented in the Australian review where farming of two salt-tolerant fish species, the Japanese meagre or mullet (*Argyrosomus japonicus*) and the rainbow trout (*Oncorhynchus mykiss*) has been successfully demonstrated. Another example, is the case of Namibia where farming of the Mozambique tilapia (*Oreochromis mossambicus*) in floating cages is showing interesting production results from disused mine pits that would otherwise remain unproductive.

Apart from the farming of table fish as the two species mentioned above, other commercially important and valuable organisms, tolerant to high salt concentrations and high temperatures, are available and attractive candidates for commercial production in arid regions. The small brine shrimp, *Artemia* sp. and the unicellular green algae, *Dunaliella* sp. are two examples. Currently, Australia farms and supplies over 60 percent of the world's natural β -carotene extracted from *Dunaliella salina* which is mainly produced in large saline evaporation ponds in South and Western Australia (Benemann, 2008).

The excessive use of underground, as well as surface water resources in many countries with extensive arid regions have forced many fish farming entrepreneurs and research institutions in developing water-saving strategies including the harvesting of run-off water, sharing water from reservoirs with green crops and the exploitation of saline water sources not fit for human consumption or agriculture (Mires, 2007). On the other hand, for those countries with the opportunity of developing mariculture, it may probably be the most efficient way to overcome inland aquaculture water shortages. However, mariculture and particularly open water mariculture operations still require a certain level of investment and modern technology which is certainly not affordable to rural populations living in desert and arid lands.

The integration of aquaculture with agriculture has been practised for a long time in many countries; however, it is becoming increasingly attractive in areas where water is a limited resource. In fact, such systems can reduce the water requirement for the production of quality fish protein and fresh vegetable products relative to both culture systems operated independently (McMurtry *et al.*, 1997). Furthermore, innovative fish/vegetable coculture systems use the nutrient by-products of fish culture as direct inputs for vegetable production, constantly recycling the same water (e.g. aquaponics). Such recirculating systems are also unaffected by soil type, using a fraction of the water required by pond culture for the same yields and are efficient in terms of land utilization (Rakocý, 1989). Israel is certainly leading important innovations in the use of rain-fed irrigation water for integrated fish production systems as shown in the review published in this document including greenhouse technology that provides a certain level of control on parameters such as humidity, temperature, light and radiation penetration. The use of this technology does not necessarily require significant investments and can be used for commercial, as well as small-scale aquaculture initiatives. This secondary use of water for fish culture improves the efficiency in water usage and reduces the cost of water needed for fish culture in conventional earthen ponds (Kolkovski *et al.*, 2011).

Microalgal mass production, such as the unicellular green algae mentioned above and filamentous cyanobacteria *Spirulina* offer interesting alternatives for biomass production in certain arid and semiarid zones, using brackish water or saline water

not suitable for conventional agriculture (Richmond and Preiss, 1980). The northern regions of Chile which are poor in water resources and unsuitable for agriculture do, however, have suitable conditions for the production of *Spirulina* and other microalgae as a novel industrial activity (Ayala and Vargas, 1987). At present, in the middle of the Atacama Desert the “Solarium Appropriate Biotechnology Group for Desert Development” has developed a culture and processing system for producing this filamentous cyanobacteria. *Spirulina* is cultured in polyvinyl chloride-lined raceway ponds covered with translucent UV-resistant polyethylene film to maintain adequate temperatures in the culture medium (Habib *et al.*, 2008).

Although climatic conditions in many arid territories makes it virtually impossible to obtain enough water to sustain livelihoods (<250 mm/year), there are many areas rich with underground water sources. In some places, these sources are currently being used to supply local populations with daily rations of water for personal use. Depending on a variety of factors, these sources of water can be diversified between providing water for irrigation, aquaculture or for drinking purposes. The focus of utilizing these underground water sources is to integrate the three activities for maximizing the productivity reducing at minimum water wastage.

Vertical and horizontal integration of these three uses has been fully adopted in some areas. Such is the case for some of Egypt’s rural communities, in which the successful integration of these fields has given them extensive practice and have been successfully able to produce and maintain three different crops (fish, green crop and livestock) using the same quantity of water which functioned as a vector for energy transport from each activity (Sadek *et al.*, 2011).

All of the above farming systems are possible in arid regions where surface and/or underground water is both available and accessible. However, the selection of a specific farming system will nevertheless remain closely dependent on the local ground conditions, existing infrastructures (e.g. road networks, availability of utilities, feed and seed plants), level of capital availability, acquisition of the farming technology and support from local and central authorities. The institutional support will undoubtedly play a key role in supporting the development of desert aquaculture, particularly in community-based aquaculture projects. Such initiatives certainly deserve attention also to engage young people that may otherwise remain unemployed due to the remoteness of their rural communities, as well as to contribute to local food security. As such, many countries are already supporting fish production strategies by stocking dams with fish fingerlings.

SUITABLE SPECIES FOR DESERT AQUACULTURE

A large variety of organisms can be cultured in arid conditions, particularly if the technology used is adequate for the proliferation of the farmed species. However, in the selection of species to be reared in desert and arid environments, a few general criteria are recommended. The species should be particularly tolerant to hyper-saline waters, have high tolerance to large temperature fluctuations and be a relatively fast growing species to face off water limited conditions typical of these arid areas. The choice of the species is obviously also influenced by other factors such as the availability of farm inputs, market value and volume, local consumption and preferences and dietary habits. Currently, the most suitable fish species for water-limited aquaculture systems include the tilapias (*Oreochromis* spp.), barramundi or the Asian seabass (*Lates calcarifer*), carps and mullets (*Mugil cephalus* and *Liza ramada*) and several catfishes species (*Clarias gariepinus* and *Bagrus* spp.).

In the case of tilapias, they can be reared intensively in mono, as well as in polyculture systems with other compatible and commercial species such as carps and mullets. They are a hardy group of fish that can be farmed in a wide range of salinities with relatively short production cycle (6 to 8 months to market size). In many countries,

where indigenous species of tilapia or hybrids, such as the red tilapia (*O. mossambicus* x *O. niloticus*), are produced they fetch a good market price and are in high demand.

With regard to shrimp, the Indian white prawn (*Penaeus indicus*) represents a successful example of marine aquaculture production at large commercial scale (e.g. in Saudi Arabia). This penaeid species has in fact a wide tolerance to salinity variations and hence, a suitable candidate for aquaculture under such environmental conditions. In Egypt, among other countries, good results have been achieved with the rearing of the European seabass (*Dicentrarchus labrax*) and the gilthead seabream (*Sparus aurata*) in brackish waters. These marine species, however, require the use of advanced technology and technical skills which are not always available.

As already mentioned in the previous section, other than suitable finfish and crustaceans, microalgae and the filamentous *Spirulina* are suitable candidates currently being produced in several arid coastal regions around the world. However, the production of these latter organisms may necessitate large capital investment and technical skills in order to produce them at costs that are competitive in the current markets. Worth mentioning is also the ornamental fish farming subsector which has been gaining importance with an export market value growing at an average annual rate of approximately 14 percent (FAO, 2010).

Species diversification remains an important issue and challenge for those countries interested in developing desert aquaculture as the rigid environmental conditions impose the selection of species adaptable to such conditions. As a result, non-indigenous species are often identified, selected and sometimes introduced without undertaking adequate risk analysis assessments to avoid potential negative impacts on local species and the environment (FAO, 1996, 2007).

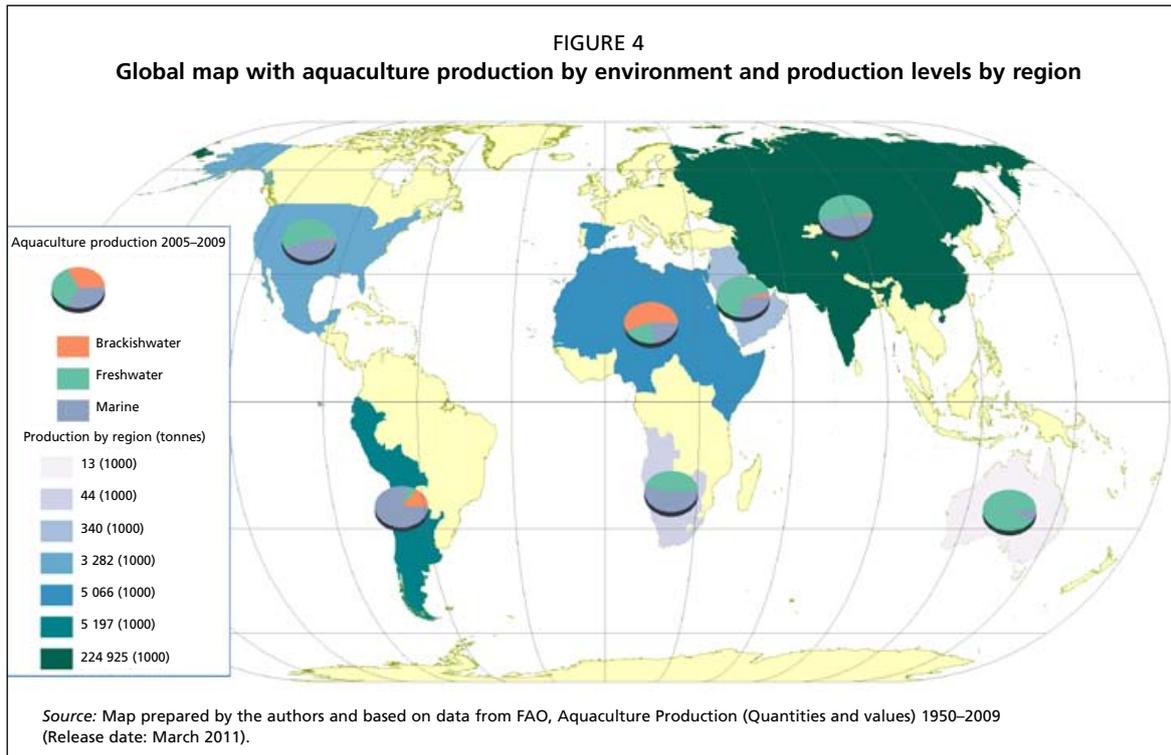
PRODUCTION

The FAO aquaculture production statistics are currently available for a large number of farmed species and can easily be sorted by the production environment, i.e. whether the species has been produced in the marine, brackish water or the freshwater environment. Unfortunately, it is not possible to extrapolate what amount of any given species is produced in areas considered deserts and arid land. For example, in 2009 Egypt produced approximately 600 000 tonnes of fish in brackish waters and just over 105 000 tonnes of fish in freshwater. This vast aquaculture production comes mainly from the Nile Delta region, while a smaller number of commercial facilities are in the immediate area surrounding the delta. This region is certainly not water-poor and hence, one could justifiably question whether this important aquaculture output falls within the true definition of desert aquaculture even though other harsh factors (e.g. high solar radiation; high rate of evaporation) still persist.

Probably, the FAO aquaculture production statistics for Israel are the only ones that may somehow provide an indication on the potential of producing fish from arid zones when water and suitable production technologies are available. Israel, in fact, produced in 2009 over 17 300 tonnes of freshwater fish, mainly tilapias and common carp, while only a couple of thousand tonnes of fish in marine and brackish waters.

An example of marine aquaculture production in arid areas is represented by the Kingdom of Saudi Arabia where huge investments have been carried out for the establishment of the National Prawn Company (NPC) along the Red Sea coast to rear the Indian white prawn (*Penaeus indicus*) in high salinity waters. The success of shrimp production has led the NPC to produce, in 2009, approximately 17 500 tonnes.

A success story worth noting is the case of Algeria where the government has provided support to the private and public sector for the development of aquaculture particularly in arid regions. In 2009, five freshwater aquaculture projects were setup in Algeria. These facilities have an annual production capacity of between 500 to 1 000 tonnes of tilapia. There are also more than 13 small-scale freshwater aquaculture



projects with an annual tilapia production of <500 tonnes. The private company “Pescado de la Duna” has established its facilities (i.e. hatchery, a feed and a processing plant) in the middle of the desert in the District of Ouargla (about 800 km south of Algiers) using underground water. This company is currently producing 500 tonnes/year of red and Nile tilapias which are harvested, processed and sold in local market (Crespi, 2009)

In the United States of America, as indicated in the review published in this document, there are currently around 40 aquaculture farms located in desert regions of six states, producing about 1 percent of the total annual national fish production or about 4 000 tonnes. Although these aquaculture facilities make use of advanced technologies which are not always available in developing countries, they represent a good example of adaptation to harsh environment.

ADVANTAGES AND DISADVANTAGES

It is not easy to clearly define which are the main advantages and disadvantages of practising aquaculture in desert and arid lands. It is obvious that aquaculture can be more easily carried out in areas where abundant and accessible water is available, however, the presence of subsurface water represents a realistic opportunity in arid regions that may otherwise remain unproductive. The success of farming fish in such arid territories will finally be determined by the price that such fish can fetch from the market be it local or export. Therefore, the overall production costs which includes transportation expenses of farm inputs to the farm site itself and the transportation of fish to a receptive market will play an important role in determining the commercial feasibility of any such farm. Table 2 lists some of the advantages and disadvantages of aquaculture in desert and arid lands along with potential measures to face off specific issues.

WAY FORWARD

The main goal in developing desert aquaculture is to maximize the sustainable use of existing water resources for food production also through doable integrated agriculture-aquaculture systems. Other key targets in such a development may include the creation

TABLE 2
Principal advantages and disadvantages of aquaculture in desert and arid lands

Advantages	Disadvantages	Measures
Large aquifers of fresh or brackish waters are commonly found in desert and arid territories (e.g. geothermal water) often only partially used for agriculture	<ul style="list-style-type: none"> • High temperatures, solar radiation and scarce precipitation • Low water exchange rate • Risks of water salinization 	<ul style="list-style-type: none"> • Good water management through the adoption of suitable farming technologies and species
Constant water temperatures from geothermal sources (in winters) and water cooling in summer as a result of the dry climate	<ul style="list-style-type: none"> • High evaporation rates • High temperature variations 	<ul style="list-style-type: none"> • Use of polyethylene sheet or other locally available material such as palm leaves for protection and maintenance temperature levels (e.g. greenhouses)
High quality water – reduced or low introduction risk of viral diseases (geographical isolation of water provides natural quarantine) and low risk of pollution due to absence or limited industrial activities	<ul style="list-style-type: none"> • High cost of water • Competition in the use of limited water resources 	<ul style="list-style-type: none"> • Developing water saving strategies (e.g. harvesting of run-off water; sharing water used for agriculture; exploitation of saline or brackish water not used for human consumption or agriculture activities)
Aquaculture products can be produced all year round and the possibility of growing highly priced off-season fish, vegetables and fruits	<ul style="list-style-type: none"> • Exceeded aquaculture production 	<ul style="list-style-type: none"> • Successful market strategy. • Adequate infrastructures (e.g. processing plants; temperature controlled storage facilities and vehicles; good roads)
Increasing the efficiency of water use for the production of high quality food products (e.g. fish, vegetables)	<ul style="list-style-type: none"> • Increasing soil salinization • Low oxygen level 	<ul style="list-style-type: none"> • Greenwater tanks. • Provision of aeration (e.g. through paddle wheels, air injectors or splashers supplied with renewable energy sources)
Sand beds used as biofilters, hydroponic plant growth substrate, and locus for oxidation of organic solids (active solid suspension)	<ul style="list-style-type: none"> • Construction costs 	<ul style="list-style-type: none"> • Use of existing ponds and reservoirs • Involvement of local farmer communities
Abundant inexpensive land	<ul style="list-style-type: none"> • Limited surface and subsurface water supplies 	<ul style="list-style-type: none"> • Closed recirculation aquaculture system • Integrated aquaculture-agriculture systems • Desalinization • Mariculture
Integration of aquaculture with agriculture	<ul style="list-style-type: none"> • Reluctance of farmers to use recycled water from fish ponds • Poor technical capacity and trained personnel 	<ul style="list-style-type: none"> • Promotion and training on smart use of water for agriculture and aquaculture purposes
Possibility of culturing aquatic organisms without endangering ecological systems or environmental balance	<ul style="list-style-type: none"> • Low promotion and limited private and governmental funds 	<ul style="list-style-type: none"> • Promotion of the benefits of desert aquaculture • Subsidies and investments from the government and private sector

of business and thus, employment opportunities and the use of available and generally underexploited land areas. Furthermore, the targeted support to rural/small-scale aquaculture projects merit particular attention considering the often arduous living conditions of sparse desert communities in many parts of the world.

One important aspect in supporting small rural fish production facilities is the availability of farming inputs, particularly fish feed which often represents a major developmental bottleneck. The provision of technical assistance in the formulation and production of low cost feeds using locally or regionally available ingredients appears to be important as feeds may represent 40–60 percent of production costs. This technical assistance could be delivered in the form of training programmes on farm-made feeds.

Desert and arid land aquaculture certainly does offer new, but challenging opportunities to lessen the global fish supply and demand gap, as well as improving the living conditions of rural communities located in harsh and remote areas and where rainfed agriculture is usually not possible or likely to be irregular (Goodin and Northington, 1985). Farmed fish could therefore, represent an additional crop and income for these small-scale farmers, as well as ensuring some fish supply in communities distant from the coast.

To encourage the development of this aquaculture subsector interested states should, as much as possible, provide support and incentives in terms of accessible and

alternative energy sources and acquisition of technical know-how, as well as for the industry to become self-sufficient in relation to feed and fish fingerling production. National strategies aiming at supporting the development of desert and arid land aquaculture should include the following key elements:

- Promotion of aquaculture farming systems adapted to desert environments focusing on the smart use of water resources.
- Integration, as far as possible, of aquaculture activities with other existing production systems (agriculture, animal production, etc.).
- Inventory and chemical analysis of available surface and subsurface water resources to facilitate selection of suitable farm sites and species to be cultured.
- Support capacity building programmes to strengthen national/local technical capacities through farmer field schools and ad hoc training initiatives.
- Provision of incentives for the establishment, upgrading and modernization of national feed processing plants.
- Support national programmes on farm-made feed production to reduce dependency from expensive and often imported commercial feeds and improve the efficiency of on-farm feeding strategies particularly within more intensive farming systems.
- On-farm high quality fingerlings production programmes to give greater degree of independence for the farmers to obtain seed locally reducing at minimum the acquisition of the seed for small-scale aquaculture farmers living in remote areas. Small-scale aquaculture farmers would benefit from having local sources of seed available for stocking ponds/cages following a harvest. Long transport distances increase costs and reduce the viability of fingerlings stressed by high temperature and low oxygen levels.
- Promotion of national programmes for the utilization of renewable energy sources (e.g. solar and wind energy) in remote areas not served by the national electricity grid.
- Establishment of national programmes for minimum data set collection to monitor the status and trend of this aquaculture subsector.

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An overview on desert aquaculture in Australia

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SUMMARY

The majority of Australia's land is considered to be arid or semi-arid. Deserts occupy 18 percent of Australia's continent, most of which are virtually uninhabited. Within the extension of the large Australian deserts, groundwaters are found in abundance, each with their unique physical-chemical qualities. Several of these water sources may provide service for aquaculture purposes, including: groundwater pumped as part of the Salt Interception Schemes (SIS) to reduce the saline water levels, water pumped as a by-product of the coal seams gas drills, groundwater wells, pit lakes and disused open mine pits. The water quality present within these groundwater sources is a major concern, as they are distinguished by low levels of pH and ionic composition. In fact, potassium ions (crucial for fish physiological processes) are completely deficient within these waters. During the past decade, attention was given to the research and development of aquaculture using saline groundwater, mainly in semi-arid locations. A number of demonstration centres were established in several Australian states showcasing the available technology, in which different systems were developed and tested with several freshwater and marine species. Although several fish species were grown in saline groundwater, only two species were found to have commercial potential: Japanese meagre (mulloway, *Argyrosomus japonicus*) and rainbow trout (*Oncorhynchus mykiss*). Currently, only microalgae *Dunaliella salina* and *Artemia* sp. are being reared commercially along Australia's arid coastal areas. Western and Southern Australia are known for their extensive aquaculture of *D. salina*, reared in large shallow lagoons and ponds, as its importance is highly attributed to the natural beta-carotene used in food, cosmetic and pharmaceutical industries, as well as an important source of food for the rearing of *Artemia* sp. During the past several years, Australia's eastern states suffered severe droughts which reduced groundwater availability. As a result, even the efforts of the SIS were reduced significantly due to the low groundwater levels. Therefore, a lack of suitable water sources supplying large volumes is one of the main challenges expanding the development of saline-groundwater desert aquaculture. The emphasis and priorities for the development of this type of aquaculture have shifted towards other aspects. The current funds available for research and development and/or commercial ventures in this area are not sufficient for their protraction. Aside from microalgae and *Artemia*, there are no desert (or semi-arid) aquaculture commercial projects in Australia.

RÉSUMÉ

La plus grande partie des terres australiennes sont considérées comme étant arides ou semi-arides. Les zones désertiques couvrent 18 pour cent de l'île continent et ne sont pratiquement pas habitées. Dans ce vaste espace, on trouve des eaux souterraines en abondance, qui présentent toutes des caractéristiques physiques et chimiques particulières. Plusieurs d'entre elles peuvent être utilisées à des fins aquacoles, notamment celles qui sont pompées dans le cadre des Plans d'interception du sel visant à réduire leur taux de sel, celles qui sont pompées en tant que sous-produits des forages des gisements houillers ou encore celles qui proviennent des puits, des carrières inondées ou des mines à ciel ouvert qui ne sont plus exploitées. La qualité de l'eau de ces sources souterraines pose problème car celles-ci se caractérisent par un pH bas et une faible composition ionique. Les ions potassium (fondamentaux pour les processus physiologiques des poissons) sont en effet complètement absents de ces eaux. Au cours de la dernière décennie, l'attention s'est notamment concentrée sur la recherche et le développement d'une aquaculture ayant recours aux eaux souterraines salines, principalement dans des zones semi-arides. Des centres de démonstration ont été créés dans plusieurs États australiens pour présenter les technologies disponibles. Différents systèmes d'élevage y ont été mis au point et testés avec diverses espèces marines et d'eau douce. Différentes espèces de poisson ont ainsi été élevées dans des eaux salines d'origine souterraine, mais seules deux d'entre elles se sont avérées avoir un véritable potentiel commercial : le maigre du sud (*Argyrosomus japonicus*) et la truite arc-en-ciel (*Oncorhynchus mykiss*). Actuellement, seule *Dunaliella salina* et *Artemia* sp. sont cultivées à des fins commerciales dans les zones arides situées le long des côtes australiennes. L'Australie occidentale et méridionale est connue pour son aquaculture extensive de *D. salina*, réalisée dans de grandes lagunes aux eaux peu profondes et en étang. Cette source naturelle de bêta-carotène est très importante pour les industries agro-alimentaires, cosmétiques et pharmaceutiques. C'est aussi une source importante d'aliments pour la culture d'*Artemia* sp. Au cours des dernières années, de graves sécheresses ont frappé les États de l'est de l'Australie et ont réduit les réserves d'eaux souterraines. En conséquence, même les efforts entrepris dans le cadre des Plans d'interception du sel ont été considérablement réduits du fait des faibles niveaux des eaux souterraines. Le manque de sources d'eau appropriées permettant d'obtenir de grands volumes est par conséquent l'un des principaux défis auxquels est confronté le développement de l'aquaculture en milieu désertique ayant recours aux eaux souterraines salines. L'accent mis sur le développement de ce type d'aquaculture, et son caractère prioritaire, appartiennent au passé. Les fonds actuellement disponibles pour la recherche et le développement et/ou pour les entreprises commerciales présentes en milieu désertique ne sont pas suffisants pour leur maintien. À l'exception de la production de micro-algues et d'*Artemia*, il n'existe pas de projets aquacoles commerciaux dans les déserts ou ans les espaces semi-arides australiens.

ملخص

تعتبر غالبية الأراضي الأسترالية قاحلة أو شبه قاحلة. وتشكل الصحاري ما نسبته ثمانية عشر في المائة من هذه الأراضي، والتي معظمها في الواقع غير مسكونة. وعلى إمتداد الصحاري الأسترالية الكبيرة، فإن المياه الجوفية موجودة بوفرة، وكل منها يتميز بخصائص كيميائية فيزيائية فريدة. والعديد من هذه المصادر للمياه الجوفية يمكن ان توفر خدمات من اجل تربية الأحياء المائية، وتتضمن: ضخ المياه الجوفية كجزء من أنظمة مواجهة الملوحة (SIS) لخفض مستويات المياه المالحة، وضخ المياه كناتج ثانوي من الفحم المنشق من تنقيبات الغاز، وأبار المياه الجوفية، وبحيرات الحفر وحفر المناجم المفتوحة غير المستخدمة. ونظرا لتميزها بالمستويات المنخفضة لمعامل الحموضة والتركيب الأيوني، فإن جودة المياه في هذه المصادر للمياه الجوفية تشكل قلقا رئيسيا. وفي الحقيقة، فإن أيونات البوتاسيوم (وهي حاسمة للعمليات الفيزيولوجية للأسماك) هي ناقصة بشكل كامل في هذه المياه. وخلال العقد الماضي، تم الاهتمام بالبحوث والتنمية في تربية الأحياء المائية باستخدام المياه الجوفية المالحة، وبشكل أساسي في المواقع شبه القاحلة. وتم تأسيس عدد من المراكز الإيضاحية في العديد من الولايات الأسترالية والتي تعرض التقنية المتوفرة التي يتم فيها تطوير وتجربة أنظمة مختلفة للعديد من أنواع الأسماك البحرية وأسماك المياه

العذبة. وعلى الرغم من نمو عدد من الأنواع السمكية في المياه الجوفية المالحة، إلا أن هناك نوعين فقط لديهما إمكانية تجارية: سمك النعاق الياباني (ملوأي، *Argyrosomus japonicus*) وتراوت قوس قزح (*Oncorhynchus mykiss*). وفي الوقت الحالي، فإن الطحالب المجهرية *Dunaliella salina* والارتيميا *Artemiasp.* هما فقط الذين يتم تربيتهما بشكل تجاري في المناطق الاستوائية الساحلية الجافة. إن المناطق الاستوائية الغربية والجنوبية معروفة باستزراعها الواسع للطحالب من نوع *D. Salina* والتي يتم تربيتها في بحيرات وأحواض ضحلة كبيرة وأهميتها تعزى بشكل كبير إلى البيتا كاروتين الطبيعية المستخدمة في الصناعات الغذائية، والتجميلية والدوائية، بالإضافة إلى كونها تشكل مصدرا مهما كغذاء في تربية الارتيميا. وخلال عدد من السنوات الأخيرة، عانت الولايات الشرقية الاستوائية من جفاف حاد والذي ساهم في تخفيض وفرة المياه الجوفية. وكنتيجة لذلك، حتى جهود أنظمة مواجهة الملوحة (SIS) قد انخفضت بشكل كبير بسبب المستويات المنخفضة للمياه الجوفية. وبالتالي، فإن النقص في مصادر المياه التي توفر كميات كبيرة هو أحد التحديات الرئيسية أمام توسيع تنمية تربية الأحياء المائية الصحراوية التي تستخدم المياه الجوفية المالحة. إن التركيز والأولويات نحو تنمية هذا النوع من تربية الأحياء المائية قد تتغير نحو جوانب أخرى. والتمويلات الحالية المتوفرة للبحوث والتنمية و/أو المشاريع التجارية في هذا المجال هي غير كافية تماما لإطالتها. وفيما عدا الطحالب المجهرية والارتيميا، لا يوجد هناك مشاريع تجارية للاستزراع الصحراوي (أو شبه القاحلة).

INTRODUCTION

Australia is a large continent characterized by a relatively small population concentrated along the coastal areas, with low seafood consumption per capita. When compared to other countries, the Australian aquaculture industry is composed entirely of small-scale operations, with no history of large-scale aquaculture ever present. The majority of species production found throughout Australia is composed of yellowtail amberjack (*Seriola lalandi*), giant tiger prawn (*Penaeus monodon*), barramundi (*Lates calcarifer*), edible oysters (*Saccostrea glomerata* and *Crassostrea gigas*), and silverlip pearl oyster (*Pinctada maxima*), as well as relatively large-scale production of salmon.

Diversification from traditional agriculture products was thought to benefit rural Australia. In fact, large semi-arid and arid areas with large reservoirs of groundwater were considered to have potential interest for inland aquaculture. As a result, Australia, both at federal and state government level, has invested in research and development focusing on aquaculture opportunities utilizing this untapped resource.

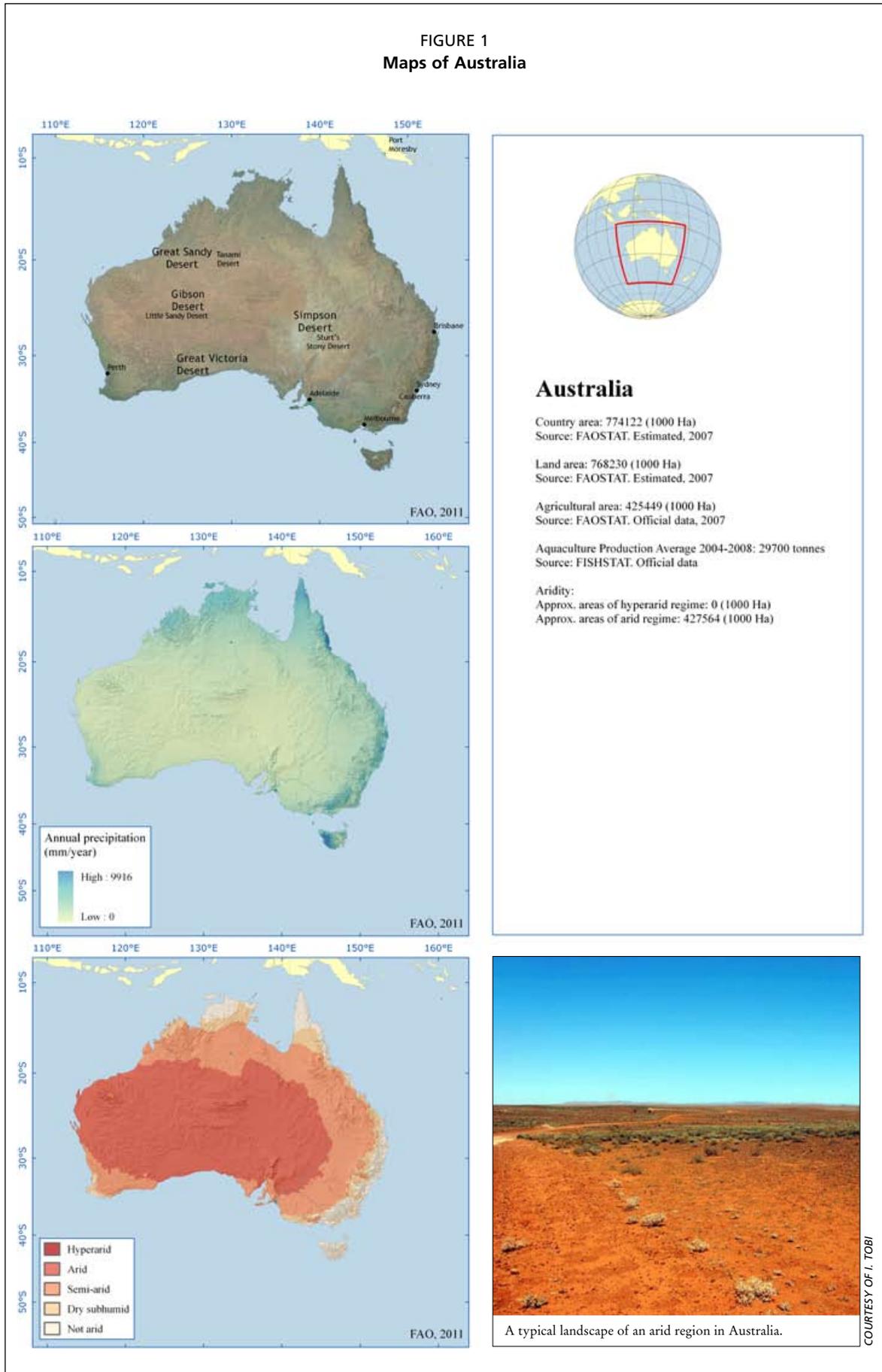
GEOGRAPHY

Australia comprises a land area of almost 7.7 million km². The bulk of the Australian land mass lies between latitudes 10° 41' south (Cape York, Queensland) and 43° 38' south (South East Cape, Tasmania) and between longitudes 113° 09' east (Steep Point, Western Australia) and 153° 38' east (Cape Byron, New South Wales). The most southerly point on the mainland is South Point (Wilson's Promontory, Victoria) 39° 08' south. The latitudinal distance between Cape York and South Point is about 3 180 km, while the latitudinal distance between Cape York and South East Cape is 3 680 km. The longitudinal distance between Steep Point and Cape Byron is about 4 000 km (Figure 1).

The land area of Australia is almost as great as that of the United States of America (excluding Alaska) and about 50 percent greater than Europe (excluding the former Union of Soviet Socialist Republics [USSR]). Apart from Antarctica, Australia is the lowest, flattest and driest of the continents. Australia's population in 2010 is just over 22 million, of which the majority of the population concentrates around the coastal areas (Australian Bureau of Statistics – www.abs.gov.au).

The largest part of Australia is considered to be desert or semi-arid land (Figure 1). Most of the deserts lie in the central and northwestern reaches of the country (Figures 2a and 2b). The combined desert area in Australia is 1 371 000 km² and occupies 18 percent of the continent (Table 1). Most of the deserts in Australia are uninhabited, or are inhabited by small towns, large farms and/or small aboriginal communities.

FIGURE 1
Maps of Australia



WATER SOURCE

Groundwaters abound in Australia, even within the expanse of the significantly large deserts. Water chemistry, quality and quantities vary significantly from place to place. The hydrogeological map of Australia (Commander, Jacobson and Lau, 1987) indicates the major aquifers' location, volume and yield. There are several major groundwater areas in Australia with salinity in the range of 20–40 g/litre including:

1. The lower Murray Hydrogeological Basin (Victoria);
2. Eyre Peninsula (South Australia);
3. Central Australia and Northern Territory;
4. Southwest of Western Australia.

Areas of brackish groundwater (1.5–5 g/litre) usually surround the higher salinity regions and include most of South Australia, Western Australia and areas of New South Wales, Victoria and Northern Territory and some areas in southwest and eastern Queensland (Allan, Banens and Fielder 2001; Allan, Heasman and Bennison, 2008).

Salination of both land and water resources is a critical problem in Australia that has rendered large areas of agriculture unproductive and is deteriorating the surface water quality in many areas (Figures 2a and 2b).

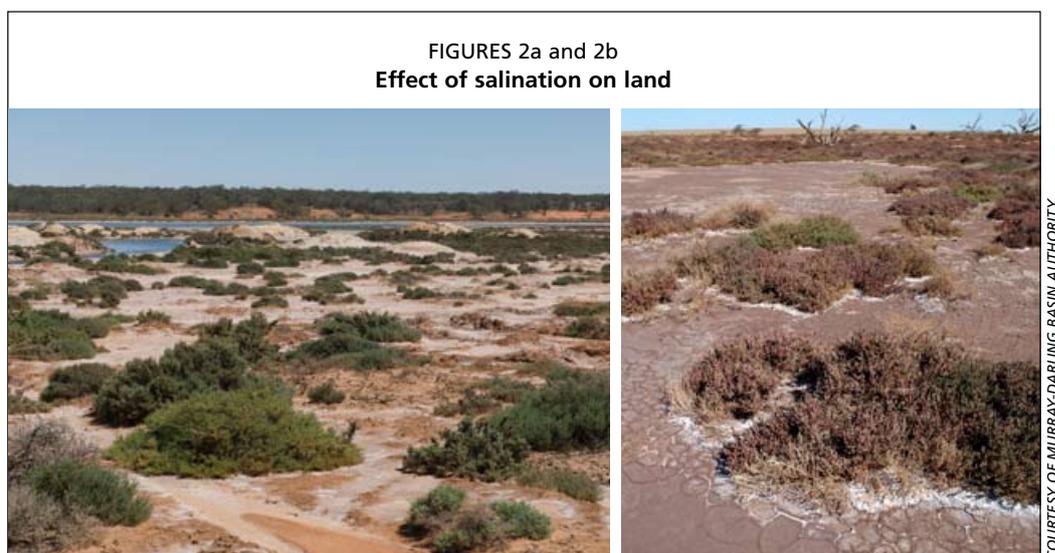


TABLE 1
Australian deserts

Desert	State/Territory	Size		Proportion of Australian landmass %
		km ²	Mi ²	
Great Victoria Desert	Western Australia, South Australia	348 750	134 650	4
Great Sandy Desert	Western Australia	267 250	103 190	3.5
Tanami Desert	Western Australia, Northern Territory	184 500	71 200	2.4
Simpson Desert	Northern Territory, Queensland, South Australia	176 500	68 100	2.3
Gibson Desert	Western Australia	156 000	60 000	2.0
Little Sandy Desert	Western Australia	111 500	43 100	1.5
Strzelecki Desert	South Australia, Queensland, New South Wales	80 250	30 980	1.0
Sturt Stony Desert	South Australia, Queensland, New South Wales	29 750	11 490	0.3
Tirari Desert	South Australia	15 250	5 890	0.2
Pedirka Desert	South Australia	1 250	480	0.1



The cause of the rising saline groundwater is due to the impacts of land-use by people. This form of salination occurs within irrigation systems (irrigation salinity) and/or dryland farming management (clearing trees, etc.) systems (dryland salinity). This anthropogenic salination mobilizes salt in the soil profile that reaches the groundwater and is transported to the surface as the water table rises (Gavine and Bretherton, 2007).

In 2000, it was estimated that at least 2.5 million hectares (less than 5 percent) of cultivated land in Australia were affected by salinity (AFFA, 2000) and 5.7 million hectares

are under high risk (Allan, Heasman and Bennison, 2008), with a predicted increase to 12 million hectares (22 percent) and up to 17 million hectares by 2050 (ANRA, 2001). The land and water degradation in Australia is considered to be one of the biggest challenges faced by the agriculture sector, costing more than AUD3.5 billion annually (AFFA, 2000).

To combat the rising salinity, Salt Interception Schemes (SIS) were developed in many areas (mainly in Victoria and New South Wales [NSW]). The SIS are engineered work solutions which intercept saline water flows and dispose of them, usually by evaporation (Figure 3). The use of evaporation basins for this purpose is not new (first recorded by Jutson in 1917). The scale and size of these projects vary between areas and states. A thorough survey of saline water resources around Australia was published by Allan, Banens and Fielder (2001). More recent reviews were published by Partridge, Lymbery and George (2008) and Allan *et al.* (2009). These studies looked at the potential aquaculture use of saline groundwater and evaporation basins.

The majority of the SIS occur in the Murray-Darling Basin (MDB), the biggest irrigated agriculture zone in Australia, accounting for 60 percent of the country's irrigated agriculture.

The MDB SIS, considered being the biggest in the world, discharge saline water to around 190 evaporation basins (Allan, Banens and Fielder, 2001; MDBC, 2008, 2010). These evaporative basins represent an opportunity for aquaculture projects. Allan, Banens and Fielder (2001) identify 11 evaporation basins in the MDB, covering an area of 6 250 ha, which may be suitable for aquaculture in terms of water quality and quantities, logistics and other criteria. However, in recent years, due to the effectiveness of the scheme and long-term drought, the pumping rates from the SIS have decreased, highlighting the risks for long-term commercial viability for potential aquaculture projects (MDBC, 2010). The saline groundwater level significantly subsided and many of the evaporation basins are, in fact, dry.

A slightly different approach to deal with salination is used in the Wheatbelt region of Western Australia (WA). This region accounts for more than 70 percent of the state's salinized land (Doupe', Lymbery and Starceвич, 2003). Western Australia does not have centralized management of SIS and in most cases is struggling to combat salination resulting from earthwork and open drains on farms or in townships (Trewin, 2002). Partridge, Lymbery and George (2008) suggested that, with already 38 towns in rural Western Australia under threat from rising salinity (George *et al.*, 2005), groundwater pumped from beneath these towns might become a source for aquaculture

ventures. However, in most cases, due to overlying rock or granite aquifers, the pumping yield is relatively small (George, 1990).

Another potential source of water could lie in the extraction of liquified natural gas from coal-seams for energy use. This relatively new industry (expanded from ten gas well drills in the 1990s to 600 in 2007/2008, Queensland Mines and Energy, Department of Employment, Economic Development and Innovation), based mainly in Queensland, produces, as a by-product, large volumes of water during the extraction of gas from drilled wells, usually with low salinity. Brinckerhoff (2004) reported that 65 percent of the 393 registered wells (in 2004) in Queensland have salinity of 3 g/litre or lower and only 1 percent have salinity over 18 ppt. Volumes vary significantly; however,

total water yield (Vink *et al.*, 2008) for 2007 was 34 000 m³/day with a predicted increase to 1 370 000 m³/day by 2020. Currently, some of the water is piped back into the aquifers, but the majority of the water is diverted into evaporation basins without any secondary use. In 2009, the Queensland Government changed the regulations in relation to the discharge water, forcing the mining companies to find a solution for the disposal of the water. Currently, there are still no solutions for treating the water. Irrigation and aquaculture are currently being looked at, however, the waste water from any potential aquaculture project will still need to be disposed of, by pumping it back into the aquifer or by other methods.

One of the limitations of using groundwater from active mining operations is the dependence on the mine activity. Cheap (or at no cost) access to water can only be secured while the mine is operating. If the mine or the pumping activity stops for any reason, the cost of pumping will have financial and logistical implications for the aquaculture operation.

Disused open-cut mines may present an opportunity for small-scale aquaculture ventures. Once pumping and de-watering stops, and surface and groundwater equilibrate, the open voids may form pit lakes (Castro and Moore, 1997; McCullough and Lund, 2006). There are an estimated 1 800 disused open-cut pits in Western Australia alone ranging in size and volumes from a few hectares and a few meters deep to several km² and hundreds of meter deep (Johnson and Wright, 2003) (Figure 4).

WATER QUALITY

Groundwater sources in Australia vary significantly (Allan *et al.*, 2009; Kumar, McCullough and Lund, 2009) in quality and quantity between areas, regions and even between similar close-by resources. Salinity, pH, ionic composition, temperature, contaminants (heavy metals, herbicides, etc.) vary between aquifer types, SIS drainage basins, evaporation basins, open-cut pits, and need to be tested at every location for their intended use (Table 2).

FIGURE 4
Disused open-cut mine



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TABLE 2
Water chemistry for different water sources around Australia

	Salinity ppt	pH	Alkalinity	Cl ⁻ mg/l	% ion relative to seawater	Ca ²⁺ mg/l	% ion relative to seawater	Mg ²⁺ mg/l	% ion relative to seawater	K ⁺ mg/l	% ion relative to seawater	Na ⁺ mg/l	% ion relative to seawater	SO ₄ ²⁻ mg/l	% ion relative to seawater	Reference
Coastal seawater	35	8.02	114	20 000	100	375	100	1 150	100	370	100	9 800	100	1 050	100	Kolkovski, 2010, personal comm.
Wakool (New South Wales)	19.6	7.9	195	11 000	55	504	134.4	820	71.3	9.2	2.5	4 210	43			¹ Fielders et al. 2001
Pyramid Salt groundwater (Victoria)	Vary (salt works)	–	–	21 000	105	590	157.3	1 400	121.7	90	24.3	–	–	–	–	¹ Gavin and Bretherton, 2007
Undrea (Victoria)	10	nr	Nr	4 130	20.7	350	93.3	470	41	25	6.8	2 700	27.5	1 280	122	¹ Ingram et al. 1990
Waikerie SIS (South Australia)	16.5	7.2	–	9 374	46.9	260	69.3	407	35.4	87	23.5	5 966	60.8	1 430	136	Hutchinson and Flowers, 2008
Stockyard Plains Disposal Basin discharge (South Australia)	17.2	7.1	–	9 861	49.3	431	115	506	44	88	23.8	5 161	52.6	1 644	156.6	Hutchinson and Flowers, 2008
Wannamal (Western Australia)	32	Nr	–	15 800	79	592	158	1 537	133.7	80	21.6	8 026	83.6	1 614	153.7	¹ Prangnell and Fotedar, 2006
Quirindi CSG ²	5	7.5–8	Nr	700	3.5	10	2.7	30	2.6	Nr	–	3 000	31.2	nr	–	¹ Dutney, pers comm
Stuart basin CSG ²	1.2–4.3	8–9	nr	590–1 900	2.9–9.5	3–9	0.8–2.4	1–3	0.08–0.26	Nr	–	300–1 700	3.1–7.2	5–10	0.47–0.95	¹ Anon, 2004
Collie basin (coal mine, Western Australia)	Nr	3.8–5	–	–	–	2.3–6	0.6–1.6	0.077–16.3	0–1.4	–	–	–	–	–	–	Kumar et al. 2009

¹ from Allan et al. 2009.

² CSG – Coal-seams gas.

Salinity – The salinity in groundwater vastly depends on the source of the water. In evaporation SIS basins, the salinity tends to be higher and depends on the rate of evaporation/recharge (Mazor and George, 1992). The authors reported that 66 percent of 88 wells tested in Western Australia's Wheatbelt (southeast region) had a salinity of 5–45 g/litre, suitable for euryhaline fish, while the salinity range between the wells was 0.28–320 ppt. These figures might be higher due to the increase in salination in the past decades.

Mine lakes and flooded open-cut pits are also prone to increase salinity, especially in arid and semi-arid areas with high evaporation and low (or no) recharge. For example, Johnson and Wright (2003) reported that the salinity in the Mount Goldsworthy pit increased from 14 to 55 g/litre over 14 years with an even more extreme increase from 15 to 79 g/litre over three years evident in the Keringal mine lake.

Pit water quality is influenced by many factors including climate, groundwater, depth (some of the pits are a few hundred metres deep), wind (or lack of it in sheltered mine pits) and local mineralogy (Boland and Padovan, 2002; Jones *et al.*, 2008; McCullough, 2008).

Ionic composition – Ionic composition of groundwater (of any source) represents a major challenge in terms of suitability of water (at any salinity) for growing any aquatic organism. Partridge, Lymbery and George (2008) noted that, although the main source of salt in the Australian landscape is oceanic (Mazor and George, 1992; Zaluzniak, Kefford and Nuggeoda, 2006), the ionic composition of saline groundwater varies considerably from seawater. Both Partridge, Lymbery and George (2008) and Allan *et al.* (2009) compared several elements that consisted of the majority of seawater ions (by dry weight; Spotte, 1992) seawater to several saline groundwater sources (Table 3). They noted that, aside from potassium, deficiencies or excesses vary between locations and sources.

Potassium, however, was deficient in all the water sources. Usually, the deficiency is caused by the uptake of potassium by clay soils over sodium (Stumm and Morgan, 1996).

Potassium has a pivotal role in many physiological cycles of cultured species and specifically in fish involved in osmo-regulation, as well as acid-base balance (Marshall and Bryson, 1998; Evans, Piermarini and Choe, 2005) and, therefore, its deficiency from groundwater is most significant. Potassium deficiency in groundwater was reported to cause mortality in several fish species. Fielder, Bardsley and Allan (2001) reported mortality of silver seabream (*Pagrus auratus*) reared in 19 g/litre groundwater with 5 percent K-equivalence to seawater (100 percent seawater). The mortality was reduced when the potassium content adjusted to 40 percent of seawater, but with significantly lower growth compared to fish reared in 60 percent K-equivalence. The same results were evident with Japanese meagre (mulloway, *Argyrosomus japonicus* – Doroudi *et al.*, 2006; Hutchinson and Flowers, 2008), barramundi (*Lates calcarifer* – Partridge and Creeper, 2004), and silver perch (*Bidyanus bidyanus* – Ingram, Mc Kinnon and Gooley, 2002; Fielder, Bardsley and Allan, 2001; Doroudi *et al.*, 2007). These authors found that the susceptibility to potassium deficiency is related to salinity, i.e. the lower the salinity, the higher the survival in potassium-deficient water.

pH – The pH range for fish culture is between 6.5–8.5, with 7.5–8 considered to be optimal. In many cases, groundwater is acidic with pH lower than 6 (Partridge, Lymbery and George, 2008; Hutchinson and Flowers, 2008; Allan, Banens and Fielder, 2001; Allan *et al.*, 2009). In many cases, the low pH is associated with high levels of metals such as iron and copper that are also toxic to fish (Lee, 2001; Gooley and Gavine, 2003). Buffering and removing or binding the metals is possible (Hunt and Patterson, 2004), however, not in a way that would be commercially feasible for large volume of waters.

TABLE 3
Open-cuts and disused mines characteristics

Parameter	Collie Basin, Western Australia	Collinsville, North Bowen Basin, Queensland	Mount Morgan, Queensland	Mary Kathleen, Queensland	Ranger Mine, Northern Territory	Kemerton, Western Australia	St Barbara Mines, Western Australia	Thalanga Mine, Queensland
Ore type	Coal	Coal	Au, Cu	U	U	Silica sand	Au	Cu-Pb-Zn
Depth (m)	8–70	4–14	–	–	–	6	–	70
Area (km ²)	0.06–1.03	0.01–0.06	–	–	–	–	0.006–0.95	–
pH	3.8–5.0	1.5–4.9	2.8	6.1	7.6	8.5	8.0–8.6	7.7
Total P	<0.005–0.009	<0.005	–	–	0.01	0.02	–	–
Total N	<0.05–1.5	0.51	–	–	1.96	0.573	7.3–22.8	–
Dissolved Organic Carbon	3.1–7.3	1–59	–	–	–	22	–	–
Salinity (gr litre ⁻¹)	<3	5–15	6.9	3	0	1	–	0.5
Sulphate	31–107	300–25 000	12 100	1 840	782	296	2 570–7 190	7 950
Aluminium (mg litre ⁻¹)	0.001–0.006	23–1 300	740	0.032	0.026	0.1	0.02–0.06	<1
Calcium	2.3–6.0	124–519	520	464	0.02	67	334–1 120	718
Cadmium	<0.002	<0.01–0.023	0.15	–	<0.0002	–	0.0002	0.16
Cobalt	<0.005	0.6–7.2	–	–	0.0005	–	–	–
Chromium	<0.10	<0.01–0.47	–	–	<0.002	–	0.002	–
Copper	<0.002–0.05	<0.05–2.5	36	1.17	0.0024	–	0.03	<1
Iron	0.0003–.005	139–2 463	248	3.23	<20	0.14	<0.05–0.06	0.575
Lead	–	<0.1–6.3	–	–	0.001	<0.1	–	<1
Magnesium	0.077–16.3	197–2 239	1 240	140	115	58	865–3 150	1025
Manganese	0.0002–1.2	13–150	81	–	0.041	<0.01	–	–
Nickel	0.03–0.34	1.2–17	–	0.69	0.0053	–	0.09	–
Uranium	–	0.020–0.029	–	0.460	1.76	–	–	–
Zinc	0.0005–6.9	1–46	25.3	0.088	0.0037	0.15	0.01	53.5
Chlorophyll α ($\mu\text{g litre}^{-1}$)	0.1–64	0–64	–	–	–	6.5–8.5	–	–

Many groundwater sources, especially from SIS (Hutchinson and Flowers, 2008), are acidic (as low as pH 2.5) due to the high levels of dissolved carbon dioxide (carbonic acid leached from carbonate-based soils). This low pH might be remedied by degassing the carbon dioxide. Depending on the acidity of the water and water volume, this process might be viable (Hutchinson and Flowers, 2008).

Other contaminants – Chemical (nutrients, heavy metals, herbicides and insecticides, organic compounds and others) and biological (pathogens and micro-organisms) contaminants exist in groundwater. Open-cut mines (Table 3), pit lakes, surface water and shallow groundwater are more prone to contamination than deep groundwater (i.e. coal-seam water). Several publications demonstrate different types of contamination in groundwater (Doupe', Lymbery and Starceovich, 2003; Fitzpatrick *et al.*, 2005; Sarre *et al.*, 1999; Scott and Solman, 2004; Nott *et al.*, 2004; Partridge, Lymbery and George, 2008).

CULTURED SPECIES

During the past decade, efforts were made to culture many aquatic organisms in most of Australia's states. Many experiments were conducted to look at the suitability of both fresh and marine species to groundwater (Partridge, Lymbery and George, 2008; Hutchinson and Flowers, 2008; Allan *et al.*, 2009). More than ten species of fish, microalgae, as well as *Artemia* and *Parartemia* have been tested. Most of the fish species tested were found to be susceptible to the groundwater conditions, mainly the ionic composition and pH.

Marine species such as snapper and yellowtail amberjack (*Seriola lalandi*) have been investigated using saline groundwater and/or manipulated groundwater. Although found to survive and grow (even though, in most cases, significantly less than in seawater), these species were not considered to be suitable for groundwater culture (Partridge, Lymbery and George, 2008). Barramundi, with its broad salinity susceptibility, was also tested (Partridge and Lymbery, 2008). However, its susceptibility to potassium, as well as the temperature drop during the night in inland saline areas, made this species not commercially viable for this type of culture (unless the use of an intensive indoor culture system is considered).

Other freshwater species such as silver perch that do not need potassium adjustments were also looked at (Allan, Heasman and Bennison, 2008; Allan *et al.*, 2009). However, day/night water temperature fluctuations up to 5 °C limited the growth.

Black bream seems to be an ideal species for groundwater culture, being euryhaline and robust (Doupé *et al.*, 2005). However, a very slow growth rate and a limited market prevents this species from becoming commercially viable.

In South Australia, Hutchinson and Flowers (2008) conducted proof-of-concept grow-out experiments with Japanese meagre (mulloway) in intensive and semi-intensive systems supplied with saline groundwater from SIS. The results demonstrated high survival and good growth rates but also identified high levels of dissolved carbon dioxide in groundwater, which was a limiting factor that would need to be addressed to improve performance of this species. Based on these results, an expression of interest for commercial use of saline groundwater from SIS in South Australia was presented. However, no commercial investment has eventuated to date.

Rainbow trout (*Oncorhynchus mykiss*) farming was trialled both in New South Wales (Allan *et al.*, 2009; Johnston, 2008) and Western Australia (WA) with small commercial production in WA. Currently, a very small production (a few tonnes per year) of trout is carried out in WA using groundwater.

Currently, only the microalgae, *Dunaliella salina* and *Artemia* are cultured on a large scale in Australia. *D. salina* is cultured both in South Australia (SA) and WA for its natural carotenoids by Cognis Australia (the company owns both sites in SA and WA and supplies more than 60 percent of the world's natural β -carotene).

Artemia is cultured both extensively and intensively. In SA, *Artemia* is cultured in large shallow natural saline ponds, with no added nutrients or feed, while in WA, the *Artemia* production is of a high-intensity and adjunct to the *D. salina* production lakes (Kolkovski, Curnow and King, 2010).

FARMING SYSTEMS

Different rearing systems were tested over the years. Recently, Partridge, Lymbery and George (2008) and Allan *et al.* (2009) reviewed many of these systems.

Pond-based systems – Allan, Banens and Fielder (2001) suggested that pond culture might be the most commercially viable production system for inland aquaculture. Ponds are considered to be the lowest capital investment system with, usually, the lowest maintenance costs. However, aside from biomass limitation, the potential areas for pond culture (salt affected areas, SIS water discharge areas, etc.) are located in inland areas (Figure 5), where temperatures in large water surface bodies, such as ponds, vary significantly between seasons with high daily fluctuations (Partridge, Lymbery and George, 2008; Allan *et al.*, 2009; Hutchinson and Flowers, 2008).

Allan *et al.* (2009) tested floating solar covers that completely cover a 500 m² Japanese meagre (mulloway) pond. The floating covers increase mean minimum winter and summer temperature by 1.5 °C and 3 °C, respectively, and had little effect on the major water quality parameters compared to uncovered, ambient ponds. The authors reported

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that after 12 months of grow-out, Japanese meagre cultured in solar-covered ponds achieved 20 percent more biomass than Japanese meagre in uncovered ponds. However, the commercial feasibility of covers (capital investment vs weight gain) was not reported.

Complete static pond systems are virtually impossible in arid and semi-arid areas of Australia due to the high evaporation rate and the need to compensate it. Luke, Burke and O'Brien (1987) calculated that five hectares of ponds in Western Australia's Wheatbelt (southeast region of Western Australia) would require 350 m³/day of water during

the summer months to compensate for evaporation.

Partridge, Lymbery and George (2008) also noted that even in static ponds, it might be that potassium ions will still need to be added due to the high affinity between this ion and the clay soils. The need for ion supplementation might not be commercially feasible for large-scale production systems. Allan *et al.* (2009) also reported reduced growth in static trout ponds due to build-up of organic matter.

It was considered that flow-through pond systems adjoining the evaporation basins and SIS might be viable, as long as there was no need for ion supplementation (Partridge, Lymbery and George, 2008). The ponds' discharge into evaporation basins is believed to result in very little environmental impact. However, even with a high flow-through regime, water temperature fluctuation in arid and semi-arid areas will still present significant issues.

However, Allan *et al.* (2009) reported that trout growth might be feasible. The authors reported good growth rates over a period of three months. Trout stocked at 40 g had an average wet weight of >310 g with near 100 percent survival during the winter months. The survival decreased as pond temperature exceeded 21 °C, suggesting that even 60 percent daily water exchange was insufficient to reduce the temperature increase.

Economic analysis for rainbow trout culture in raceways (Johnston, 2008) indicated that farms with a 200 tonnes/year production capacity might be viable and could produce an attractive rate of return on investment.

COURTESY OF PAUL SKORDAS (SARDI)



Tank culture – Production of Japanese meagre (mulloway) in large tanks supplied with groundwater from an SIS was found to be feasible at the Waikerie Inland Saline Aquaculture Centre, South Australia (Hutchinson and Flowers, 2008; Figure 6). The authors also tested the water chemistry from several sections of a major SIS and the systems disposal basin over 12 months.

The authors reported that the trials demonstrated that the level of salinity and potassium of SIS groundwater collected from the discharge point to the Stockyard Plain Disposal Basin did not significantly affect growth and metabolism of Japanese meagre (mulloway) in tanks.

Although potassium was only 40 percent of seawater levels, there was no effect on survival or growth. The authors pointed out that the elevated levels of dissolved CO₂, resulting in low pH, was a major issue with groundwater and needed to be addressed. To reduce the levels of dissolved CO₂, a degasser column with high ratio of air to water (>10:1) was installed to treat all incoming groundwater before use in culture systems. A similar problem with high CO₂ was also identified in the northwest of Western Australia, where bore (well) water was used for culturing common dolphinfish (*Coryphaena hippurus*). A degassing column (5 m high × 1 m Ø) increases the water pH from 6.5 to 7.9.

Enclosed tanks – A new tank system was developed to culture *Artemia*. The tanks are completely enclosed, aside from the manhole at the top. The designed 32 000 litre tanks addressed the biosecurity issues of rearing *Artemia* near *D. salina* ponds. The system includes an individual filtration system to each tank and unique aeration system to support high-oxygenated water at high salinities (Kolkovski, Curnow and King, 2010).

Shallow lakes – Shallow lakes and large shallow ponds are used for the production of microalgae. Currently, the only microalga cultured in Australia is *D. salina*. The private company Cognis Australia cultures the algae both in Western Australia (Hutt Lagoon, Port Gregory) and South Australia (Whyella). The lagoons were divided by dykes on the bed of the coastal lagoon, taking advantage of the impermeable hyper-saline crust. The ponds are shallow (0.2–0.4 m) to allow light penetration and high evaporation. The required salinity is managed by pumping seawater or beach wells through inlet channels diverted to each of the production ponds. The production process is summarized by Borowitzka (1995, 1999). The rate of harvesting and the growth period varies with changing climatic conditions throughout the year. The ponds are unlined and there are no mixing devices; the only mixing is by wind and thermal action.

An innovative system designed to reduce nutrients input into ponds by collecting the solid wastes was developed in Western Australia (McRoberts Aquaculture Systems – Partridge *et al.*, 2006). The system was designed to increase the production of the static pond by installing the semi-intensive floating tank system (SIFTS) tanks in the ponds. Partridge *et al.* (2006) described a series of growth experiments with Japanese meagre (mulloway), barramundi and rainbow trout using a prototype unit conducted in (relatively) small ponds using saline groundwater (14 g/litre). The SIFTS units' design and construction materials incorporate a reinforced liner, which forms a "suspended tank" fixed to a moulded module. These modules provide buoyancy to the structure, as well as a working platform around the tank. Large volumes of water are pumped through the SIFTS using air-water-lifts, which allow high stocking densities of fish to be cultured, without the need for pure oxygen. However, the authors did not encourage commercial interest in the use of SIFTS for inland saline aquaculture in Western Australia due to system limitation and constraints of available groundwater in large quantities, restricting the system to static ponds (Allan *et al.*, 2009).

ACTIVITY IN AUSTRALIA

Across Australia, man-made or naturally occurred salination of land and water is causing major impacts on agricultural production, rural infrastructure, drinking water, irrigation and aquatic biodiversity (Allan, Banens and Fielder, 2001). Aquaculture has been identified as one of the potential adaptive uses of saline groundwater.

In 1997, the Australian Centre for International Agricultural Research organized the first national workshop on inland saline aquaculture. Following this workshop, the Fisheries Research and Development Corporation (FRDC) supported the preparation of a research and development plan for developing commercial saline aquaculture in Australia (Allan, Digman and Fielder, 2001).

The interest in desert aquaculture (i.e. inland saline aquaculture, usually located in arid or semi-arid areas) has occurred because of the potential advantages and benefits it offers, as well as a solution to the increased salination problem. These advantages and benefits include:

- Providing opportunities to increase aquaculture production in Australia that, like in many other countries, is limited by a shortage of suitable coastal sites with the necessary characteristics for successful production. Such sites are often reserved for housing or tourist-related development, or judged to be of too high environmental value for aquaculture, while “unwanted” land and water affected by salination provides opportunities for inland saline aquaculture.
- Establishment of cost savings attributed to the low cost of land compared to coastal locations.
- In some situations, aquaculture species growth advantages are provided by the constant elevated water temperature of saline groundwater over-production in ambient water temperature conditions.
- Ability to operate production facilities in a biosecure manner due to the location and water supply from deep aquifers being isolated from parasites and diseases and their vectors.

Combined, these factors stimulate interest in finding ways to exploit saline groundwater resources for commercial aquaculture. The majority of research and development activities during the past decade were concentrated in the use of saline water for aquaculture. Several reports, business plans and scientific publications were generated (www.australian-aquacultureportal.com/saline). Allan, Heasman and Bennison (2008) and Allan *et al.* (2009) summarized the research and development carried out within the participating states. However, aside from microalgae and *Artemia* production, almost all the activity remained at the experimental/research stages.

Victoria – The Victorian Government through the Department of Primary Industries is strongly supporting a multi water-use, integrated agri-aquaculture systems (IAAS) approach to diversification of the irrigated agriculture sector in the Victorian reaches of the Murray-Darling Basin. The primary focus of Victorian IAAS development is to add value and sustainability to irrigation water through application of multi water-use systems based on open-water cage culture of Murray cod (*Maccullochella peelii*) in large-scale private irrigation storages. The most recent IAAS developments in Victoria as part of the Our Rural Landscape initiative are reported by Gooley *et al.* (2007). Present Victorian Government-funded IAAS research and development activity is being delivered as part of the Aquaculture Futures Initiative for the period 2008–2009 to 2011–2012. Research and development priorities include development of better management practices for open-water cage culture of Murray cod, as well as development of a marker-assisted selective breeding programme for a large-scale supply of high performing, elite strains of Murray cod seed stock.

Currently, there is no Victorian Government-funded research and development on inland saline aquaculture.

Queensland – The Queensland Department of Primary Industries and Fisheries investigated the potential for inland saline aquaculture in several regions where groundwater salinity is suitable for shrimp production. Research effort has focused on determining the suitability of groundwater for prawn farming at salinities ranging from

almost fresh to full-strength seawater. In 2002, these studies were applied to a series of trial ponds in collaboration with an existing red claw crayfish (*Cherax quadricarinatus*) farm at Bauple, north of Brisbane (Collins *et al.*, 2005). Investigations were conducted to assess the suitability for aquaculture to utilize waste groundwater produced as a by-product during coal seam gas (methane) extraction. This research and development was undertaken in collaboration with an energy company that operates power generation systems in the Darling Downs where extensive coal-seam gas resources are being exploited. (Source: Modified from www.australian-aquacultureportal.com).

New South Wales – The Inland Saline Aquaculture Research Centre (ISARC) was established by the NSW Government in partnership with Murray Irrigation Limited (MIL). MIL operates the Wakool-Tullakool Subsurface Drainage Scheme at Wakool, NSW. This is the largest saline groundwater evaporation scheme in Australia, pumping up to 13 000 000 m³ per annum of saline groundwater to 1 600 hectares of evaporation ponds. ISARC was constructed in a corner of one of the evaporation ponds.

This facility has supported investigations on the survival and growth of several species in saline groundwater, including silver perch, Japanese meagre (mulloway), giant tiger prawns (*Penaeus monodon*), kuruma prawns (*Penaeus japonicus*), rainbow trout, New Zealand rock oysters (*Saccostrea glomerata*), and snapper (Allan, Heasman and Bennison, 2008; Allan *et al.*, 2009; Doroudi, Allan and Fielder, 2003; Doroudi *et al.*, 2006; Fielder, Bardsley and Allan, 2001). Pilot-scale trials with trout resulted in very good growth rates (initial wet weight of 37 g and final average wet weight of 298 g after three months with 100 percent survival). Production trials (2006/2007) have identified that the best opportunity for commercial inland saline aquaculture development in southern New South Wales is (relatively) medium-scale (200 tonnes/year) farming of rainbow trout. Currently, the major limitation to inland saline aquaculture in this area is the lack of saline groundwater following a number of years of drought that has caused the water table to retreat progressively deeper (Allan, Heasman and Bennison, 2008).

The Department of Primary Production was involved in co-coordinating with the National Aquaculture Council, the fragmented inland saline aquaculture research in Australia through several federal-funded projects. This involved an earlier resource inventory (Allan, Banens and Fielder, 2001) and national research and development plan (Allan, Digman and Fielder, 2001). Results from the following project (2004–2008) are summarized in the final report (Allan, Heasman and Bennison, 2008). Currently, there is no NSW Government-funded research on inland saline aquaculture.

South Australia – The South Australia Research and Development Institute (SARDI) has previously investigated the use of saline groundwater for aquaculture at Cooke Plains Inland Saline Aquaculture Research Centre (CPISARC). This facility was established in collaboration with the Coorong District Council and the research was conducted from 1997 to 2003. At this location, the source of saline groundwater was a shallow aquifer 1–2 m below the soil surface in an area impacted by dry land salinity that is extensive in this region. The volume of saline groundwater available at this location was limited with water temperature varying seasonally and similar to ambient soil temperature. The species cultured at CPISARC were Japanese meagre (mulloway), snapper, brine shrimp (*Artemia* spp.), Pacific oyster (*Crassostrea gigas*), seaweed (*Ulva* sp.) and microalgae (*Dunaliella salina*).

The South Australia Research and Development Institute has identified that saline groundwater from a major SIS in the Riverland region offers an opportunity for aquaculture, including the consistent supply of a relatively high volume (350 litre/sec) of pressurized water with a relatively stable elevated water temperature (20–22 °C) and moderate salinity (19–21 g/litre). This situation differed to other states where available saline groundwater was supplied from evaporation ponds from a large subsurface

drainage scheme (NSW) or naturally occurring saline lakes (WA). A semi-intensive aquaculture system was installed by SARDI at the Waikerie Inland Saline Aquaculture Centre (WISAC) to investigate the use of SIS discharge water for aquaculture. Research and development activities undertaken at WISAC established Japanese meagre (mulloway) as a potential species (Hutchinson and Flowers, 2008).

Small-scale operations exist for inoculating and harvesting *Artemia* in saline lagoons. The private operator is seeding natural lagoons with *Artemia* cysts and harvests them from time to time. This is an extensive operation with an estimated 10 m³ harvest per annum. The only major commercial operation is *D. salina* (Cognis Australia) culture in large ponds in Whyella.

Western Australia – Although during the past decade research into the development of inland saline aquaculture was given some priority and funding from both Federal and State agencies, this is not the case anymore.

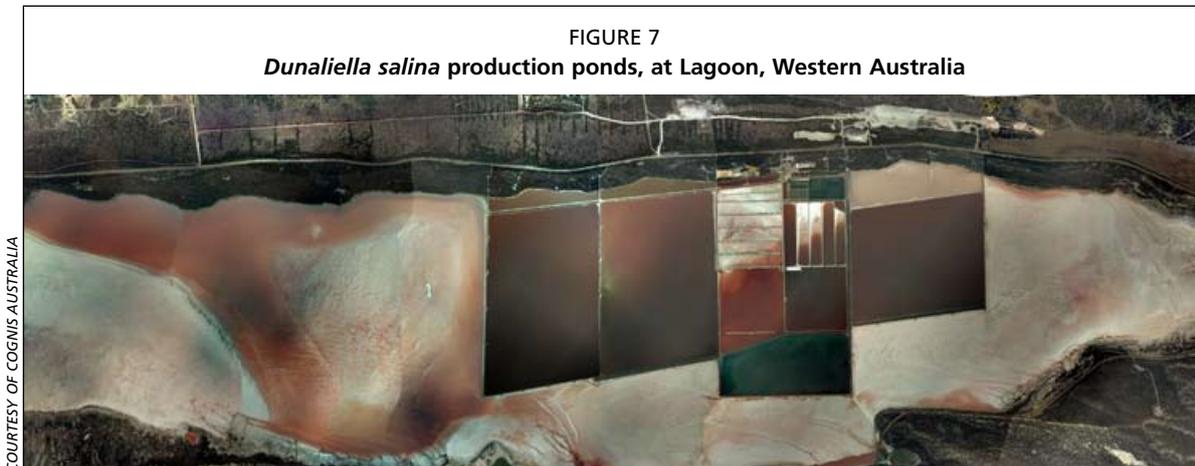
The Western Australian (WA) inland saline aquaculture research effort was comprised of researchers from Challenger TAFE (Technical and Further Education, Tertiary Education Institute) Aquaculture Development Unit (ADU), CY O'Connor TAFE, Western Australia Department of Agriculture and Murdoch University. Collectively, these organizations made up the Inland Saline Aquaculture Applied Research Group (ISAARG). Particular effort has been directed towards development of the SIFTS patented by McRobert Aquaculture Group and the ADU (see 'systems' section). Species investigated for inland saline aquaculture in WA include barramundi, Japanese meagre (mulloway), snapper, black bream, rainbow trout, ornamental fish (range of species, mostly live-bearers) and black tiger prawn. No commercial activities resulted from the ISAARG research efforts.

The only commercial desert aquaculture in Western Australia is *D. salina* and *Artemia* aquaculture at Hutt Lagoon, Port Gregory (Figure 7). (Source: Updated extracts from www.australian-aquacultureportal.com).

Demonstration research facilities – Research or demonstration facilities that focus on inland saline aquaculture were established in a few states, including Queensland, New South Wales, South Australia and Western Australia. At all locations, demonstration facilities were used to hold open days and to provide a source of biological and technical information to potential investors, government officials and members of the public.

A federal-funded communication and coordination project was established to facilitate and coordinate the research and development work on a national level (Allan, Heasman and Bennison, 2008). As part of the project, an investment directory was developed, providing a single point source for information on inland saline aquaculture. This contained contact details of researchers, salinity managers, government policy

FIGURE 7
Dunaliella salina production ponds, at Lagoon, Western Australia



makers and those involved with farming. A research and development priorities plan was highlighted and a comprehensive risk analysis framework developed (www.australian-aquacultureportal.com).

IMPEDIMENTS TO DEVELOPMENT

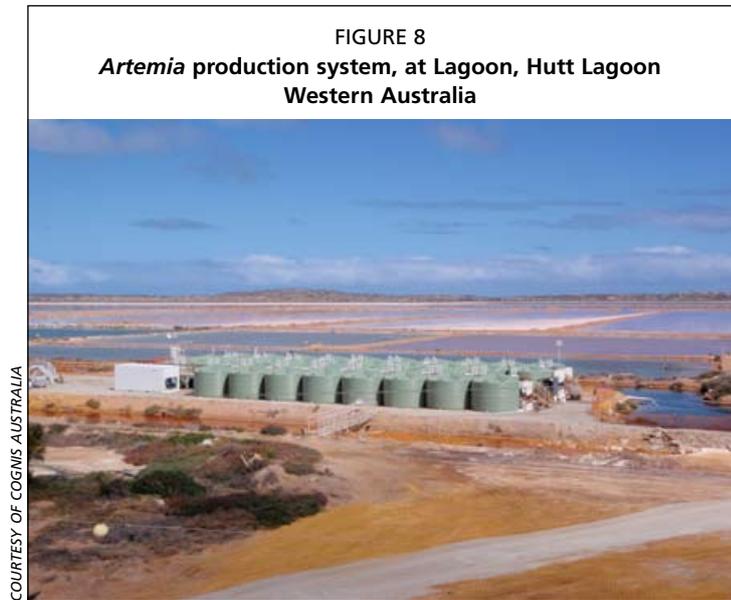
Water source – The biggest constraint to commercial development of inland saline/desert aquaculture in NSW, Victoria and Southern Australia (SA) is the deficit of saline groundwater as a result of severe, long-term drought in most of the eastern and southern Australia regions and specifically in the Murray-Darling Basin (MDB) system (Allan, Heasman and Bennison, 2008; Allan *et al.*, 2009). The extended drought has meant that little or no freshwater irrigation has been available and no significant rainfall (and in some parts, none at all) in the MDB for several years. As a result, the groundwater table has not been recharged and the saline groundwater table significantly dropped. Therefore, salinity interception schemes were reduced and were not needed. Allan, Heasman and Bennison (2008) reported that in the Wakool-Tullakool subsurface drainage scheme, the pumping volume of saline groundwater dropped from 35 000 m³/day to 4 000–5 000 m³/day.

Suitable species – Although some fish species, such as Japanese meagre (mulloway), were identified as potential species for saline aquaculture, most of the species tested were found to be not suitable for saline aquaculture due to improper water ion profile and water temperature. Although ions can be supplemented to the rearing system, it does not seem to be commercially viable in large systems. In many areas, species could only be reared part of the year, while during the rest of the year, the growth would be suspended or the fish would die. For example, barramundi and Japanese meagre could be grown in the warmer months of the year but would not survive (barramundi) or will stop growing (Japanese meagre) during the winter months. Trout is the opposite example as it grows very well during the winter, but does not survive the summer months. Although Partridge, Lymbery and George (2008) suggested that alternate species according to the season might be possible, this option is yet to be tested on a commercial basis.

Water quality, in many cases, is also presenting a major obstacle with low pH, salinity and, as mentioned above, ion profile. Indeed, each one of these obstacles can be resolved, but at a cost. In large commercial-scale operations, this option would, in all likelihood, not be viable.

Environmental, social and economic issues – In many cases, groundwater sources are located in rural Australia, making transportation to and from aquaculture locations expensive. Cost of labour, power and associated work with the establishing aquaculture venture is expensive. For example, in most cases, fish feed needs to be transported from Tasmania or Queensland to Western Australia, a few thousands kilometres away, significantly adding to existing feed costs. These costs are especially high compared to neighbouring countries in Southeast Asia. Therefore, it will be hard to compete on the frozen white flesh segment market, although it might be possible to compete in some niche markets (as proven with rainbow trout). In many cases, people interested in starting an aquaculture venture are farmers that are interested in diversifying their activities. In these cases, the scale of production is usually limited to a few tonnes, making these ventures unfeasible.

Markets – Australian markets are relatively small, with a population of only 22 million and moderate seafood consumption compared to other countries such as Japan, Mediterranean countries, etc. Although niche markets exist for certain species (trout, live and fresh barramundi and others), in general, it is hard to compete with the influx of imported frozen seafood from Southeast Asia.



SUCCESS STORY

Dunaliella salina and brine shrimp culture

During the last five years, the Department of Fisheries – Western Australia (DoFWA) and Cognis Australia developed a unique system incorporating rearing *Artemia* sp. in tanks adjunct to *D. salina* rearing ponds (Kolkovski, Curnow and King, 2010) (Figure 8).

The microalga *D. salina* is cultured in large, shallow ponds in Hutt Lagoon, Port Gregory, WA (600 km north of Perth). The lagoon is divided into very large and shallow ponds in a similar way to salt works evaporation ponds. Salinity is monitored and kept

at its optimum by pumping seawater through incoming water channels (Figure 8). The algae, usually green at low salinity, produce carotenoids (mainly beta-carotene) in a high salinity environment. As the algae reach the required level of carotene, they are harvested and concentrated into a paste using a proprietary process. The water returned to the ponds and the carotenoids are then extracted from the algae biomass, which is then discarded. Several years ago, a natural bloom of *Artemia* occurred in the ponds.

The company teamed up with DoFWA to eradicate the *Artemia* from the algae ponds. Following successful removal of the *Artemia* from the ponds, it was suggested to try to culture the *Artemia* in separate ponds. A research and development project was launched and funded by the FRDC (a federal funding agency). Early attempts to culture *Artemia* were conducted in 18 m³ shallow ponds, where a number of issues were identified.

The primary concern with pond production was contamination of the biomass product. Therefore, the decision was made to culture *Artemia* in covered flow-through tanks, which would allow much more control over the quality of the product. However, at this point, adequate filtration, aeration, culture media delivery and culture methods needed to be developed in order to succeed.

Of great concern to Cognis was the issue of biosecurity, due to the fact that *Artemia* are the primary pest species for the *D. salina* production. Therefore, in parallel to developing culture systems and techniques for growing *Artemia*, biosecurity such as outlet screening, safety control and spillage containment needed to be developed.

The rearing system is based on closed plastic-moulded (aside from the manhole at the top) 32 000 litre tanks with a water inlet and filters that retain the *Artemia* in the tank on the outlet (see Figure 8).

Development efforts were given to design a new, innovative filtration system that allow the flow of tens of thousands of litres per hour through the screens without damaging the *Artemia* or becoming blocked with the *Artemia* waste.

An outlet biosecurity/harvest screen was also designed, constructed and installed within the main drainage manifold. This apparatus enabled the harvesting and separating of different size *Artemia* and cysts in one pass. Effluent is then safe to return to the ponds directly into the effluent channel. The returned water is rich with nutrients from the *Artemia* waste, helping fertilizing the algae ponds.

The *Artemia* tanks receive a mix of seawater and pond water to adjust and optimize the salinity. The *Artemia* is also receiving the algae biomass and water (still containing high level of algae cells) after the extraction of carotenoids.

This link between the algae production and the *Artemia* production made the project commercially-viable with the existing infrastructure for the algae production, as well as skilled operators that can work on both production systems.

The system is vertically integrated, linked to feed (*D. salina*) production on-site, packaging and freezing facilities. Currently, the main product is frozen biomass. Other products such as cysts, feed attractant (patented) and enriched *Artemia* will follow shortly.

While there are other *Artemia* grow-out sites around the world, the majority of them are based on open ponds, low-tech production systems and investment. The *Artemia* rearing system at Hutt Lagoon, WA is the first super-intensive *Artemia* rearing system in the world.

THE WAY FORWARD

During the past decade, intensive efforts were invested in ‘inland saline’ aquaculture in Australia both by federal and state agencies. Water sources, suitable species and culture systems were investigated and developed. However, in most cases, the high investment and strong interest by potential investors, farmers and companies did not translate to commercial projects. One of the reasons for the lack of commercialization is the severe drought in Australia’s eastern states. Over the last ten years, the emphasis has gone from a national priority to address salinity (with a multi-billion dollar budget) to a lack of water in many areas. For example, in the NSW SIS schemes, all 60–70 pumps have been turned off for the first time in 30 years. In addition, the landowners who would have been expected to invest in inland saline aquaculture have no financial means due to the drought.

Unfortunately, very little, if any, research and development funding is currently available for arid/semi-arid and inland saline aquaculture. Coupled with the reduced availability of groundwater across Australia, the development of large-scale commercial aquaculture ventures based on groundwater in the Australian arid/semi-arid areas does not appear to be viable in the near future.

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An overview on desert aquaculture in Central Asia (Aral Sea Drainage Basin)

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SUMMARY

Central Asian countries are bounded in the northwest by the Aral Sea, a basin which dominates the whole region. The climate is extremely continental and arid. The average annual precipitation is about 100–200 mm in the plains; 30–50 percent of the total rainfall is in the spring, 25–40 percent in winter, 10–20 percent in autumn and 1–6 percent in summer. There are three main climatic zones in the Republic of Kazakhstan, Republic of Turkmenistan and the Republic of Uzbekistan: (sand) deserts and dry semi-deserts (steppes); foothills (piedmont areas); and mountains. The history and present status, traditions, main production systems, technologies, cultured fish species, etc., in desert and arid lands aquaculture development in all former Soviet Republics/Central Asian countries have very common characteristics. The end of commercial fishery in the Aral Sea in 1983 due to desiccation has had a significant impact on the aquaculture development of this region. Uzbekistan can be considered as a model for this review as it has typical characteristics for the region. The aquaculture sector in the Aral Sea Drainage Basin (ASDB) countries was established under Soviet rule. Before 1961, the only fish available on the market originated from capture fisheries, mainly originating from the Aral Sea. Fisheries managers already knew that the Aral Sea was drying up and that fisheries in reservoirs and lakes could not produce enough fish to meet the demand of the rapidly growing population of Central Asia. The attention of policy makers, therefore, shifted slowly to aquaculture development. In the early 1960s, local governments, in cooperation with the All-Union Ministry for Fisheries, managed a large-scale programme of aquaculture development, establishing >30 farms with a total pond area of ~31 000 hectares in Central Asia, including the southern part of Kazakhstan. Most were in Uzbekistan. This programme included the development of new technologies and the establishment of research and education facilities. The technology mainly promoted was extensive and semi-intensive cyprinid polyculture in earthen ponds. The species reared were common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. nobilis*) and grass carp (*Ctenopharyngodon idellus*). As a result, the fish farms of Central Asia produced ~38 000 tonnes in the 1980s. By the beginning of the 1990s, ~21 000 tonnes of pond fish were produced annually in Uzbekistan alone.

Currently, pond culture of cyprinids is still prevalent in all Central Asian countries. Silver carp became the most cultured species and constitutes 70–85 percent of total production. However, the total area of ponds in the desert and arid lands of the ASDB has decreased considerably and is estimated to be ~15 000 hectares; this has been caused by economic difficulties and permanent water deficit, which makes filling the huge fattening ponds difficult. As in all other countries, consumer demand for fish is increasing in Central Asia, along with general development and increasing incomes. Generally, the consumption of fish in the 1980s was ten times what it is today. The current demand is, therefore, at least ten times more than existing annual fish production.

RÉSUMÉ

Les pays d'Asie centrale sont bordés au nord-ouest par la mer d'Aral, un bassin qui domine l'ensemble de la région. Le climat y est extrêmement continental et aride. Les précipitations annuelles y sont en moyenne comprises entre 100 et 200 mm dans les plaines, avec 30 à 50 pour cent des précipitations au cours du printemps, 25 à 40 pour cent pendant l'hiver, 10 à 20 pour cent durant l'automne et seulement 1 à 6 pour cent en été. On relève trois grandes zones géographiques et climatiques dans cette région formée par la République du Kazakhstan, le Turkménistan et la République d'Ouzbékistan : les déserts (de sable) et semi-déserts secs (steppes), les contreforts montagneux (zones au pied des montagnes) et les montagnes. En matière de développement de l'aquaculture en milieu aride ou désertique, l'histoire comme la situation actuelle, les traditions, les principaux systèmes de production, les technologies, les espèces de poissons élevées, etc. ont des caractéristiques communes dans toutes les anciennes républiques soviétiques et dans tous les pays d'Asie centrale. La fin de la pêche commerciale dans la mer d'Aral en 1983, due à son assèchement, a eu des effets importants sur le développement de l'aquaculture dans la région. Dans le cadre de cette étude, l'Ouzbékistan peut être considéré comme un modèle car il représente des caractéristiques typiques pour la région. Le secteur aquacole a été créé dans les pays du bassin de la mer d'Aral conformément à la législation soviétique alors en vigueur. Avant 1961, les seuls poissons disponibles sur le marché provenaient de la pêche de capture, principalement dans la mer d'Aral. Les responsables du secteur savaient déjà que la mer d'Aral allait disparaître et que la pêche pratiquée dans les réservoirs et dans les lacs ne pourrait pas produire suffisamment de poissons pour satisfaire la demande d'une population croissant rapidement dans la région. L'attention des décideurs politiques s'est donc lentement déplacée vers le développement de l'aquaculture. Au début des années 1960, en coopération avec le ministère soviétique de la Pêche, les autorités locales ont lancé un programme de développement de l'aquaculture à grande échelle, avec la création de plus de trente exploitations dont les étangs couvraient une superficie totale d'environ 31 000 hectares en Asie centrale, y compris dans la région sud du Kazakhstan. La majorité de ces fermes piscicoles ont été créées en Ouzbékistan. Le programme comprenait la mise au point de nouvelles technologies et la création de structures de recherche et de formation. Les technologies encouragées visaient essentiellement la polyculture extensive ou semi-intensive de cyprinidés en étang. Les espèces cultivées étaient la carpe commune (*Cyprinus carpio*), la carpe argentée (*Hypophthalmichthys molitrix*), la carpe à grosse tête (*H. nobilis*) et la carpe herbivore (*Ctenopharyngodon idellus*). Dans les années 1980, la production des exploitations piscicoles d'Asie centrale s'élevait à environ 38 000 tonnes. Au début des années 1990, la production de poissons élevés en étang atteignait environ 21 000 tonnes seulement en Ouzbékistan. Actuellement, l'élevage de cyprinidés en étang domine toujours la production piscicole en d'Asie centrale. La carpe argentée est devenue la principale espèce élevée. Elle représente entre 70 et 85 pour cent de la production totale. Cependant, à cause des difficultés économiques rencontrées et d'un déficit permanent en eau qui rend difficile le remplissage des immenses étangs d'engraissement, la superficie totale des étangs a considérablement baissé dans les zones

désertiques et arides du bassin de la mer d'Aral. On estime qu'ils couvrent aujourd'hui environ 15 000 hectares. En Asie centrale comme partout ailleurs dans le monde, la demande en poissons ne cesse d'augmenter. Elle accompagne le développement global et l'augmentation des revenus. De façon générale, la consommation de poissons était dans les années 1980 dix fois supérieure à celle d'aujourd'hui. La demande actuelle est donc au moins dix fois supérieure à la production.

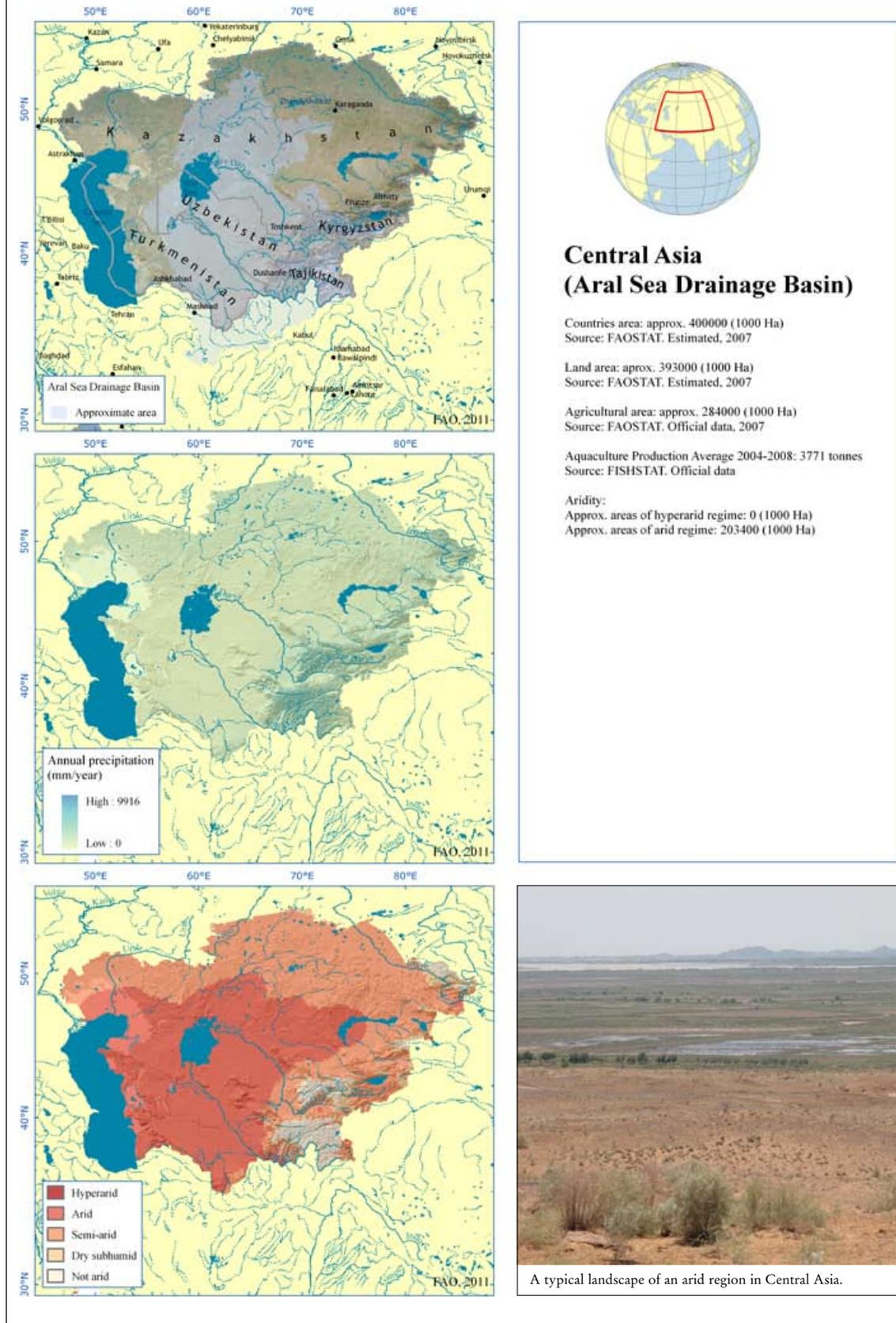
ملخص

يحد بحر الاورال بلدان آسيا الوسطى من الجانب الشمالي الغربي، وهو بمثابة حوض يسيطر على المنطقة بأكملها. والمناخ هو قاري وجاف جدا. ويصل متوسط المعدل السنوي لسقوط الأمطار الى 100 200 ملم في السهول؛ و 30 و 50 في المائة من إجمالي كمية الأمطار تسقط في فصل الربيع، و 25 و 40 في المائة في فصل الشتاء، و 10 و 20 في المائة في الخريف و 1 و 6 في المائة في فصل الصيف. هناك ثلاثة مناطق مناخية رئيسية في جمهورية كازخستان، وجمهورية تركمنستان وجمهورية اوزبكستان: الصحاري (الرمل) وشبه الصحاري القاحلة (السهول)؛ التلال (مناطق سفوح الجبال)؛ والجبال. ان تاريخ والحالة الحالية، والتقاليد، وأنظمة الإنتاج الرئيسية، والتقنيات، والأنواع السمكية المستزرعة، الخ. في تنمية تربية الأحياء المائية الأرضية الصحراوية/الجافة في جميع بلدان آسيا الوسطى/الجمهريات السوفيتية السابقة لديها صفات عامة مشتركة. ان نهاية الصيد التجاري في بحر الاورال في عام 1983 بسبب الجفاف كان له تأثير مهم على تنمية تربية الأحياء المائية في هذه المنطقة. ويمكن اعتبار اوزبكستان نموذجا لهذه الدراسة وذلك لكونها تتميز بصفات مثالية في المنطقة. وقد تم تأسيس قطاع تربية الأحياء المائية في بلدان حوض تصريف بحر الاورال (ASDB) وذلك في ظل الحكم السوفيتي. وقبل عام 1961، فان السمك المتوفر في الأسواق كان مصدره قطاع المصايد التقليدية، وبشكل أساسي كان مصدره بحر الاورال. ويعلم مدراء المصايد السمكية الآن ان بحر الاورال يموت وان المصايد في البحيرات والخزانات المائية لايمكن ان توفر كميات كافية من الأسماك للوفاء بالطلب المتزايد بشكل مضطرب للسكان في آسيا الوسطى. وبالتالي، فإن اهتمام صانعي السياسة قد تحول بشكل بطيء الى تنمية تربية الأحياء المائية. وفي بدايات الستينات من القرن الماضي، قامت الحكومات المحلية بالتعاون مع جميع وزارات الثروة السمكية في بلدان الاتحاد بإدارة برنامج كبير لتنمية تربية الأحياء المائية وذلك بتأسيس أكثر من ثلاثين مزرعة بمساحة إجمالية للأحواض وصلت الى 31000 هكتار في آسيا الوسطى، وتتضمن الجزء الجنوبي من كازخستان. ومعظمها كان في اوزبكستان. ويتضمن هذا البرنامج تطوير تقنيات جديدة وتأسيس تسهيلات للبحوث والتعليم. والتقنية التي طبقت بشكل أساسي كانت هي الاستزراع المتعدد الموسع وشبه المكثف للشبوبيات في الأحواض الترابية. والأنواع المستزرعة كانت الكارب الشائع او ما يسمى بالشبوط (*Cyprinus carpio*)، والكارب الفضي او الشبوط الفضي (*Hypophthalmichthys molitrix*) والكارب ذو الرأس الكبير او الشبوط كبير الرأس (*H. nobilis*) والكارب العشبي او الشبوط العشبي (*Ctenopharyngodon idellus*). وكننتيجة لذلك، فان مزارع الأسماك في آسيا الوسطى أنتجت 38 000 طن في الثمانينات من القرن الماضي. ومع بداية التسعينات من نفس القرن، يتم إنتاج 21 000 طن سنويا من أسماك الأحواض في اوزبكستان وحدها. وحاليا، فان استزراع الأحواض للشبوبيات مايزال هو السائد في جميع بلدان آسيا الوسطى. وقد أصبح الشبوط الفضي أكثر الأنواع المستزرعة ويمثل 70 و 85 في المائة من الإنتاج الكلي. ومع ذلك، فان المساحة الإجمالية للأحواض في الصحراء والأراضي الجافة في منطقة حوض تصريف بحر الاورال (ASDB) قد انخفضت بشكل كبير وتم تقديرها تقريبا بـ 15 000 هكتار؛ وذلك بسبب الصعوبات الاقتصادية والنقص الدائم في المياه، والذي جعل من الصعوبة ملء أحواض التسمين الكبيرة. وكما هو الحال في جميع البلدان الأخرى، فان طلب المستهلكين على الأسماك قد ازداد في آسيا الوسطى، سوية مع التنمية العامة وزيادة الدخل. وبشكل عام، فان استهلاك الأسماك في الثمانينات من القرن الماضي كان أكثر بعشر مرات عن معدل الاستهلاك الحالي. وبالتالي فان الطلب الحالي أكثر على الأقل بعشر مرات عن الإنتاج السنوي الحالي للأسماك.

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

Central Asia (CA) covers an area of 3 994 300 km² (Figure 1), about two-thirds of which are drylands and include some of the most sparsely populated regions in the world. CA is bounded on the northwest by the Aral Sea, a basin which dominates the whole region. The Aral Sea Drainage Basin (ASDB), which is situated within CA and covers an area of 2.2 million km² and is home to around 50 million people, comprises

FIGURE 1
Maps of Central Asia countries around the Aral Sea Drainage Basin



the drainage area of two major rivers – the Amudarya and the Syrdarya – and the Aral Sea itself.

The climate is extremely continental and arid. January is generally the coldest month (with a mean temperature of -2 to 0 °C in the south and -12 to -8 °C in the northwest) and July is the warmest (mean temperatures of 25 to 30 °C in the plains and 20 to 25 °C in the mountains). The average annual precipitation is about 100 – 200 mm in the plains, which is lower than the rate of evaporation. Downstream Amudarya and desert zones are the areas with the lowest precipitation, having an average rainfall of <100 mm (UNDP, 2008). Thirty to 50 percent of the total rain falls in the spring, 25–40 percent in winter, 10–20 percent in autumn and 1–6 percent in summer. Most rivers and lakes freeze over from late December until early January/mid-February. The waters supported the development of economically and culturally rich civilizations around oases based on the development of irrigated agriculture, which has been continuously and sustainably practised in the region for thousands of years.

The development of agriculture, including aquaculture and capture fisheries, in arid and desert lands within the ASDB has a common problem – a deficit of river water because of its irrational and inefficient use for irrigation. The distribution of water resources is extremely unfavourable in the vast plain areas occupied by deserts and semi-deserts. During the Soviet period, irrigation activities in Central Asia were directed mainly to the growing of cotton. The production of other agricultural goods, especially the production of meat and fish, was widely neglected. This situation was aggravated by the drying of the Aral Sea itself; now the protein supply for the population can only be met through the import of meat and fish (Karimov, 2003; Karimov, Keyser and Kurambaeva, 2002; Karimov *et al.*, 2004, 2005).

The historical and current development of aquaculture has many similarities in all the arid and desert areas of the ASDB. Five newly independent states appeared in the ASDB after the breakdown of the Soviet Union in 1991 (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan). These countries have embarked upon independent and regional approaches to nature conservation, including fisheries issues.

The Aral Sea is the world's fourth largest lake, but it was only recently that the scientific community of the region was allowed to talk about the catastrophic ecological changes in it and its river deltas. As a direct result of Aral Sea desiccation, about 500 000 hectares of spawning areas and fish migratory patterns have been totally destroyed.

The history, traditions, main production systems, technologies, species, etc., in desert and arid lands aquaculture development in all countries of the former Soviet Republics/Central Asian countries have the same characteristics. Uzbekistan can be considered as a model country having most of the typical characteristics of these countries; this review, therefore, concentrates on this country.

The per capita consumption of fish in Uzbekistan is very low (estimated to be 0.4 kg/year). This situation is typical of other CA countries, except Kazakhstan, where it is ~ 8 kg/year. Enhancing per capita fish consumption at levels recommended by health specialists would have social and economic importance. It is therefore, a priority of the governments in Uzbekistan, Tajikistan, Turkmenistan and Kazakhstan to improve the yield of fish from small and large water bodies. More attention should also be paid to the development of aquaculture, for which climatic conditions are highly suitable. Some preliminary experience in the development of aquaculture in small fish ponds exists.

Traditions in desert aquaculture development in the region

The fisheries sector in ASDB countries was established under Soviet rule. In Uzbekistan and Kazakhstan before 1961, the only fish available on the market was from the capture fisheries, mainly from the Aral Sea and the deltaic water bodies of the Amudarya and

Syrdarya rivers. The landlocked Aral Sea was rich in fish species, and Uzbekistan captured an average of 25 000 tonnes of valuable fish per year and another 20 000 tonnes was captured by Kazakhstan (Tleuov, 1981, Karimov and Razakov, 1990). By the 1960s and 1970s, fish yields had decreased sharply in the Aral Sea, and in 1983 the last catch officially recorded was only 50 tonnes (Kamilov, Karimov and Keyser, 2004). The fishing industry in Uzbekistan had to find new sources to supply fresh fish to the market. Up to 6 000 tonnes of fish were caught annually in the reservoirs and lakes of Uzbekistan in the 1970s and 1980s. However, the fisheries managers of the former USSR already understood in the 1960s that capture fisheries could not produce enough fish to meet the demand of the rapidly expanding population of the CA Republics.

The attention of scientists and policy makers moved slowly towards aquaculture development. In the early 1960s, the governments in cooperation with All-Union Ministry for Fisheries managed a large-scale programme of aquaculture development including the establishment of more than 30 fish farms (totalling ~31 000 ha) in the CA. Most were established within Uzbekistan. The development of new technologies and the establishment of research and education centres for fisheries and fish culture were other key components of that programme. The main technology promoted was extensive and semi-intensive cyprinid polyculture. As a result, fish farms in Uzbekistan alone produced 20–25 000 tonnes/year in the 1960s and 1970s; productivity was the highest of all the regions of the former USSR, averaging 3 to 3.5 tonnes/hectare in Uzbekistan and as much as 4 tonnes/hectare in the Tashkent region.

In Tajikistan, the first hatchery was established in 1951 (Thorpe and van Anrooy, 2009). Originally covering 72 ha, the farm expanded within 20 years to >200 hectares and produced 14 million larvae for domestic and export purposes. Between 1970 and 1990, new ponds with an area of 2 500 hectares were established in Tajikistan, including a spawning-nursery pond in the Kayrakkum fish farm in the arid north of the republic. In 1988, a fish reproduction complex of regional significance, with a capacity of 250 million larvae of carp and phytophagous fish species, was created at the foot of the Djami Fish Farm. This complex was unique in the CA and included semi-intensive culture and extensive polyculture of carps in earthen ponds. The species cultured were *Cyprinus carpio*, *Hypophthalmichthys molitrix*, *H. nobilis* and *Ctenopharyngodon idellus*. Aquaculture provided 3 298 tonnes of fish or 70–80 percent of the marketed fish before its independence in 1991 (Thorpe and van Anrooy, 2009). However, after independence, aquaculture production sharply decreased; by 2006, only 210 tonnes were produced – only 20 percent of that were reared before independence (Thorpe and van Anrooy, 2009). According to A. Khaitov (personal communication, 2008), this decline is attributed to institutional failure following the deterioration of economic relations with the former USSR (especially with Uzbekistan, Kazakhstan and the Russian Federation); this led to sharp increases in the market price of fish feeds, petroleum, oil and lubricants and a lack of spare parts to repair fish culture equipment and hatcheries; in addition, the civil war damaged the economic and social life in Tajikistan.

In Kazakhstan, aquaculture began in 1970 and by the end of 1980s there were 12 farms with a total area of 5 041 hectares (3 313 hectares of fattening ponds and 728 hectares of fingerling ponds). By the beginning of the 1990s, the number of fish farms had risen to 47. During the period from 1970 until 1990, the volume of fish production through aquaculture increased from 692 tonnes to 9 883 tonnes (Timirkhanov, Chaikin and Makhambetova, 2007). In the desert and arid regions of Kazakhstan – the so-called Aral-Syrdarya basin (the Syrdarya, Shardara and Shymkent fish farms [South-Kazakhstan] and Kosjar [Kamyshlybas] fish farm in Kosjar Village at Lake Kamyslybas [Kyzylorda region]) mainly produced fish seeds and reared common carp, silver carp and grass carp in polyculture and functioned successfully until the beginning of the 1990s. However, by the year 2004, most of the 17 fish farms had already ceased operations. By 2006, only 175 tonnes of fish were produced in the

remaining 12 fish farms (Timirkhanov, Chaikin and Makhambetova, 2007). Today, the situation in these enterprises is very poor for many reasons, including the absence of broodstock or fish breeding programmes, new technologies, low quality of feeds, lack of specialists, etc. This has been exacerbated by a sharp increase in fish imports (herring, salmonids, etc.) which has made farming fish uneconomic (Timirkhanov, Chaikin and Makhambetova, 2007). The development of aquaculture in Kyrgyzstan started in the late 1950s with the establishment of the Chui state fish farm (now the joint-stock company Balyk) as a regional fish hatchery with a total pond area of 370 ha. In addition to the production of table fish, various carp species were also provided for stocking. The main cultured species in arid and desert land aquaculture were similar to the other republics: silver carp, common carp and grass carp. The Uzgen fish farm (Osh region), with an annual capacity of 500 tonnes, started in 1968. The Talass fish farm existed in 1975; at best it produced ~300 tonnes of common carp and Chinese carps per year. At the end of the 1980s, there were about 1 310 hectares of ponds, but after its independence in 1991, these farms were practically closed because of well-known economic problems. Aquaculture production fell from ~1 500 tonnes in 1989 to about 30 tonnes in 2006 (Niyozov *et al.*, 2007).

The Republic of Turkmenistan possesses one of the largest sandy deserts in the world – the Karakum Desert. The total production of fish in 2006 was ~15 000 tonnes. Pond aquaculture with a total surface area of about 1 400 hectares was practised in the Ashgabat (Gerens), Tedzhan and Karamat-Niyaz fish farms, which were constructed during the Soviet period. Between 1991 and 1995, aquaculture production declined by 50 percent (from 2 100 to 1 050 tonnes) and by 1997 it had decreased further to 342 tonnes. This was largely attributed to the lack of domestically produced fishmeal and other feed components and the rapidly progressing deterioration of ponds, mainly due to siltation. Currently, aquaculture and inland capture fishery production is insignificant. At present, the only active fish hatchery facility in the country is Biotilsimat, which provides fingerlings and fry to the state for restocking activities and to two private small-scale fish farmers (Thorpe and van Anrooy, 2009). Neither inland capture fisheries nor aquaculture is considered to be a priority by the government.

In Uzbekistan, aquaculture has been the main fish producing sector since 1985, but the proportion decreased from a peak of 85 percent in 1983 to a trough of 52 percent in 2008, as the proportion from capture fisheries increased. Recognizing the collapse of the Aral Sea Fishery, two fish farms were constructed in the lower reaches of the Amudarya River in Karakalpakstan, mainly to produce fish for restocking. However, both the Nukus and the Muynak fish farms are now abandoned. Rehabilitation of these facilities and the development of fish farming provide opportunities to use limited water resources in the lower reaches of rivers to produce more marketable fish. The present potential productivity in fish farms in Uzbekistan is ~3 000 kg/ha, as opposed to 5–10 kg/hectare (or 30 kg/hectare in the case of restocking of common carp and Chinese carps) in natural water bodies. The Muynak fish farm alone, with its 500 hectares of fish fattening ponds, could produce at least 1 500 tonnes of fish/year (Karimov *et al.*, 2005). The rehabilitation and intensification of aquaculture in the Nukus fish farm (which has not functioned for the last 20 years, but in 2007, the newly established Karakalpak-Russian joint venture Nukusbalik Ltd. began rehabilitation measures) provides the potential to produce at least 3 000 tonnes/year of valuable fish. These may be used to supply the Muynak canning factory. There are also other possibilities to develop small fish farms, e.g. cage culture in irrigation canals and drainage water collectors.

A modern motto for fisheries development in the desert and arid areas of the Aral Sea Region could be: “*Move from unpredictable capture fisheries in unstable water bodies to intensive fish farming that provides constant fish yields and jobs for the local population*”.

FIGURE 2
Fish harvest from a large fish pond in the Khorezm Fish Farm



COURTESY OF B. KARIMOV

The main farmed fish production unit in the northwestern part of Uzbekistan since 1974 has been the Khorezm fish farm, constructed on a non-conventional desert land area on the periphery of an agricultural oasis. Until the early 1990s, the Khorezm fish farm (with 1 484 hectares of ponds) produced about 3 000 tonnes/year, mainly of silver, common, bighead and grass carps (Figure 2). However, during recent years, it has produced only about 1 000 tonnes of fish/year, due to economic difficulties, water scarcity and the absence of formulated (balanced) fish feed.

Main production systems, technologies and species

The prevalent type of aquaculture in the desert and arid areas of the CA is the polyculture of cyprinids in large earthen ponds. The species cultured are common carp, silver carp, bighead carp, and grass carp. Crucian carp (*Carassius auratus*), wels (*Silurus glanis*) and snakehead (*Channa argus*) are cultured as additional or accidental species in some fish farms. The growing season lasts from late March/April to October/November. Market-size fish are produced within a two-year production system: during the first year, small fry are raised in fingerling ponds (10–50 ha) to at least 25 g; after the winter season, they are transferred to fattening ponds – grow-out ponds – (70–150 ha) where they grow to marketable sizes of 500 g to 1 kg. The total duration of this full production system is ~540 days. Where farms only operate part of the production cycle, fattening takes ~270 days and the rearing of fingerlings takes 180 days.

Historical review

Uzbekistan (and other CA countries) had a relatively good production of fish from desert and arid land aquaculture before and immediately after its independence in 1991 (Table 1). The average pond productivity was 3.0 to 3.3 tonnes/hectare in the 1970s and 1980s, which was high compared to the average of 1.5 to 1.7 tonnes/hectare in the former USSR during the same period. At that time, aquaculture produced about 20 000–21 000 tonnes/year (Kamilov, Karimov and Keyser, 2004).

During the Soviet era and in the early 1990s, liming and fertilization were common practices in pond management. These activities stimulated the development of plankton in the water body as natural feed for silver carp and bighead carp and of plants for grass carp. Supplementary feeds were given to common carp and, partly for grass carp. Good quality commercial fish feeds were available; these had protein levels of 28–32 percent for fry and early fingerlings and 24–28 percent for grow-out. All farms had well equipped laboratories, with good management and well educated experts. Broodstock were available and larvae from several hatcheries were transported to all regions of the Republics of Central Asia. Fish production and reproduction technology was well documented and financing for fish farms was available. Successful results of research work were applied. Generally, the support for aquaculture development was considered effective. Cyprinid culture was well developed in Uzbekistan and other republics. In addition, there was one small trout farm called Tavaqsay that produced 20–50 tonnes per year (1970s and 1980s) in Uzbekistan and another – the Turgenev trout farm – in Kazakhstan. There were also some experimental intensive aquaculture projects, including the introduction of new species, such as channel catfish (*Ictalurus punctatus*),

TABLE 1
Fish production in Uzbekistan, 1980–2009 ('000 tonnes)

Year	Total fish production	Fish production	
		Fish pond farms	Natural water bodies
1980	16.7	11.5	5.2
1990	26.5	20.4	6.1
1991	27.2	20.3	6.9
1992	28.1	20.9	7.2
1993	23.4	16.8	6.6
1994	15.3	12.2	3.1
1995	12.5	8.9	3.6
1996	8.0	5.8	2.2
1997	8.4	5.3	3.1
1998	8.8	6.1	2.7
1999	8.2	5.5	2.7
2000	8.7	5.3	3.4
2001	8.8	5.4	3.4
2002	7.8	5.2	2.6
2003	5.4	3.3	2.1
2004	4.3	2.4	1.9
2005	6.1	3.2	2.9
2006	7.2	3.8	3.4
2007	7.1	4.0	3.1
2008	7.9	4.1	3.8
2009	9.2	5.1	4.1

Siberian sturgeon (*Acipenser baieri*), three species of buffalo fish (*Ictiobus cyprinellus*, *I. bubalus* and *I. niger*), some strains of rainbow trout (*Oncorhynchus mykiss*), etc. However, even when research projects proved to be successful, the centrally planned economy maintained the emphasis on carp culture (Uzbekistan was one of the biggest carp producers in the former USSR).

Present status

The pond culture of cyprinids remains prevalent in Uzbekistan and other CA countries. No improvements have occurred because of the lack of investment after the cessation of the USSR. As inorganic fertilizers are much cheaper than fish feeds, most attention is paid to liming and fertilization in order to stimulate phytoplankton development. Commonly used fertilizers are urea, ammonium nitrate and ammonium phosphate, in addition to cattle manure (Figure 3). For this reason, silver carp became the main cultured species and now represents 70 to 85 percent of total aquaculture production. Common carp, together with grass carp and bighead carp, are now considered additional fishes. Some farmers use supplementary feeds (mainly bran, cottonseed husk, wheat) for common carp feeding, while other farmers do not provide supplementary feeds. Occasionally, grass carp are fed with freshly cut plants (mainly reeds).

FIGURE 3
Use of cattle manure in the Khorezm Fish Farm



COURTESY OF B. KARIMOV



COURTESY OF B. KARIMOV

Artificial reproduction, using hormonal or pituitary injections, incubation (Figure 4), and larvae and fry rearing to fingerlings (so-called summerlings) are commonplace. Over-wintering is generally carried out in smaller ponds than in former times. Large ponds (50–100 hectares or more) are filled with fresh river water every year in spring and stocked with the yearlings. This requires considerable expense and labour to ensure forage reserves are available (to make the water fertile). Stocking densities for yearlings of 15–25 g are between 1 500 and 2 000/ha; these are cultured until autumn. Forage is added to the ponds in the summer season (in well-managed ponds, 5 kg of forage produces 1 kg of fish).

According to our observations, most ponds (~93 percent) are used for fish production. The rest (usually small enterprises) combine the cultivation of fish with rice (paddy-cum-fish farming) and ducks.

In autumn, the water, with its accumulated fertility, is discharged from the ponds and all the fish have to be sold within a few days. Then the ponds remain empty from autumn to spring. In the spring, they are refilled with fresh “infertile” water. Under the planned economy, fish farmers were mainly concerned to meet their production targets, not to

consider commercial aspects. Currently, private farmers are seeking ways to reduce costs and increase productivity. In large fish farms (e.g. Khorezmbalikmakhsulotlari), aquaculturists have started to market table fish gradually, keeping them until January in deep wintering ponds.

Some large fish farms stock at higher densities (up to 3 000–4 000 fish/ha), resulting in the need to raise the fish for a third year. These farms aim to produce more valuable fish weighing 1.5–3.0 kg. This practice is profitable because there is still no real competition and taxes on land and water use are low.

There are problems with fish diseases, the most widespread being saprolegniosis. *Ichthyophthiriosis*, *diplostomosis*, *lerneosis* and krasnuha (spring viraemia of carps or roseola) are also frequent. Frequently damaged species are common carp and grass carp (Sidorov, 2005). In some cases, water quality problems are accepted as the main cause of fish diseases and mass mortality. Fish diseases may become more important as more intensive methods become utilized.

During 1991–2007, there were no attempts to modernise aquaculture production systems. The only new private fish farm oriented towards intensive fish culture is the NT Fish Farm (Tashkent Region), which was established at the end of 2007. Flow-through tanks for trout were constructed and operations began in 2008. This farm was based on the results of the German Uzbek Research Project funded by the German Federal Foundation for Environment (Wecker *et al.*, 2007). However, this farm is situated in the foothills with high rainfall.

Potentially, the fish ponds of Uzbekistan have the capacity to produce 26 000 tonnes of fish annually. However, for over 15 years, they have not been well maintained,

as funds were generally lacking. Thus, total aquaculture production gradually decreased from about 20 000 tonnes at the beginning of the 1990s to not more than 4 000–5 000 tonnes in 2007–2009 (see Table 1). The combined nursery ponds in the country can produce as many as 93 million yearlings annually. However, due to poor financing and management, actual production is much lower (estimated to be not more than 10 million/year).

The German-Uzbek Research project was followed in 2007 with support from the FAO TCP/UZB/3103(D) Project, which developed a working plan for the development of aquaculture and fisheries in Uzbekistan for 2008–2016. This document has gained government attention, but the resultant programme is primarily concerned with the rehabilitation of existing fish farms. Despite this, several hundred new small private fisheries enterprises have appeared, but most are concerned with capture fisheries; only a few started to cultivate carps in ponds using old production systems, technologies and species. Modern technologies will only be introduced when the government makes financial resources and other necessary facilities available.

HUMAN RESOURCES

Since ancient times, fisheries have been one of main sources of food for local people. During Soviet times, the fishing industry was a main branch of the economy of the whole Karakalpakstan autonomous republic. Traditionally, fish and fisheries meant everything for the people of the Amudarya River delta. They used to catch fish and process them in the Muynak Fish Canning Factory (MFCF). Muynak traditionally had three main types of employment: fishermen, fish cannery workers and cattle breeders. According to Tleuov (1981), there were about 1 200 fishermen involved in 12 capture fishery collective farms. They had 113 fishing boats and caught about 75 percent of total fish in the country.

The MFCF was a significant employer and was equipped with modern fish processing equipment imported from Germany in the 1933–1941 era. It included five other smaller fish processing plants situated on the southern and southwestern coastlines of the Aral Sea. During the years of favourable ecohydrological conditions, MFCF was a major producer of canned fish and other fish products in the ASDB. However, by 1974, production had been cut by half and other plants had ceased to exist at the end of the 1970s. The supply of frozen oceanic fish imports from Russia dried up and the factory became unprofitable, but it continued to function on a reduced scale using locally produced silver carp. Today, the factory is practically out of operation.

In those days, many people worked in ship maintenance plants, the Aral shipping company or in other branches of local industry engaged in fishing or fish processing. A few were also involved in the coastal tourism industry.

It is not possible to differentiate employment data between aquaculture and capture fisheries. In the 1980s, more than 70 farms and enterprises were active in the fisheries sector (capture fisheries and aquaculture) and 5 600 to 5 800 people were employed by the enterprises of the republican Fisheries Committee, Uzbekribvod (the Commission for the protection of fish resources) and Ribsbit (Fish trade). Under the planned economy, all of them worked as full-time employees. In addition, about 100–150 specialists worked at the Central Asian Branch of Gidroribproekt (Institute for the promotion of fisheries projects) and the Central Asian ichthyo-pathological laboratory (both situated in Tashkent).

During the independence, in the period 1994–2003, significant changes took place in the sector, job security and salaries were low and there were no new entrants. At the start of the privatization process, the trading companies left the sector. Other enterprises followed suit and only a few fish farms and capture fisheries enterprises remained active. As a consequence, the number of people employed in the sector decreased significantly, particularly in the early years of the privatization process.

When the full privatization of fisheries was permitted, the number of enterprises increased as existing enterprises were split into several smaller units and new enterprises were created. The number of people employed in the sector also slightly increased (Karimov *et al.*, 2009). It is estimated that about 5 700 people were employed in 2007 in fisheries activities. Of these, more than 2 000 worked in 21 fish farms. Total employment in fisheries in Uzbekistan, including all the support services, is much higher, being estimated at ~10 000 (Karimov *et al.*, 2009). Most of those with diplomas in fisheries, fish breeders, mechanics, technical and engineering employees can be found in Tashkent (44 percent of total workers), while the rest are spread between the remaining four provinces (Ferghana, Navoi, Andijan and Karakalpakstan). Currently there is a lack of qualified personnel in the aquaculture sector.

In 2008–2009, there were 2 022 people employed full-time in fish farming in Uzbekistan (FCDC MAWR, unpublished data), of which 1 693 were men. There were also 337 employed part-time (301 men).

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

At present, the total pond surface area of all fish farms in desert and arid ASDB has considerably decreased compared to the early years of independence, due to economic difficulties and permanent water deficit for filling the unmanageable gigantic fattening ponds. While there were 18 fish farms in Uzbekistan in 1991 with a total pond surface of more than 20 000 ha, by 2007 there were 21 farms with a total pond surface area estimated at 10 237 hectares (Karimov *et al.*, 2009), i.e. only 49 percent of ponds were in use. After the issuance of the State Programme on measurements of fisheries sector development in the republic in 2009–2011 in 2009, which created favourable conditions for the establishment of new fish farms in all parts of the country, the number of fish aquaculture farms started to increase rapidly. By the middle of 2009, the total number of new farmers registered as culturing fish in ponds and other artificial water bodies in Uzbekistan reached 700 (FCDC MAWR, unpublished data). The total pond surface area was 12 630 ha, including 10 932 hectares of fattening/grow-out ponds and 1 698 hectares of nursery ponds (see Table 2 for more details). Most of them were created in the Tashkent, Samarkand and Andijan regions. The expected total production of fish from aquaculture was 5 550 tonnes but the actual production in 2009 was 5 162 tonnes. Most of this total production came from large-scale aquaculture enterprises that were established already in Soviet times. According to our analyses, only 107 fish farms produce fish today in quantities of more than one tonne/year. Most of the newly established enterprises actually capture fish or are involved in culture-based fisheries, introducing Chinese carps and common carp fingerlings.

Current estimates are that the total area of fish ponds in desert and arid ASDB is presently is not more than 15 000 ha.

CULTURED SPECIES

The fish species contributing most of the aquaculture production are the following, in descending order of value:

- silver carp (*Hypophthalmichthys molitrix*);
- common carp (*Cyprinus carpio*);
- bighead carp (*Hypophthalmichthys nobilis*);
- grass carp (*Ctenopharyngodon idellus*);
- crucian carp (*Carassius auratus*).

PRODUCTION

According to FCDC MAWR (Karimov *et al.*, 2009) it is mainly phytophagous fish that are being reared in the large fish farms (Table 3) – mainly silver carp, grass carp and bighead carp, which constitute about 88.5 percent of total production. Common

TABLE 2
Details of fish farms in the Central Asia countries

No.	Province	Town/village	District	Names of the farm	Year of foundation	Pond area, ha			Full-time employees	Fish production 2009, tonnes
						Total	Fattening	Nursery		
KAZAKHSTAN (Kyzylorda and south Kazakhstan regions)										
1	Kyzylorda Region	Kosjar	Aralsk	Kosjar fish farm	1966	176	0	176	103	**
2	South-Kazakhstan Region	Shardara	Shardara	Shardara fish nursery	-	-	-	-	-	**
KYRGYZSTAN (only southern part)										
1	Osh region	Uzgen	Uzgen	Uzgen fish farm	1968	290	224	66	-	7.7 (in 2007)
2	Talass region	Bakai-Atin	Bakai-Atin	Talass fish farm	1975	364	296	68	-	15 (in 2007)
TAJIKISTAN (only northern part)										
1	Sogd region	Kayrakkum	Khodjand	Shukufon	1992	-	0	-	-	-
TURKMENISTAN										
1	-	-	-	Biotilsimat	-	-	0	-	-	**
UZBEKISTAN										
1	Karakalpakstan	Nukus	Nukus	Nukusbalyk Ltd.	1974	46	0	46	36	2
2		Turtkol	Turtkol	Antika fish	2008	10	9	1	-	10
3		-	Chimboy	Khudaybergen Guidaga	2009	9.8	-	-	-	5.3*
4		-	Konlikul	Atabek	2009	2	-	-	-	2*
5	Andijan	Balikchi	Ulugnor	Olimp Koshonasi Lmtd.	2008	84	74	10	-	40
6		-	Andijan	Andijanbalyk JS	1975	986	894	92	-	362
7		-	Andijan	Zh.Kabilov sahovati	2009	2	-	-	-	4*
8		-	Andijan	U.Mashrabjon	2009	3	-	-	-	6*
9		-	Asaka	Asaka sazan	2009	1.4	-	-	-	4*
10		-	Balikchi	Abad yurt fayzi	2009	5	-	-	-	10*
11		-	Boz	O. Toshboev	2009	3	-	-	-	6*
12		-	Jalakuduk	Ok amur karp	2009	2	-	-	-	4*
13		-	Izboskan	Mukarramhon umidlari	2009	3.3	-	-	-	7*
14		-	Hojabad	Kora amur	2009	3	-	-	-	5*
15		-	Shahrihon	R.Razakov	2009	18.3	-	-	-	20*
16		-	Altinkul	F.Vohidov	2009	4	-	-	-	8*
17	Bukhara	-	Bukhara	Bukharabalyk Ltd.	-	574	428	146	-	-
18	Kashkadariya	-	Nishan	Sof Khavzalar Ltd.	2004	90	-	-	7	80
19		-	Karshi	Kashkadaryabalyk Ltd.	1980	409	359	50	32	200
20		-	Mirishkor	Olim ogli Sherzod	2009	6	-	-	-	4*
21		Mirishkor	Mirishkor	Achin baliklari Ltd.	2008	-	-	-	-	7.5
22	Namangan	Pap	Pap	Namanganbalyk Ltd.	1976	800	600	200	-	226
23		Pap	Pap	Madaminjon Ota Ltd.	-	90	90	0	-	-
24		-	Mingbulok	Altin zamin barakasi	2008	30	-	-	-	14.3*
25		-	Mingbulok	Mashrab Kadir	2008	12	-	-	-	10.8*
26		-	Narin	M.Parpiev	2008	65	-	-	-	70*
27		-	Narin	K. Mingboev	2009	3.5	-	-	-	4*
28		-	Uychi	Nodirbek	2009	4.5	-	-	-	2*
29		-	Ichkurgan	Ok amur royasi	2009	1.5	-	-	-	1.5*
30	Navoi	M. Troynik	Kiziltepa	Belly amur	2004	22	-	-	2	-
31		Kiziltepa	Hatirchi	Aqua-Todakul	2003	128	80	48	120	**
32		Shogolon	Hatirchi	Turkumbalik plus	2009	15	-	-	3	-

TABLE 2 (continued)

No.	Province	Town/village	District	Names of the farm	Year of foundation	Pond area, ha			Full-time employees	Fish production 2009, tonnes
						Total	Fattening	Nursery		
33	Samarkand	Payarik	Payarik	Ashurota farm	2008	93.3	68.7	24.6	–	73
34		Payarik		Sherali farm	–	116.3	59	57.3	–	20
35		Balikchi	Katakurgan	Taidyl AV farm	2003	93.4	70	23.1	–	50
36		U-Yangi Kurgancha		Navruz fish farm	1998	10	7	3	13	48.5
37		–		O. Dostov	2009	5	–	–	–	5*
38		–		Abdikadir polvon	2009	2	–	–	–	2*
39		–		Ismollov ata	2009	2	–	–	–	1.2*
40		–		Jarkishlok elita baliklari	2008	7	–	–	–	5*
41		–		D. Gozikhanov	2009	2	–	–	–	1.5*
42		–		Akhun	2009	2	–	–	–	2.5*
43	–	Pakhtachi	2009	2	–	–	–	2.5*		
44	–	Samarkand	Ok amur balik	2008	2	–	–	–	2*	
45	–	Urgut	S.K. Amriddin	2009	2.1	–	–	–	2.5*	
46	–	Nurobod	Khakim bobo	2009	35	–	–	–	8*	
47	Surkhandarya	Uzun	Uzun	Azizbobo farm	2008	34	34	0	–	8*
48		Uzun		At-Termizij farm	2008	34	34	0	–	8*
49		Uzun		Abu-Hurairo farm	2008	32	32	0	–	8*
50		–		Jorakul Hasan	2009	17	–	–	–	8*
51		Gur-gur		Oktepa Golden fish Farm	2009	15	–	–	2	11*
52	Termez	Termez	Surkhonbalik Lmtd.	2010	18	–	18	5	–	
53	–	–	Chegara koshin otryadi	2008	105	–	–	–	5*	
54	–	–	Undina Gulmohi	2009	50	–	–	–	7*	
55	Syrdarya	Sardoba	Mirzaobod	Syrdaryabalyk Ltd.	1985	980	980	0	–	100
56		58 Railway station		Yangierbalyk Ltd.	2003	400	400	0	15	140
57		SFU		Durgoyakhor farm	2001	160	–	–	5	5
58		Shirin		Shirin	Sirdarya IES	2009	4	–	–	–

TABLE 2 (continued)

No.	Province	Town/village	District	Names of the farm	Year of foundation	Pond area, ha			Full-time employees	Fish production 2009, tonnes		
						Total	Fattening	Nursery				
59	Tashkent	Balikhchi	Kuyi Chirchik	Balykchi JSC	1950	2 573	2 351	222	-	2 200		
60		-	-	Ogonek Lmtd.	2008	301	-	-	-	450		
61		-	-	Olim Saidhodja	2009	19	-	-	-	3*		
62		-	-	I. Shokir balikchi	2009	4.7	-	-	-	3*		
63		-	-	Barakali hovuz Ltd.	2009	34	-	-	-	3*		
64		-	-	Beijing Kaoya	2009	2	-	-	-	3*		
65		-	Damachi	Zangiata	Damachi Balyk Ltd.	1940	275	275	0	-	300	
66		-	Chinoz	Chinoz	T.Mirahmedova	2009	151	-	-	-	20*	
67		-	-	-	Intexnol Ltd.	2009	150	-	-	-	15	
68		-	-	-	Ummon sahovati	2009	5	-	-	-	5*	
69		-	Kush yogoch	Yangiyul	"MBP" SHK	1975	258	0	258	30	38	
70		-	-	-	Cof balik baraka	2009	3.3	-	-	-	3*	
71		-	-	-	K.Dicimboev	2009	10	-	-	-	3*	
72		-	-	-	U.Mirahmedova	2009	20	-	-	-	4*	
73		-	Uzbekistan	Pskent	Toshkentbalyk Ltd.	-	133	133	0	-	16	
74		-	-	-	IIV GUIN	2008	63	-	-	-	10*	
75		-	Yukori Chirchik	Yukori Chirchik	Balik tayyorlash business Ltd.	2009	53	-	-	16	17	
76	-	-	-	Delfin	2009	10.4	-	-	-	12		
77	-	Boka	Boka	Jahongir-Sevara	2009	6.6	-	-	-	4*		
78	-	-	-	Tilanboy Bobur	2009	11.2	-	-	-	5*		
79	-	-	-	Kaldirgoch	2009	4.8	-	-	-	3*		
80	-	-	Ahangaran	Ahang Abad Pilat Diyor	2009	16	-	-	-	3*		
81	-	-	Tashkent	Agro-Omad	2009	8.1	-	-	-	4*		
82	-	-	-	Eshonhodja ota	2009	20	-	-	-	3*		
83	-	-	Akkurgan	Saadat kamolot sari	2009	11	-	-	-	3*		
84	-	-	-	Afgan urush katnashcisi	2009	2	-	-	-	1*		
85	-	-	OrtaChircik	Islam Global Business	2009	22	-	-	-	15		
86	-	-	-	Toytepa hovuzi	2009	41	-	-	-	10		
87	-	Madaniyat	Kibray	NT Fish farm	2008	2	-	-	-	25		
88	-	-	-	Gulistan tanga	2009	2	-	-	-	2*		
89	-	Tavaksay	Bostanlik	Forel Ltd.	2008	4	-	-	-	4*		
90	-	-	-	R. Saidahmedov	2009	1	-	-	-	2		
91	-	-	-	Kh. Akmal baraka	2009	12.3	-	-	-	1*		
92	Ferghana	Besharyk	Besharyk	Besharykbalyk Ltd.	-	503	385	118	-	145		
93		-	-	-	R.Abdullajonovns	2009	3.5	-	-	-	6*	
94		-	-	-	U.Kambarov kelajagi	2009	2.1	-	-	-	20*	
95		-	-	-	I. Rakhimov	2009	10.4	-	-	-	12*	
96		-	-	-	S. Norbutaev	2009	20	-	-	-	17*	
97		-	Dangara	Dangara	Ural Ltd.	2008	334	314	20	-	30	
98		-	Kuvasay	Kuvasay	M.Joraev Omad	2009	4.5	-	-	-	7*	
99		-	-	Toshlok	Sotvoldi bobo	2009	15.7	-	-	-	20*	
100		Khorazm	Kattabag	Yangarik	Horazmbalykmahsulot JS	1975	1 473	1 112	361	130	570	
101			-	Tashkent	Bagat	Sh. Karimboboe ogli	2009	10	-	-	-	14.4*
102			-	Dehkonabad	Gurlan	Shaykh bobo	2009	2.9	-	-	-	5.4*
103			-	Ovshar	Khazarasp	Rozmat Davlat	2009	1.5	-	-	-	2.9*
104			-	Beshta	-	Kenja Yakutjon	2009	14	-	-	-	8.1*
105			-	Pichokchi	-	Hodji Saidmurod	2009	35	-	-	-	11.5*
106			-	Pichokchi	-	Matmurod bobo	2009	4.7	-	-	-	5.8*
107			-	Pitnak	-	Masharip Davron	2009	22.3	-	-	-	8.6*
TOTAL UZBEKISTAN						12 630	10 932	1 698	-	5 552		

carp production is equivalent to ~11 percent (range: 3.9 to 27.23 percent). Average data for all fish farms in Uzbekistan for the year 2009 show similar results; the share of phytophagous fish and common carp is about 80 and 17 percent, respectively (Table 4).

According to surveys conducted in 2009, the average wholesale price per kilogram of: silver carp was UZS2 750, common carp and grass carp UZS5 000, trout UZS18 000 and crucian carp UZS2 000 (USD1 = UZS1 550). Based on actual wholesale domestic market prices, the total value of the fish produced by aquaculture in 2009 was equivalent to USD11 332 859.

TABLE 3

Major fish species reared in three large farms in Uzbekistan (in tonnes)

Species	Balikchi		Khorezm		Yangierbalik		Average %
	2006	%	2009	%	2009	%	
Common carp	86	5.5	186	27.2	3.9	5.0	11.3
Silver carp	1 375	88.3	453	66.4	74	95.0	84.6
Bighead carp	7	0.4	-	-	-	-	-
Grass carp	49	3.2	44	6.4	-	-	4.1
Crucian carp	41	2.6	-	-	-	-	-
Total	1 558	100.0	683	100.0	77.9	100.0	100.0

TABLE 4

Total aquaculture production and value by species in Uzbekistan in 2009

Species	Production		Total value (USD)
	tonnes	%	
Common carp	854.8	16.5	2 761 004
Grass carp	618.3	12.0	1 997 109
Silver carp	3 503.7	67.9	6 201 549
Trout	13.0	0.3	150 930
Others (crucian carp, snakehead)	172.3	3.3	222 267
Total	5 162.1	100	11 332 859

MARKET

Both before the independence in 1991 and at present, fish (low value cyprinids: silver carp, grass carp and common carp) from farms situated on desert and arid lands are mainly produced for the domestic market. Due to the limited quantities of fish available in recent years, fish is currently mainly sold fresh, with very small volumes sold smoked or salted. During the Soviet era, some of the large fish farms, such as Khorezmbalikmakhsulotlari, Balikchy JSC, etc., had their own fish processing and storage facilities. This enabled them to store part of their fish production for sale later or to process them by smoking or salting. After the independence, processing and storage facilities have commonly deteriorated and do not now operate throughout the country. This has been caused partly by the limited supply of fish, resulting in most fish being distributed in live and fresh forms and also the lack of investment in this subsector.

Fish farms are often situated near urban populations, which harvest and market their fish production in the autumn. Part of the harvested fish is sold to wholesalers and retailers in small lots (up to 200 kg) at the farm gate, for which contracts are generally concluded during the growing season. Another part of the production is sold by the farmers in nearby markets and to local retail shops. However, aquaculturists from provincial fish farms intending to earn high profits may transport their cultivated fish themselves to the Chinaz wholesale market. From this market, fish are transported on a daily base to Tashkent, which is about 70 km distant. Most of the fish originating from this market comes from natural lakes (Aydar-Arnasay lake system in Uzbekistan and Shardara reservoir situated in Kazakhstan). The transportation of fish and other aquatic products officially has to be accompanied by a copy of the declaration of origin

and a veterinary certificate. The major cultured fish species sold are common, silver, bighead and grass carps. Large fish are popular among consumers and are, therefore, about twice as expensive as small fish.

Despite the decline in processing facilities, some enterprises are slowly becoming interested again in fish processing in the past 2–5 years. They have also begun to open their own private fish shops and restaurants in large cities. For example, frozen silver carp products (gutted, free of scales and decapitated) are available at Balykchi JSC situated in Tashkent Province.

Fish retailing can only be performed in places allocated by the local authorities of cities and districts (hokimiyats). Fish sales are only allowed if the retailer has documents confirming the legality of the catch or can show evidence of purchase of the products, and if he has a certificate confirming the quality and safety of the products on sale. There are special sections in the markets for the sale of fish, which are generally equipped with tanks for live fish and have access to tap water (Figure 5). The markets also possess refrigerators or power outlets to which refrigerators/freezers can be connected. Each retailer has its own table. The fish retail sections have special containers for waste, which is frequently removed. Generally, there are also open sewerage systems, with covering grids, which are used for the waste water. Upon consumer demand, the purchased fish can be gutted, decapitated and cleaned.

All fish wholesalers and retailers are licensed. The marketing of fish is highly seasonal; therefore, there are only a few enterprises specialized in this activity. The middlemen active in fish marketing have a marketing margin of 10 to 20 percent.

Most fish (60 percent) are sold in markets; more than 15 percent are sold through shops and supermarkets; and about 25 percent (mainly frozen and processed) are sold from warehouses to special consumers and wholesale buyers.

CONTRIBUTION TO THE ECONOMY

As Uzbekistan develops, priorities are changing. In recent years, the government has started to pay attention to the development of the fisheries sector, recognizing the necessity to market fish as the most valuable food. It has definitively identified the development of the fisheries sector as a social-economically important trend in the agrarian sector of this state. Primarily, the government has used its available administrative resources for the rehabilitation of available capacities.

The fisheries sector in Uzbekistan, composed of inland capture fisheries and aquaculture subsectors, has a potentially important role in the development of the rural economy of the country. However, in recent years the contribution of the sector to gross domestic product (GDP) was less than 0.1 percent. In spite of the vast water resources available for fisheries sector development (ponds, reservoirs, lakes, rivers, irrigation canals, etc.), total fish production declined significantly from 27 200 tonnes in 1991 to 7 200 tonnes in 2006 (Umarov, 2003; FAO, 2003; Karimov *et al.*, 2005; Karimov, Lieth and Kamilov, 2006). Of the production in 2006, the contribution of aquaculture was only 3 800 tonnes (Karimov *et al.*, 2009). Imports of fish and fisheries products also decreased during this period. As a consequence, per capita consumption decreased to less than 500 g/year in 2006, which means a reduction of over 90 percent

FIGURE 5
Fish section of the market in the city of Tashkent



COURTESY OF B. KARIMOV

compared to the 4.5 to 5 kg annual per capita consumption of fish and fisheries products in the late 1980s.

In 2007, with the support of the FAO (TCP/UZB/3103(D)), leading specialists of the sector, concerned ministries and agencies organized two national participatory workshops and developed a Draft Conception of the Development of Aquaculture and Fisheries in Uzbekistan for the years 2008–2016, which was approved by the Resolution of the Committee for Agrarian, the Water-Management and Ecological Issues of the Legislative Chamber of Oliy Madjlis (Parliament) of the Republic of Uzbekistan on 18 December 2008. The most pleasing symbolic event that followed was that in 2008–2009 the government paid attention to the fisheries sector, confirming its social and economic importance and the necessity to develop it as a priority. After the issuance of the programme on measurements of fisheries sector development in the republic in 2009–2011, signed by the Prime Minister of the Republic of Uzbekistan on three march 2009, No. 03/1–348, the volume of fish production from aquaculture started to increase slightly. In 2009, it reached about 5 000 tonnes. Most of the increase came from large-scale aquaculture enterprises such as Balikchi JSC, Khorazmbalikmahsulot, Damachi, etc. Based on this programme, about 200 new fisheries and aquaculture enterprises were established in various provinces of Uzbekistan. However, they only capture fish and have not yet started aquaculture activities.

The results from surveys of 30 large, medium and small fish farms in Uzbekistan during 2009–2010 have revealed that 90 percent of respondents stated that aquaculture was their main activity (FCDC MAWR, unpublished data). The main factor that influenced them to commence fish farming was its high profitability (80 percent). About 7 percent of farmers stated that the availability of technology was an important factor, and 13 percent gave other reasons. These results show the elevated role and potential of desert and arid land aquaculture in food security, employment, and poverty alleviation in rural areas.

As stated above, about 2 400 people are employed directly in aquaculture enterprises. If support services such as transport, processing, retailing (mainly women) and wholesaling, ice suppliers, etc., are included, total employment increases to 5 000. Aquaculture development and its intensification will contribute to increased sustainable production of fish in Uzbekistan and other CA countries, generating alternative new employment and increasing income in rural areas.

INSTITUTIONAL FRAMEWORK

In the ex-USSR, fisheries in Uzbekistan and in other CA Republics were a part of the All-Union Ministry of Fisheries and each republic had its own State Committee of Fisheries. For the first four years of independence in Uzbekistan, the company Uzbalyk functioned as the state agency responsible for fisheries development and sector management. In 2003, the management of the fishery sector was entrusted to the Ministry of Agriculture and Water Resources (MAWR).

The Main Administration for Development of Animal Husbandry, Poultry Farming and Fishery, consisting of 12 officers, was established in 2003 to manage the sector but only one of them has an educational background in aquaculture.

As part of this development, the Uzbek Research centre of Fish Culture Development (FCDC) was established under the control of MAWR. The main objectives of the centre are:

- developing scientific and methodological recommendations on the fish industry and its forage reserve development;
- carrying out research on fish breeding, capture fisheries, developing fish disease treatment and preventive measures, and improving the brood fish quality and acclimatization of new species;
- providing fisheries and fish breeding farms with high quality selective materials;

- organizing training and raising the qualification and skills of fish industry personnel.

Departments for the development of animal husbandry, poultry farming and fisheries have also been established in regional departments for agriculture and water management. Non-governmental associations of fisherfolk and fish-breeders were set up in the Provinces of Karakalpakstan (2006), Bukhara (2007) and Samarkand (2008). The main task of these associations is the protection of the interests of fish farms at a regional level. There is no fisherfolk association at the national level.

GOVERNING REGULATIONS

Since independence, the management of farms, including fish farms, is regulated by codes, laws and decrees of the President of Uzbekistan and enactments of the Cabinet of Ministers (Karimov *et al.*, 2009), namely:

- The Law “On Protection of Nature” of 9 December 1992.
- The Law “On Water” of 6 May 1993.
- The Law “On Farm” of 30 April 1998.
- Decree of the President of Uzbekistan No.VII–2086 of 10 October 1998 “On introduction of a single land tax for agricultural producers”.
- Enactment No. 350 “On measures to intensification of de-monopolization and privatization in the fishery sector” of 13 August 2003.
- Enactment No. 1292 registered by the Ministry of Justice of 20 December 2003 “On the approval of the regulation of the calculation and levying of rent payment for the use of natural water bodies by fish farms”.
- Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 508 of 28 October 2004: “Enhancement of Oversight over the rational use of biological resources, and their imports and exports in the Republic of Uzbekistan”.
- The Hunting and Fish Catching Regulations on the Territory of Uzbekistan, No. 1569, registered at the Ministry of Justice on 2 May 2006.
- The “programme on measurements of fisheries sector development in the republic in 2009–2011” signed by the Prime Minister of the Republic of Uzbekistan of 3 March 2009, No. 03/1–348.

APPLIED RESEARCH, EDUCATION AND TRAINING

The collapse of the Soviet Union had an extremely negative impact on aquaculture research in all CA post-soviet republics. Research laboratories previously staffed by highly qualified and trained scientists have seen a significant exodus of staff due to the shortage of research funds and low salaries. Many research institutions need urgent upgrading of laboratory facilities and skilled young scientists.

Research on fish breeding is conducted under the umbrella of the Coordination Committee on Science and Technologies Development under the Cabinet of Ministers of the Republic of Uzbekistan, created on the resolution of the President of the Republic of Uzbekistan of 7 August 2006 “On measures to improve the coordination and management of science and technology development”.

- There is one research institute solely devoted to aquaculture and fisheries (FCDC MAWR), but there are another four research institutions with departments conducting research in the fields of ichthyology, hydrobiology, fisheries and aquaculture: Laboratory for the Problems of Intensive Aquaculture and Fisheries.
- Laboratory for Ichthyology and Hydrobiology at the Institute of Zoology of Uzbekistan Academy of Sciences (UzAS).
- Institute of Bioecology of the Karakalpak Branch of UzAS (located in Nukus).
- Department of Ecology, National University of Uzbekistan.

There is a fund for the development of fish breeding, to which part of the funds realized by the privatization of the state share of property in fish farms was allocated,

as well as part of the funds for the use of rented water bodies. This fund is used for the functioning of FCDC MAWR, but it is insufficient for large-scale studies on up-to-date technologies.

In order to render real support to state goals and objectives for the development of the fisheries sector from 2009 to 2011, as well as for the development of the recommendations of the FAO Project TCP/UZB/3103(D) in Uzbekistan and the “Conception of the development of aquaculture and fisheries in Uzbekistan until the year 2016”, the administration of the Institute of Zoology of the UzAS supported the initiative of the leading scientists of this sector to establish a new specialized Laboratory for the Problems of Intensive Aquaculture and Fishery, as noted above. This laboratory commenced its activities on 1 April 2009 and currently consists of a Head of Laboratory and two associates (one Doctorate in Biology and two Candidates of Biology), as well as three assistants. In the past three years, the staff of this laboratory has published a number of important methodical guidelines and monographs on the development of the fisheries sector in the basin of the Aral Sea, with support from the FAO Subregional Office for Central Asia. This laboratory could become a scientific and applied research centre for the introduction of advanced technologies and experience from developed countries, taking into account the natural climatic and socio-economic conditions in Uzbekistan and adjoining states.

All the higher educational institutions are under the authority of the Ministry of Higher and Secondary Specialized Education of the Republic of Uzbekistan. This ministry determines the number of places in the masters and bachelor courses for each specific specialty. The Ministry of Agriculture and Water Resources, as well as other concerned agencies, can submit their proposals to the Ministry of Higher and Secondary Specialized Education about the number of students to be admitted to the institutions for higher studies.

In the past, higher education in aquaculture and fisheries was supplied by central All-Union Fisheries Institutes in the actual Russian Federation and the Ukraine and at Tashkent State University. In the Department of Hydrobiology and Ichthyology in the Biology Faculty of Tashkent State University (now the National University of Uzbekistan), 8–20 students graduated each year. However, in 2003 that department was transformed into the Department of Ecology; now there is no national centre for higher education for the fishery sector. This means that neither researchers nor lecturers and technologists with specialization in aquaculture are entering the sector. Currently, those that work in the sector as specialists were trained in subjects related to fisheries at the National University (biologists), Agro University (agriculture experts), Technical University (engineers, food industry experts). Today, vocational training and other practical training opportunities for fish farmers are non-existent in the country.

TRENDS, ISSUES AND DEVELOPMENT

The reasons why per capita fish consumption in Uzbekistan remains low (~0.5 kg/year compared to 4.5–5.0 kg/year in 1991) have been stated earlier in this review.

Until 2007, aquaculture development was not regarded as a priority in Uzbekistan, causing major constraints in technology, management, extension, access to credit, etc. A special (and perhaps unique) feature of the aquaculture and fisheries sector of Uzbekistan and other desert and arid CA countries is that it is a secondary user of already relatively scarce freshwater. In addition, it can sometimes unwittingly receive water that comes from residual irrigation discharges, i.e. water that may be contaminated with chemicals from crop run-offs. This raises problems of fish health and food safety. It will be necessary to tackle this issue by interagency and intersectorial cooperation, which is facilitated by the fact that fisheries are also under the Ministry of Agriculture and Water Resources. In this sense, water is not a sectorial issue.

Taking these factors into account, prominent scientists and experts in Uzbekistan drew attention to the necessity for the comprehensive development of the fisheries sector in the early 2000s (Karimov *et al.*, 2004; Kamilov, Karimov and Keyser, 2004), as noted earlier in this review. As a result, the government began to pay attention to this sector in 2008–2009 and confirmed its social and economic importance and the necessity to include it among state development priorities. However, the programme that emerged primarily envisaged the rehabilitation of the available capacities of fish farms with extensive and slightly semi-extensive technologies. So far, the improvement of education, training and research in this sector has not yet been activated.

At present, all fisherfolk and people in rural areas are involved only in informal/artisanal, small-scale capture fisheries; this is neither economically feasible nor ecologically sustainable. There are many cases of unregistered, unregulated and illegal fisheries, which make it extremely difficult to get real statistical data and to develop scientifically based recommendations for the improvement of capture fisheries. At the same time, the country has very convenient natural and socio-economic conditions for aquaculture development that have been neglected until recently.

Various regional and national initiatives in recent years have shown that one of the main constraints to development of the aquaculture sector is the lack of availability of and access to high quality fish feeds. No high quality fish feeds are being produced in the region and this hampers development. This resulted in the initiation of the FAO TCP/RER/3205 project “Advice to Central Asian Governments on the feasibility of commercial fish and livestock feed production”.

A strengths, weaknesses, opportunities and threats (SWOT) analysis, prepared by a regional workshop conducted in Antalya, Turkey in 2007 (van Anrooy, Marmulla and Celebi, 2008), showed the following weaknesses:

- There are generally no national fishery sector policies or regulatory frameworks in place that assist the sector in its development in a sustainable manner.
- Fisheries were not a priority sector for government development planning (now some countries like Uzbekistan since 2009 have started to pay attention to the sector).
- There are generally no fisheries departments, and financial means available for the administration/management of the sector are insufficient (fisheries administrations should be equipped with highly qualified staff and modern means of communication and transport).
- Lack of extension services at regional and country level.
- Diversity in fish species culture is limited. Culture practices are based on the culture of silver carp, common carp, grass carp and bighead.
- The fishery sector research institutes in the region do not have the technical and financial capacity to undertake the necessary research to assess fisheries resources and support the development and management of fisheries.
- No high quality fish feeds for aquaculture are being produced in the region.
- There are no hatchery facilities in some countries for restocking inland waters and aquaculture ponds with fish seed (where such facilities exist they are functioning at low levels of efficiency or are underutilized).
- The collection of fisheries statistics is not coordinated properly and data collection and analysis is not done in a scientific and systematic manner (which affects decision making processes negatively).
- There is a general lack of access to credit facilities from banks and incentives (subsidy) from the government in support of fisheries sector development.
- Insurance facilities are not extended to the fisheries sector (in contrast to insurance for the agriculture sector).
- There is a generally low level of training and education of human resources in the sector.
- Limited access to knowledge and technology from elsewhere (limited contacts with other regions).

- Poor and inappropriate fishery resources management is common in the region.
- The lack of marketing facilities for fisheries products reduces profitability (a supply chain approach is missing and means of transport for fish are generally not available).
- Lack of public awareness on fishery sector aspects and low interest in solving fishery sector problematic.

SUCCESS STORIES

Considering the period after independence (1991), there are no real success stories in desert and arid land aquaculture in countries in the CA region to report. Private entrepreneurs are only now beginning to show some interest in increasing fish production as profitable ventures. As the privatization process in the sector finished in 2003–2004, there were no positive developments for some time (up to 2006). However, some new fish farm owners (investors from outside the sector) have purchased and tried to implement semi-intensive technology recently. A few of these private ventures have shown good progress. For example, Asia Agro Alliance became the owner of the Damachi fish farm in 2005 and had an initial fish production of 75 tonnes. The enterprise restored the old soviet technology that was already in place and financed fish feed and fertilizers. The enterprise harvested 400 tonnes in 2005 and 490 tonnes in 2006. As no commercial high quality fish feeds are available in the country, the enterprise uses farm-made feeds comprised of wheat and bran. The enterprise markets its production at the following sizes: silver carp 1 200–1 500 g; common carp 800–1 500 g; and grass carp 1 000–1 500 g. In recent years, its productivity has been 2.1 tonnes/hectare and net profitability is estimated at 30–40 percent.

WAY FORWARD

The Uzbek population has increased rapidly, from 8.4 million in 1960 to 26.9 million in 2007 (UN, 2010). Consumer demand for fisheries and aquaculture products in CA is rising with increasing incomes. Generally, the consumption of fish in the 1980s was ten times what it is today; there is a big demand and especially older people still have a tradition of eating fish. Profit margins of producers on species like trout and grass carp are considerable at present; there is also potential to increase profitability through the introduction of modern technologies, augmenting species diversity and improving product quality and safety.

In Uzbekistan, since its independence, the per capita supply of many types of food has either considerably increased or remained at about the same level. However, at the same time, the consumption of fish has been drastically reduced to 0.5 kg/year, as stated earlier in this review. Aquaculture productivity is low: <2 tonnes/hectare or <130 g/m³ of water used (about 75 g/m³ taking into account high evaporation losses). Meanwhile, according to FAO (2007), global aquaculture productivity is typically 50–200 kg/m³ and the average consumption has reached 16.6 kg per capita/year, while the minimum level recommended by regional medicine authorities in the CA is 12 kg per capita/year. This implies that Uzbekistan needs at least ~270 000 tonnes of additional fish per year in the domestic market.

It is impossible to achieve a significant increase in fish production based on the available technologies and cultured species alone (Karimov *et al.*, 2009). They are outdated, fall short of market relations, require significant land and water resources and show a low productivity. Alpeisov (2005) suggests the inclusion of additional high value species such as sturgeons, paddlefish (*Polyodon spathula*) and striped bass (*Morone saxatilis*) in Kazakhstan aquaculture. However, the technology for their cultivation in the natural conditions of CA is not yet developed.

TABLE 5

Main strategies for desert and arid land aquaculture development in the Central Asia region

Aquaculture systems	Flow-through systems alongside irrigation and drainage canals, cage-culture on all suitable water bodies, small earthen ponds, integrated and recirculating aquaculture systems
Main fish species for aquaculture	Common carp, grass carp, silver carp, channel catfish, wels, tilapia, pike-perch*
Water bodies and watercourses for aquaculture development	Ponds in fish farms, water reservoirs, irrigation and drainage canals, rivers, peripheral lakes of irrigational origin, etc.
Fish-productivity	An average of 40–50 kg/m ³ in all stated systems with possible further increase

* i.e. warmwater species, although it is possible to culture coldwater fish such as trout during the cold period from October to April.

The development of the aquaculture sector must be based only on modern intensive technologies (Table 5). The main emphasis in desert and arid land aquaculture development should be placed on the following:

- aquaculture in order to increase fish yields;
- aquaculture using available water resources;
- aquaculture using water and resource saving technologies;
- culture-based fisheries;
- recreational fisheries and ecotourism;
- development of recirculating aquaculture systems; and
- international cooperation and transfer of advanced intensive aquaculture technologies.

The development of new technologies requires that new fishery policies, strategies and programmes be adopted by the Governments of CA. For example, Uzbekistan, with its centuries-old experience in agriculture, can significantly improve the production of fish by using a small quantity of water so that it will not only provide the local market with this valuable food, but also significantly develop its export potential.

At a regional level, all ASDB countries have developed their “Policy and strategy of aquaculture and capture fisheries development” for the coming decades under the guidance of the FAO Subregional Office for Central Asia in Ankara, Turkey. The proposed strategies have the goal to adapt world-wide expertise to ASDB conditions during the next ten years, creating the necessary infrastructure, research and educational potential and equipping private entrepreneurs with attractive technologies that will stimulate their involvement in the sector (aquaculture is one of the most beneficial types of rural businesses in all regions of the world). In modern economic conditions, highly profitable technologies are in demand, both for private individual small-sized family farms and for large enterprises. The Governments of ASDB countries should approve policies and strategies that are designed to stimulate the development of the sector.

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An overview on desert aquaculture in Israel

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SUMMARY

The State of Israel has a very diverse climate. Most of the country is in a semi-arid zone, with distinct short winter (wet) and long summer (dry) seasons, and a low annual rainfall of around 500 mm (an overall multi-annual average). The country can be divided into two climatic regions: (1) the southern arid/semi-arid areas have very low annual precipitation (<100 mm) and consist of the Negev Desert and the Arava Valley; this arid zone extends also to the Jordan Valley where annual rainfall is below 300 mm; (2) the central-north of the country that has a temperate, Mediterranean climate and a relatively high annual rainfall (>600 mm). Israel has suffered from a chronic water shortage for years. In recent years, however, the situation has developed into a severe crisis; since 1998, the country has suffered from drought, and the annual rainfall was short of the multi-annual average in most of the years. The agricultural sector has suffered most because of the crisis. Due to the shortage, water allocations to the sector had to be reduced drastically causing a reduction in the agricultural productivity. In spite of the obvious climatic constraints and overall shortage of water, both agriculture and aquaculture are highly developed in Israel. Israeli agriculture depends, to a large extent, on irrigation of crops during the dry summer. To deal with these impediments, different solutions and methods to maximize water use and enable production of fresh edible fish have been developed, including: (i) reservoirs to store rainwater during the wet season, many of which are used for fish culture in integrated farming systems; (ii) large-scale recirculating systems, in which water from outdoor fish ponds, raceways and tanks is passed into sediment ponds to remove the solids; (iii) highly-intensive recirculating systems that incorporate water filtration systems, such as drum filters, biological filters, protein skimmers and oxygen injection systems; and (iv) greenhouse technology was adopted from desert vegetables and flower agriculture

and includes environmental control, i.e. humidity, temperature, light and radiation. These conditions are important in arid areas, which have large temperature changes between day and night and summer and winter. Desert aquaculture in southern Israel began in 1979 with the discovery of locally available geothermal water near a village in the Arava Valley. The idea of using hot ground water for highly-intensive aquaculture, to achieve maximum growth throughout the year, has subsequently been developed commercially. Of five model pilot-scale farms established during the 1980s and 1990s, two were expanded to a full commercial scale of aquaculture production. The semi-arid Bet Shean and Jordan Valleys and Gilboa grow 60 percent of the common carp (*Cyprinus carpio*), 82 percent of the tilapias and 78 percent of the flathead grey mullet (*Mugil cephalus*) produced in Israel, and together account for 73 percent of total aquaculture output. The Negev grows all the barramundi (*Lates calcarifer*) and gilthead seabream (*Sparus aurata*) cultured in brackish water and half of the hybrid striped bass (*Morone chrysops* x *M. saxatilis*), accounting for less than 3 percent of the total aquaculture output. During the past decade, most of the pilot edible fish farms established in the desert area have failed. Water sources, suitable species and culture systems were investigated and developed. In most cases, the reasons for the failures were management mistakes done by owners or managers, coupled with the economic trends in the sector during that period. There is plenty of brackish water that can be used, but the regions lack tradition in fish farming and at the moment no new entrepreneurs show interest in launching new farms, or reviving those that closed recently. An alternative ornamental fish culture sector has developed which is flourishing and has great potential for expansion. Fish culture in the arid zone is where development is more likely, although even there, the profitability of some farms is in question.

RÉSUMÉ

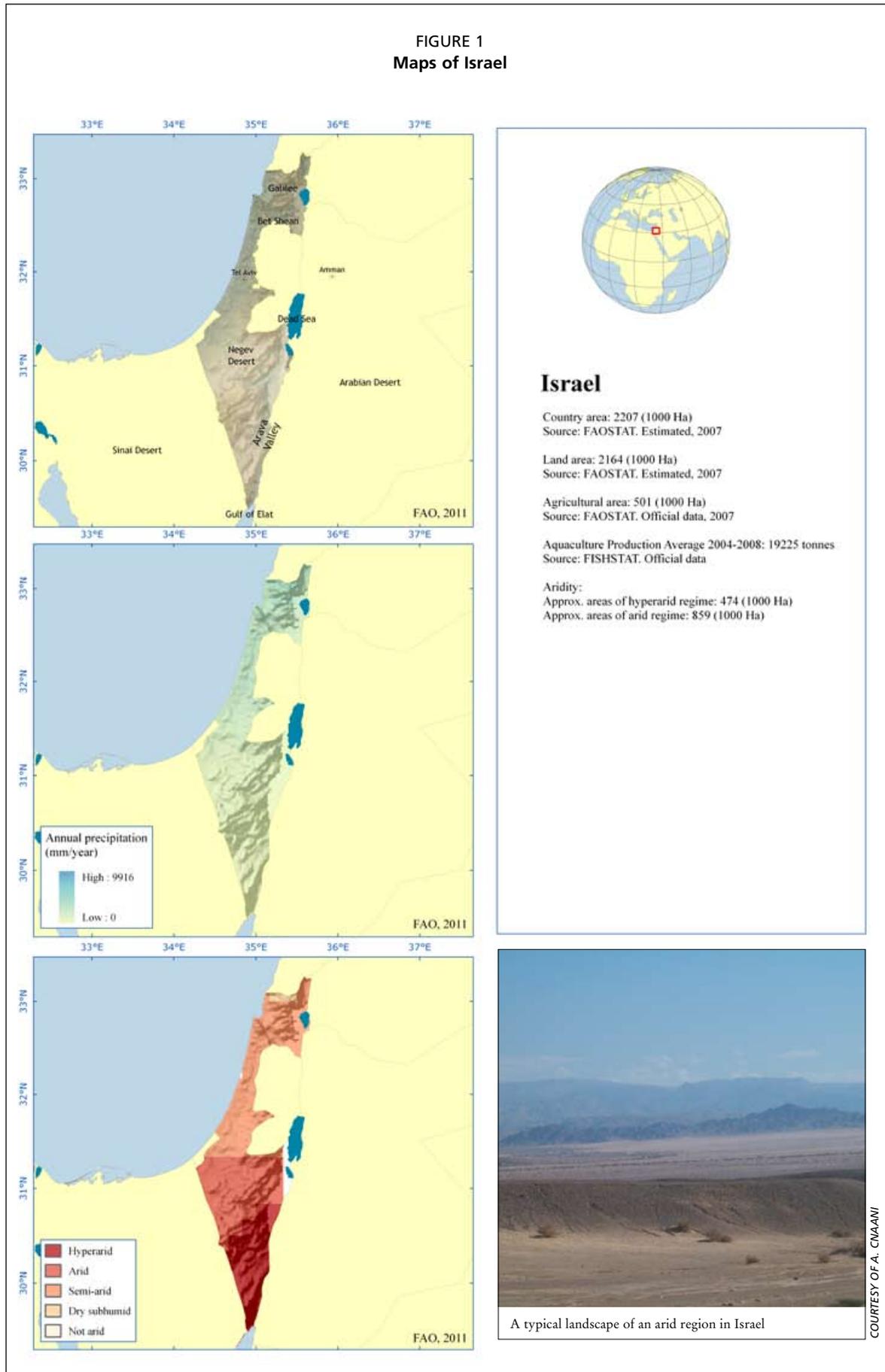
L'État d'Israël jouit d'un climat très contrasté. La plus grande partie du pays se trouve dans une zone semi-aride, qui se caractérise par un hiver court et humide et un été long et sec, accompagné de pluies sporadiques d'environ 500 mm (moyenne obtenue sur plusieurs années). Le pays peut être divisé en deux régions climatiques : 1) la zone sud aride/semi-aride, composée du désert du Néguev et de la vallée d'Arava, avec des précipitations très faibles (inférieures à 100 mm), qui s'étend jusqu'à la vallée du Jourdain, où les pluies annuelles sont inférieures à 300 mm ; 2) le centre et le nord du pays, avec un climat tempéré de type méditerranéen et des précipitations annuelles relativement élevées (supérieures à 600 mm). Israël souffre depuis des années d'une pénurie chronique en eau, qui s'est toutefois récemment transformée en une crise sévère. Depuis 1998, le pays est victime de la sécheresse et les précipitations sont très fréquemment inférieures aux moyennes annuelles. Le secteur agricole est celui qui a le plus souffert des effets de cette crise. En raison du manque d'eau, le secteur agricole a vu ses attributions hydriques drastiquement réduites, ce qui a entraîné une réduction de sa productivité. Malgré les évidentes contraintes climatiques et la pénurie générale en eau, l'agriculture et l'aquaculture sont deux secteurs très développés en Israël. L'agriculture israélienne dépend, pour une bonne part, de l'irrigation des cultures pendant les mois secs de l'été. Pour contourner ce problème, diverses solutions et méthodes ont été mises au point afin d'optimiser l'utilisation de l'eau et de permettre une production de poissons frais destinés à la consommation humaine : i) l'eau de pluie est stockée dans des réservoirs pendant la saison humide puis utilisée en grande partie à des fins piscicoles dans des systèmes d'élevage intégré ; ii) des systèmes à recirculation d'eau à grande échelle permettent le passage de l'eau des étangs piscicoles, des raceways et des bassins extérieurs dans des bassins de décantation pour en ôter les matières solides ; iii) des systèmes à recirculation d'eau très intensifs sont adoptés avec des systèmes de filtration de l'eau (filtres à tambour, filtres biologiques, écumeurs à protéines ou systèmes à injection d'oxygène) ; et iv) une technologie inspirée des serres destinées à la culture des légumes et des fleurs en milieu désertique est adaptée à l'aquaculture

et permet de maîtriser les conditions environnementales, c'est-à-dire l'humidité, la température, la lumière et les rayonnements. Ces conditions sont importantes dans les zones arides où l'amplitude thermique est très importante entre le jour et la nuit et entre l'été et l'hiver. L'aquaculture en milieu désertique a démarré dans le sud israélien en 1979 avec la découverte d'eaux géothermales disponibles à proximité d'un village de la vallée d'Arava. L'idée d'utiliser des eaux souterraines chaudes pour une aquaculture très intensive, visant à obtenir une croissance maximale des poissons au cours de l'année, a ensuite été développée commercialement. Sur les cinq exploitations pilotes créées pendant les années 1980 et 1990, deux ont poursuivi leur développement jusqu'à une commercialisation de leur production aquacole. La région de Gilboa, et les vallées semi-arides de Beït Shéan et du Jourdain concentrent 60 pour cent de la production israélienne de carpes communes (*Cyprinus carpio*), 82 pour cent de celle de tilapias et 78 pour cent de celle de mulets à grosse tête (*Mugil cephalus*). Elles représentent ensemble 73 pour cent de la production aquacole totale du pays. La région du Néguev produit quant à elle toutes les perches barramundi (*Lates calcarifer*) et dorades royales (*Sparus aurata*) élevées dans des eaux saumâtres, ainsi que la moitié des bars d'Amérique hybrides (*Morone chrysops* x *M. saxatilis*), qui ne représentent que trois pour cent du total de la production aquacole. Au cours de la dernière décennie, la plupart des exploitations pilotes de production de poissons destinés à la consommation humaine créées en milieu aride ont cependant échoué. On a alors analysé quels étaient les sources d'eau, les espèces et les systèmes de culture les plus appropriés pour développer le secteur. Dans la plupart des cas, l'échec est dû à des erreurs de gestion de la part des propriétaires ou des exploitants, liées à l'évolution de la situation économique du secteur pendant cette période. D'abondantes ressources en eau saumâtre sont disponibles mais il manque encore une véritable tradition piscicole dans les régions arides et, pour le moment, aucun entrepreneur ne manifeste d'intérêt pour lancer de nouvelles exploitations ou relancer celles qui ont été fermées récemment. Le secteur de l'élevage de poissons d'ornement s'est par contre développé et apparaît florissant, avec un formidable potentiel d'expansion. La pisciculture en milieu aride semble toutefois être celle qui offre les meilleures opportunités de développement, même si la question se pose de la rentabilité de certaines exploitations.

ملخص

يعتبر مناخ دولة إسرائيل متنوعا جدا. ومعظم أراضي هذه الدولة تقع في منطقة شبه جافة، مع موسم شتاء واضح وقصير (رطب) وموسم صيف طويل (جاف)، ومعدل سنوي منخفض لسقوط الأمطار عند 500 ملم (معدل إجمالي سنوي متعدد). ويمكن تقسيم البلد الى منطقتين مناخيتين: (1) المناطق الجنوبية الجافة/شبه الجافة والتي لديها معدل سنوي منخفض جدا لسقوط الأمطار (>100 ملم) وتتألف من صحراء النقب ووادي عرقة؛ وتمتد هذه المنطقة الجافة أيضا الى وادي الأردن حيث المعدل السنوي لسقوط الأمطار أقل من 300 ملم؛ الوسط الشمالي للبلد والذي يتميز بمناخ معتدل متوسطي ومعدل سنوي عالي نسبيا لسقوط الأمطار عند (<600 ملم). وقد عانت إسرائيل من نقص مزمن في المياه لعدة سنوات. ومع ذلك، وفي السنوات الأخيرة، فإن الوضع قد تطور الى أزمة حادة؛ فمنذ عام 1998 والبلد تعاني من الجفاف، والفترة السنوية لسقوط الأمطار كانت قصيرة وأقل من المتوسط السنوي المتعدد في معظم السنوات. وقد عانى قطاع الزراعة أكثر بسبب الأزمة. وبسبب النقص، كان لا بد من تخفيض حصص المياه للقطاع بشكل كبير مما سبب خفض في الإنتاجية الزراعية. وبالرغم من القيود المناخية الواضحة والنقص العام في المياه، فإن كل من الزراعة وتربية الأحياء المائية قد تطورا بشكل كبير في إسرائيل. وتعتمد الزراعة الإسرائيلية الى حد كبير على ري المحاصيل خلال فصل الصيف. وللتعامل مع هذه العوائق، تم تطوير حلول وطرق مختلفة لتعظيم استخدام المياه والسماح بإنتاج أسماك طازجة صالحة للأكل، وتتضمن: (i) خزانات لتخزين مياه الأمطار خلال موسم الشتاء، والتي العديد منها يستخدم لتربية الأسماك في أنظمة التربية التكاملية؛ (ii) أنظمة التدوير كبيرة النطاق، والتي يتم فيها تمرير المياه الخارجة من أحواض الأسماك الخارجية، والقنوات والأحواض في أحواض الترسيب وذلك لإزالة المواد الصلبة؛ (iii) أنظمة التدوير عالية الكثافة والتي تتضمن أنظمة فلترة المياه، مثل مرشحات البرميل، والمرشحات البيولوجية، ومزيلات البروتين وأنظمة حقن الأكسجين؛ و (iv) تم تكييف تقنية البيوت المحمية من زراعة الخضراوات والزهور وتتضمن التحكم البيئي، ونعني بذلك الرطوبة، ودرجة الحرارة،

FIGURE 1
Maps of Israel



والضوء والإشعاع. وهذه الظروف مهمة في المناطق الجافة، والتي لديها تغيرات كبيرة في درجة الحرارة بين الليل والنهار والصيف والشتاء. وقد بدأت تربية الأحياء المائية الصحراوية في جنوب إسرائيل في عام 1979 مع اكتشاف المياه الأرضية الحرارية المتوفرة محليا في قرية بالقرب من وادي عرفة. إن فكرة استخدام المياه الجوفية الساخنة في تربية الأحياء المائية عالية التكلفة، لتحقيق أكبر نمو خلال العام، قد تم تطويرها فيما بعد بشكل تجاري. ومن المزارع الخمس النموذجية التجريبية التي تأسست خلال الثمانينات والتسعينات من القرن الماضي، اثنتان فقط توسعتا لتصبحا ذات نطاق تجاري بشكل كامل في إنتاج تربية الأحياء المائية. إن مناطق بيسان ووادي الأردن وجبل جلبوع تقوم بزراعة 60 في المائة من الكارب العام أو الشبوط الشائع (*Cyprinus carpio*) 82 في المائة من البلطي و 78 في المائة من البوري مفلطح الرأس (*Mugil cephalus*) المنتج في إسرائيل، وسوية تمثل 3 في المائة من إجمالي إنتاج تربية الأحياء المائية. وتقوم النقب بتربية جميع أسماك القاروص (*Lates calcarifer*) والكوفر ذهبي الرأس أو ما يسمى بالقجاج (*Sparus aurata*) المستزرع في المياه شبه المالحة ونصف القاروص المقلم (*M. saxatilis x Morone chrysops*)، ويمثل ما نسبته أقل من 3 في المائة من إجمالي إنتاج تربية الأحياء المائية. وخلال العقد الأخير، فإن معظم المزارع التجريبية للأسماك الصالحة للأكل التي تأسست في منطقة الصحراء قد فشلت. وقد تم فحص وتطوير موارد المياه، والأنواع المناسبة وأنظمة التربية. وفي معظم الحالات، فإن أسباب الفشل كانت أخطاء إدارية قام بها المالكون أو المدراء، مقترنة بالاتجاهات الاقتصادية في القطاع خلال هذه الفترة. هناك الكثير من المياه المالحة التي يمكن استخدامها، ولكن المنطقة ينقصها تقليد تربية الأسماك وفي الوقت الحاضر لا توجد مشاريع جديدة تظهر اهتماما في البدء بمزارع جديدة، أو تنعش التي تم إغلاقها حديثا. وقد تم تطوير قطاع بديل لتربية أسماك الزينة والذي يزدهر ولديه الإمكانية الكبيرة للتوسع. إن تربية الأسماك في المنطقة الجافة تزدهر حيث تكون التنمية أكثر على الأرجح، مع أن حتى في هذه الحالة، فإن الربحية لبعض المزارع تكون موضع سؤال.

INTRODUCTION AND GEOGRAPHY

Israel is located on the eastern end of the Mediterranean Sea, at 29°30'–33°30' north latitude and 34°15'–35°30' east longitude. Israel's area (excluding the occupied territories) is approximately 20 700 km². It borders Lebanon in the north, the Syrian Arab Republic and Jordan (and the West Bank) in the east and Egypt in the southwest.

CLIMATE

While only 424 km long, from north to south, Israel has a very diverse climate. Most of the country is in a semi-arid zone, with distinct short winter (wet) and long summer (dry) seasons, and a low annual rainfall of around 500 mm (an overall multi-annual average). Israel can be divided into two climatic regions (Figure 1):

- The southern arid/semi-arid areas have very low annual precipitation (<100 mm) and consist of the Negev Desert and the Arava Valley. The latter is part of the Syrian-African Break. The Negev and Arava regions are in fact a section of the desert covering Egypt and the Sinai Peninsula to the west, and the south of Jordan to the east, and continuing eastward to the Syrian Arab Republic, Iraq and Saudi Arabia.
- The Arava Valley sits between two mountain systems: the Jordan from the east and the Negev from the west. It starts at the southern end of the Dead Sea, some 400 m below sea level and finishes at the Gulf of Eilat (an extension of the Red Sea). This arid zone extends also to the Jordan Valley.
- The central-north of the country (including the flats near the Mediterranean Sea, the hilly area towards the east that borders the Lake of Galilee and the Galilee and Golan mountains in the north) has a temperate, Mediterranean climate (with even snow-caps on the high mountains) and a relatively high annual rainfall (>600 mm). This region is the most populated area of Israel and the competition for resources is intense. It is the southwestern most end of the ancient "Fertile Crescent" that was first populated around 8000 BC.

ISRAEL'S CHRONIC WATER PROBLEM¹

Water is considered as a national resource of utmost importance. Water is vital to ensure the population's well-being and quality of life and to preserve the rural agricultural sector. The only large inland water body is the Lake of Galilee, which mainly supplies freshwater for human consumption. Moreover, in the central-north areas of Israel, where the majority of the rainfall occurs, the hilly and mountainous land cannot naturally hold water. Israel has suffered from a chronic water shortage for years. In recent years, however, the situation has developed into a severe crisis; since 1998, the country has suffered from drought, and the annual rainfall was short of the multi-annual average in most of the years.

The 2002 cumulative deficit in Israel's renewable water resources amounted to approximately two billion m³, an amount equal to the annual consumption of the country. The deficit has also led to the qualitative deterioration of potable aquifer water resources that have, in part, become either of brackish quality or otherwise became polluted. The causes of the crisis are both natural and man-made. The drought and the increase in demand for water for domestic uses (caused by population growth and the rising standard of living) together with the need to supply water pursuant to international undertakings have led to over-utilization of its renewable water sources. The agricultural sector has suffered most because of the crisis. Due to the shortage, water allocations to the sector had to be reduced drastically causing a reduction in the agricultural productivity.

Conventional water resources – The total average annual potential of renewable water amounts to some 1 800 million m³, of which about 95 percent is already exploited and used for domestic consumption and irrigation. About 80 percent of the water potential is in the north of the country and only 20 percent in the south. Israel's main freshwater resources are: Lake Kinneret – the Sea of Galilee (700 million m³), the Coastal Aquifer – along the coastal plain of the Mediterranean Sea (320 million m³), and the Mountain Aquifer – under the central north-south (Carmel) mountain range (370 million m³). Additional smaller regional resources are located in the Upper Galilee, Western Galilee, Bet Shean Valley, Jordan Valley, the Dead Sea Rift, the Negev and the Arava – altogether 410 million m³.

The increasing demand for water in the Negev Desert prompted a thorough study of the water potential of its deep aquifers (1–5 km deep), which formed in rocks of the Jurassic and Paleozoic eras. In the 1960s, the search for water led to the discovery of fossil water aquifers at depths of 400–1 000 m and >1 000 m. These aquifers are not currently being replenished because of the arid climate of the Negev Desert (50–100 mm rainfall annually). Recharge probably took place during the more humid conditions that prevailed in this area in the Pleistocene (Nativ, Bachmat and Issar, 1987). For further reading, see a sample of publications by Issar that are listed in the references. These aquifers hold huge reserves, billions of m³ of ancient, unpolluted, brackish geothermal water. Though resting deep in the ground, the desert water is easily accessible as it rises by artesian pressure to nearly sea level. In the Ramat Negev district (~400 000 ha) alone, six wells (600–750 m deep) currently supply ~7 million m³ of brackish (1 225 mg/litre of chlorides) geothermal (38–40 °C) desert water per annum to ten farming settlements.

Non-conventional water resources and conservation – After drawing on nearly all of its readily available water resources and promoting vigorous conservation programmes, Israel has long made it a national mission to stretch existing sources by developing non-

¹ Adapted from Israel Ministry of Foreign Affairs' Web site (2002):
www.mfa.gov.il/mfa/facts%20about%20israel/land/israel-s%20chronic%20water%20problem

TABLE 1
Water supply and demand – Israel 1998–2020 in million m³/year

Water supply							
Year	Population (Million)	Water sources					Total
		Surface water	Ground water	Brackish	Treated effluents	Desalination	
1998	6.0	640	1 050	140	260	10	2 100
2010	7.4	645	1 050	165	470	100	2 430
2020	8.6	660	1 075	180	565	200	2 680

Water demand						
Year	Urban sector	Water sources			Total	Total
		Natural	Brackish	Waste water effluents		
1998	800	920	120	260	1 300	2 100
2005	980	750	95	380	1 225	2 430
2010	1 060	680	75	490	1 245	2 680
2020	1 330	600	60	640	1 300	2 680

conventional water sources, while promoting conservation. These efforts have focused on the following: reclaimed wastewater effluents; intercepted runoff and artificial recharge; artificially induced rainfall – cloud seeding; and desalination.

Water conservation is the most reliable and least expensive way to stretch the country's water resources, and the challenge is being met in all sectors. In agriculture, the wide-scale adoption of low volume irrigation systems (e.g. drip, micro-sprinklers) and automation has increased the average efficiency to 90 percent as compared to 64 percent for furrow irrigation. As a result, the average requirement of water per unit of land area has decreased from 8 700 m³/hectare in 1975 to the 2002 application rate of 5 500 m³/hectare. At the same time, agricultural output has increased 12-fold, while total water consumption by the sector has remained almost constant. Table 1 summarizes the balance of supply and demand of water as projected in the year 2020.

In the domestic and urban sectors, conservation efforts focus on improvements in efficiency, resource management, repair, control and monitoring of municipal water systems. Citizens are urged to save water. The slogan “Don't waste a drop” is known in every home in Israel. Parks have been placed under a conservation regime, including planting of drought-resistant plants and watering at night.

Steps taken to mitigate national water shortage:

- The construction of desalination plants with an installed annual capacity of 400 million m³ for seawater and with an annual 50 million m³ capacity for brackish water.
- The rehabilitation of polluted and depleted wells with an annual total yield of up to 50 million m³.
- Increase the amounts of treated sewage effluents suitable for irrigation up to 500 million m³.

For more details, see Arlosoroff (2007).

Water quality – Water quality is an issue of equal importance to water scarcity, and water quality degradation is a considerable issue in water management. The quality of supplied water in Israel varies from very low salinity water (10 mg/litre of chlorides) from the Upper Jordan River, 200 mg/litre from the Kinneret, and more than 1 200 mg/litre from groundwater sources in the south. Groundwater exploitation is controlled to prevent seawater intrusion to the Coastal Aquifer and movement of saline water bodies within the Karstic Limestone Aquifer.

Despite the limits on water withdrawal, due to global warming and frequent droughts, the regime of the natural flows are decreasing. At the same time, the influx of pollutants from human activity and negligence above the aquifers is increasing,

resulting in the increase of mineral and other pollutants in the groundwater. Due to unbalanced exploitation and return flow from irrigation, an increase in the salinity of the groundwater has occurred in many wells. The most advanced technology and practices are being applied to protect and minimize the pollution of water resources. Water conservation maps, restricting land use activities above groundwater resources, were produced to protect the underlying resources. Regular monitoring of water resources, including: water recharge, water table levels, abstraction, salinity (chlorides) and pollution (nitrates) data are regularly monitored and reported. The data provides an effective tool for influencing the planning, the development process, and permissible emission of pollutants to the environment.



Water distribution – Mekorot Water Company Ltd.² is a government-owned company and, as Israel's national water company, is responsible for managing the country's water resources, developing new sources and ensuring regular delivery of water to all localities for all purposes. Mekorot is in charge of the wholesale supply of water to urban communities, industries and agricultural users. Mekorot produces and supplies about two-thirds of the total amount of water used in Israel. The remainder is provided through privately-owned facilities. In 1997, Mekorot supplied 1 380 million m³ of water, of which 745 were supplied for irrigation, 540 for domestic use, 94 for industry and 27 to replenish over-pumped aquifers. Water was also supplied to Jordan and the Occupied Palestinian Territory, in accordance with the peace accord. The shortage of water in the southern, semi-arid region of Israel required the construction of an extensive water-delivery system that supplies water to this region from resources in the north (Figure 2). Thus, most of the country's freshwater resources were interconnected into the National Water Carrier, commissioned in 1964. The National Water Carrier supplies a blend of surface and ground water. Water not required by consumers is recharged into the aquifer through spreading basins and dual-purpose wells, which helps to prevent evaporation losses and, in the coastal area, intrusion of sea water. The National Water Carrier supplies a total of 1 000 major consumers, including 18 municipalities and 80 local authorities.

SOCIAL AND ECONOMIC BACKGROUND

The data in this section is mostly extracted from the Web site of Israel's Central Bureau of Statistics (CBS, 2010).

² www.mekorot.co.il/Eng/Activities/Pages/default.aspx

The population of Israel at the end of September 2010 was approximately 7.65 million inhabitants, in approximately 2.09 million households – an increase of 1.7 percent compared with 2007. Gender distribution is almost equal, females constituting 50.5 percent of the population. By 2030, the population is expected to reach 9.5–10.6 million inhabitants (according to low and high scenarios, respectively).

The southern (desert) half of the country is sparsely inhabited – only around 15 percent of the population live there at a population density of 76/km² (compared to national density of nearly 330/km², and to 7 425/km² in the dense urban area of Tel Aviv district). Unemployment in 2010 was a little over 6 percent; average monthly wage (August 2010) was USD2 360 for Israelis and USD1 970 for foreign workers.

Gross domestic product (GDP) was approximately USD210 000 million in 2009, and the net national income approximately USD180 000 million.

Perception of personal economic situation – In 2002–2008, satisfaction with the economic situation increased (from 48 percent of respondents who were satisfied with their economic situation in 2002 to 55 percent who felt this way in 2008), satisfaction with labour income increased (from 44 to 53 percent), and the percentage of those who expect their economic situation to improve in the coming years increased (from 36 to 48 percent). In 2008, the proportion of those who managed to cover their monthly household expenses was 55 percent.

Agriculture land – Total agricultural land in 2009 was 295 000 hectares, aquaculture being only a tiny fraction at approximately 2 800 hectares. Inland aquaculture comprises only 1 percent (approximately USD65 million) of the total value of 2009 agricultural output, which amounted to around USD7 000 million, of which USD2 745 million are animal produce (54 percent meat; 26 percent milk; 7 percent eggs). Its major significance, however, is supplying the local market with fresh fish. Inland aquaculture for human consumption is practised by some 45 farms, mainly located in the northern coastal plain and the Bet Shean and Jordan Valleys, while only a few farms operate in the Negev Desert area. It should be noted, however, that the Bet Shean and Jordan Valleys, which account for 62 percent of Israel's inland aquaculture output, are arid zones with annual rainfall below 300 mm (Figure 3 and Annex).

ISRAELI INLAND AQUACULTURE IN BRIEF

As already mentioned in previous paragraphs of this review, Israel is located in a semi-arid zone, with a wet winter and dry summer. In spite of the obvious climatic constraints and

FIGURE 3
Location of edible fish farms (□) and
ornamental fish farms (○) in the Israeli desert
and arid lands



overall shortage of water, both agriculture and aquaculture are highly developed in Israel (Mires, 2000). Israeli agriculture depends, to a large extent, on irrigation of crops during the dry summer. Nowadays, one of the common usages of irrigation reservoirs is for fish culture.

To deal with these impediments, different solutions and methods to maximize water use and enable production of fresh edible fish have been developed (Kolkovsky, Hulata and Simon, 2011). These solutions include:

- Reservoirs to store rainwater during the wet season. Israeli agriculture is now largely intensive and depends on irrigation from these reservoirs during the dry summer. Recently, it has become common to use irrigation reservoirs for fish culture in integrated farming systems. These integrated agriculture-aquaculture systems use the water twice: (i) within an aquaculture production system; and (ii) subsequently, to supply irrigated agriculture systems. This system, now a few decades old, was a significant step in the intensification of inland fish culture in Israel (Hepher, 1985; Sarig, 1988).
- Large-scale recirculating systems, in which water from outdoor fish ponds, raceways and tanks is passed into sediment ponds to remove the solids. The water is then passed to an adjacent water reservoir, and good quality water is then returned from the reservoir to the fish rearing systems.
- Highly-intensive recirculating systems that incorporate water filtration systems, such as drum filters, biological filters, protein skimmers and oxygen injection systems. Highly-intensive systems may support up to 50 kg of fish/m³ of water. Culture is intensive, as the stock is entirely dependent on a comprehensive artificial diet and there is acute management of water parameters. These systems are usually compact, take up a relatively small area and are extremely efficient with water usage. However, at the current operation costs and market price of fish produced, they are at best marginally profitable.
- Greenhouse technology was adopted from desert vegetables and flower agriculture and includes environmental control, i.e. humidity, temperature, light and radiation. These conditions are important in arid areas, which have large temperature changes between day and night and summer and winter.

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

Culture practices

Fish farming in this region started in the 1930s, when the common carp (*Cyprinus carpio*) was imported from former Yugoslavia, and production practices common to Central Europe were implemented. The first fish ponds in Israel were established in the Kurdani marshes in Haifa Bay, and the first commercial farm was setup by members of Kibbutz Tel Amal (Nir David) in the Bet Shean Valley. Production spread to other areas in Israel: the Yizre'el, Jordan and Hula Valleys, as well as to the coastal region, from Acre in the north to south of Hadera. In the last two decades, fish farms are also being developed in the arid south of Israel, in the Negev Desert and the Arava Valley (for additional information on aquaculture development in the Negev Desert, see the following paper by Samuel Appelbaum).

Traditionally, fish are raised in ponds. There is a wide range of ponds, which differ in structure, type of bottom and depth. A typical fish pond (earthen pond) is dug in the ground and has a soil bottom. Ponds are usually dug in heavy clay soil, which provides natural sealing against seepage. When a pond is dug in sandy soil, the bottom of the pond is usually covered with clay soil that is brought to the site, to achieve impermeability. The size of ponds in Israel is usually between 100 m² and 10 hectares. Small ponds are used for reproduction, nursing and holding before marketing, and the larger ones are used for grow-out. The average depth of an

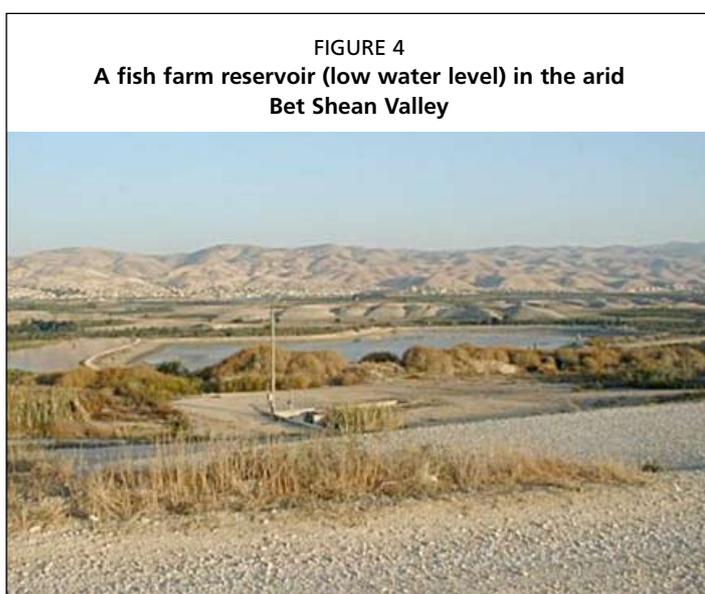
earthen pond is between 1.5 to 3 m. Annual fish output from earthen ponds in Israel is 5 000 to 10 000 kg/hectare.

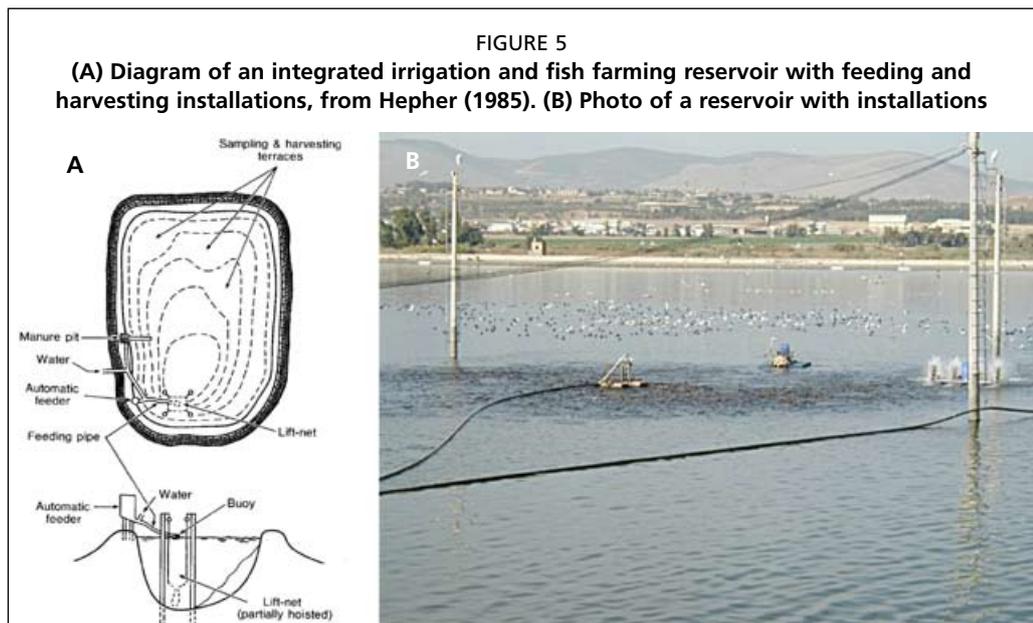
Another type of pond is the reservoir. The main difference between an earthen pond and a reservoir is the depth of the water. The average depth of a reservoir ranges between 4 and 15 m, and its size between 5 and 20 hectares. There are irrigation reservoirs, fish-farming reservoirs and integrated (dual-purpose) reservoirs. Originally, irrigation reservoirs were built to collect rain and flood waters in winter to be used to irrigate crops in summer. These reservoirs are usually managed by Mekorot, the national water utility company, as part of the national water system. Fish are introduced into these reservoirs only to maintain water quality and there is no investment in fish farming systems. Historically, the first reservoirs were constructed in the 1960s in the Harod Valley to serve the needs of the kibbutz (communal) settlements in that region. The total surface area of five reservoirs was 90 ha, and they were used solely for irrigation. These were rather shallow reservoirs, which collected brackish spring water flowing year round, and stored it for use during the dry summer. In order to catch the larger amounts of rainwater during winter, the reservoirs were deepened. The fish farmers of these communal settlements decided to use them for fish culture, in addition to their original purpose. In a few years, it became evident that rearing fish in such reservoirs was profitable, though professional and technological know-how was still lacking. The secondary use of water for fish culture, by introducing them into irrigation reservoirs improved the efficiency of water usage, and reduced the cost of water needed for fish culture in conventional earthen ponds. However, the main drawback was harvesting the fish from these reservoirs, since the engineers planning their construction did not take such activity into consideration. This led to a dramatic technological development during the late 1970s, and many new reservoirs were constructed, specifically planned for dual use, i.e. they were equipped with a range of solutions for efficient harvesting of the fish. This development has, in turn, changed the emphasis and in the newly constructed reservoirs fish culture became the primary activity and crop irrigation a by-product. Most fish farms in Israel now operate such reservoirs (Figure 4), which are an efficient and profitable tool for fish culture.

Integrated reservoirs reduce the cost of water for fish farming, as some of the costs are recorded as irrigation costs. These reservoirs are usually deeper than 5 m, to allow irrigation during the summer and to ensure that there is sufficient water until the end of the fish production season in the autumn.

Heavy investments are necessary in these reservoirs to install the equipment required for fish production and harvest (Figure 5).

Due to the large volume of the reservoirs, the fish output is much higher than in the regular earthen pond, reaching 10 000 to 20 000 kg/hectare a year. This quantity of fish is too high to be harvested from the pit at the end of the season, and there may be dangerous overcrowding when the water level in the reservoir drops during the summer. As a result, fish farmers usually harvest some of the fish that have reached market size during the season to cull the population. The reservoirs are equipped with harvesting facilities, such as sampling terraces for net





harvesting, or lifting nets attached to motorized booms that are lifted with the catch. The fish gather into a sleeve, which can be detached and dragged to the reservoir bank, where the fish are removed.

Some of the reservoirs have concrete pits at the end of the reservoir's outlet pipe outside the reservoir by the drainage canal. These enable convenient harvesting of fish from the reservoir, and handling them after they are removed via the pipe. The pits have strainers for separating the fish from the water, as well as life-support installations to ensure the welfare of the fish (Figure 6).

In recent years, due to increased salinity of the water (reaching up to 2 ppt in the summer) to levels preventing their use for irrigation, especially in the Harod Valley, some of the reservoirs are no longer used as dual purpose reservoirs but only for fish culture. This level of salinity slows carp growth rate, and is mostly suitable for tilapias.

Common problems in operating deep dual-purpose reservoirs result from stratification. During summer, surface water temperature can be 30 °C or more, while at depth of >5 m it may be 20–22 °C. This thermal stratification affects various aspects of water quality. While the upper, photic layer of the reservoir is oxygen-rich, sometimes even supersaturated, the bottom layer accumulates nitrogenous and organic metabolites, is depleted of oxygen and tends to be toxic to the fish. At final draining of the reservoirs, the fish are held in water of very low quality, which make the harvesting operation very risky. Moreover, wind regimes during summer may break the stratification, and lead to upwelling of lower layer to the surface. This can lead to catastrophes due to change of water colour, algal blooms and crashes, mass mortality of fish due to low oxygen concentrations and/or poisoning by sulphuric compounds (Milstein, Zoran and Krambeck, 1995; Zoran, Milstein and Krambeck, 1994). The extension and research systems are trying to tackle this problem through improved management practices. One solution, which was tested in recent years, is employing a floating water pump, which mixes the water column continuously and prevents the stratification (Zoran and Milstein, 1998; Milstein, Krambeck and Zoran, 2000; Milstein, Zoran and Krambeck, 2001; Milstein and Zoran, 2001).

ECONOMIC EVALUATION OF RESERVOIRS VS. CONVENTIONAL (SHALLOW) EARTHEN PONDS

Freshwater fish are typically cultured in Israel, both in ponds and reservoirs, in a polyculture system of common carp and tilapias as major species and silver carp

and grey mullet as minor species (Hepher, 1985). The fish stocked into the reservoirs are nursed to a certain size in ponds in preparation for grow-out in the reservoirs. No fish can grow from 1 g size fingerling to market size from spring to autumn, which is the operational period of a reservoir. Thus, the farm must have service ponds in order to efficiently operate a reservoir. These will be also used at harvest time, to hold fish until they are marketed (all year round), since a farm cannot market the whole harvest of a reservoir at once. Thus, the ponds are operated all year round, rearing fish in the spring and summer and holding fish for market or for stocking the reservoirs (in the spring) during the winter. The stored fish are fed maintenance ration during winter, and this is added to pond expenses.

Production costs per unit of fish in dual-purpose reservoirs are favourably lower compared to those in conventional earthen ponds (Table 2 and 3). For the production of 1 kg of tilapia, 4.0 m³ are used when cultured in reservoirs, compared to 7.4 m³ in conventional earthen ponds, and 4.6 m³ in intensive concrete ponds, though only 1.4 m³ in an industrial, indoors super-intensive culture system. A detailed breakdown

FIGURE 6
A composite picture showing technology for harvesting fish from reservoirs. Top right – drained reservoir with lift-net poles; bottom – draining pipe coming from the reservoir into an external concrete harvesting pit; top left – portable sorting table and “Archimedes screw” fish lift



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TABLE 2
Costs of producing 1 000 kg of fish in ponds and reservoirs

Data	Dual-purpose reservoirs	Earthen ponds	Comments
Water	-	50 000 m ³ /ha	Reservoir water price is charged to irrigated field crop
Feed	1 300 kg	2 200 kg	Ponds are used for storage during winter
Labor	5 days	4 days	
Seed	4 000	5 000	
Energy	5 000 kW	7 000 kW	
Depreciation	500 USD	600 USD	

TABLE 3
Itemized direct costs of producing 1 kg of fish in dual-purpose reservoirs (in USD)

Item	Unit	Quantity	Unit price	Cost (USD)
Water	m ³			
Feed	kg	1.3	0.5	0.65
Fingerlings (50g)	#	3	0.15	0.45
Energy (pumping, aeration)	kWh	5	0.1	0.50
Maintenance, machinery		1	0.1	0.10
Marketing		1	0.2	0.20
Manpower, management	days/ton	3	100	0.30
TOTAL for 1 kg				2.15

of production costs of fish in dual-purpose reservoirs is presented in Table 3.

RECENT DEVELOPMENTS

Until the year 2000, most Israeli fish culture reservoirs produced a rather ‘stable’ combination of the three leading species: common carp (*Cyprinus carpio*), tilapias

and flathead grey mullet (*Mugil cephalus*). In addition, small quantities of red drum (*Sciaenops ocellatus*), silver (*Hypophthalmichthys molitrix*), grass (*Ctenopharyngodon idellus*) and black (*Mylopharyngodon piceus*) carps were also reared in these reservoirs. Common annual yield was around 0.8 tonnes/ha. To obtain such a yield by the end of the season (December–January) the reservoirs were stocked in the previous April with 20 000/hectare tilapias (~100 g), 5 000/hectare common carp (~300 g) and 1 250/hectare grey mullet (~200 g), giving a total of around 25 000 fish/hectare.

Fish culture is mainly concentrated in the semi-arid northeastern region of Israel, i.e. Bet-Shean, Yizre'el and Harod Valleys. This is the region where dual-purpose reservoirs were originally developed. Developments occurring in the decade starting in the late 1990s resulted in remarkable changes in the practices of reservoir fish culture:

- Profitability of field-crops deteriorated, leaving a surplus of brackish water not suitable for irrigation, but well suited for fish culture. This has triggered fish farmers to invest in construction of more reservoirs.
- Fresh fish consumption has increased and farmers felt a need to increase production to supply the increasing demand.
- Fish farms started to invest in constructing water reservoirs specifically for fish culture, disconnected from the irrigation systems. This, however, required proving economic feasibility, since the investment required a minimal annual yield of 15 tonnes/hectare.
- Fish culture extension officers succeeded in convincing the feed mills and the fish farmers to invest in an extruder, allowing production of higher quality floating feed pellets. Due to the improved feed, the limit on daily feeding rate increased from 200 to 350 kg/hectare, which in turn enabled increasing stocking density and, respectively, obtaining higher production.
- Energy supply was expanded, so that more aerators could be added to fish culture reservoirs.

Culture practices and management of large farms (150 hectares) have improved, including stocking at appropriate time and partial harvesting of marketable-size fish during the culture season for lowering the total biomass. These improvements enabled increasing the gross annual yields to rise from 10 to 20 tonnes/hectare, with outstanding farms producing as much as 30 tonnes/hectare/year, and had positive effect on the professional and economic performance of Israeli fish culture reservoirs.

The proportional allocation of water among production reservoirs, service (propagation and nursing) ponds, and storage ponds for marketing have been optimized, and is currently 60–70 percent, 10–20 percent, and 10–20 percent, respectively.

A third type of pond has walls and usually also a solid bottom – intensive culture ponds. These ponds are used for intensive fish production, where a much higher density of fish is produced than in earthen ponds and reservoirs. This requires water circulation in the pond to collect the faeces and unconsumed feed and remove them from the pond. These ponds are excavated in the earth and lined with plastic sheets for sealing and to provide smooth walls and floor. The vertical walls are built from blocks and the earth bottom is lined with plastic sheets. Some ponds are constructed with reinforced concrete (walls and floor). The main difference from an engineering point of view is the smoothness of the surface. Even when the plastic sheeting is spread carefully, there are still wrinkles. The smoother the pond walls, the better the release of water and concentration of solids into the removal area. Intensive culture ponds can be circular, polygonal, rectangular or elongated with rounded edges. The engineering structure influences the efficiency of the water circulation, as well as the cost of the construction (a round pond costs more to build than a polygonal one). Water is usually circulated in the culture pond by paddle wheels (oxygenators) which introduce air (oxygen) into the water and generate a current. There are both outdoor and indoor ponds for intensive fish production.

Intensive culture units also accompany dual purpose irrigation/fish culture reservoirs, which serve as a biological filter and water source. Water is pumped from the fish ponds to a settlement pond for solids removal and then pumped to the main irrigation reservoir. In most cases, the reservoir is very large with a capacity of several million m³ of water. The effluent water from the fish farm is 'diluted' in the reservoir which acts as a biological filter, so the water that is pumped back into the pond systems is relatively clean.

Outdoor intensive ponds are located near a large pond or reservoir and connected by the water system, so that water and waste from the intensive culture ponds flow into the large pond, and are replaced by water flowing or pumped from that pond. The large production pond or the reservoir serves as a biological filter. One example is the facility of Kibbutz Neve Eitan fish farm (32°28' N 35°32' E) that includes 8 × 200 m³ circular concrete ponds (Figure 7). The water returning to the intensive culture ponds from this pond or reservoir has a much higher quality than the water leaving them. When intensive culture ponds are inside greenhouse structures, filters are installed close to or inside the structure to recycle the water from the production ponds. The filtration system includes a physical filter to remove solids and a biological filter to break up soluble waste products. Sometimes equipment for dissolving oxygen is added to the water treatment system to maintain an optimum oxygen concentration according to the stocking density. Annual fish output in intensive culture ponds in Israel reach up to 40 kg/m³.

FIGURE 7
Open-pond intensive fish farm adjacent to a reservoir serving as a biofilter (Kibbutz Neve Eitan, Bet Shean Valley)



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AQUACULTURE IN GEOTHERMAL WATER

Desert aquaculture in southern Israel began in 1979 with the discovery of locally available geothermal water (at 40 °C) near Faran, a village in the Arava Valley (30°22'–N 35°09' E). The idea of using hot ground water for highly-intensive aquaculture, to achieve maximum growth throughout the year, has subsequently been developed commercially. Combined greenhouse heating of microalgae cultures (*Spirulina* and *Dunalliella* species) and fish ponds has also been successfully trialled, but did not prove to be economically valid.

For both economic (cost of one m³ of brackish water in Israel is about USD0.05) and ecological reasons, the design of integrated aquaculture projects with agriculture areas as end-users is essential in arid areas. Contrary to the central-north areas of Israel, integrated aquaculture in the southern, more arid, areas is based on highly-intensive systems with very tight water budgets. Water loss is minimal and is predominantly due to evaporation. However, even when there is no need for heating during the summer, most of the fish farms have water exchange of at least 10 percent/day to maintain water quality. A small fish farm of 2 000 m³ will, therefore, use about 200 m³ of water/day, which in turn will irrigate about four hectares of crops in the desert summer. In winter, when a larger amount of water is needed to supply the heat energy to the fish ponds in the aquaculture system, there is a need to find a solution for the surplus output water or effluent.

There are two options for transferring heat energy to the fish ponds in these production systems:

- 1) A closed system using heat exchangers. When using a closed system, the geothermal water is used for heating the fish pond via a heat exchanger.

FIGURE 8
Interior of greenhouse containing large tanks for intensive fish culture in Israeli arid Negev. Green plastic is installed to prevent algal blooms in the tanks



COURTESY OF Y. SIMON

This is not practical for large open ponds, but can be efficiently used for indoors ornamental fish farming (see below).

2) Direct supply of water to the fish pond. When a direct supply of geothermal water to the fish pond is used for heating, the water is also used for flushing the organic matter from the pond and to contribute overall to the water quality of the pond. Accordingly, the outlet water is loaded with suspended solids, micro-organisms, algae and plankton due to the high nutrient loading on the intensive rearing system.

When the end-user of the effluent is drip irrigation, the water needs to be filtered or otherwise treated prior

to being distributed under pressure through the dripping system. Usually, a small reservoir (0.1–1 hectare surface area) is attached to the fish farm for this purpose. This reservoir, together with water treatment facilities, is used to provide a buffer between the agriculture project (e.g. greenhouse, orchard or open field) and the aquaculture system. Fish are also reared in this reservoir, but at relatively low biomass/unit volume or area.

The water treatment facilities typically include high-pressure pumps, a chlorine injection system (or other form of disinfection) and an automatic filtration system. Secondary filtration is undertaken at each irrigation head to ensure good water quality for final reticulation and to prevent drippers from clogging with particulate waste matter.

Knowing the bore water salinity is crucial for any agricultural crop, with 0–5 percent salinity being an acceptable concentration in most cases in Israel. Most of the geothermal water available in Israel is considered too saline (8–12 percent), especially if increased salinity occurs due to evaporation in fish ponds. Rearing sensitive crops is not feasible at these higher salinities, although other crops, e.g. watermelons, alfalfa and tomatoes, are highly successful. ‘Desert sweet tomatoes’, a brand name for a very sweet variety of tomato that was developed in Israel and is produced in saline groundwater, is extremely successful in both local and European markets. Salinities up to 8 percent can be used to produce a variety of crops, such as date palms, olives, certain citrus varieties and varieties of green vegetables.

Of five model pilot-scale farms established during the 1980s and 1990s, two were expanded to a full commercial scale of 200–400 tonnes/year of aquaculture production. These farms were built from modular units of $8 \times 300 \text{ m}^3$ capacity ponds under a greenhouse (Figure 8). The ponds are connected to a water treatment unit that includes a settlement pond (100–200 m^3 capacity) together with an ‘activated suspension’ method (Bio Flocc Technology, BFT) for nitrification (conversion of nitrogen as ammonium and organic) into protein by bacteria (Avnimelech, Mokady and Schroeder, 1989; Avnimelech, Kochva and Diab, 1994; Avnimelech, 1998, 2009; Avnimelech *et al.*, 2008).

LIMITATIONS AND CONSTRAINTS

The developments described above and the economic advantage of reservoir-based fish culture over other systems (see below) are not without problems and limitations.

Growing fish in large, deep reservoirs is a major challenge and high-risk operation. It involves a day to day effort to cope with biological and technologically unforeseen difficulties, where the ability of the farm manager to respond to unexpected events is negligible due to the large volume of water and biomass of fish at hand.

The price of water for agricultural use is continually increasing. Fish farmers are forever seeking ways to make more efficient use of water, in order to lower the production cost of fish. Dual-purpose reservoirs, recirculation of water on farms and their use for irrigation were a remarkable effort toward achieving this goal. However, the high evaporation rate during the hot summer and the recent dry winters have led to increased salination of impounded water in some northern regions in Israel, to the extent that the water can hardly be used for irrigation of traditional crops or even for growing common carp. Thus, some previously dual-purpose reservoirs are currently used solely for culture of more salt-tolerant fish species (e.g. tilapias and marine species), affecting their economy. Another important issue is the environmental protection regulations that become more and more strict. Close cooperation is required between farm operators and environmental protection officers to coordinate the release of large amounts of water when draining reservoirs in a way that will benefit, rather than harm, the natural environment in the region.

In spite of technology improvements, many of the desert aquaculture pilot farms failed due to a combination of mismanagement and economical difficulties. The most suitable species for desert aquaculture are tilapias that were the backbone of the farms in the Negev in the 1990s; however, their market prices in Israel collapsed and were not able to cover investment costs. One farm, in Kibbutz Mashabe Sade (31°00' N 34°32' E), succeeded to overcome this problem by substituting to growing barramundi that fetches high prices on the market and is currently economically stable.

Another solution adopted by many fish farmers was the shift to culture of ornamental tropical fish, which became a real success story. Taking advantage of the climate conditions and lower water requirement, intensive culture units were established to grow high-quality tropical ornamentals for export to Europe and elsewhere. These farms use freshwater pumped from local underground aquifers, or desalinated brackish water. Currently, there are some 15 active farms in the Arava region, and 15 more in the Negev. The size of the farms is typically between 0.1–0.3 ha, in green-houses or indoors. The total volume of water is estimated at 10 000 m³. Two farms take advantage of being remote from carp and koi farms in the north which are infested with the koi herpes virus and produce cold-water ornamentals (koi and goldfish) in biosecure (virus-free) closed systems to meet the strict regulations for export to the European Union. Among the major ornamental fish species cultured commercially in the desert farms in Israel are: guppy (*Poecilia reticulata*); platyfish (*Xiphophorus maculatus*); swordtail (*Xiphophorus helleri*); angelfish (*Pterophyllum scalare*) and selected catfishes from South American rivers, namely bottom-feeding fish from the Loricariidae family.

HUMAN RESOURCES

In 2010, the Israeli inland aquaculture industry consisted of some 30 farms producing edible fish (two in the Negev and around 20 in the arid zone of Gilboa, Bet Shean and Jordan Valleys). Edible fish farms are almost exclusively operated by communal kibbutz farms. These fish farms employ some 300 people in management and planning, production and marketing. Education level varies accordingly.

Five packaging and processing plants employ some 60 workers. A further 100 people are engaged in transportation of fish to the markets, insurance and risk assessment.

The supporting research and development (R&D) units employ some 50 workers (scientists, technicians and engineers, pond workers, etc.). Among these are the experimental station in the Arava Regional R&D Center and the “Bengis Center for

Desert Aquaculture” of the Institute for Desert Research, Sde Boker campus of the Ben-Gurion University of the Negev in Beer Sheba.

The ornamental fish sector consists of some 120 farms, 30 of which are located in the Negev and Arava regions. On average, an ornamental fish farm employs some ten workers. Many of these farms are single-family owned.

The whole aquaculture sector is supported by three extension officers. These support the farmers by direct contacts, advising them on all aspects of advances in production systems, planning production and investments for expanding farms, etc. The extension service also organizes transfer of know-how from the experimental stations and research sector to the farmers and organizes training courses.

CULTURED SPECIES IN DESERT AND ARID LANDS OF ISRAEL

The main cultured species reared in the Israeli desert and arid lands are the following:

- common carp (*Cyprinus carpio*);
- tilapia (hybrid derivatives of Nile tilapia, *Oreochromis niloticus*, and blue tilapia, *O. aureus*; red tilapias);
- flathead grey mullet (*Mugil cephalus*);
- grass carp (*Ctenopharyngodon idellus*);
- silver carp (*Hypophthalmichthys molitrix*);
- hybrid striped bass (hybrid between the striped bass *Morone saxatilis* and the white bass *M. chrysops*);
- red drum (*Sciaenops ocellatus*);
- barramundi (*Lates calcarifer*);
- gilthead seabream (*Sparus aurata*);
- North African catfish (*Clarias gariepinus*);
- ornamentals (mainly guppy and molly – genus *Poecilia*; angelfish – genus *Pterophyllum*).

The common carp was introduced from central Europe in the early 1930s. Blue (Jordan) tilapia is endemic, whereas Nile and red tilapias were introduced in the 1970s and 1980s. Flathead grey mullet is caught in the local Mediterranean estuaries or imported from Spain. Chinese carps – grass carp (*Ctenopharyngodon idellus*) and silver carp (*Hypophthalmichthys molitrix*) – were introduced from Southeast Asia in the 1970s (Hepher and Pruginin, 1981). Hybrid striped bass and red drum were introduced from the United States of America; they tolerate brackish water and can be cultured in land based intensive farms. The barramundi was introduced from Australia and Thailand in the early 1990s. The barramundi has been found to be a highly suitable candidate for Israeli desert aquaculture because it thrives in the warm brackish desert water. It has been well accepted by consumers due to the sweet-buttery taste and the delicate flesh texture. Barramundi is produced in Israel only in the desert and is consumed fresh locally. Gilthead seabream is a Mediterranean marine species. It is capable of adapting to environments of different salinities and temperatures, and therefore, can be farmed in coastal ponds and lagoons, with extensive and semi-intensive methods; or in land based intensive farming installations. North African catfish is endemic to the upper Jordan river system; it can tolerate low salinity brackishwater available from well at the Negev Heights.

In Israel, both in conventional earthen ponds and in reservoirs, freshwater fish are typically cultured in a polyculture system, stocked with different species of fish (Hepher and Pruginin, 1981; Hepher, 1985). Most reservoirs are stocked with 80 percent common carp and tilapia (at various proportional combinations) and 20 percent accompanying species, such as flathead grey mullet, grass carp, red drum and the silver carp x bighead carp hybrids. Intensive ponds, outdoors and indoors alike, are stocked in monoculture.

Rearing tilapias in reservoirs, either in monoculture or polyculture, poses a real challenge – biological, as well as economic. Being tropical fish in origin, winter

water temperatures in Israel preclude their stocking during winter (January–April, when temperatures are below 15 °C). Thus, the annual production cycle is geared to stocking tilapias, previously nursed to weight of at least 50 g and over-wintered, in the spring so that they can reach market size before temperatures drop down in the fall. These tilapias are already sexually-matured when stocked into the reservoir, and capable of reproducing if both males and females are stocked. This, in turn, will lead to a population explosion, competition on resources, resulting in large amounts of unwanted fish filling the reservoir. Stocking of all-male, or nearly all-male (>95 percent males) seed will practically eliminate the problem. Adding predators, such as European seabass (*Dicentrarchus labrax*) or red drum, can further reduce the numbers of tilapia fingerlings surviving in the reservoir.

Production of barramundi was restricted to the Negev desert area when introduction permit was issued by the Department of Fisheries, as a protection measure against its infiltration into the national water system in the northern part of the country (specifically the Lake of Galilee). Climatic conditions, as well as availability of heated geothermal water in the region support its temperature requirement of 26–30 °C for optimal growth.

CURRENT TOTAL PRODUCTION (VOLUME AND VALUE)

Descriptive data of the Israeli aquaculture sector (Shapiro, 2011) in the last decade are presented in Tables 2 and 3. Due to local economic difficulties, the number of active farms went down and some ponds were dried up, as reflected in the area used for fish culture. Production, however, decreased only slightly. Variation in value reflects the collapse of market prices in 2002–2004, and recovery in the following years (Table 4). Common carp and tilapias together account for about 75 percent of Israeli inland aquaculture (Table 5). The arid Bet Shean and Jordan Valleys and Gilboa grow 60 percent of the common carp, 82 percent of the tilapias and 78 percent of the

TABLE 4
Aquaculture production and gross income in the last decade in Israel

Year	No. of farms	Area (ha)	Yield (MT)	Yield (kg/0.1ha)	Value of yield (USD)	Average value (USD/MT)
2000	73	3 095	17 184	5.55	54 685	3 182
2001	73	3 095	18 157	5.87	57 944	3 191
2002	73	3 095	19 200	6.20	45 480	2 369
2003	73	3 090	17 667	5.72	42 725	2 418
2004	65	2 848	18 949	6.65	45 546	2 404
2005	55	2 808	19 208	6.84	53 875	2 805
2006	55	2 808	19 382	6.90	55 028	2 839
2007	55	2 808	19 168	6.83	61 458	3 206
2008	45	2 808	17 731	6.32	63 714	3 719
2009	45	2 693	18 442	6.85	60 986	3 307

Source: Shapiro, 2011.

TABLE 5
Aquaculture yields by species in the last decade (in tonnes) in Israel

Year	Carp	Tilapias	Mullet	Silver & grass carp	Trout	Hybrid striped bass	Red drum & seabass	Barramundi	Seabream	Other
2000	6 281	7 059	1 661	744	605	302	–	–	–	532
2001	6 208	8 217	1 633	718	448	378	313	48	–	44
2002	7 748	7 819	1 824	616	374	495	146	66	–	17
2003	7 339	6 826	1 705	713	352	385	250	–	–	97
2004	5 765	9 270	1 792	903	331	292	503	15	–	78
2005	6 413	7 404	2 108	1 607	424	453	488	90	181	40
2006	6 560	8 235	2 087	1 102	449	290	472	115	72	–
2007	6 737	7 973	1 983	1 135	431	147	–	100	17	645
2008	6 448	6 751	2 121	1 022	428	182	573	67	139	–
2009	5 892	7 789	2 048	1 094	379	–	–	–	–	1 240

Source: Shapiro, 2011.

TABLE 6
Pond area and yield by regions in 2006–2009 (production in desert/arid zones emphasized)

Region	2009			Average 2006–2008		
	Area (ha)	Yield (MT)	Yield (kg/ha)	Area (ha)	Yield (MT)	Yield (kg/ha)
Rainy zone						
Galilee	200	638	3 190	323	1 198	3 710
Coastal plain	815	3 913	4 800	815	4 385	5 380
Arid zone						
Gilboa	440	2 007	4 560	440	1 777	4 040
Bet Shean and Jordan Valleys	1 225	11 406	9 310	1 225	11 135	9 090
Negev	13	478	37 640*	5	265	58 960*
Total	2 693	18 442	6 850	2 808	18 760	6 680

* Intensive systems only.

mullet produced in Israel (Table 6). The Negev grows all the barramundi and seabream cultured in brackishwater and half of the hybrid striped bass.

MARKET AND TRADE

The edible fish produced by the inland aquaculture sector are oriented toward the domestic market, whereas, the ornamental fish are produced mainly for export. The market is supplied weekly with some 400 tonnes of fish. Common carp reaches the markets alive and all other species are shipped chilled on ice. A small proportion of the fish goes to processing plants and the products are marketed frozen as whole gutted fish or as fillets. Currently, there are two major wholesale marketing companies serving the industry and supplying the country's demand, though some farms sell part of their product through retail farm-gate outlets. When the fish farms were started in the Negev, they did not have marketing quotas because marketing was fully controlled by the Fish Breeders Association, a cooperative founded in 1940. At that time their solution was to supply their products (mainly tilapias) directly to hotels and restaurants in the region, as well as to private households (by orders) and at farm-gate. The Revivim fish farm, culturing the North African catfish, is still marketing mainly at farm-gate. All fish farms in the arid zone, as well as those in the Negev (currently only one in addition to the catfish farm) market mainly through the whole-sale market channels.

CONTRIBUTION TO THE ECONOMY (FOOD SECURITY, EMPLOYMENT, POVERTY ALLEVIATION)

The aquaculture sector is a relatively small player (1 percent) in Israeli agriculture. The total product value is about USD70 million (80 percent edible fish and the rest ornamental fish), compared to about USD14 billion product value of the poultry sector. In Israel, no aquaculture activities involve poor rural households. Most edible fish production nationwide (including the desert/arid zones) is practiced by kibbutz (communal) settlements. The few edible fish farms in the desert founded and managed by private owners failed. On the other hand, the ornamental fish farms are almost exclusively family-owned businesses.

As mentioned earlier, the arid zone Bet Shean and Jordan Valleys account for 62 percent of Israel's inland aquaculture output. In these regions, integrated fish culture increases the return from water used by 50 percent compared to non-aquaculture uses. The fish culture integrated with crop irrigation is a dominant activity in the economic development of the region, especially where most other agricultural branches cannot use the brackish water and slightly salted soil.

Since Israel imports about 2/3 of the fish consumed, it would be incorrect to talk about contribution to food security. However, local production in all areas supplies the

fresh fish market. This ensures continuous supply of high quality, veterinary inspected fish to consumers, just like other types of animal protein products (beef, lamb and poultry meat).

The ornamental fish sector in the Arava Valley exports annually around USD5 million worth of tropical fish. This, again, is only a small contribution to the economy of the region which exports bell peppers at USD100 million annually and produces a few other products such as melons, cut flowers, etc.

INSTITUTIONAL FRAMEWORK

The lead government agency vested with administrative control of aquaculture is the Division of Fisheries and Aquaculture, Ministry of Agriculture and Rural Development (MoAG), operating under the Fisheries Ordinance 1973.

Address:

Agriculture Center, HaMaccabim Road, Rishon Lezion; PO Box 30, Beit Dagan 50250

Tel.: +972 3 9485427

Fax: +972 3 9485735

E-mail: chaima@moag.gov.il (Mr Chaim Anjeoni, Director)

Web site: www.fishery.moag.gov.il/fishery (in Hebrew)

The division operates under the authority of the Director General of MoAG and consists of four departments:

1. inland water aquaculture;
2. mariculture;
3. marine fisheries;
4. fishing ports and inspection.

Among the division's roles and activities are:

- supervising and preventing transgressions of the Fisheries Ordinance;
- coaching, promoting and developing the inland and marine aquaculture industries;
- preventing the invasion of fish species that might damage the fish and the natural environment;
- introducing new species in quarantined areas;
- veterinary service to the aquaculture sector;
- assisting in prescribing medications for the use of farmers;
- promoting fisheries and aquaculture research;
- issuing export and import permits;
- coaching and training different and diverse model fish farms;
- collecting data regarding the fisheries and aquaculture agriculture industries, and publishing it in an annual report;
- providing professional support to entrepreneurs and investors;
- managing a fishing interface in the Mediterranean Sea, Eilat Bay and Lake Kinneret;
- issuing individual fishing permissions and for fishing boat owners;
- restoring and maintaining the fishing ports.

The Department for Inland Aquaculture

The Department has three research stations: the Aquaculture Research Station in Dor, the Aquaculture Research Station in Genosar, and the Central Fish Health Laboratory in Nir David. It is engaged in research and providing assistance to aquaculture farmers on: disease research; veterinary service; new technologies; water saving; fish growing techniques; product quality; quality standards on all levels; and organic aquaculture.

GOVERNING REGULATIONS

In 2004, the Department of Inland Aquaculture, in cooperation with the Extension Service, completed and published (in Hebrew) “aquaculture production protocols” that govern all aspects of aquaculture in the country. Health control of fish and fish farming is regulated by the basic law – “The Animal Diseases Ordinance [New Version]” 1985. The National Food Service in the Ministry of Health is responsible for the inspection and marketing of fishery products within Israel. Relevant regulations include: the “Business Licensing law 1968”, the “Business Licensing Regulations (hygienic conditions for transportation of meat, fish, poultry and their products) 1971”, and the “Business Licensing Regulations (sanitary conditions for food manufacturing businesses) 1972”. For some of these regulations, only a Hebrew text is available. Penalties and fines provided by law, in cases of non-observance, are detailed in the relevant regulations and are updated from time to time.

APPLIED RESEARCH, EDUCATION AND TRAINING

Agriculture research, including aquaculture in Israel, is carried out by the public and the private sectors although is primarily funded by the public sector (85 percent), of which the MoAG (www.moag.gov.il) provides the major share (www.science.moag.gov.il). Other sources of funding include national, binational and international funds. The farming sector funds research through the production and marketing boards, and the Farmers Organization. The private sector funds the other 15 percent of the agricultural research, which is carried out mainly by manufacturers of agriculturally related products (e.g. fertilizers, seeds, irrigation equipment, pesticides) and is partially supported by the Office of the Chief Scientist of the Ministry of Industry and Trade. Aquaculture research is conducted in various public organizations, universities and regional R&D centres. Some research projects are conducted on-farm, but most are conducted in research laboratories, and results verified on experimental stations or farms. Research is prioritized by national committees for each production branch or by regional committees for R&D, and are peer-reviewed before research grants are allocated.

The Department of Fisheries, Ministry of Agriculture and Rural Development operates two experimental stations (at Dor and Ginossar) and the Central Fish Health Laboratory (at Nir David). The Agricultural Research Organization has an aquaculture Research Unit, under its Institute of Animal Science. Scientists involved in aquaculture research are staff members at the Faculty of Agriculture of the Hebrew University in Jerusalem (Rehovot Campus), Department of Life Science of the Ben-Gurion University of the Negev, the Faculty of Environmental Engineering of the Technion, Israel Institute of Technology, and various other colleges.

Desert aquaculture research is practised at the “Bengis Center for Desert Aquaculture” of the Albert Katz Department of Dryland Biotechnologies, Institutes for Desert Research at the Ben-Gurion University, Sde Boker Campus, at the National Center for Mariculture, Israel Oceanographic and Limnological Research Ltd., and at the Central Arava regional R&D Center, Yair Farm, Hazeva. Research in the latter involves scientists from various universities and research institutes.

Veterinary research and service to the aquaculture sector are provided by the Central Health Laboratory (mainly in the north of the country), research laboratories at the Institute of Desert Research, the National Center for Mariculture (mainly in the Negev Arava region), and by a private company (Aqua-Vet Ltd. – www.aqua-vet.co.il).

Results are shared through conferences organized by aquaculture extension officers. The aquaculture section of the national Extension Service, MoAG, consists of three officers and covers the whole industry. Aqua-Vet and various feed mills (private sector) also provide guidance to farmers. Apart from individual training, which benefits from modern technology (cellular phones, e-mail, and Internet), the extension

system plays a major role in supporting investment plans. The extension officers analyse the performance of the farm, its production plan, management, life-support systems and adherence to environmental quality directives. When investment for expansion is judged positive, the extension officer provides the investor with a letter of recommendation and takes part in the negotiations with MoAG officials to answer professional and economic issues raised. Similar support is provided to new investors seeking to establish new farms.

Aquaculture training is offered by the Faculty of Agriculture of the Hebrew University (B.Sc. in Animal Science, M.Sc. and Ph.D.). The Ruppin Academic Center and the Eilat Campus of Ben-Gurion University of the Negev offer some courses as part of their B.Sc. programmes in marine biology and marine biotechnology, respectively. Non-degree training for farmers is offered occasionally by the Extension Services, MoAG, and by the Division for External Studies, Faculty of Agriculture of the Hebrew University.

TRENDS, ISSUES AND DEVELOPMENT

While the arid land aquaculture is flourishing, the desert aquaculture development, a younger sector initiated only about 20 years ago (compared to 70 years of inland aquaculture in the north) suffers from lack of tradition and experienced man-power. Three of five pilot farms were closed during the last decade, and currently, only two are in operation. The potential and technology are there, but at the moment no new farms are planned. The main constraints and challenges to the aquaculture sector are: (i) water quality and availability; (ii) feed costs; (iii) import; and (iv) birds and environmental quality directives.

Water shortage is a serious constraint. Although much of the water used for aquaculture in the desert and arid lands is not suitable for crop irrigation and currently available for aquaculture, it can potentially be desalinated for use by the nation's domestic and industrial sectors. This may limit its availability for aquaculture, or increase its price. The desert aquaculture is integrated with irrigation of (mainly) olive orchards, which minimizes the cost of water charged to fish production.

Increasing feed costs during the last decade, coupled with increased imports of products cultured locally (especially tilapia), had strong effect on the profitability of the sector. The relatively small size of the desert farms, and hence, production volume, enable them to find niche markets for their live product and maintain reasonable profit. However, if they grow or new farms are established, they will have to join the whole sale marketing system and their income will go down.

The migratory birds pose high losses to fish farms in the arid lands – Bet Shean and Jordan Valleys – where most fish are produced in earthen ponds and reservoirs, but is not a problem in the desert aquaculture farms where the fish are cultured under cover. Environmental quality directives which restrict discharge of water from culture facilities pose increased water treatment expenses and may lead the marginally profitable operations to deficits and eventually closure.

SUCCESS STORIES

The development of an ornamental fish aquaculture sector in the desert is a major success story. Farmers specializing in growing vegetables in open fields and green houses, and having struggled with developing edible fish production using the brackish water underground reservoirs with no advantage, developed family-based systems for growing tropical ornamental fish. Vision, imagination and excellent farming experience were coupled with good climate conditions and available (even though limited) water resources. Focusing initially on species that are relatively simple to grow but have worldwide demand – the guppies – these farms developed high management and marketing standards and increase production for export continuously. Currently,

producers in Israel (not just in the desert) hold about 4 percent of the global market, and there is the objective of expanding this subsector by adding new cultured species.

WAY FORWARD

During the past decade, most of the pilot edible fish farms established in the desert area have failed, including aquaculture recirculation systems (Rana, 2007). Water sources, suitable species and culture systems were investigated and developed. In most cases, the reasons for the failures were management mistakes made by owners or managers, together with the negative economic trends in the sector during that period. There is plenty of brackish water that can be used, but the region lacks tradition in fish farming, and at the moment no new entrepreneurs are showing interest in launching new farms, or rehabilitating those that closed recently. Fish culture in the arid lands is where development is more likely, although even there the profitability of some farms is in question.

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Annex – Details of aquaculture fish farms in the desert and arid lands of Israel

TABLE 1
Details of ornamental fish farms in the desert and arid zone of Israel

Farm name	Coordinates	E-mail	Web site	Tel.	Fax	Mobile
Desert						
Ein Hazeva - Beauty Fish Guy Kaplan	30°47'N 35°14'E	guyk@arava.co.il	-	-	-	052-3666607
Ein Yahav - Assaf Shaham	30°39'N 35°14'E	assaf@arava.co.il	-	-	-	052-4260124
Ein Yahav - Evyatar Ginat	30°39'N 35°14'E	ginat@arava.co.il	-	-	-	052-8666022
Ein Yahav - Gideon Cnaani	30°39'N 35°14'E	cnaani@arava.co.il	-	-	-	052-3666723
Ein Yahav - Yoram Levi	30°39'N 35°14'E	ruthie@arava.co.il	-	-	-	052-3666221
Faran - Idan Barkan	30°21'N 35°09'E	barkano@arava.co.il	-	-	-	052-4260876
Hazeva - Adi Faber	30°46'N 35°16'E	faber@arava.co.il	-	-	-	052-3449365
Hazeva - Colors	30°46'N 35°16'E	colors@arava.co.il	www.colors-il.net	08-6582381	08-9954599	054-2666543
Hazeva - Evyatar Manor	30°46'N 35°16'E	evyatarm@bgu.ac.il	-	-	-	052-3666406
Hazeva - Nir Aviner	30°46'N 35°16'E	aviner@arava.co.il	-	-	-	052-3666340
Hazeva - Rotem Porat	30°46'N 35°16'E	rafiradin@gayavalley.com	-	-	-	052-3666440
Hazeva - Negev Angels Shaul Harel	30°46'N 35°16'E	harel@arava.co.il	-	-	-	052-2391725
Hazeva - Shaul Rokach	30°46'N 35°16'E	rshaul@arava.co.il	-	-	-	052-3666072
Hazeva - Yafa Malka	30°46'N 35°16'E	malka@arava.co.il	-	-	-	052-4260469
Idan - Ran Segev	30°48'N 35°18'E	segevsr@arava.co.il	-	-	-	052-3665912
Idan - Ronen Cohen	30°48'N 35°18'E	ronel72@walla.com	-	-	-	052-8666293
Ketura - Micha	29°58'N 35°03'E	ketura-aquaculture@ketura.ARDOM.co.il	http://ketura-aquaculture.com	-	08-6306319	052-3258326
Mashabe Sade - Gissis	31°00'N 34°47'E	-	-	-	-	-
Neot Hakikar - Shemaya Toledano	30°56'N 35°22'E	shmayato@bezeqint.net	-	-	-	052-2769589
Revivim - Of Hachol (Phoenix)	31°03'N 34°43'E	antignust@gmail.com	-	-	-	054-2250098
Zofar - Yossi Ben	30°33'N 35°10'E	bens@arava.co.il	-	-	-	054-4791533
Arid zone						
Kelachim - Itay Zach	31°27'N 34°40'E	-	-	-	-	-
Maslul - Tal-fish	31°19'N 34°35'E	discus@netvision.net.il	-	-	-	-
Nir Bahim - Boaz Gil	31°40'N 34°45'E	-	-	-	-	-
Revaha - Dageiron	31°38'N 34°44'E	-	-	-	-	-
Sde Nitzan Dag-Noy	31°13'N 34°25'E	-	-	-	-	-
Segula - Dagei Noy	31°39'N 34°46'E	-	-	-	-	-
Shekef - Fabio	31°30'N 34°56'E	dalianav@shaham.moag.gov.il	-	-	-	-
Shekef - Star Fish	31°30'N 34°56'E	-	-	-	-	-
Talmey Yossef - Prizma	31°12'N 34°21'E	-	-	-	-	-
Telamim - Fishzone	31°33'N 34°40'E	-	-	-	-	-
Yevul - Yonik	31°11'N 34°19'E	ami100000@walla.com	-	-	-	-

TABLE 2
Details of edible fish farms in the desert and arid zone of Israel

Farm name	Coordinates	Area (ha)	Annual production (tonnes)	Fish species	E-mail	Tel.	Fax	Mobile
Desert								
Mashabe Sade	31°00'N 34°47'E	0.2ha closed system	150	Barramundi, hybrid S. Bass	Desert-shrimp@kms.org.il	08-6565411	08-6565413	050-7827894
Revivim	31°02'N 34°43'E	0.1	100	African catfish	–	–	–	054-2401140
Arid zone								
Afikim	32°40'N 35°34'E	45.4	300	Carp, tilapia, mullet (polyculture)		04-6754235	04-6754235	050-5764261
Bet Alfa	32°30'N 35°25'E	71	600	Carp, tilapia, mullet (polyculture)	fishba@betaifa.org.il	04-6533052	04-6533571	–
Ein Hanatziv	32°28'N 35°30'E	69.5	700	Carp, tilapia, mullet (polyculture)	liora@hanatziv.org.il	–	04-6481042	050-8254316
Ein Harod Ihud	32°33'N 35°22'E	50	400	Carp, tilapia, mullet (polyculture)	dgilboa@en-harod.org	–	–	052-2799250
Gesher	32°37'N 35°33'E	56	350	Carp, tilapia, mullet (polyculture)	midgesher@012.net.il	04-6753612	04-6753612	050-5249723
Geva	32°33'N 35°22'E	40.6	200	Carp, tilapia, mullet (polyculture)	omr@kvgeva.org.il	04-6535887	04-6535887	054-6633301
Hamadiya	32°30'N 35°31'E	75	300	Carp, tilapia, mullet (polyculture)	–	04-6589022	–	–
Hamra	32°11'N 35°26'E	0.1ha closed system	80	Tilapia	–	–	02-9941312	050-5349072
Hefziba	32°31'N 35°25'E	46.5	300	Carp, tilapia, mullet (polyculture)	midge@hefzi.org.il	04-6586336	–	054-6634454
Kfar Rupin	32°27'N 35°33'E	150	1 300	Carp, tilapia, mullet (polyculture)	Fish5@kfar-rupin.org.il	04-6068460	04-6068462	–
Maoz Hayim	32°30'N 35°32'E	112	1 500	Carp, tilapia, mullet (polyculture)	fishpond@maoz.or.il	04-6064591	04-6064465	–
Merav	32°27'N 35°25'E	22	150	Carp, tilapia, mullet (polyculture)	mkbz@merav.net	04-6480327	04-6481807	052-3237672
Messilot	32°30'N 35°28'E	48.6	500	Carp, tilapia, mullet (polyculture)	mesifish@messilot.org.il	04-6066285	04-6066285	054-6754162
Neve Eitan	32°30'N 35°31'E	93	750	Carp, tilapia, mullet (polyculture)	midgeh_sergj@bezeqint.net	04-6063523	04-6063523	–
Neve Ur	32°35'N 35°33'E	65	450	Carp, tilapia, mullet (polyculture)	midgenvr@neve-ur.org.il	04-6063330	04-6063330	050-8381257
Nir David	32°30'N 35°27'E	148.4	1 500	Carp, tilapia, mullet (polyculture)	fishfarm@nir-david.org	04-6488003	04-6488063	050-5266749
Reshafim	32°29'N 35°28'E	80.5	800	Carp, tilapia, mullet (polyculture)	midgue@terraflex.co.il	04-6065127	04-6065156	054-7860127
Sde Eliyahu	32°26'N 35°31'E	35	200	Carp, tilapia, mullet (polyculture)	ronfish@sda.org.il	04-6096522	04-6096522	054-5640640
Sde Terumot	32°26'N 35°28'E	0.2ha closed system	100	Hybrid Striped Bass	Shaul06@bezeqint.net	–	04-6401901	0528-398-800
Shlulhot	32°27'N 35°28'E	60	550	Carp, tilapia, mullet (polyculture)	midgea@shlulhot.org.il	04-6062184	04-6581344	054-6746084
Tel Yosef	32°33'N 35°22'E	96	1 000	Carp, tilapia, mullet (polyculture)	midge_ty@telyosef.co.il	04-6534043	04-6534054	057-2321000
Tirat Zvi	32°24'N 35°32'E	150	1 250	Carp, tilapia, mullet (polyculture)	nizan_tz@tiratzvi.org.il	04-6078706	04-6480335	052-5254282
Yizre'el	32°33'N 35°19'E	15	100	Carp, tilapia, mullet (polyculture)	dagim@yizrael.com	–	04-6598022	052-3865570

Aquaculture experiences in the Negev Desert in Israel

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INTRODUCTION

As mentioned in the overview on desert aquaculture in Israel, two-thirds (about 13 000 km²) of the country is covered by the Negev and the Arava desert regions. Annual rainfall varies between 60–100 mm (and less), and the desert regions are inhabited by just 2–3 percent of the country's population.

For nearly three decades, Israeli research at the Bengis Center for Desert Aquaculture (Albert Katz Department of Dryland Biotechnologies, Institutes for Desert Research of Ben-Gurion University of the Negev in Beer-Sheva, Israel) has shown that the accessible, low-cost, subsurface, brackish geothermal water found in the desert with its moderate salinity (3–7 ppt), mineral composition, constant warmth (at 39–41 °C), purity, and availability regardless of weather conditions is highly suitable for aquaculture (Applebaum, 1995; Appelbaum and Yogev, 1997; Applebaum, 1998; and Appelbaum *et al.*, 2008). This so-called desert water has been successfully used for the irrigation of agricultural crops in the Negev Desert, easing the pressure on Israel's scarce freshwater resources. Since the late 1980s, aquaculture has also been introduced into the Israeli desert using this desert water. Through the entire Negev and Arava region, in which air and water temperatures are kept constant throughout the year, yields have been up to 35 times higher than those of fish grown in subtropics in conventional outdoor ponds, and have been achieved in half the growing cycle (Rothbard and Peretz, 2002). Currently, 15 commercial fish farms are operating in the Negev Desert producing edible and ornamental fish and crustaceans. All edible fish are produced and sold on the domestic market while most of the ornamental fish produced are exported (Figure 1).



Species of edible fish currently being cultured in the Negev Desert, highland district, are the following: barramundi (*Lates calcarifer*); red drum (*Sciaenops ocellatus*); European seabass (*Dicentrarchus labrax*); North African catfish (*Clarias gariepinus*); and Nile tilapia (*Oreochromis niloticus*).

COMMERCIAL AQUACULTURE FARMS IN THE NEGEV HIGHLANDS DISTRICT

Kadesh Barnea Farm is the pioneer fish farm in the Ramat Negev (highland) district. In 1998, this farm started growing European eel (*Anguilla anguilla*) primarily because fresh eels could easily be exported to the European market due to Israel's geographical proximity to Europe and its position as an associate member of the European Union, and secondly due to Israel's favourable climatic conditions for raising eels. However, for cost related reasons, eel cultivation was subsequently discontinued. The farm's current facilities include ten plastic-covered fish ponds receiving brackish (4.5 ppt = 1400 mg chloride/l) geothermal (~40 °C) water from a 700 m deep local well. During the summer months, a minimum of 10–15 percent of the total volume of the ponds is renewed. During the winter months, an additional 5–10 percent of brackish water is added to maintain higher water temperatures. The temperature in the rearing ponds reaches 30 °C in the summer. The farm utilizes ca. 75 000 m³ of water annually. Nile tilapia (*Oreochromis niloticus*), red tilapia (*Oreochromis mossambicus* × *Oreochromis niloticus*), North African catfish (*Clarias gariepinus*), barramundi (*Lates calcarifer*), striped bass (*Morone saxatilis* × *M. chrysops*) and gilthead seabream (*Sparus aurata*) were raised. While the tilapia fingerlings were produced at the farm, fingerlings of the other species were purchased from other producers. At present, the farm is undergoing a restructuring of its facilities with the aim of producing barramundi and gilthead seabream as primary fish and tilapia and North African catfish as secondary fish.

Revivim Catfish Farm is the pioneer catfish producer which, in 1991, began raising the North African catfish (*Clarias gariepinus*) using desert water. In 1995, a semi-commercial system consisting of 14 cement ponds (8 m³ each) was built within a greenhouse. The water in the ponds is refreshed at a rate of 10 percent of the daily system volume. The potential annual production in this system is about 70 tonnes, i.e. fish density can reach 125 kg/m³. Fingerlings, at an initial weight of about 5 g, can reach 800–900 g within 180 days, i.e. a daily growth rate of 2 percent. As a major producer of North African catfish, this farm has recently completed a new, highly modern, closed water recirculation system for its super-intensive catfish production with the aim of exceeding 100 tonnes per year at a harvest stocking density of nearly 300 kg/m³ of water. Catfish fingerlings were initially purchased from another producer, but the farm currently produces its own fingerlings.

Mashaabei Sadeh Farm started fish farming in 1992. A water reservoir (3 hectares) containing 70 000 m³ was built together with a number of covered 250 m² rearing ponds. Water from the fish ponds is pumped to the water reservoir for biological treatment and returned cleaned to the fish ponds. The daily renewal rate of water varies between 10–30 percent of the total water volume, depending on the season. Fish receive recycled brackish geothermal water, which is used in the final stages for irrigating jojoba, olives, and melons. Initially, Nile tilapia (*Oreochromis niloticus*) and barramundi (*Lates calcarifer*) were raised. In 1997, the farm started raising the white leg shrimp (*Litopenaeus vannamei*) on a semi-commercial basis. Starting in 1998, only shrimp were raised, aiming at an expected yield of 4 kg/m³ of fresh shrimp exports to Europe with two crops annually. Shrimp production on the farm was ongoing for about two to three years, but was discontinued because of a decline in retail prices on the European market caused by imports from China.

At present, this farm is producing barramundi (*Lates calcarifer*), the farm's most successful product, as well as European seabass (*Dicentrarchus labrax*), red drum (*Sciaenops ocellatus*), and Nile tilapia (*Oreochromis niloticus*). Fingerlings of these species are purchased from a fingerling producer. Currently, this farm is planning to expand its facilities and significantly increase its present annual production to about 200 tonnes.

Re'em Farm, established in 1992, is the largest fish culture system based on recirculating water technology in the country and in the Middle East (Figures 2, 3 and 4).

It has 15 cement ponds of 600 m³ each and ten cement ponds of 1 500 m³ each. Water flows from the fish ponds into a biological filter (300 × 10 × 1.5 m) and back into the rearing ponds. The volume of the entire system is 30 000 m³. Geothermal-brackish water (4 ppt at 36–38 °C) from an adjoining well – equal to 5–10 percent of the entire system volume – enters the system daily.

Barramundi (*Lates calcarifer*), striped bass (*Morone saxatilis* × *M. chrysops*), European seabass (*Dicentrarchus labrax*), red drum (*Sciaenops ocellatus*), Nile tilapia (*Oreochromis niloticus*), and common carp (*Cyprinus carpio*) have been raised on the farm. The average density of fish is about 25 kg/m³. The farm requires 1–1.5 m³ of water for the production of 1 kg of fish. Fish production reached a high of 400 tonnes in 2004. In addition to fish culture, Re'em Farm supplies 120 hectares of olive trees with effluents from the fish rearing ponds for irrigation. Olive trees need water throughout the year (with the demand in winter being 10 m³/h/day and in the summer 70–100 m³/h/day). At present, the farm is undergoing structural changes.

FIGURE 2
Re'em Fish Farm, a typical desert fish farm



FIGURE 4
High density red tilapia cultured in a raceway in the Re'em Fish Farm



FIGURE 3
Raceways with aerators in a greenhouse of the Re'em Fish Farm



Matan Farm was established in 2000 with the aim of rearing and exporting fresh white leg shrimp to the European market. This was based on a study showing shrimp growth of 0.5 g/week at densities >100 individuals/m³ and with a 70 percent survival rate. Evidently, white-leg shrimp can be successfully raised in the desert water (Appelbaum *et al.*, 2002). One major advantage of raising shrimp in inland brackish water and isolated from the sea is that the shrimp are not exposed to marine viruses that cause heavy or total losses. However, due to a significant drop in the price of shrimp in the European market, this farm changed its production from shrimp to finfish.

Erez Thermoplastic Products located in Erez farm is specialized in manufacturing PVC sheets for covering greenhouses and bottoms of fish ponds to conserve energy, to reduce water loss in the pond and to maintain higher water temperatures. Colours are applied to the sheets to make them photoselective and to prevent the penetration of red and blue light rays that promote the growth of green algae. Both sides of the sheet are varnished for easy cleaning of dust and water residues. Under desert conditions, these sheets last for more than three years.

EFFICIENT USE OF DESERT WATER

It is both feasible and economically viable to combine aquaculture and agriculture into so-called integrated farming systems by using desert water for agricultural irrigation and commercial production of fish.

In practice, this means that the effluent from fish ponds, rich with organic waste produced by the cultured species, is used for field and orchard irrigation, making a more rational use of desert water, reducing the use of fertilizers, and creating a chain of users. Israeli fish farms in the southern arid regions have successfully combined aquaculture and agriculture into integrated farming systems that exploit the abundant subsurface saline water. These applied farming technologies in the desert also improve water use and conservation minimizing the waste of this limited and valuable resource.

ORNAMENTAL FISH PRODUCTION IN THE ISRAELI DESERT

The culture of ornamental fish has gained enormous importance worldwide over the past few decades, and interest appears to be continuously growing, making it a potentially profitable business opportunity. Indeed, the market for ornamental freshwater and marine species is an important component of international trade currently worth more than USD10 billion annually. In Israel, raising ornamental and tropical fish for export began more than three decades ago, and continuously high demand is driving its recent expansion. Today, Israel boasts about 20 tropical fish farms, most of which are located in the desert. Farm size is typically between 0.1–0.3 hectares, with each farm operating in separate greenhouses isolated from the others with no common water system. The major ornamental fish species cultured commercially in the desert farms in Israel include guppy (*Poecilia reticulata*); platyfish (*Xiphophorus maculatus*); green swordtail (*Xiphophorus helleri*); freshwater angelfish (*Pterophyllum scalare*); and armoured catfish (*Corydoras* spp.).

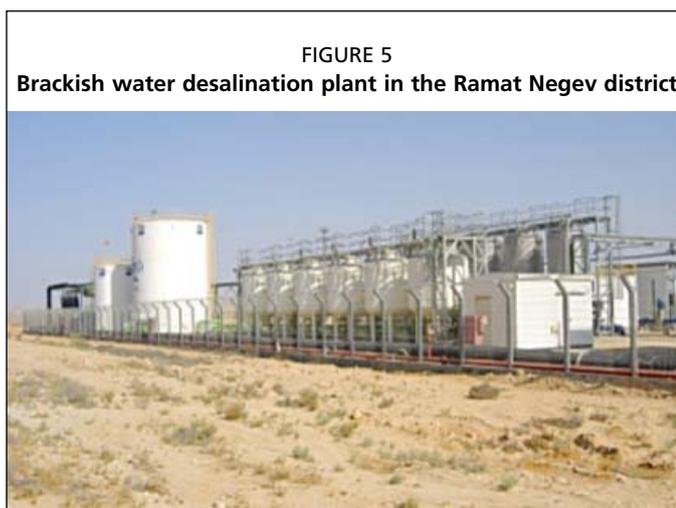
DESALINATION OF DESERT WATER

Seawater desalination has been one of the major steps taken to alleviate the problems associated with the country's severe shortage of fresh water. Present (and future) desalination of inland brackish water (i.e. desert water) results in the accumulation of brine that, unlike seawater, cannot be redirected to its source. To reduce its continuously growing volume, accumulated brine from desalinating inland brackish water is deposited into evaporation ponds. These evaporation ponds can be used not only for growing fish and other aquatic species, but also for the reproduction of those marine species that grow well in the lower salinity of desert water but will only reproduce at

higher salinities resembling seawater or at brine concentration.

The desalination plant in the Ramat Negev district near the Israel-Egypt border (Figure 5) produces 4 million m³ of freshwater annually while, at the same time, producing thousands of m³ of brine as a by-product.

Preliminary studies by Appelbaum and Arockia Raj (2008) have shown the suitability of brine from the desalination plant in the Ramat Negev district for growing several of the edible species previously mentioned.



THE WAY FORWARD

To expand its aquaculture activities and to remain competitive in the lucrative global export market, it has become necessary for Israel to increase the use of available marginal water, i.e. existing brackish geothermal desert water and desalinated sea and brackish water. Expansion of aquaculture in the Negev Desert of Israel, adapting and developing technologies for intensive fish culture and agriculture, with an emphasis on integrated operations, is a matter of necessity.

The hydrologists estimate that billions of cubic metres of water are stored underground, which can be exploited during hundreds of years, supplying demand of the growing population and agricultural development (Rothbard and Peretz, 2002).

Thus, the intensive utilization of the treasure of brackish geothermal water resources in the Israeli desert for integrated agriculture/aquaculture advances the continued expansion of Israel's aquaculture industry and facilitates the significant reduction in the use of Israel's scarce freshwater resources. Desert aquaculture is not a technological revolution; rather, it is an innovative approach that differs from conventional fish farming. Arid or desert lands with subsurface water resources have huge potential for developing and sustaining aquaculture and agricultural farming. Research findings continue to show that the possibility of using inland brackish water for farming aquatic species is a promising and realistic alternative to many of the more traditional operations. Further development of Israeli aquaculture will have to go hand-in-hand with the expansion of the existing domestic desert aquaculture. Technologies applied in desert and arid lands must strive to minimize their negative effects on the unspoiled desert environment and should maximize the preservation of the land in addition to facilitating efficient use of water. Ideally, this can be achieved by integrating aquaculture with agriculture, thereby conserving water through the expansion of the chain of users utilizing the same water (Kotzen and Appelbaum, 2010). The steadily growing consumer market for high quality aquaculture products and the vast amounts of unpolluted brackish geothermal water accessible beneath the Israeli desert suggest that the production of thousands of tonnes of fish and other aquatic organisms in the national desert and arid lands is a realistic opportunity. The development and expansion of Israeli aquaculture in the Negev Desert, associated with and guided by local applied research, should be of great importance to Israeli farmers and policy-makers alike.

CONCLUSIONS

Studies and trials have shown that growth rate, metabolic rate, feed intake, feed conversion, and survival in fish are influenced largely by the salinity of the water in which the organism is cultivated (osmoregulation). Israel's brackish desert and arid lands water has proven to be highly suitable for aquaculture because:

- Desert water provides an osmoregulatory advantage to fish and is detrimental to fish parasites.
- Fish can adapt well to desert aquatic conditions and can respond with good growth and survival.
- Desert water is free of pollutants, and therefore, is suitable and beneficial for producing high-quality aquaculture products.
- New technologies are under development to allow intensified use of desert water while preserving the environment.
- It is expected that, following the continued development of aquaculture in the desert, fish processing and transportation facilities will be established in the desert facilitating shipment to domestic and foreign markets.

This paper describes many reasons to pursue the development of desert aquaculture. The possibilities of desert aquaculture and its generated activities together with initial investment, should generate enough interest to be viewed as a viable business for many local farmers in remote areas. Israel's experience in the practical development of its desert is one example of the sustainable use of arid land and can contribute to the development of arid lands in other countries in such a way that their valuable resources can be utilized while having minimal impact on their environments and natural resources.

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An overview on desert aquaculture in Southern Africa

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SUMMARY

Southern Africa is a 15-member country block, located south of the equator and often referred to as the Southern Africa Development Community (SADC) Region. The SADC, which comprises the Republic of Angola, the Republic of Botswana, the Democratic Republic of the Congo, the Kingdom of Lesotho, the Republic of Madagascar, the Republic of Malawi, the Republic of Mauritius, the Republic of Mozambique, the Republic of Namibia, the Republic of Seychelles, the Republic of South Africa, the Kingdom of Swaziland, the United Republic of Tanzania, the Republic of Zambia and the Republic of Zimbabwe, has a favourable environment and the necessary natural resources for aquaculture production. Although the aquaculture sector in this subregion is generally regarded as being in its infancy, significant growth has been noted in a number of countries over the past 20 years. Aquaculture development has recently become a priority topic in all of the countries in Southern Africa, as dwindling traditional supplies of fish (capture fisheries) and the potentially positive economic gains that aquaculture can generate (in terms of food security, employment creation, poverty alleviation, improved national economies and other associated socio-economic gains). Namibia, for example, through its Ministry of Fisheries and Marine Resources (MFMR) is spearheading the development of national aquaculture at the community level in order to empower rural communities to be self-sufficient in food production, and to derive income through fish production integrated with existing and potential agricultural practices wherever natural conditions permit. Similarly, the Government of South Africa, through its national Department of Agriculture, Forestry and Fisheries (DAFF) and other support sectors is taking steps to accelerate the development of aquaculture production at a commercial level. Other countries in the region, such as Mauritius, Mozambique, United Republic of Tanzania and Zambia (including countries with limited surface water resources such as Botswana), have begun drafting specific aquaculture-oriented legal frameworks and are developing strategic plans to support the sector. Until now, very little has been achieved with regard to developing aquaculture in the deserts and arid lands of Southern Africa. A lack of available technical information has caused the concept to be relatively unknown. This fact is probably due to the general belief that aquaculture can only be practised where abundant surface water is guaranteed. This belief has led to the idea that erecting a fish farm in arid lands is costly, risky and, therefore, unsustainable in

the long term. Ongoing innovations, through research and development, are gradually modifying this attitude. Potential areas for arid land aquaculture are being identified through the examination of water availability and quality, environmental suitability and provision of technical know-how. Competition for land use in deserts and arid lands is limited since these lands are considered unsuitable for crop production except where irrigation facilities are available or livestock ranching is practised. The ever-rising prices of fish, caused by increasing demand and diminishing supplies, are encouraging private commercial farmers to consider developing aquaculture wherever feasible, including in arid locations where adequate surface or subsurface water is available and easily extractable. Naturally, commercial farmers always seek to establish and operate ventures that realize a sustainable return on investment; their operations are therefore, strongly market-oriented.

RÉSUMÉ

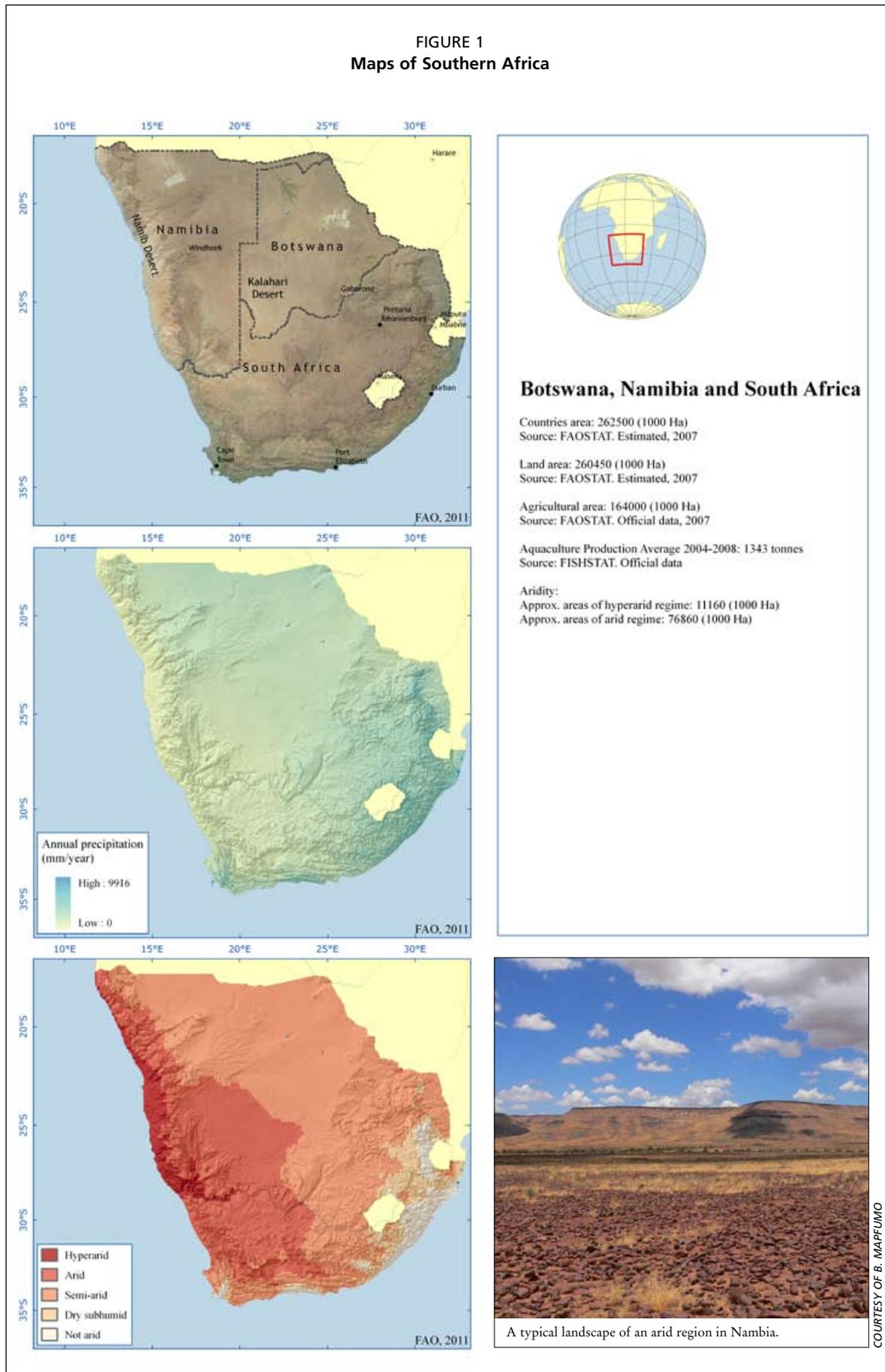
L'Afrique australe est un ensemble de 15 pays situés au sud de l'équateur. Souvent évoqué sous le nom de Communauté de développement de l'Afrique australe (SADC), cette région rassemble la République d'Angola, la République du Botswana, la République démocratique du Congo, le Royaume du Lesotho, la République de Madagascar, la République du Malawi, la République de Maurice, la République du Mozambique, la République de Namibie, la République des Seychelles, la République sud-africaine, le Royaume du Swaziland, la République-Unie de Tanzanie, la République de Zambie et la République du Zimbabwe. L'Afrique australe jouit d'un environnement favorable et des ressources naturelles nécessaires à la production aquacole. Même si l'on considère en général que l'aquaculture y est encore à ses débuts, on a noté une croissance importante de ce secteur dans plusieurs pays de la région au cours des vingt dernières années. Le développement de l'aquaculture est récemment devenu une question prioritaire dans tous les pays d'Afrique australe, surtout à un moment où l'approvisionnement traditionnel en poissons (la pêche de capture) baisse et alors que l'on constate que ce secteur peut avoir des conséquences positives dans différents domaines (du point de vue de la sécurité alimentaire, de la création d'emplois, de la lutte contre la pauvreté, de l'amélioration des comptes nationaux ou encore de bénéfices sur le plan social et économique). La Namibie, par l'intermédiaire de son ministère de la Pêche et des ressources marines, développe ainsi une aquaculture nationale au niveau communautaire, qui vise l'autosuffisance des communautés rurales en matière de production alimentaire et la création de revenus, grâce à une production piscicole intégrée aux pratiques agricoles existantes et potentielles, là où les conditions naturelles le permettent. De la même façon, le gouvernement sud-africain, par l'intermédiaire de son ministère de l'Agriculture, des forêts et de la pêche, et d'autres secteurs d'appui, est en train de prendre des mesures visant à accélérer le développement de la production aquacole à un niveau commercial. D'autres pays de la région, comme Maurice, le Mozambique, la Tanzanie et la Zambie (ainsi que des pays ayant des ressources limitées en eau, en termes de superficie, comme le Botswana), ont commencé à élaborer des projets de cadres juridiques spécifiques destinés à l'aquaculture et mettent au point des plans stratégiques pour appuyer le secteur. Jusqu'à présent, très peu de résultats concrets ont été obtenus en matière de développement de l'aquaculture dans les zones désertiques et arides d'Afrique australe. Il s'agit d'un concept encore relativement peu connu à cause d'un manque d'informations techniques disponibles. On pense en effet généralement que l'aquaculture ne peut être pratiquée que là où de grandes surfaces d'eau sont garanties. Cette conviction est telle que l'on estime qu'il est très coûteux et très risqué de créer une exploitation piscicole dans une zone aride et qu'une telle entreprise n'est pas viable à long terme. Les innovations en cours, grâce à la recherche-développement, invitent progressivement à revoir cette idée. Les espaces susceptibles

d'accueillir des activités aquacoles en milieu aride sont en cours de repérage grâce à l'examen des ressources en eau et de leur qualité, de leur environnement approprié ou non et de l'existence d'un éventuel savoir-faire technique. La pression exercée sur les terres désertiques et arides reste faible car elles ne sont pas considérées comme appropriées pour la production agricole, mis à part là où il existe des systèmes d'irrigation ou pour l'élevage. L'augmentation ininterrompue du prix du poisson, due à une demande croissante et à des approvisionnements en baisse, encourage les exploitants commerciaux privés à prendre en compte le développement de l'aquaculture là où c'est possible, notamment dans des milieux arides où des eaux appropriées, de surface ou souterraines, sont disponibles et faciles à extraire. Les exploitants commerciaux cherchent évidemment toujours à créer et à gérer des entreprises qui assurent un bon retour sur investissement et leurs activités sont par conséquent nettement orientées vers le marché.

ملخص

تتألف أفريقيا الجنوبية من مجموعة خمسة عشر بلد عضو، والتي تقع جنوب خط الاستواء وغالبا ما يشار إليها بمنطقة مجتمع تنمية أفريقيا الجنوبية (SADC). ان هذه المنطقة التي تتألف من جمهورية أنجولا، وجمهورية بتسوانا، وجمهورية الكونغو الديمقراطية، ومملكة ليسوتو، وجمهورية مدغشقر، وجمهورية مالاوي، وجمهورية موريشيوس، وجمهورية موزمبيق، وجمهورية ناميبيا، وجمهورية سيشل، وجمهورية جنوب أفريقيا، ومملكة سوازيلاند، وجمهورية تنزانيا المتحدة، وجمهورية زامبيا وجمهورية زيمبابوي (الشكل 1)، لديها البيئة المناسبة والموارد الطبيعية الضرورية لإنتاج تربية الأحياء المائية. وعلى الرغم من اعتبار قطاع تربية الأحياء المائية في هذه المنطقة الفرعية بشكل عام في بداياته، فإنه قد تمت ملاحظة نمو هام في عدد من البلدان خلال العشريون سنة الأخيرة. وقد أصبحت تنمية تربية الأحياء المائية مؤخرا موضوع ذو أولوية في جميع البلدان في أفريقيا الجنوبية، وذلك لكون المعروض التقليدي المنخفض من الأسماك (المصايد التقليدية) والأرباح الاقتصادية الإيجابية المحتملة التي يمكن ان توفرها تربية الأحياء المائية (من ناحية الأمن الغذائي، وإيجاد الوظائف، ومحاربة الفقر، وتحسين الاقتصاديات الوطنية والأرباح الأخرى الاجتماعية الاقتصادية المرتبطة) قد تم إدراكه. وناميبيا على سبيل المثال، من خلال وزارتها للثروة السمكية والموارد البحرية فإنها تقود تنمية تربية الأحياء الوطنية على مستوى المجتمع وذلك بهدف تمكين المجتمعات الريفية من ان تكون مكتفية ذاتيا من الإنتاج الغذائي، وللحصول على دخل من إنتاج الأسماك التي يمكن التكامل بينها وبين الممارسات الزراعية الموجودة والمحتملة حيثما تسمح الظروف الطبيعية. وبالمثل، فإن حكومة جنوب أفريقيا، ومن خلال إدارتها الوطنية للغابات الزراعية والمصايد السمكية (DAFF) والقطاعات الأخرى الداعمة تقوم بخطوات لتسريع تنمية إنتاج تربية الأحياء المائية على المستوى التجاري. والبلدان الأخرى في المنطقة، مثل موريشيوس، والموزمبيق، وتنزانيا وزامبيا (وتتضمن البلدان ذات الموارد المحدودة من المياه السطحية مثل بتسوانا)، قد بدأت بصياغة إطار قانونية موجهة وخاصة بتربية الأحياء المائية وتقوم بتطوير خطط إستراتيجية لدعم هذا القطاع. وحتى الآن، تم تحقيق القليل جدا من الانجازات فيما يخص تطوير تربية الأحياء المائية في الأراضي الصحراوية والجافة في منطقة أفريقيا الجنوبية. ان النقص في المعلومات التقنية المتوفرة قد أدى الى ان يكون المبدأ غير معروف نسبيا. وهذه الحقيقة من المحتمل ان تكون بسبب الاعتقاد العام بأن تربية الأحياء المائية يمكن ان تمارس فقط في حالة ضمان وجود كميات وفيرة من المياه السطحية. وهذا الاعتقاد أدى الى وجود فكرة بأن إقامة مزرعة سمكية في الأراضي الصحراوية هو أمر مكلف وخطر وبالتالي هو غير مستدام على المدى الطويل. ان الابتكارات المستمرة من خلال البحوث والتطوير تقوم بتعديل هذا الاتجاه بشكل تدريجي. ويتم تحديد المناطق المحتملة لتربية الأحياء المائية في الأراضي الجافة من خلال فحص وفرة وجودة المياه، والاستدامة البيئية، والتزود بالمعرفة التقنية. ان المنافسة محدودة حول استخدام الأراضي في الصحاري والمناطق الجافة وذلك لكونها تعتبر أراضي غير مناسبة لإنتاج المحاصيل باستثناء في حالة توفر تسهيلات الري او عند ممارسة تربية الماشية. ان الأسعار المرتفعة دائما للأسماك، والتي يسببها الطلب المتزايد والمعروض المتناقص، تشجع المزارعين التجاريين الخاصين على الأخذ في الاعتبار تطوير تربية الأحياء المائية كلما كان ملائما، وتتضمن المواقع الجافة عند توفر مياه سطحية او شبه سطحية كافية وسهلة الاستخراج. وطبيعيًا، فإن المزارعين التجاريين يقومون دائما بالبحث عن تأسيس وتشغيل المشاريع التي تحقق ربح او استثمار مستديم؛ وبالتالي فإن عملياتهم هي بشكل قوي باتجاه السوق.

FIGURE 1
Maps of Southern Africa



THE GENERAL ENVIRONMENT

There are two major deserts in Southern Africa: the Kalahari Desert (large portions in Botswana) and the Namib Desert (Namibia). In addition, there are large tracts of arid lands that receive less than 250 mm rainfall per annum in countries such as South Africa, Zimbabwe, Angola, Zambia and Mozambique. These areas are also characterised by high temperatures, especially in the summer and thus high water evaporation rates.

The Kalahari Desert is a large arid to semi-arid sandy area with an area extending to 900 000 square kilometres that covers much of Botswana and parts of eastern Namibia. The Kalahari is ranked the fourth largest desert in the world. However, it should be noted that most of the Kalahari is not a true desert, as it forms part of the temperate savannah (Warder, 2010). The rainfall in this desert is barely 75–300 mm per year and summer temperatures are very high. The surrounding Kalahari Basin covers an additional 2 500 000 square kilometres extending further into Botswana, Namibia and South Africa, and encroaching into parts of Angola, Zambia and Zimbabwe (Figure 1).

Very little aquaculture development is recorded in the main desert area, although some momentum has recently been created further westwards in the Omaheke Region of Namibia, where some community-based small-scale fish farms are being promoted by the Namibian Government. This review focuses mainly on aquaculture developments in Namibia, which has recently achieved good progress in developing its aquaculture sector, even in arid lands. Very little information is available on Botswana and South Africa, apart from the large-scale ventures being planned there, and expected to be producing in the next few years¹. The remaining 12 countries of the region are predominantly tropical to sub-tropical, hence do not have deserts, but contain some patches of arid lands that receive <250 mm rainfall per annum. There is very little information available about aquaculture development in the arid lands of these countries.

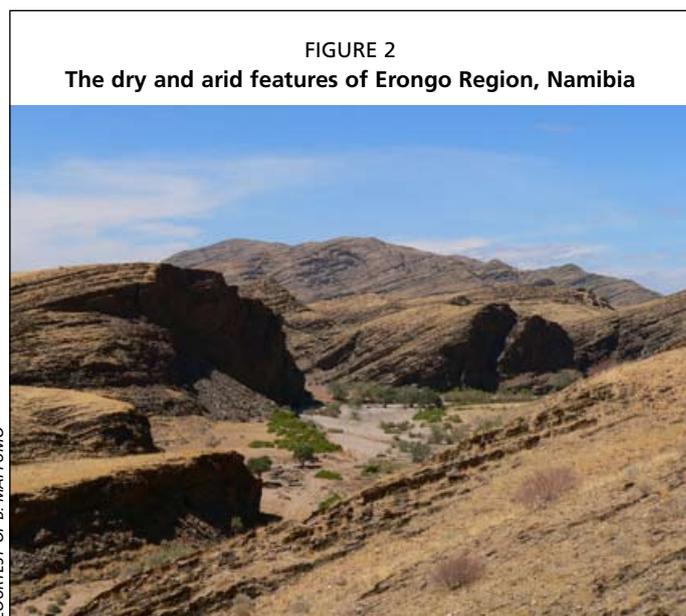
In the southwestern part of Africa lies the Namib Desert. This desert occupies an area of ~80 900 km², stretching for about 1 600 km along the Atlantic Ocean coastline. Its east to west width varies from 50–160 km. Though primarily in Namibia, the Namib Desert also extends into the southwest of Angola. Having been arid or semi-arid for at least 55 million years, this desert is considered to be the oldest in the world. It has sporadic, unpredictable rainfall without a clear seasonal pattern, in most cases less than 10 mm annually, and is almost completely barren.

There are a few on-shore mariculture operations located in the Namib Desert area, in the coastal towns of Walvis Bay, Henties Bay, Swakopmund and Luderitz². These produce shellfish such as oysters (*Crassostrea gigas*, *Ostrea edulis*) and abalone (*Haliotis midae*), utilizing pumped water from the Atlantic Ocean. Apart from this, the bulk of mariculture operations in Namibia are in offshore-based systems. Oysters and abalone produced in Namibia are destined for export markets and have been attractive enterprises for the commercial sector. Until now, mariculture operations in Namibia, which are worth about USD10 million per year, have been the driving force behind aquaculture development there. However, the industry has recently suffered a major setback due to harsh environmental conditions experienced in the Atlantic, where sulphur eruptions and algal blooms within the grow-out areas have led to mass mortality of oysters.

There are a few potential sites for aquaculture development, identified by the Government of Namibia and some private investors, that are close to the Namib Desert, in the very arid Erongo Region (Figure 2) in the west of Namibia.

¹ The author has visited many sites in Namibia and one key site in both Botswana and South Africa. These sites have been highlighted in the review.

² Although these few on-shore mariculture farms are located within the Namib Desert area, the fact that they utilize water from the Atlantic Ocean disqualifies them from the scope of this review.



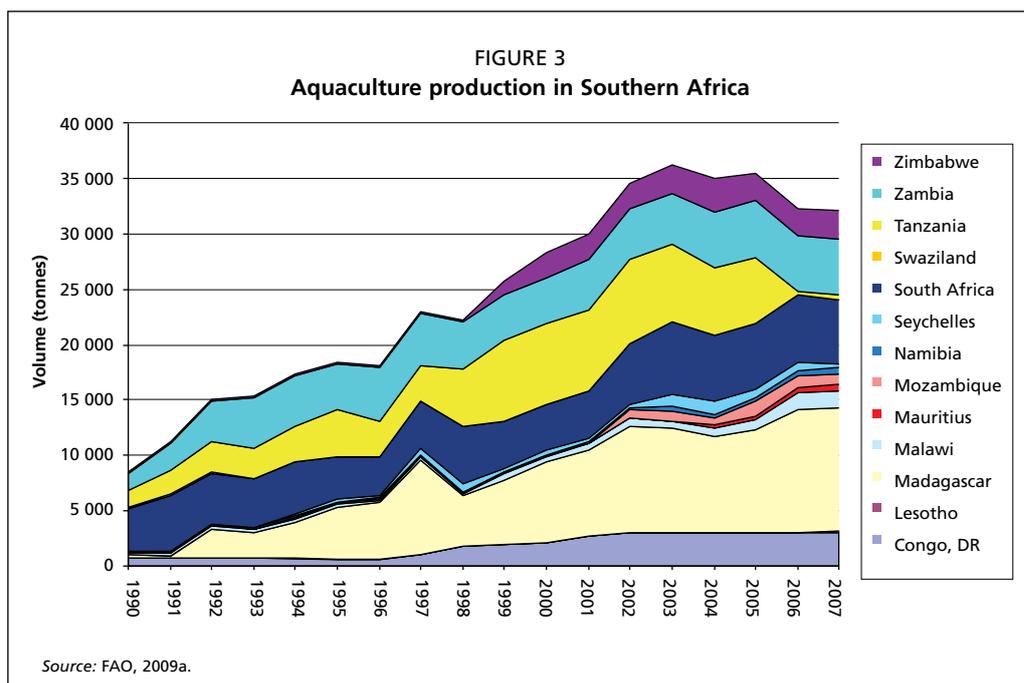
Beside the Kalahari and the Namib deserts, there are other vast areas of arid/semi-arid lands in Namibia, South Africa, Angola, Mozambique, Zambia and Zimbabwe. Much of these lands are either irrigated farm lands or are used for livestock ranching, or are completely underutilized due to their state of aridity. Stronger solar radiation, extreme temperatures and higher levels of water evaporation characterize much of these areas. There is little rainfall occurring during the summer periods (November to April). Groundwater, accessed through drilled boreholes, is the main source of water supply, unless the area has a perennial river or reservoir.

The upper Karoo districts of South Africa, in Eastern Cape Province (dubbed the “place of great thirst”), which receive less than 200 mm of rainfall per year are an example. There is a large-scale freshwater aquaculture project called the Camdeboo Satellite Aquaculture Project (CSAP) that is being established just beyond the small town of Graaf Reinet. This large-scale project aims mainly to utilize borehole groundwater and is starting production in 2011.

In Northern Botswana, near the border with Zimbabwe and just outside the main Kalahari Desert, a multi-million dollar, vertically integrated tilapia project is being planned as part of an integrated large-scale agricultural/aquaculture complex, jointly developed under a private and public partnership scheme between the Government of Botswana (GoB) and a multinational investment company, the TAHAL Group, based in Israel (GoB, 2008). This project, called the Zambezi Integrated Agro-Commercial Development Project, aims to utilize water pumped from the Zambezi River (via a pipeline that stretches for about 50 km). Production is expected to start in 2014. A few small-scale fish farms are also proliferating in this area.

Unlike in other countries such as Egypt, very little is known or recorded about the success of aquaculture in deserts and arid lands so far, since it is an activity that is in its early stages within the region. Aquaculture in Southern Africa dates back to the 1960s and was introduced by governments and donor agencies on a small-scale subsistence basis and for rural development, and was intended to complement agricultural practices mainly for food security reasons. Fish farms were mainly sited in tropical/subtropical lands where water is in abundance; probably none were established in arid lands. Production systems were characterized by small ponds constructed near existing water sources such as rivers, reservoirs, etc., and managed at low cost. Some ponds were even rain-fed during the summer periods.

Species such as tilapia (*Oreochromis* spp.), North African catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*) were mainly cultured for domestic consumption. Unlike in many Asian countries, small-scale subsistence-oriented aquaculture has been a general failure in Southern Africa. There are new interventions in the pipeline in many countries that aim to change the situation and produce sustained growth in this sector. One example of this is the FAO Special Programme for Aquaculture Development in Africa (SPADA) (FAO, 2008). Such approaches, if implemented well, provide good potential for an accelerated aquaculture development in Africa, as they aim to promote the development of profitable small- and medium-scale aqua-businesses. Large-scale commercial ventures, both freshwater and mariculture, peaked in the late 1990s and



early 2000s. These have been the driving force behind aquaculture production in Southern Africa so far (Figure 3). However, the large-scale commercial investments planned in the desert and arid lands of South Africa, Botswana and Namibia have the potential to outclass those that are in areas with better potential in terms of water supply.

In addition to those activities mentioned above, culture-based fisheries have existed for many years. Water bodies such as dams, reservoirs, natural water-holes, disused mine pits, natural fountain pools, etc., exist in the arid lands of Southern Africa, and can be used for this extensive form of aquaculture. In many countries, culture-based fisheries have provided a large source of fish at minimal cost and, in some cases, have become an important recreational fishing ground. These water bodies are managed to ensure their long term sustainability. In fact, the Ministry of Fisheries and Marine Resources of Namibia has been enhancing fish stocks in many of its state owned water bodies for many years. A number of these dams are located in arid lands.

GEO-HYDROLOGICAL MAPPING

Geo-hydrological patterns can be an important indicator to determine areas with good aquaculture development potential. For instance, while vast areas in Namibia have little water, a geo-hydrological survey has shown that, despite low rainfall, there are pockets of the country with very good groundwater reserves. The underlying rocks are structured to allow good containment of groundwater, which is constantly recharged or replenished by annual rainfall.

In some cases, there are “underground rivers” that stretch for hundreds of miles. One commercial farmer in Pretoria, South Africa, has reported that his efficient borehole, which is capable of producing over 90 m³ of water per hour, lies within a “crack” of the Okavango underground river line. The mighty Okavango River (one of the largest in Southern Africa) stretches for about 1 600 km from Angola to Botswana via Namibia and through the Kalahari Desert, where it then forms the Okavango delta, northwest of Botswana. The Okavango basin itself stretches for thousands of square kilometres and studies have revealed that massive volumes of water from the river have recharged groundwater reserves in the dry, arid lands of Namibia, Angola, South Africa and Zimbabwe.

Namibian geohydrological maps also provide data on the buried rock structures. As well as indices to estimate the volumes of groundwater potentially available, and the possible annual recharge/replenishment patterns, the rock structures also determine the feasibility of water extraction by boreholes and the drilling depth required for access. Such surveys, supported by additional research information, have aided the Ministry of Fisheries and Marine Resources and other potential aquaculture developers to map potential aquaculture zones based on the availability of water and other associated economic factors. In this context, the author was involved in conducting a feasibility study and research for freshwater aquaculture development in a relatively arid region of Omaheke, located in the eastern part of Namibia, that covers a surface area of about 85 000 km².

It is important to note that the quality of the groundwater is generally geothermic and has variable concentrations of salinity, heavy metals and minerals; water quality determination is, therefore, essential during feasibility studies. Fish stock trials are also important to anticipate the potential growth in such water resources. For example, Mozambique tilapia (*Oreochromis mossambicus*), a candidate fish species for most arid regions of Namibia, can tolerate brackish water at salinity levels of up to 40 ppt. Water needs to be tested to ensure it is of good quality and that heavy metals are within threshold limits for optimum fish growth and survival and for food safety reasons. Good water quality is also useful for crop/horticultural irrigation, which may be part of an integrated agriculture-aquaculture practice.

HUMAN RESOURCES

One of the main attractions of accelerating aquaculture development in Southern Africa is the sector's potential to generate employment, thus, contributing to poverty alleviation and food security for millions of poor people. This potential is being taken into consideration at the policy level by governments of the region. However, in reality, employment opportunities in the sector so far are still very limited as the sector is still gradually expanding.

Namibia has one of the most organized aquaculture policy and management structures in Africa. In 2003, a Directorate of Aquaculture was set up within the Ministry of Fisheries and Marine Resources to administer and regulate all aquaculture operations in the country. The directorate has its central administrative functions in the capital, Windhoek, and has regional one-stop information centres where well-trained extension agents, technicians, biologists and other resource persons are based. These are essential human resources for small-scale communities and extension programmes. The Namibian aquaculture sector alone currently has about 76 permanent government employees, with an additional 95 employees as farm attendants at its country-wide cooperative fish farms. Hundreds of self-employed small-scale subsistence oriented fish farmers stand also exist in this country. Larger-scale pipeline projects in arid lands are expected to expand employment in the sector. Spin-off sectors, such as fish feed production, marketing, etc., are also expected to generate additional employment.

There are thousands of unemployed youths in Namibia, and the government earmarked 2010 as the “year for the youths” in terms of development. Various incentives were designed to encourage young people to develop aquaculture in the country, wherever resources permit, either as self-employed or working in cooperatives under government initiated pilot projects. However, such youths require extensive and effective training to obtain the necessary technical skills.

Similarly, the gender sensitive CSAP project in South Africa intends to employ many unemployed youths and women within the areas of Graaf Reinet. Many of these women and youths are currently undergoing a comprehensive skills development programme to enable them to be fish farm attendants, supervisors, etc. (L. de la Harpe, personal communication, 2010).

According to the 2009 Aquaculture Institute of South Africa (AISA) – Aquaculture Benchmarking Survey (AISA, 2009), the South African aquaculture industry employed 1 837 full-time and 355 part-time employees in 2008 (Britz, Lee and Botes, 2009). Employment in aquaculture grew by approximately 80 percent between 2005 and 2008. Significant employment opportunities are also expected once the large-scale aquaculture project in Botswana becomes operational. Currently, less than 100 people are employed in the aquaculture sector in Botswana (FAO, 2007). At the private commercial level, the rate of employment is generally based on the intensity of the operation, the production level and the associated profitability of the operation. Farmers try to avoid high labour costs; generally, the farm owner serves as his own farm manager but may recruit a few farm attendants to assist on a part-time or temporary basis, as and when needed.

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

Generally, production systems for fish farming projects in desert and arid lands vary based on the water resource type, its availability and the surrounding environments, also taking cognisance of associated investment and construction costs. Intensive, semi-intensive and extensive systems have been identified in the arid lands under review. Some of the identified aquaculture projects in desert and arid lands are listed in Table 1.

TABLE 1

List of selected aquaculture projects in desert and arid lands in Southern Africa

Country	Fish farm/project	Location	Region/province	Status	Water resource
Namibia	Eco-Fish Farm (Pvt.) Ltd.	Mariental town outskirts, Hardap Dam	Hardap	In operation Private	Hardap dam (from Fish River)
Namibia	Hardap Inland Aquaculture Centre	Mariental town outskirts, Hardap Dam	Hardap	In operation Government initiated project	Hardap dam (from Fish River)
Namibia	Fontetjje Fish Farm Project	Keetmanshoop town outskirts	Karas	In operation Government initiated project	Groundwater (boreholes)
Namibia	Uis Aquaculture Farming (Pvt.) Ltd.	Uis District, disused mine pit, Uis Centre (1)	Erongo	In operation (pilot scale) Private	Disused mine pit groundwater reservoir
Namibia	Uis Youth Project on Aquaculture	Uis District, disused mine pit, Uis Centre (2)	Erongo	Initiation phase Community Youth-JICA-MFMR pilot project	Disused mine pit groundwater reservoir
Namibia	Leonardville Village Aquaculture project	Leonardville town outskirts	Omaheke	Under construction Government initiated pilot project	Groundwater Borehole/fountain
Namibia	Community based water point tanks	Whole of Omaheke Region	Omaheke	In operation/ planning phase Government initiated pilot project	Groundwater/ Borehole
South Africa	Camdeboo Satellite Aquaculture Project	Graaf Reinert	Eastern Cape	Establishment phase Multi-stakeholder	Groundwater/ boreholes
Botswana	Zambezi Integrated Agro-commercial Development Project	Pandamatenga District	Northern Botswana	Planning phase Public/Private Partnership Scheme	Water drawn from the Zambezi through long pipeline
Zimbabwe	Lowveld Cocrodile & Fish Farming Project	Chiredzi District	Masvingo	In pilot phase	Water drawn from sugar cane irrigation dams

Recirculation aquaculture systems – Water conservation is the main aim of using recirculation aquaculture systems (RAS). Many commercially operated ventures that extract underground water or that are in areas of high evaporation rates use this form of highly intensive production system. Fish are reared in concrete or plastic tanks that allow zero water seepage and the water is conserved through recycling and reuse. In some cases, the rearing unit is hosted in a greenhouse to maintain optimum water temperatures, especially when warmwater fish, such as tilapias and catfish are reared. The extreme cold of the winter season can occupy about four months in Southern Africa (from May to August).

In Namibia, this type of culture system has been erected by the Hardap IAC, Ecofish Farm (Pvt.) Ltd. (Figure 4) and the Fontetjie Fish Farm and is also being set up at the Leonardville site. Similarly, the CSAP in South Africa has planned to use

RAS on many of its satellite farms for hatchery and grow-out operations. A number of South African fish farms have even developed advanced RAS and aquaponics systems. Nutrient rich effluent water is further utilized for irrigation purposes, thus, comprising integrated aquaculture.

Cage culture – In some cases, the water contained in water bodies (dam, reservoir, disused mine pit, etc.) may be adequate enough to accommodate floating cages for grow-out purposes, providing the water quality is good. A private commercial farmer has established a small-scale floating cage unit within an open disused mine pit in Uis, Erongo Region of Namibia (Figure 5). A hatchery that supplies fingerlings is located a few kilometres away from the cage site. This farmer aims to produce ~5 tonnes of market size fish per month. Namibia, with its rich mineral resources, has many disused mine pits that contain groundwater with the potential for aquaculture development.

Earth pond culture – Depending on local available water volumes, soil quality and water seepage rates, fish farms may use open pond, semi-intensive culture systems. The ponds may be plastic lined to prevent water seepage if the soils are highly permeable (like those in sandy deserts). Open pond culture requires large volumes of water as most are flow-through systems.

The Zambezi Integrated Agro-Commercial Development Project being planned in Botswana will extract

FIGURE 4
A recirculation aquaculture system in action, covered by a greenhouse, Hardap Region, Namibia



COURTESY OF B. MAPFUMO

FIGURE 5
Floating cages in a small ground water reservoir, Uis, Erongo Region, Namibia



COURTESY OF B. MAPFUMO

water from the Zambezi River and then utilize both open water pond systems and RAS. Another private farm located in Leonardville, Omaheke Region of Namibia, grows tilapia in open pond systems utilizing groundwater from an aquifer (Figure 6). Similarly, the large-scale pilot project in existence in Chiredzi, lower Zimbabwe has large commercial, flow through ponds.

Open tank culture – Semi-intensive/extensive tank culture has been recorded in Namibia and some parts of South Africa. In such systems a borehole is drilled and a water storage tank (tank volumes vary, but most are ~60 m³; Figure 7) is erected for livestock and further utilized for small-scale fish rearing. It costs ~USD30 000 to drill a borehole to about 100 m depth. In Namibia, one private farmer in the Omaheke region rears some ornamental fish (koi carp *Cyprinus carpio*) in multi-purpose water storage tanks. In addition, in the same region, the Ministry of Fisheries and Marine Resources of Namibia has begun stocking some of the community based water points with fingerlings from its hatcheries. About 37 small-scale fish farmers in arid lands received fingerlings from the government in 2008.

Stock enhancement practices in small water bodies – Small water bodies located within desert and arid lands can be important resources for farmed fish. Such water bodies derive their water from seasonal rivers, as is the case with the Fish River that feeds the Hardap dam in Namibia. Alternatively, they may be low-lying natural or artificial water reservoirs/pools fed by groundwater through springs or aquifers. The advantages of this form of aquaculture are that costly facilities are not required and management is limited; thus, the fish are produced at lowest possible cost (Rouhani and Britz, 2008). Recreational fishing has been noted within most of these small water bodies (Figure 8).

FIGURE 6
Private farms at Leonardville, Omaheke, growing tilapia in earth ponds utilizing aquifer waters



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FIGURE 7
Private farms at Leonardville, Omaheke, growing tilapia in earth ponds utilizing aquifer waters



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FIGURE 8
Harvesting of a state-owned dam in arid lands, Namibia



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CULTURED SPECIES

In general, aquaculture policy in countries in Southern Africa favours culturing their indigenous species for environmental and biodiversity concerns. There are trepidations that some highly invasive species such as Nile tilapia (*Oreochromis niloticus*) not indigenous to Namibia, South Africa and Botswana, but an attractive candidate for commercial aquaculture, can easily replace endemic tilapia species such as the Mozambique tilapia (*O. mossambicus*), three spotted tilapia (*O. andersonii*), longfin tilapia (*O. macrochir*), blue tilapia (*O. aureus*) and others within the local ecosystems, mainly through hybridization. Nile tilapia is believed to have spread throughout Southern Africa uncontrollably since its introduction about 50 years ago (van der Waal, 2002). Despite these concerns, the Nile tilapia is the most favoured candidate for aquaculture in Southern Africa to date. Indigenous species are however still regarded as important for extensive aquaculture practices, i.e. for stock enhancement. Tilapias have a better market share than carps and catfish in most parts of Southern Africa (van der Waal, 2002).

The national authorities in Botswana, Namibia, and South Africa are highly cautious, and only allow the introduction of alien species after a risk assessment in the area and surrounding ecosystem. However, many potential commercial farmers claim that some of the indigenous species mentioned above are not as economically viable in terms of growth rates, food conversion efficiency, disease resistance and management as Nile tilapia. Hence, many commercial farmers prefer rearing introduced, fast growing hybrids for better returns on investments. In any case, they need to obtain authorization from the relevant authorities.

The indigenous species that are cultured by smallholder farmers in the area under review include Mozambique tilapia (*O. mossambicus*), three spotted tilapia (*O. andersonii*), redbreasted tilapia (*Tilapia rendalli*) and North African catfish (*Clarias gariepinus*). The common carp (*Cyprinus carpio*), which was introduced many years ago, is now well-established within the ecosystems and is a good candidate species because of its positive production characteristics. There are several other indigenous species that are still being investigated for potential freshwater aquaculture, including the giant river prawn (*Macrobrachium rosenbergii*). Apart from molluscs, the production of land-based marine or brackishwater finfish species is still very limited in the arid land areas of Southern Africa (Table 2).

In Namibia, trials have indicated that, with good feed, water quality and management, the hybrid all-male red tilapia (*Oreochromis* spp.) being grown at the

TABLE 2
Cultured species produced at fish farms located in arid lands

Country	Fish farm/project	Species grown
Namibia	Eco-Fish Farm (Pvt) Ltd	Hybrid red tilapia (<i>Oreochromis</i> spp.) special licence of introduction provided
Namibia	Hardap Inland Aquaculture Centre	Indigenous (<i>O. mossambicus</i>), <i>C. Carpio</i> , Yellowfish, mudfish (trials)
Namibia	Fontetjie Fish Farm project	Indigenous (<i>O. mossambicus</i>), <i>C. Carpio</i>
Namibia	Uis Aquaculture Farming (Pvt) Ltd	Indigenous (<i>O. mossambicus</i>), <i>O. andersonii</i> (<i>C. gariepinus</i>) trials
Namibia	Uis Youth Project	Indigenous (<i>O. mossambicus</i>) trials
Namibia	Leonardville Village project	Indigenous (<i>O. mossambicus</i>) trials
Namibia	Community based tank farms in Omaheke	Indigenous (<i>O. mossambicus</i>), (<i>C. gariepinus</i>) trials
South Africa	Camdeboo Satellite Aquaculture project	Indigenous (<i>O. mossambicus</i>), (<i>C. gariepinus</i>) (<i>C. Carpio</i>) trials
Botswana	Zambesi Integrated Agro-commercial Development Project	<i>Oreochromis</i> spp.
Zimbabwe	Lowveld Crocodile & Fish Farming Project	<i>Oreochromis</i> spp., <i>C. Carpio</i>

Ecofish Farm in Hardap (Figure 9) can grow from fingerling stage (20 g) to market size (700 g) in about eight months, in RAS (F. Naviloski, personal communication, 2010). This is a good result for commercial aquaculture that is oriented to export markets. In comparison, given the same conditions, the indigenous *O. mossambicus* takes a year to grow to 250–400 g, as experienced in Namibia. Both *Clarias gariepinus* and *Cyprinus carpio*, although only cultured in Namibia on a small-scale, have generally performed when grown under favourable conditions.

Recently, the culture of ornamental fish including koi carp (*Cyprinus carpio*) is becoming big business in Southern Africa, practised mainly by commercial farmers. In 2008, this industry was worth almost USD1.5 million in South Africa alone and, after trout and abalone, ornamental fish are considered one of the most valuable commercial species groups.

CULTURE PRACTICES

Hatcheries

The Namibian Government has begun setting up hatcheries in regional centres around the country for the production and supply of broodstock, fry and fingerlings to government initiated pilot projects and interested private farmers. These hatcheries mainly produce indigenous species such as Mozambique tilapia (*O. mossambicus*), three spotted tilapia (*O. andersonii*), redbreasted tilapia (*T. rendalli*), North African catfish (*C. gariepinus*), as well as common carp (*C. carpio*). Other species are being investigated prior to the grow-out phase. The hatcheries basically consist of indoor RAS for fry production (Figure 10) and outdoor secondary nursery ponds for fingerling production. If the hatcheries are located outside the main grow-out area, the government has also provided transport and equipment for fingerling distribution. So far, the hatcheries operating within the arid lands of Namibia are:

- Hardap IAC hatchery (supplying fingerlings to the southern and eastern regions).
- Uis Aquaculture Farming (Pvt.) Ltd. hatchery (supplying fingerlings for own cage farm and with potential to supply interested farmers in the area).
- Leonardville hatchery (supplying fingerlings throughout the Omaheke Region, once in operation).

Other hatcheries located in non-arid zones, but also important for broodstock and fingerling production around the country, are:

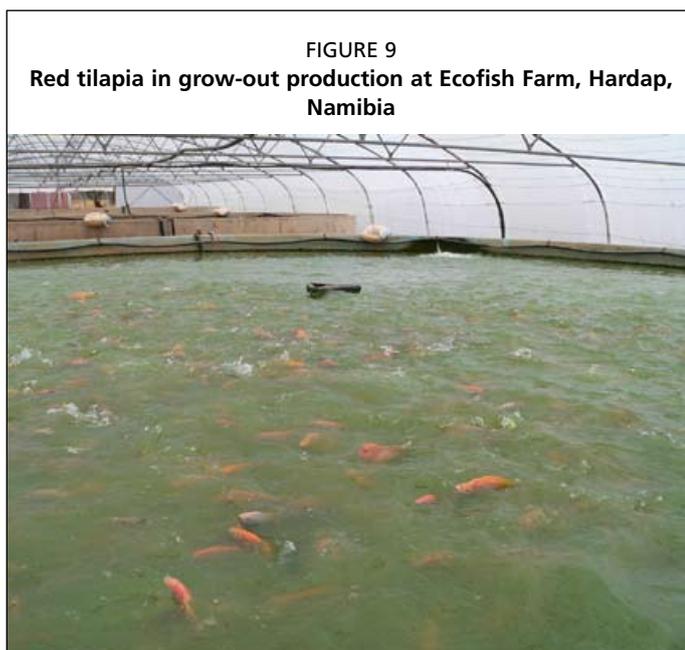


FIGURE 9
Red tilapia in grow-out production at Ecofish Farm, Hardap, Namibia

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FIGURE 10
Indoor fish fry production unit, Omahenene/Onavivi, Namibia

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- Omahenene/Onavivi hatchery, in the Omusati region (supplying fingerlings within the northwest regions of Namibia).
- Ongwediva hatchery, in the Oshana region (supplying fingerlings within the northwest regions of Namibia); Kamutjonga Inland Fisheries Institute hatcheries (supplying fingerlings within the northeast regions of Namibia).

The most significant hatchery projects in South Africa and Botswana are:

- CSAP in South Africa, which is setting up its own hatchery on-site for tilapia, catfish and common carp. The hatchery will supply fingerlings to all the satellite farms located in the surrounding areas.
- The Zambezi Integrated Agro-Commercial Development Project in Botswana will also have its own tilapia hatcheries on-site. This project aims at producing 40 000 tonnes of market size fish once in full operation. Usually, private commercial fish farmers also have their own hatcheries. Cooperation between hatchery research projects at Stellenbosch University, Rhodes University and private hatcheries in South Africa have resulted in improved quality of start-up broodstock and fingerlings.

Grow-out farms

In Namibia, grow-out farms in desert and arid lands use farming systems varying from intensive, semi-intensive to extensive. Highly intensive systems such as RAS (in green house) have been set up at Fontetjie, Hardap IAC, Ecofish Farm (Figure 11), the latter having the capacity to produce 360 tonnes of fish per annum. Such RAS are also being established at Leonardville and several other sites under investigation across the country. However, a number of community based, small-scale ponds and on-farm water storage tanks of different sizes are also used as grow-out systems in the arid regions. The Karoo districts of South Africa are very dry; hence, the CSAP intends to use integrated and intensive RAS for grow-out production.

A pilot-scale, intensive cage culture system has been set up at the Uis Aquaculture Farm (Pvt.) Ltd. This floating cage farm aims to produce ~60 tonnes of fish per year. Within the same area, in Uis, a floating cage project for youth development is being established and is expected to produce a minimum of 30 tonnes of fish per year.

Plastic lined ponds are used in mariculture for the rearing of spat oysters and for oyster quarantine purposes onshore, for example in Walvis Bay. This coastal town is in the middle of the highly sandy Namib Desert. The Zambezi Integrated Agro-

Commercial Development Project in Botswana will utilize both intensive RAS and open earth ponds on a large-scale for its grow-out production.



SECTOR PERFORMANCE

Currently, as can be observed from this review, little has been achieved in Southern Africa with regard to aquaculture in deserts and arid lands so far. Most of the operations are still in the pilot-scale phase. However, with the currently great focus on aquaculture by policy makers in the region, the potential looks bright; major developments are expected within the next ten years. Aquaculture development is being prioritized by all countries in Southern Africa.

PRODUCTION

Total freshwater aquaculture production in Namibia in 2009 was less than 100 tonnes, potentially generating an approximate value of USD250 000; in comparison, capture fisheries had a landed volume of about 400 000 tonnes valued at over USD300 million. Namibia's combined fishing sector contributes about 6 percent to GDP. The Namibian Government has already invested well over USD750 000 towards the development of aquaculture. A further investment of USD8 million is planned for the next five years, a recognition that developing aquaculture has multiple potential in terms of employment creation, improved fish supplies, the development of local associated industries (packaging, distribution, feed, etc.) and improved livelihoods for many people, especially in the rural areas (G. Kibria, personal communication, 2010). The results of these investments are not yet known, as almost all initiated community based aquaculture projects (including those in arid lands) are in a pilot-scale phase.

If successful, the large-scale integrated operation in Botswana is expected to generate significant results. Considering the magnitude of its production volume (40 000 tonnes per annum at full operation), this could be a very significant event for Southern Africa (probably one of the world's largest production volume from a single fish farm). Using current regional fish prices, this could be equivalent to an income of ~USD100 million per annum from fish alone. Additional income will be generated from its multi-integrated agricultural projects. Currently, the fisheries (mainly capture fisheries) contribution to GDP in Botswana is around 0.002 percent (Wyk and Strub, 2007).

Aquaculture production in South Africa mainly consists of abalone. Besides the CSAP project mentioned below, not much has been documented regarding aquaculture production in the arid lands of this country.

MARKET

Southern Africa has a strong tradition of consuming fish. Demand for farmed fish products, especially freshwater fish such as tilapias, is generally good. This fact has attracted many investors to consider setting up aquaculture businesses in the region. Wild catches of freshwater fish are undoubtedly dwindling and many people are gradually becoming accustomed to buying farmed fish, although supply is still very limited. The two large-scale commercial ventures (CSAP and the Zambezi Integrated Commercial Project in Botswana) described in this review aim to produce tilapias and catfish for local and regional markets, following regional market feasibility studies. Species such as catfish and carp are becoming increasingly popular in the markets of Namibia, Angola and South Africa.

Since the demand for farmed fish exceeds supply, whatever is produced is sold out immediately after harvest as fresh fish. Markets include sales to individuals at the farm gate or to local restaurants, supermarkets, seafood distribution outlets, etc. Most of the fish are either sold fresh, immediately after harvest or frozen (whole gutted). Consequently, there is little processing or fish storage.

The CSAP project in South Africa intends to grow its fish (tilapia and catfish) to a market size of <100 g and then to process the product through canning (in large cans) for distribution to schools, hospitals and prisons where, according to their marketing feasibility studies, there is huge demand (L. de la Harpe, personal communication, 2010). Fish prices vary according to location and species. The current average regional price for farmed whole gutted tilapia is ~USD2.50/kg. However, the retail prices of whole gutted and frozen tilapia in some supermarket chains in South Africa and Botswana is >USD4.50/kg. This compares favourably with international market prices.

Southern Africa is experiencing a gradual shift from a focus on international markets (European Union, United States of America, etc.) for farmed freshwater fish products towards local and regional markets. This is because costs of production in Africa are much higher than in Asia. Most operations are relatively small scale in terms of

production volumes and, hence, may not compete in terms of economies of scale. Many inputs, such as feed and equipment, have to be imported and, since freight space has become more expensive, this contributes to high production costs.

CONTRIBUTION TO THE ECONOMY

Generally, in all the 15 countries of Southern Africa, the contribution of aquaculture to the economy is relatively negligible as the sector is in its early stages and production is still low.

INSTITUTIONAL FRAMEWORK

In Namibia, the Directorate of Aquaculture has set up regional centres for the management of government initiated pilot projects, as well as the provision of extension services to small-scale fish farmers and the management of culture based fisheries in state-owned water bodies. Some of these centres, for instance, the Hardap Inland Aquaculture Center, Kamutjonga Inland Fisheries Institute (KIFI), Omahenene/Onavivi, have fingerling producing units and research facilities (Figure 12). The Directorate of Aquaculture is also supported by other directorates within the Ministry, such as the Directorate of Resource Management (responsible for scientific research and advice); the Directorate of Operation and Surveillance (responsible for monitoring, control and surveillance); the Directorate of Policy Planning and Economics (responsible for the coordination of the planning activities of the MFMR, as well as formulating fisheries policies and legislation and undertaking research and advising on socio-economic issues).

In South Africa, aquaculture is regulated by the Department of Agriculture, Forestry and Fisheries (DAFF) at the policy level. Recent political changes in South Africa may lead to institutional reforms in the fisheries and aquaculture sector. Other departments and institutions with close ties to aquaculture development in South Africa include the Department of Water Affairs, the Aquaculture Institute of South Africa (AISA) and the Aquaculture Association for Southern Africa (AASA).

In Botswana, aquaculture is within the remit of the Fisheries Unit of the Department of Wildlife and National Parks (within the Ministry of Environment, Wildlife and Tourism). This unit deals with fisheries technical matters, extension services and aquaculture. The government has recently expressed its intention to develop an aquaculture policy and strategic planning document to pave the way for the future development of the sector.

FIGURE 12
Research facility at Kamutjonga Inland Fisheries Institute,
northern Namibia



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GOVERNING REGULATIONS

There is currently no specific legislation for developing aquaculture in desert and arid lands of Southern Africa. However, a legal framework for the development of aquaculture is in place in Namibia (GoN, 2001, 2002, 2004). This legislation ensures that the sector is managed sustainably and has been harmonized with other legislation concerning the environment, biodiversity, inland fisheries management, etc.

In South Africa, the newly formed Department of Agriculture, Forestry and Fisheries is currently developing an accessible and enabling regulatory

framework to guide the development of sustainable aquaculture practices. This development follows a long period during which the sector has been fragmented and regulated by separate government departments, and many requests for a united aquaculture policy and strategy. Towards this goal, two long-term policy documents are being prepared: the National Department of Agriculture draft aquaculture policy and the Marine and Coastal Management draft marine aquaculture policy.

There is no separate fisheries regulation in Botswana, which is probably related to the absence of a national fisheries policy. The only fisheries management legislation that exists is the Fish Protection Act, CAP 38: 05 of 1975, managed under the Department of Wildlife and National Parks strategic plan which is founded on the Wildlife Conservation and National Parks Act of 1992 (GoB, 2009). The basis of this plan is that fish and wildlife resources contribute to the cultural, socio-economic and biological integrity of the nation through:

- creation of economic opportunities;
- diversification of the economic base;
- contribution to biological diversity;
- provision of resources for tourism development; and
- provision of platform for aesthetic, scientific, recreational and educational values.

In general, the current legislative framework for aquaculture in Southern Africa needs to be revisited, updated and harmonized to take into account the developments being initiated in desert and arid lands.

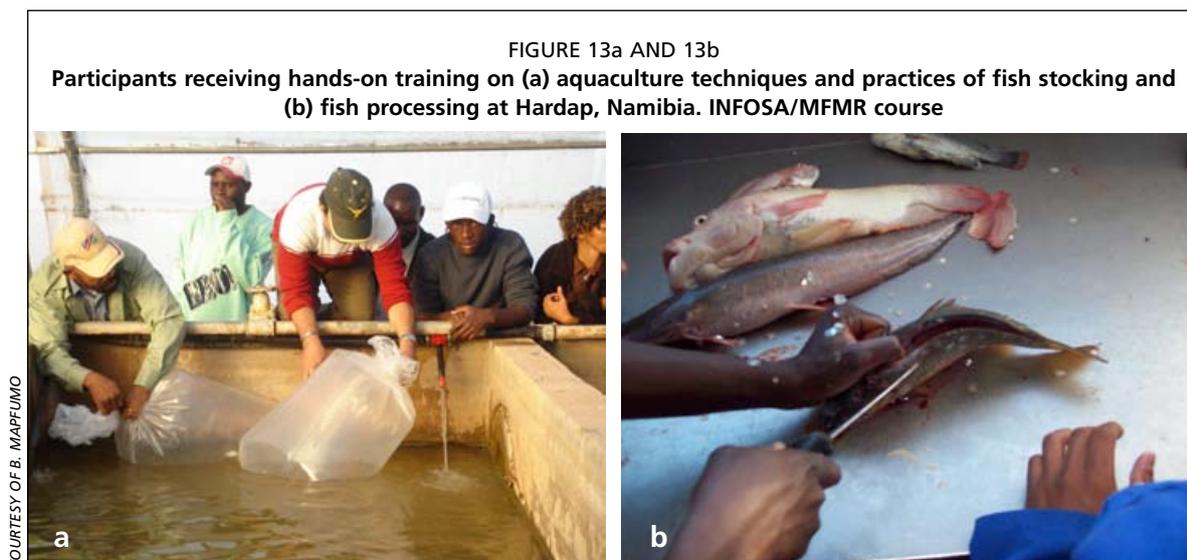
APPLIED RESEARCH, EDUCATION AND TRAINING

In Namibia, aquaculture training has been named as a priority area by the government, which has established training, extension and research facilities across the country. The MFMR begins with pilot projects, followed by research and development, in the whole value chain from fish production through to marketing. The R&D efforts will ensure that each venture is sustainable, through improvements based on lessons learnt. The Department of Fisheries and Aquatic Sciences at the University of Namibia also assists in graduate training and research for fisheries and aquaculture candidates. The Polytechnic of Namibia is planning to introduce aquaculture related courses and has already supported courses in business management, information technology, agricultural management, etc., for those operating or intending to run aqua-businesses.

In addition, fisheries and aquaculture technicians and biologists working within the Directorate are regularly sent abroad to key producer countries such as China, Norway, South Africa, Malawi, etc., to participate in further practical training and attachment courses. Technical experts from Bangladesh, China, Norway, Spain, Viet Nam, Japan, Cuba, the United States of America and many others have also visited Namibia under bilateral relations programmes and have been of great assistance. The principal aim of such relations is to develop a sustainable and effective skills base for small-scale community-based aquaculture extension.

International institutions such as FAO and the WorldFish Center are closely linked with developments in the region and offer regular training and technical advisory services on aquaculture. For instance, FAO is currently offering short-term, custom based training courses on complex subjects such as Risk Assessment in Aquaculture and Aquatic Biosecurity subjects in the region. The WorldFish Center, through its technical centres in Malawi and Zambia, has been instrumental in training, research and development on inland fisheries and small-scale aquaculture.

The intergovernmental organization for Marketing Information and Technical Advisory Services for the Fisheries Industry in Southern Africa (INFOSA) collaborates with MFMR in offering localized and tailor made training courses on aquaculture in Namibia (Figures 13a and 13b). INFOSA has trained over 100 participants in the past three years, including fish farmers from the southern arid areas of Namibia.



The CSAP in South Africa has a comprehensive training programme for youths and women who do not have any background in aquaculture. This programme, commissioned by FAO in July 2010, is integrated with adult basic education, business management and orientation programmes, with follow-up practical mentorship programmes. The training courses are also linked with national training programmes being offered by the AISA and other local institutions. The project is conducting a market research and development model for canned freshwater fish products (probably first of its kind in Southern Africa), and is also seeking funds for R&D in localized fish feed production.

Regional universities such as the Bunda College in Malawi and Stellenbosch and Rhodes universities in South Africa have traditionally been important training and research centres in all areas of aquaculture. Other universities and technical colleges in Southern Africa have begun incorporating aquaculture in their curricula.

Despite all these, the concept of developing aquaculture in desert and arid lands is still relatively novel. Thus, learning from successful operations in the pilot projects in operation today is crucially important. Most farmers, especially in the private sector, are cautious and sceptical about constructing fish rearing facilities in locations where risks, as well as infrastructural costs are potentially high, such as deserts and arid lands. Farmers will wait to see if there are success stories generated by the pilot scale farms.

TRENDS, ISSUES AND DEVELOPMENT

The main constraints and challenges in developing aquaculture in the desert and arid lands of Southern Africa include:

- Lack of well-defined policy, public sector interventions, legal frameworks and institutional capacity for the development of aquaculture in general, especially in countries such as South Africa, Botswana, Angola and Zimbabwe.
- Lack of finance and start-up capital for developing aquaculture. Financial institutions are still reluctant to lend money for aquaculture projects due to the high risk involved. These challenges are slowly being tackled in Southern Africa. In Namibia, for example, the government has to date invested over USD1 million on aquaculture development, with more funds allocated in its annual fiscal budget. The government is also encouraging financial institutions to recognize aquaculture as a potential business and to assist in its expansion.
- Lack of interest by the private sector in investing in aquaculture in desert and arid lands because of the potential risks involved, including the high costs associated

with constructing and managing the production facilities, taking into consideration the returns on investment envisaged. The private sector is the driving force behind aquaculture development in Southern Africa.

- Lack of basic infrastructure such as hatcheries, fish feed factories, etc., and in some cases, lack of basic infrastructure such as roads, electricity, communication, etc., especially in remote areas.
- For large-scale commercial aquaculture ventures, the introduction of fast growing species is needed for cost management and to provide good returns on investments; however, some governments are reluctant to issue licences for introductions unless a risk assessment has been undertaken.
- Scarcity of water resources in some areas which makes it difficult to plan for large-scale expansions as groundwater resource replenishment is based on annual rainfall. Surface water may be insufficient in drought years.
- In some places, the quality of the groundwater is not satisfactory for some freshwater aquaculture species. For example, although species such as the indigenous Mozambique tilapia (*O. mossambicus*) can tolerate higher levels of salinity, their growth rates are compromised as salinity levels increase.
- Fish feed and other raw materials are currently imported and are therefore, expensive and beyond the reach of many small-scale or large-scale fish farmers.
- There is a lack of a biosecurity framework in Southern Africa. Fish disease outbreaks have been recorded recently in Southern Africa where the region is battling with the spread of epizootic ulcerative syndrome (FAO, 2009b).
- Lack of clear-cut marketing feasibility studies on which the private commercial sector can base their business plans prior to project implementation.
- Adequate skills for aquaculture development are still limited, so training and capacity building programmes are important for the development of a vibrant aquaculture sector.

SUCCESS STORIES

One case study is provided in this section of the review.

Camdeboo Satellite Aquaculture Project, South Africa

The CSAP is located in the dry area of Graaf Reinet, in the eastern Cape Province of South Africa. The area receives about 230 mm of rain per year, with most rainfall occurring mainly during the autumn. Average temperatures range from 17 °C in June to about 30 °C in January, with coldest temperatures recorded in July at about 2.5 °C. Although very arid on the surface, the whole area has many livestock farms and the lands have pockets of good groundwater supplies, ready to be further utilized for aquaculture.

The overall goal of CSAP is to link poor, vulnerable, marginalized communities to sustainable livelihood and economic activities, while simultaneously addressing food security. CSAP has initiated a commercially viable fish production venture through the establishment of aquaculture “clusters”, each consisting of a central management and support farm and a network of satellite farms, which will benefit from economies of scale through their collaboration. The fish produced will be canned in order to increase shelf-life and sold at an affordable price in order to fill the enormous gap caused by the reduction in the South African annual pilchard quota. This could considerably alleviate poverty through the creation of sustainable self-employment for rural women, youths and the stimulation of pro-poor economic growth, whilst simultaneously producing an affordable, nutritional, food source for low income groups.

Each satellite farm is designed to produce 10 tonnes of fish per month (120 tonnes per annum). This is enough to feed over 15 500 people per annum, based on the national fish consumption rate of 7.7 kg per person per year. Fifty satellite farms are envisaged in the area.

CSAP is currently working on the basic product development, testing three fish species – Mozambique tilapia (*Oreochromis mossambicus*), North African catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*) – in a range of tomato sauce recipes. CSAP will also conduct a national market acceptance survey that will be the ultimate deciding factor in selecting the species of fish to rear. CSAP believes that the gap in the canned fish market is enormous, but it is imperative for them to develop a marketable product in order to proceed.

The project has received the approval of the DAFF – the national authority overseeing aquaculture development in South Africa. DAFF is assisting CSAP in sourcing funding for research and development to further refine the canned fish product, as well as for the development of a local fish feed based on ingredients that could be grown locally.

The project design phase of CSAP was completed in 2009. Full-scale production is expected to commence in 2011 once funding for developing the rearing infrastructure and the purchase of other raw materials is available. This will involve the construction of RAS facilities at the central farm, as well as satellite farms. The central farm will include a hatchery, which will supply all the required fingerlings to the satellite farms.

WAY FORWARD

There is a huge opportunity for Southern Africa to explore the freshwater and brackish water resources that exist in its vast deserts and arid lands, where there is generally limited competition for land from other developmental activities such as agriculture, town development, etc. However, there is a need for guidance from policy makers through the crafting of harmonized aquaculture policies, legislative frameworks, strategic plans and institutions that are aligned to potential developments in desert and arid land environments. Governments should aim at creating an enabling environment for private sector investments, promoting private sector participation, developing areas specifically designated for aquaculture and providing facilities and other necessary support services.

Role players in aquaculture should promote the new FAO initiated SPADA approach that aims to work with public and private institutions, service providers, non-governmental organizations and the private sector to establish sustainable and responsible aqua-businesses which will in turn increase employment, fish supply and investment opportunities.

There is a need for clustering small-scale farmers for their sustainability. CSAP has highlighted that the cost of operating an individual fish farm is prohibitive. Individual satellite farms can work together and thus, have bulk negotiating power when purchasing equipment, raw materials, feeds, etc. In the case of CSAP, cooperation between individual satellite farms is essential to access an existing canned fish market (where demand drastically exceeds supply) in South Africa. Such a model is worth duplicating across the SADC region.

There is a need to establish effective information exchange platforms and networks on aquaculture development throughout Southern Africa. There are responsible institutions in place, such as the AASA, WorldFish Center, INFOSA and others but these need further strengthening.

Access to finance for aquaculture development is still difficult in Southern Africa. National development banks should be encouraged to bear the risks and to provide venture capital for commercial operations.

Research, training and extension services should always be prioritized at all levels for successful aquaculture production. The concept and systems for growing fish in arid lands can be complex from a layman's perspective. In addition, more participatory action research is needed with various public and private sector stakeholders to appraise the potential role of desert and arid lands in aquaculture (Rouhani and Britz, 2008).

There is a need to set up a centralized database that integrates biophysical and socio-economic information and other parameters of importance for aquaculture development that is specific to desert and arid lands. In cases of super-intensive commercial aquaculture, there is a need to harmonize legislation that permits the introduction and rearing of fast growing species, without endangering ecological systems or environmental balance.

The next step in countries with arid lands where water is scarce and expensive is to show farmers that they could also use the water in which their fish are raised to irrigate their crops. The organic waste produced by the fish makes the water especially useful because it acts as a crop fertilizer. Such integration of aquaculture with crop production is practised in the Negev Desert of Israel, where water recycled from fish ponds irrigates desert plantations of olive, alfalfa and dates (Rothbard and Peretz, 2002). There is a need to build capacity on this subject.

There is a need for information dissemination to demonstrate the opportunities offered by desert and arid lands aquaculture in Africa to potential stakeholders and investors.

The CSAP, which is described above, is still in its pilot scale phase. Once successfully finalized, the project could have a positive effect for the Southern Africa region because of its commercial design model and for the multi-stakeholders approach that it is adopting. The theory of clustering the small-scale fish farms is essential for their sustainability and this idea is believed to have the potential to stimulate successful small-scale aquaculture ventures around the region.

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An overview on desert aquaculture in Egypt

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SUMMARY

Today, Egyptian desert aquaculture comprises more than 100 intensive tilapia rural farms and 20 commercial aquaculture farms scattered throughout seven different provinces. The approximate combined surface area of the desert commercial farms is ~893 hectares, with an approximate annual production of 13 000 tonnes. These 20 commercial farms are capable of producing up to 6 000 tonnes/year, the remaining 7 000 tonnes/year are produced in ~100 rural farms. Various finfish species are reared, particularly Nile tilapia (*Oreochromis niloticus*), red tilapia (*Oreochromis mossambicus* × *Oreochromis niloticus*), North African catfish (*Clarias gariepinus*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idellus*), flathead grey mullet (*Mugil cephalus*), European seabass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*) and a number of exotic species, mainly koi (*Cyprinus* spp.), fantail (koi variety) and molly (*Poecillia* spp.). The water source comes from underground water reserves and/or agricultural drainage. The latter varies in salinity, ranging from 0.5 to 26 g/litre, and in temperature from 22 to 26 °C. Most of the commercial farms have adopted flow-through systems (FTS) which irrigate agricultural land, giving them the advantages of producing three different crops (fish/plant/sheep). While most of the farms are strictly dependent on FTS, two of them have upgraded their systems to include recirculation aquaculture system (RAS). Among other edible and ornamental fish species, tilapia (*Oreochromis niloticus* and *O. aureus*, or sex-reversed red tilapias) are one of the most promising species. Production of tilapia (in densities of 20–30 kg/m³ to market size of 250–400 g in 6–8 months) is possible due to the suitable warm climate and abundant warm underground water present throughout the year. Although the brackish water used for aquaculture purposes varies in salt concentrations (>25 g/litre), it is utilized for integrated agriculture, e.g. the irrigation of *Salicornia* crops combined with intensive European seabass and gilthead seabream aquaculture, with a yearly production of 100 tonnes per year for both species. Most commercial farms are purchasing their fish fry from the local market, and only five have their own hatchery. Issues that affect the development of these commercial aquatic desert farms are associated with the quantity/quality of water; excess of effluent water; fingerling supply; feed quality; feed prices; production overheads cost; lack of technical experience; marine fish diseases; and poor availability of credit.

RÉSUMÉ

À l'heure actuelle, l'aquaculture égyptienne en milieu désertique compte plus de 100 exploitations rurales d'élevage intensif de tilapia et 20 exploitations aquacoles commerciales réparties dans sept provinces différentes. La superficie totale des exploitations commerciales est d'environ 893 hectares, avec une production annuelle de plus ou moins 13 000 tonnes. Les 20 exploitations commerciales peuvent produire jusqu'à 6 000 tonnes de poissons par an alors que les 7 000 tonnes restantes sont produites par la centaine d'exploitations rurales. Diverses espèces de poissons sont élevées, en particulier le tilapia du Nil (*Oreochromis niloticus*), le tilapia rouge (*Oreochromis mossambicus* x *Oreochromis niloticus*), le poisson-chat nord-africain (*Clarias gariepinus*), la carpe commune (*Cyprinus carpio*), la carpe argentée (*Hypophthalmichthys molitrix*), la carpe herbivore (*Ctenopharyngodon idellus*), le mulot à grosse tête (*Mugil cephalus*), le bar commun (*Dicentrarchus labrax*), la dorade royale (*Sparus aurata*), ainsi que des espèces exotiques, principalement les carpes koïs (*Cyprinus* spp.), notamment celle à nageoires en voile, et le molly (*Poecilia* spp.). L'eau provient des nappes phréatiques et/ou du drainage agricole. La salinité de ces dernières est comprise entre 0,5 et 26 g/litre, leur température entre 22 et 26 °C. La majorité des exploitations commerciales ont adopté des systèmes ouverts (FTS), qui irriguent les terres agricoles et offrent l'avantage de permettre trois types différents de productions (poissons, végétaux et ovins). Alors que la plupart des exploitations n'ont recours qu'aux systèmes ouverts, deux d'entre elles ont modernisé ces derniers pour y introduire des technologies de recyclage de l'eau (RAS). Les tilapias (*Oreochromis niloticus* et *O. aureus*, ou les tilapias rouges à réversion sexuelle) font partie des espèces de poissons les plus prometteuses. Grâce à un climat chaud approprié et à d'abondantes eaux chaudes souterraines, la production de tilapias est possible tout au long de l'année, à des taux de mise en charge compris entre 20 et 30 kg/m³, qui permettent d'obtenir une taille commerciale de 250 à 400 g en l'espace de 6 à 8 mois. Même si l'eau saumâtre utilisée à des fins aquacoles n'a pas toujours la même concentration en sel (> 25 g/litre), elle est utilisée dans l'agriculture intégrée, par exemple pour irriguer les cultures de *Salicornia* associées à l'élevage aquacole intensif de bars communs et de dorades royales. La production annuelle de chacune de ces deux espèces est de 100 tonnes. La plupart des exploitations commerciales vendent leurs poissons sur le marché local et seules cinq d'entre elles disposent de leur propre éclosière. Les problèmes qui affectent le développement de ces exploitations en milieu désertique sont liés à la quantité et à la qualité de l'eau, à l'excès d'effluents, à l'approvisionnement en alevins, à la qualité et au prix des aliments, aux frais généraux de production, au manque d'expérience technique, aux maladies des poissons marins et à un mauvais accès au crédit.

ملخص

تتألف تربية الأحياء المائية المصرية اليوم من أكثر من مائة مزرعة ريفية مكثفة لتربية البلطي و عشرون مزرعة تجارية في تربية الأحياء المائية تتوزع عبر سبعة محافظات مختلفة والمساحة السطحية الإجمالية للمزارع الصحراوية التجارية هي تقريبا 893 (ثمانمائة وثلاثة وتسعون) هكتارا مع إنتاج سنوي تقريبي عند 13000 (ثلاثة عشر الف) طن. وهذه المزارع العشرين قادرة على الإنتاج حتى 000 6 (ستة الاف) طن/السنة، و 7 000 (سبعة الاف) طن/السنة المتبقية يتم إنتاجها في المزارع الريفية البالغ عددها مائة. ويتم تربية أنواع سمكية زعفرية عديدة، وبالأخص البلطي النيل (*Oreochromis niloticus*)، والبلطي الأحمر (*Oreochromis mossambicus* x *Oreochromis niloticus*)، أسماك قرموط شمال افريقيا (*Clarias gariepinus*)، والمبروك العادي او الشبوط الشائع (*Cyprinus carpio*)، والمبروك الفضي او الشبوط الفضي (*Hypophthalmichthys molitrix*)، ومبروك الحشائش او الشبوط العشبي (*Ctenopharyngodon idellus*)، البوري الرمادي مفلطح الرأس (*Mugil cephalus*)، والقاروص الأوروي (*Dicentrarchus labrax*)، والدنيس (*Sparus aurata*) وعددا من الأنواع المجلوبة وبشكل أساسي الكوي (*Cyprinus* spp.)، واسماك الزعفرنة المروحية (تشكيلات من الكوي) والمولي (*Poecilia* spp.). ويأتي مورد المياه من احتياطات المياه الجوفية و/او التصريف الزراعي. ويتنوع

الأخير في الملوحة، وتتراوح ما بين 0.5 الى 26 جرام/لتر وفي درجة الحرارة ما بين 22 الى 26 م°. ومعظم المزارع التجارية قد طبقت أنظمة التدفق المستمر (FTS) والتي تقوم بري الأراضي الزراعية، مما يعطيها ميزات إنتاج ثلاثة محاصيل مختلفة (أسماك/نباتات/خراف). وفي حين ان معظم المزارع تعتمد بشكل صارم على أنظمة التدفق المستمر (FTS)، فان اثنتين منهما قد قامتا بتطوير أنظمتها لتتضمن تقنيات نظام التدوير (RAS). ومن بين أنواع الأسماك الصالحة للأكل وأسماك الزينة، فان اسماك البلطي (*Oreochromis niloticus* و *O. aureus*)، او البلطي الاحمر المحول جنسياً، هي واحدة من أكثر الأنواع الواعدة. ان إنتاج البلطي (بكتافات 20 30 كجم/م³ الى الحجم التسويقي 250 400 جرام في 6 8 أشهر) هو أمر ممكن بسبب المناخ الحار المناسب والمياه الجوفية الحارة الوفيرة المتوفرة على مدار السنة. وعلى الرغم من ان المياه شبه المالحة المستخدمة في أغراض تربية الأحياء المائية تتنوع في تركيبات الملح (< 25 جرام/لتر) الا انها تستخدم في الزراعة التكاملية، وعلى سبيل المثال، ري محاصيل الساليكورنيا سوية مع تربية الأحياء المكثفة للقاروص الأوروبي والكوفر ذهبي الرأس، مع إنتاج سنوي يبلغ 100 (مائة) طن لكل سنة للنوعين. ومعظم المزارع التجارية تقوم بشراء الزريعة السمكية من السوق المحلية، وخمسة مزارع فقط لديها مفرخاتها الخاصة. ان القضايا التي تؤثر على تطوير هذه المزارع الصحراوية المائية التجارية مرتبطة بجودة/كمية المياه؛ وزيادة في مياه التصريف؛ والمعروض من الاصصبيات؛ وجودة العلف؛ وأسعار العلف؛ وتكاليف الإنتاج؛ والنقص في الخبرة الفنية؛ وأمراض الأسماك البحرية وضعف التوافر الائتماني.

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

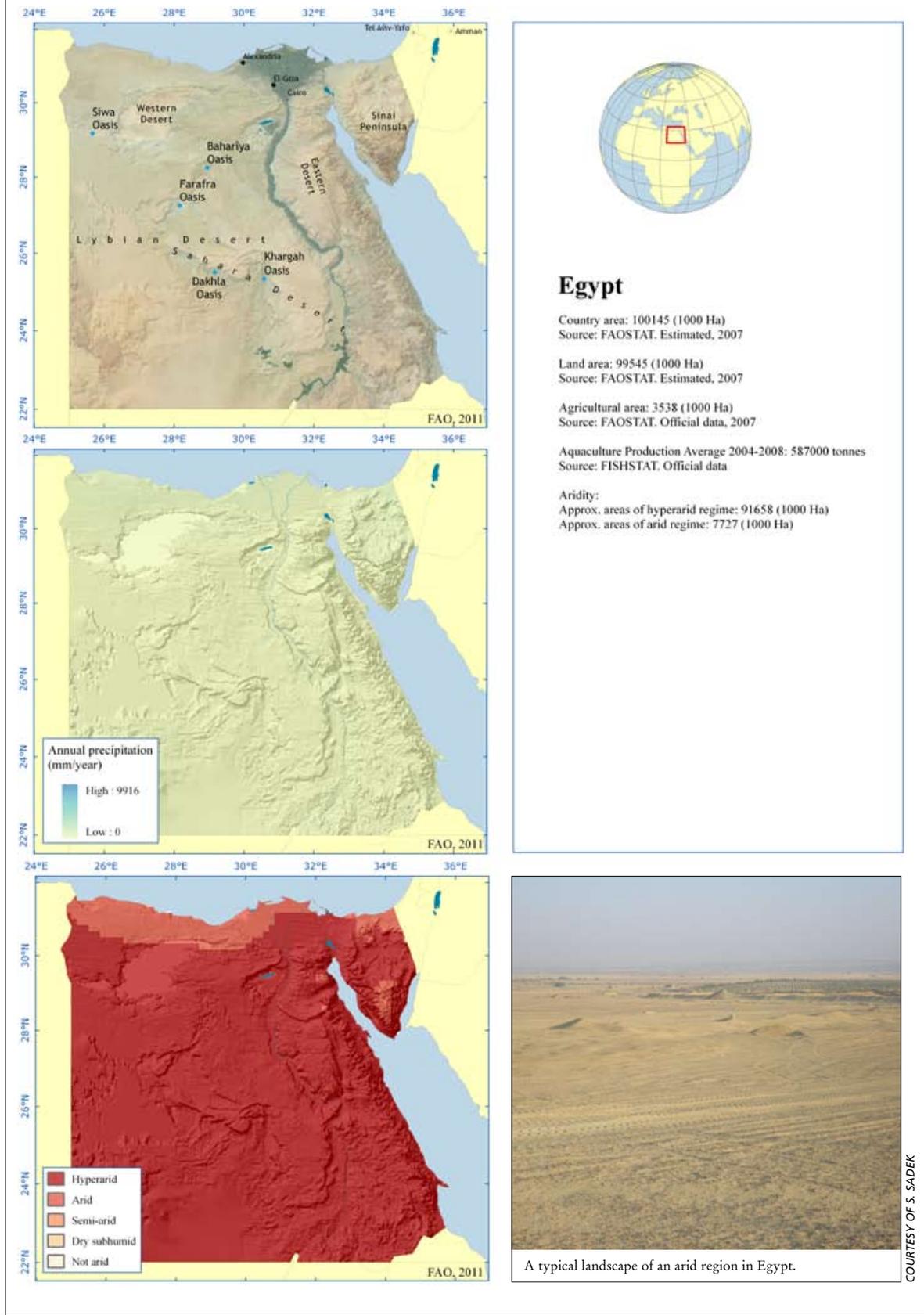
The Arab Republic of Egypt, a country almost entirely covered by desert, is located in the northeastern corner of Africa. It is bounded to the north by the Mediterranean Sea, from the east by Occupied Palestinian Territory and Israel, from the south by Sudan, and from the west by the Libyan Arab Jamahiriya. Ninety-nine percent of the entire population lives in just 5 percent of its land, all concentrated along the valley of the Nile and the northern delta. The Nile Delta, with its 230 km length and 360 km width, has a unique triangular shape covering an area of ~33 000 km², accounting for less than 4 percent of the total area. The desert is divided into three regions: the Western Desert (671 000 km²), the Eastern Desert (225 000 km²) and the Sinai Peninsula (61 000 km²). Together, they experience an annual rainfall of only 60–100 mm and are inhabited only by 2–3 percent of the Egyptian population. Egyptians depend primarily on the Nile as a source for drinking water and irrigation. The Western Desert extends from the Nile Valley in the east to the Libyan borders in the west, and from the Mediterranean in the north to Egypt's southern borders. The southwestern section includes five major oases: Farafra, Bahria, Dakhla, Khargah and Siwa (Figure 1).

Egypt has built the largest aquaculture industry in Africa, accounting for four out of every five fish farmed on the continent. Egyptian fish landings were estimated at 1 092 888 tonnes in 2009, of which 705 490 tonnes were produced from fish farms (about 65 percent of the total freshwater and marine fish production), providing a cheap source of protein for the country's 80 million people. Due to a shift to intensive rearing methods and to faster growing species such as monosex tilapia, aquaculture activity has increased more than threefold in the past ten years, having been only 226 000 tonnes in 1999 (GAFRD, 2010).

Two decades ago Nile tilapia (*O. niloticus*) and grey mullets (*Mugil cephalus* and *Liza ramada*) were the main species reared in extensive earthen ponds. Today seven finfish: tilapia, mullet, carp, North African catfish (*Clarias gariepinus*), bayad (*Bagrus* spp.), gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*), as well as four crustacean species: giant river prawn (*Macrobrachium rosenbergii*), green tiger prawn (*Penaeus semisulcatus*) and kuruma prawn (*P. japonicus*) and Indian white prawn (*Penaeus indicus*) are playing an important role in the national aquaculture production (Sadek, Osman and Mezayen, 2006) and (Sadek, 2010).

The production of aqua-agriculture integrated activities in the desert and arid zones of Egypt originates from earthen ponds (84.8 percent), cage culture (9.7 percent), common carp paddy fields (5.3 percent) and cement tanks rearing tilapia (0.2 percent), see Figure 2.

FIGURE 1
Maps of Egypt

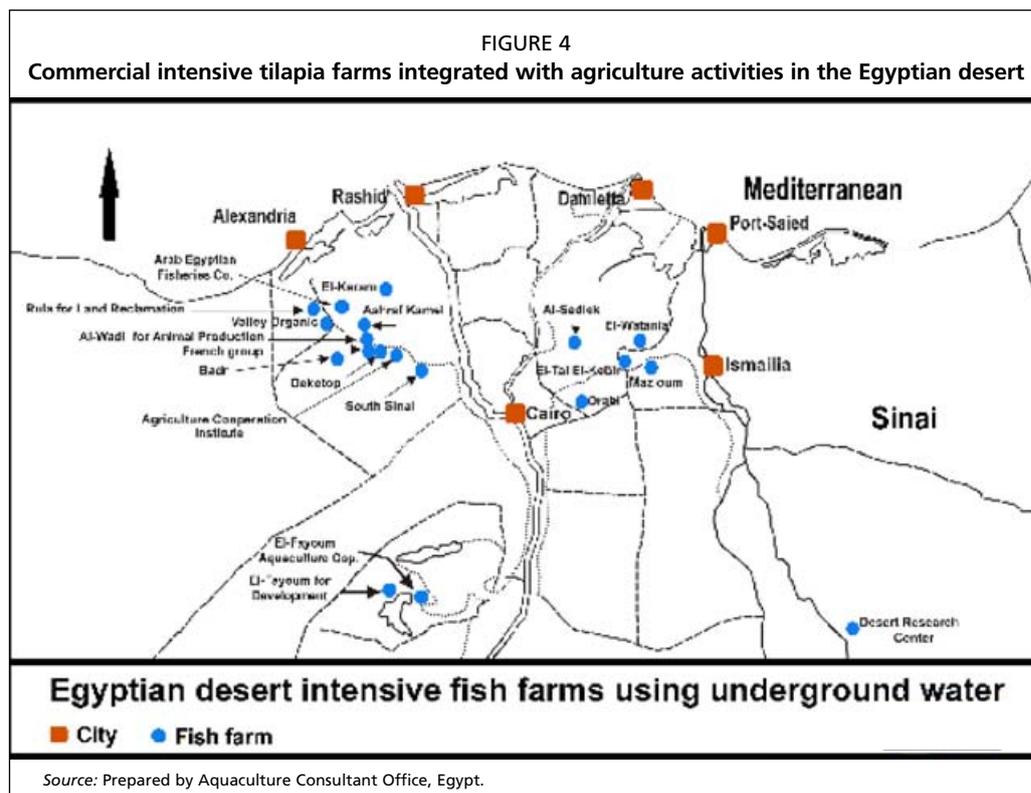
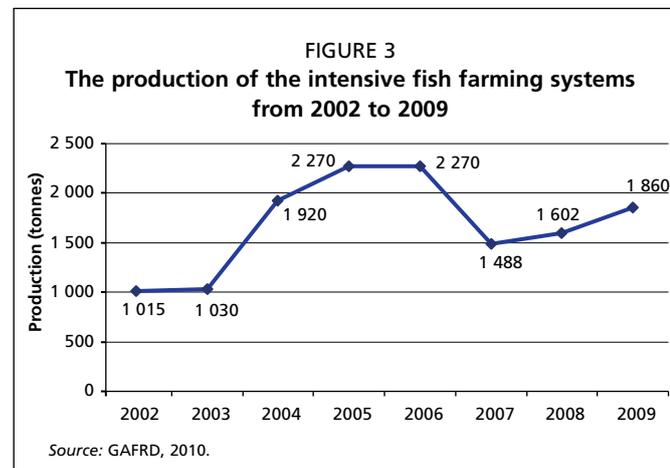
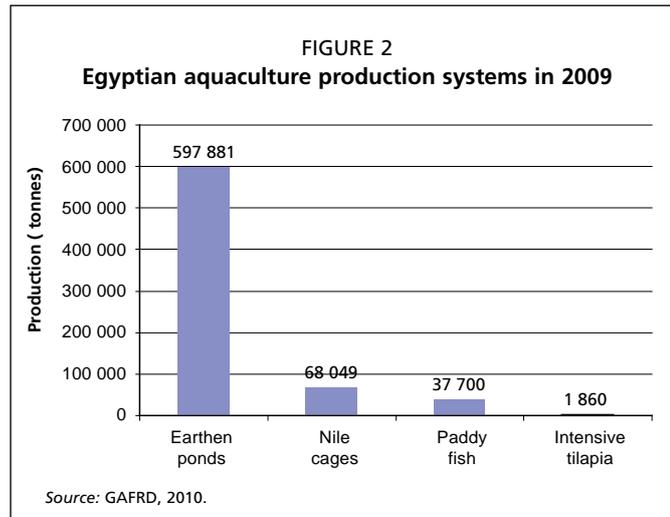


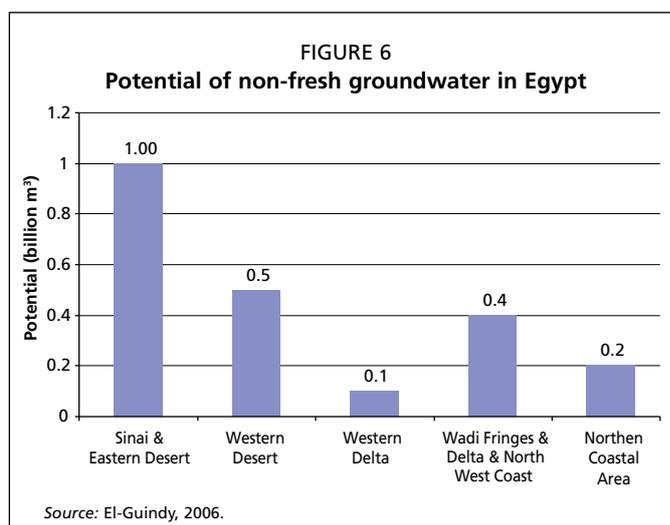
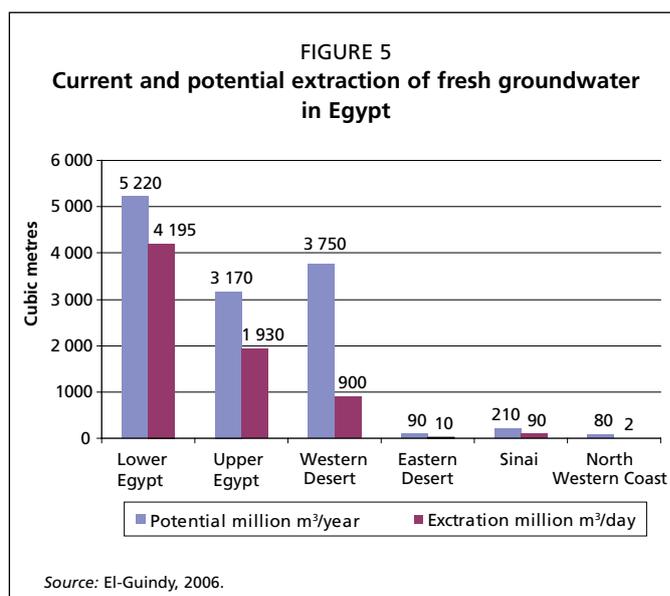
The General Authority for Fish Resources Development (GAFRD) has set a goal of 1.1 million tonnes of farmed fish annually by 2017, corresponding to about 75 percent of total fish production. Its two-pronged strategy aims to increase the productivity of aquaculture operations using underground water, while encouraging investment in marine aquaculture (Mohamed Fathy Osman, GAFRD's Chairman personal communication, 2010).

EGYPTIAN DESERT AQUACULTURE

The General Authority for Fish Resources Development in 2010 reported that intensive fish farming in the Egyptian desert had reached 1 860 tonnes in 2009 (Figure 3), but unofficial estimates are that production is about ten times greater than this.

Today, more than 100 intensive tilapia rural farms and 20 pioneer commercial fish farms are using the underground water from the Egyptian desert and its effluent water, which are very important sources for irrigation and animal production (Figure 4).





WATER SOURCE AND QUALITY

Underground water

The main water sources utilized for aquaculture purposes are underground water and agricultural drainage water (El-Guindy, 2006), which vary in salinity from 1–30 g/litre and temperature from 22 to 26 °C. This author raised concerns about the use of groundwater aquifer systems in Egypt, estimating a potential safe pumping yield of 1 744 million m³ per year (Figure 5).

El-Guindy (2006) also noted that brackish water and brine could play a significant role in the sustainable development of desert aquaculture (both environmentally and socially) by implementing:

- economically and technically feasible options, obtained through desalination of the underground brackish water; and
- cost-effective technological solutions related to underground brackish water extraction and exploitation for: human food (crops and fish); fodder (crops and aquatic products); fuel (wood and biofuel); existing plant species (halophytes); and new and more salt-tolerant agricultural products and other commodities (oils, lubricants, pharmaceuticals, fibres, etc.).

In addition, El-Guindy (2006) defined several key issues that should

be taken into consideration to achieve a sustainable intensive use of underground water (Figure 6). Firstly, there are gaps in the existing capacities for effectively using brackish water and no work on how these gaps should be filled. Secondly, the action plans considering underground brackish water resources for developmental initiatives (quantity, quality, potential uses and time perspective) need to be developed. Finally, a mechanism for interministerial coordination for brackish water utilization needs to be established.

Other water sources

Underground water with a salinity of 2–4 g/litre appears in open-cut sand mines and can be utilized to irrigate open-cut mine banks for the production of vegetables and flowers, along with extensive fish polyculture (tilapia, carps and mullets). In addition, one open-cut mine with a total water surface of 10 hectares is already developing its pit lake beside the agriculture and aquaculture activities for tourism, by constructing simple bungalows and adjusting its perimeter to facilitate fishing with lines (Figure 7).

A preliminary study (Anonymous, 2002) has shown that the brine effluent water from the desalination plant of the El-Gouna resort that is located 22 km north of Hurghada in the Red Sea Governorate is suitable for growing hybrid red tilapia,

grey mullet, gilthead seabream and European seabass. Water is supplied from three different sources: effluent brackish water (salinity 12 g/litre) from the desalination unit with a daily production of 3 000 m³; groundwater (salinity 60 g/litre) with a capacity of 60 m³/hr from different wells near the fish farm project and groundwater (4.5–6 g/litre) originating from the agriculture farm which belongs to the Orascom Company behind the mountains. The water requirements of the fish farm can be adjusted from the three above-mentioned water sources to meet a daily requirement of 3 000 m³. Salinity is adjusted for each species, at 12–20 g/litre for the hybrid red tilapia during the various rearing phases (nursing, pre-growing and growing tanks) and 4.5–6 g/litre for the broodstock maintenance and breeding tanks. Water salinity is adjusted to a maximum of 20 g/litre for marine finfish species. The effluent from the fish farm does not drain into the Red Sea; it is used to culture mangrove trees in artificial shallow lakes.

FIGURE 7
Fishing in sand mine water depression located in Ismailia Governorate, Egypt



COURTESY OF S. SADEK

CULTURED SPECIES

For desert aquaculture farms to be successful, many factors must be considered when selecting the species to be reared: low cost of feeding; ease of propagation; resistance to disease and tolerance to adverse climatic conditions; rapid growth and high survival. These factors facilitate management in relatively high population density culture systems such as those developed in the Egyptian desert areas.

Egyptian desert fish farms, both artisanal and commercial, produce various finfish including Nile tilapia, hybrid red tilapia, North African catfish, common carp, silver carp, grass carp, European seabass, gilthead seabream and ornamental species such as koi, fantail and molly. In the desert and arid lands of Egypt, Nile tilapia and North African catfish are the main cultured species when freshwater from underground reservoirs is used. However, European seabass and gilthead seabream are also reared in areas where most of the brackish and saline underground waters (>26 g/litre) are found (Sadek *et al.*, 2011).

CULTURE PRACTICES

Aquaculture integrated with agriculture

Integrated aquaculture and agriculture has expanded rapidly in the Egyptian desert since 2000. This is the most common farming system and a large number of desert land owners have established fish rearing facilities. Desert aquaculture began with growing fish in the tanks that are used as water reservoirs for irrigation. Success in this activity encouraged some farm owners to seek technical support towards integrating fish farming with their agriculture businesses. Recently, as the efficient and economical utilization of water sources becomes a necessity, aquaculture production systems are being developed. Integrated systems are particularly attractive to farmers, as water sources enriched with organic fish wastes from intensive aquaculture ponds serve as a fertilizer for land crops (such as corn and alpha-alpha), as well as providing water for breeding sheep and goats, thus, resulting in the production of three different crops from the same quantity of water.

The Qattara Depression and the Egyptian Sand Sea in the Libyan Desert, nearly 560 km from Cairo, are wellknown for their agriculture cultivation systems, as well as their medicinal and restorative properties. More than 1 500 water reservoirs with a total water volume of 1 million m³ are used for irrigation, particularly in the cultivation of dates, olives and basketry. A few farmers have cultivated tilapia in 400 m³ tanks and have succeeded in producing between 350 to 400 kg of tilapia per tank over a period of 6 to 7 months (Mustapha Said, personal communication, 2010).

Egyptians have learned how to design desert fish farming systems, manage the fish, market the final product and increase profitability on their farms by using water from the fish ponds to irrigate crops. Recently, the cities of Wadi Alnatroon (El-Beheira Governorate) and El-Salihia (Sharkia Governorate) have been selected for developing desert aquaculture farms. In total, there are currently, twenty commercial aquaculture desert farms in Egypt, located in seven different governorates, with a total surface area of approximately 893 hectares and a yearly production of approximately 13 000 tonnes. These commercial farms have a production capability up to 6 000 tonnes/year, while the remaining 7 000 tonnes are produced in ~100 rural farms. The species reared include various finfish species, of which the main two are Nile tilapia and North African catfish. Nowadays, most commercial farms are using FTS that provide irrigation for agriculture and the opportunity to produce three different crops (fish/plant/sheep). Only two commercial farms have upgraded their FTS system to RAS.

Most commercial desert aquaculture farms purchase their fish fry from private tilapia hatcheries, but five have their own hatchery with a production of 20 million fry/year. Based on a field survey, the development of these commercial farms is affected by various issues, 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 (Sadek *et al.*, 2011).

Management

Some Egyptian producers operate highly intensive desert fish farms (>10 kg/m³) without using an adequate aeration system. During the last decade, fish in several tanks in desert regions have experienced high mortality rates due to this cause. However, during the same period, other desert fish farms have invested in paddlewheel, air-injector and splasher aeration systems to provide sufficient dissolved oxygen. With the application of aeration (3 HP/350 m³ tank volume), these commercial tilapia farms have succeeded in reaching a biomass production ranging from 20 to 35 kg/m³ (Sadek *et al.*, 2008).

Algazzar, Osman and Sadek (2008) carried out experiments in a private intensive fish farm (Al-Wadi for Animal Production Company) in the Wadi-El-Natroun area (El-Beheira Governorate) on growth performance, feed utilization and pond productivity. Twelve circular 250 m³ concrete ponds were divided into four groups. Each was stocked with 8 500 fish with an initial body weight of 50 g. The experiment lasted 180 days. Underground water was used to exchange water at percentage rates of 5, 5, 10 and 20 on a daily basis for groups one, two, three and four, respectively. All experimental ponds were provided with paddlewheels (2 HP), except in group 2 where a 2 HP air injector operated in conjunction with the paddlewheels. The study also determined the feed conversion ratio (FCR). The results indicated that 20 percent water exchange with the sole use of paddlewheel aerators resulted in the highest pond productivity (4 250 kg/pond, equating to 17 kg/m³), the lowest FCR (1.3:1) and higher fish individual weight gain (510 g/fish). In conclusion, Group 4 showed the most cost-efficient production scenario and was the most suitable for desert aquaculture; the production costs have been estimated to USD0.73/kg. The results of the present field study concluded that a higher water exchange rate in intensive fish farms improved productivity in aerated concrete ponds.

Integrated aquaculture systems seem to be the most cost-efficient in Egypt for several reasons:

- They allow the farm to store water; an important factor, since ordering water from the irrigation district can take time.
- They aid irrigation in pressurized systems like drip or sprinkler systems.
- The fish wastes provided crops fertilization. Farmers have used fish water effluent for many crops, from vegetables and fruits to wheat.
- Productivity and income can be increased by using the same volume of water for two, or possibly even three crops (fish, plant and animal products).



SUCCESS STORIES

The following section describes two success stories involving tilapia, some data on production costs in Egyptian desert aquaculture, and the results of an experimental study with marine fish.

Tilapias possess an impressive range of characteristics that make them suitable for widespread culture in the desert and arid zones. They also display varying degrees of salt tolerance, a trait resulting in the expansion of their culture into brackish water and saline water. Several tilapia farms have already been integrated into Egyptian desert activities; more than 100 are intensive tilapia rural farms and 20 are pioneer commercial fish farms (Figure 8). The most successful pioneer desert farms are described below.

El-Keram – El-Keram, a trading investment company that is located between Cairo and Alexandria in the desert of Beheira, about 100 km northwest of Cairo, has applied a methodology

that involves nutrient sharing and waste recycling. Since 1990, El-Keram has demonstrated the efficient utilization of every drop of water (= water drop or droplet is a small column of liquid, bounded completely or almost completely by free surfaces) pumped from its desert wells (100 m³/hr). The El-Keram aquaculture systems have been carefully designed so that each output stage forms the input for the next stage, as summarized by El-Guindy (2006) in Figure 9 and Table 1. Adopting this strategy, the

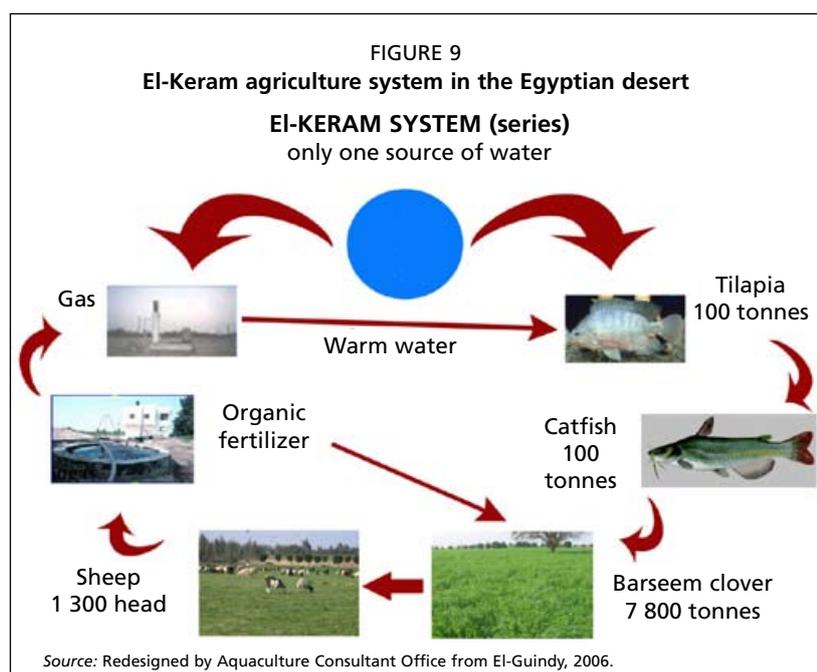
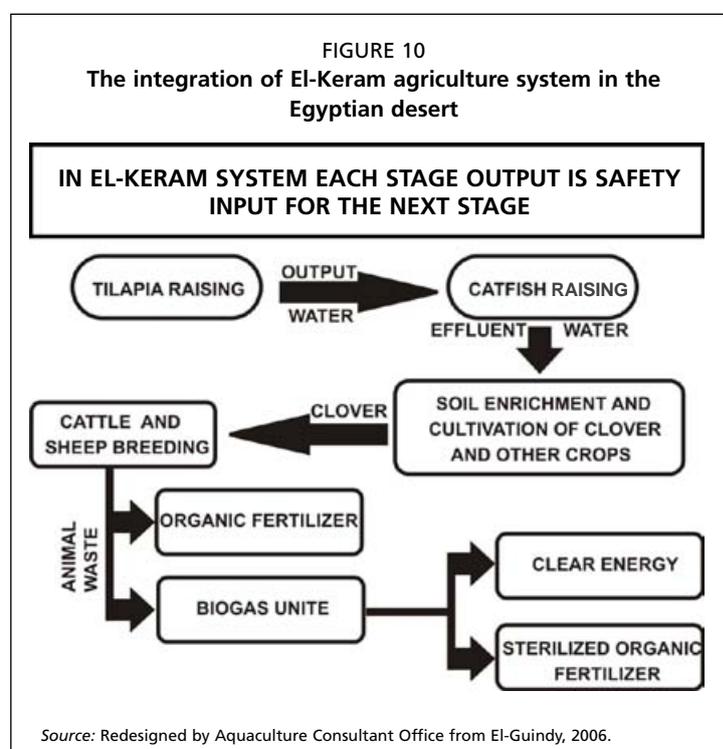


TABLE 1
Comparison between the non-integrated agriculture system and El-Keram agriculture integration project system (fish/clover/sheep/organic-fertilizer/biogas) in the Egyptian desert

Non-integrated agriculture production systems	Item	El-Keram integration systems
3	Water units	1
100 tonnes	Tilapia	100 tonnes
100 tonnes	Catfish	100 tonnes
4 500 tonnes	Clover	7 800 tonnes
1000	Sheep (head)	1 300
Nil	Warm water	Yes
Nil	Organic fertilizer	Yes
Variable	Waste	Nil
42	Irrigated land (hectares)	55
0%	Water conservation	67%

Source: Estimated by Aquaculture Consultant Office.



farm has been able to integrate the production of two different fish crop types each year, as well as arable, animal and biogas production. One hundred tonnes of tilapia can be produced alongside 100 tonnes of catfish annually. The effluent water from the fish farm is used to produce 7 800 tonnes/year of Egyptian clover, which provides fodder for 1 300 sheep/year. Ultimately, the manure of the livestock is used to produce biogas to heat water for the tilapia hatcheries (Figure 10).

Wataneya Fish Farm – Van der Heijden and Verdegem (2009) reported that the commercial tilapia desert farm El-Wataneya Fish Farm began in 1998 on 25 hectares of unused land as an integrated farm producing tilapia, chicken, vegetables (cucumbers, tomatoes, bananas, wheat, peppers, mangos, etc.) and flowers, mainly gladiolas. For crop production, freshwater is used from the Ismailia Canal, which is connected to the Nile River, together with groundwater and fish farm effluent. The only difference between these three sources is that the groundwater is used entirely for fish culture. Water in the concrete fish basins 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. Even though water is already

available at a depth of 3 m, the farm pumps water from 70 m. All fry and nursery tanks are aerated with blowers, while grow-out tanks are equipped with 2 HP paddlewheels which maintain constant levels of oxygen. In terms of profitability, tilapia is on top of the list, followed by bananas, vegetables and flowers.

Tilapia, grass carp, common carp and silver carp are placed in the drainage ponds; this results in a yield of 2 000 kg/year without any supplementary feeding. The waste water flows from the drainage ponds to the sprinkler irrigation systems, which are maintained in good working condition by the labourers. Until two years ago, the El-Wataneya farm also raised ducks, although this activity was then terminated, as the demand for ducks is only seasonal (holidays, special events, etc.).

COSTS AND RETURNS OF INTENSIVE TILAPIA FARMS IN EGYPT

Under good management, Algazzar, Osman and Sadek (2008) have shown that the intensive culture of tilapia in Egyptian desert zones has a production cost of USD1.00/kg with two crops per year. Depreciation is taken on a straight line basis over

a 20-year period. Feed was the major cost (63 percent). The production costs were fish seed (9.0 percent), labour (8.7 percent), energy (7.4 percent), depreciation (5.9 percent), water consumption (5.1 percent) and animal health maintenance (0.9 percent). The net return for tilapia production at a harvesting density of 25 kg/m³ was USD1.6/kg. The net income kg/fish was USD0.6.

EUROPEAN SEABASS AND GILTHEAD SEABREAM: A GROWTH EXPERIMENT IN THE EGYPTIAN DESERT

A study was conducted to evaluate the rearing techniques practised for European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) at a private intensive desert fish farm (Rula Land Reclamation Company, Wadi Group) in the Wadi-El-Natroun area (El-Beheira Governorate); this examined growth, water consumption, feed utilization and tank productivity (kg/tank and kg/m³ of water). Fourteen D-ended concrete raceways and circulation tanks with various water volumes (100, 180 and 340 m³) were used for the three rearing phases (nursery, pre-growing and growing under a flow through system) as shown in Figures 11, 12, 13 and 14. Tanks from each phase were stocked with 2.5, 5 and 10 kg/m³ with an initial body weight of 0.15 to 0.20, 38 to 51 and 200 to 270 g/fish, respectively (Sadek *et al.*, 2011).

The aim of these commercial experiments was to determine the general behaviour and effect of fish stocking density on fish growth, feeding and mortality during three critical periods of growing (5 months for nursery; 7 months for pre-growing and 16 months for growing). All commercial experiments were run at 26 °C with a salinity of 26 g/litre. The nursery used a RAS with a mechanical filter (97 m³/hr) connected to a biological tower (25 m³ media); the pre-growing and growing phase used a FTS.

FIGURE 11
European seabass growing facilities (total water volume 2 040 m³) covered by plastic in Rula land reclamation company, Wadi Group, El-Beheira Governorate, Egypt



COURTESY OF S. SADEK

FIGURE 12
European seabass nursery raceway tanks (100 m³) with air-diffusers in Rula land reclamation company, Wadi Group, El-Beheira Governorate, Egypt



COURTESY OF S. SADEK

FIGURE 13
D-ended shape European seabass raceway (185 m³) with 2 HP paddlewheel, in Rula land reclamation company, Wadi Group, El-Beheira Governorate, Egypt



COURTESY OF S. SADEK

FIGURE 14
European seabass circular tank (340 m³) with 2 HP paddlewheel, in Rula land reclamation company, Wadi Group, El-Beheira Governorate, Egypt



COURTESY OF S. SADEK

Stocking rates: European seabass

1. Two duplicate groups of fish were stocked in the nursery tanks at a density of 2.5 kg/m³ (mean initial wet body weight 0.15±0.09 g) and reared RAS for five months using two different sources of fry and 5–10 percent daily water exchange.
2. Two groups of fish were stocked in the pre-growing tanks at a density of 5 kg/m³ (mean initial body wet weight 37.8±1.6 g and 51.2±1.2 g). Each group was reared FTS with a 20–40 percent daily water exchange for seven months.
3. Two groups of fish were stocked in the growing tanks at a density of 10 kg/m³ (mean initial body wet weight 200±5.0 g [Group 1] and 270.8±5.1 g [Group 2]) and reared FTS with a 30–50 percent daily water exchange for 16 months.

Stocking rates: gilthead seabream

1. One group of fish was stocked at a density of 2.5 kg/m³ (mean initial body wet weight 0.11±0.08 g) and reared RAS for 4 months with a 5–10 percent daily water exchange.
2. One group of fish was stocked at a density of 10 kg/m³ (mean initial body wet weight 16±1.5 g) and reared FTS with 20–40 percent daily water exchange for 10 months.

Feed – Floating extruded pelleted feeds were used for all experiments. The diet used in the nursery phase had a

55 percent protein and 13 percent crude fat content, while the diet for the pre-growing and growing phases was 45 percent crude protein and 13 percent crude fat. The unit feed costs were USD1.68/kg for the high protein diet and USD1.51/kg for the low protein feed.

Water consumption – The average water consumption during three growing stages to produce one kilogram of European seabass or gilthead seabream was 26 m³ (Figure 15). The efficiency of the RAS in the nursery phase meant that water consumption was modest; consumption was higher in the two FTS phases. The positive results gained through the utilization of the RAS during the nursery phase should be applied for all the growing phases in order to minimize total water consumption.

Growth rate – European seabass gained weight throughout all growing phases and showed no significant differences in growth rates between the two different sources of fry. During the seven months of the nursery phase, fry grew to 31.5 g with an average specific growth rate (SGR) of 3.7 percent (Figure 16).

During the seven months of the pre-growing stage (September 2008 – February 2009), European seabass achieved a final body weight of 255 ± 10 g, with an SGR of 0.9 percent (Figure 17).

The European seabass growing stage took about 17 months, during which fish body weights reached final average weights of 770 ± 15 g (Group 1) and 900 ± 10 g (Group 2), respectively. This represented 9.50 and 14.50 kg/m³ for the two groups, respectively; the SGR were 0.25 to 0.3 percent for Groups 1 and 2, respectively (Figure 18).

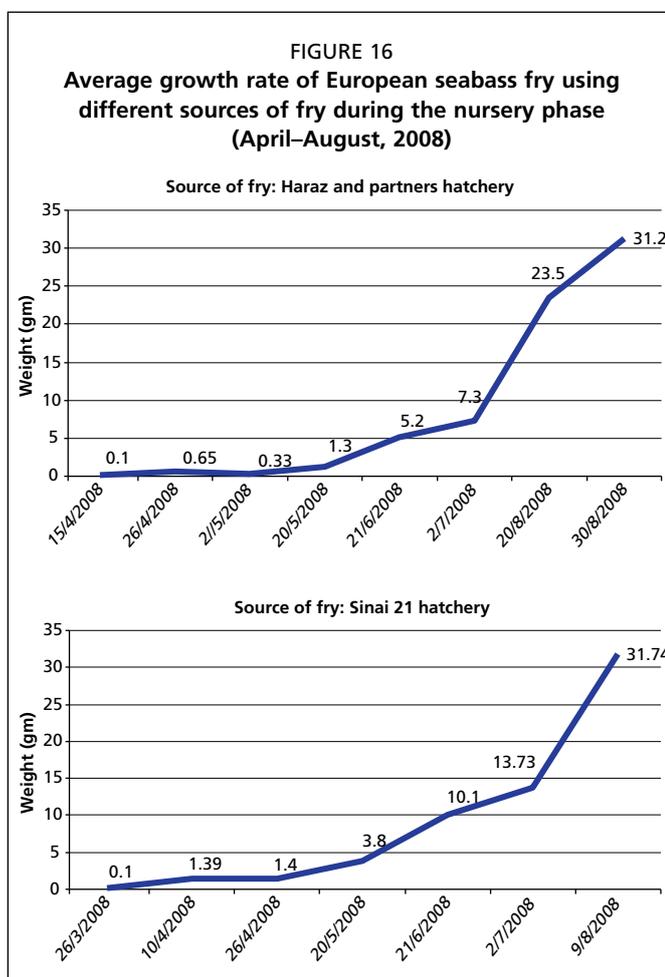
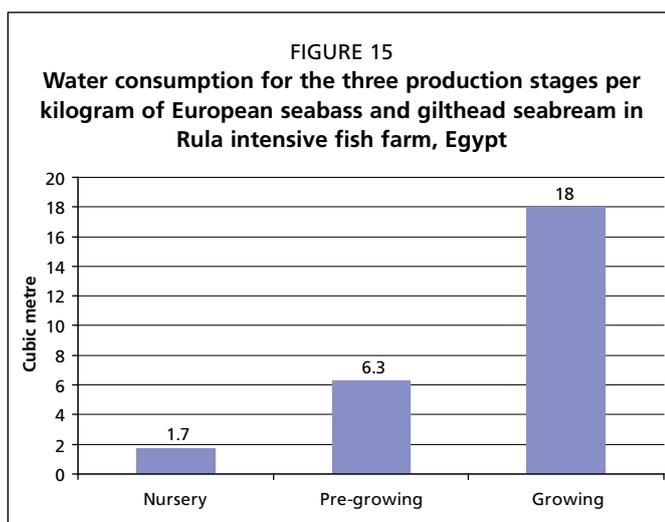
All the gilthead seabream gained weight during the two growing phases. During the four months of the nursery phase the fish grew to an average of 16.0 g. The observed average SGR during this period was 4.14 percent (Figure 19).

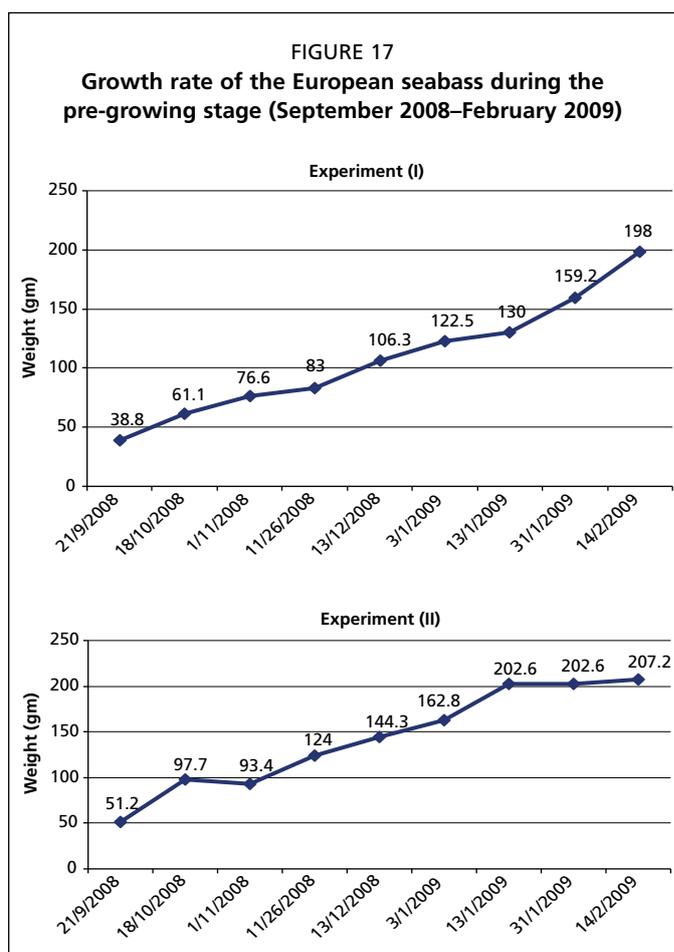
During the following 10 months of the growing stage the gilthead seabream reached a final average weight of 250.6 g. The observed SGR for the grow-out phase was lower than in the previous phase, at 0.91 percent (Figure 20).

Survival rate – High mortalities were observed in the European seabass experiment during the first phase, compared to the later phases. The mortalities were expected, as the fish matured over time. Figure 21 illustrates the values reported for the initial and final population for each phase, together with their survival rates.

The survival rate of gilthead seabream was estimated at 23.5 percent during the nursery phase and 99 percent for the growing phase (Figure 22). The reason for the high mortality during the nursery phase was contamination with the dinoflagellate *Oodinium* (*Amyloodinium ocellatum*), a saltwater

itch which usually attacks the gills and reaches densities of 30 parasites per microscopic field (magnification x 20). *Oodinium* outbreaks can occur rapidly in short periods of time and, if not diagnosed and treated immediately, the disease reaches overwhelming levels – enough to cripple the entire fish population. A treatment using 2 ppm commercial copper sulphate for a period of 14 days was adopted in an attempt to eradicate the infestation. Although mortalities occurred as a consequence of the dinoflagellate outbreak, some results were obtained from this study.





Feed conversion ratio – The feed conversion ratio (FCR) for the three separate phases of European seabass rearing (nursery, pre-growing, and growing) was calculated to be 1.1:1, 1.3:1, and 3.3:1, respectively. The overall FCR during the total 29-month period (nursery through growing phase) was calculated to be 1.9:1. Figure 23 illustrates that an ideal FCR was achieved during the first two phases of the production cycle, but FCR greatly increased in the last phase.

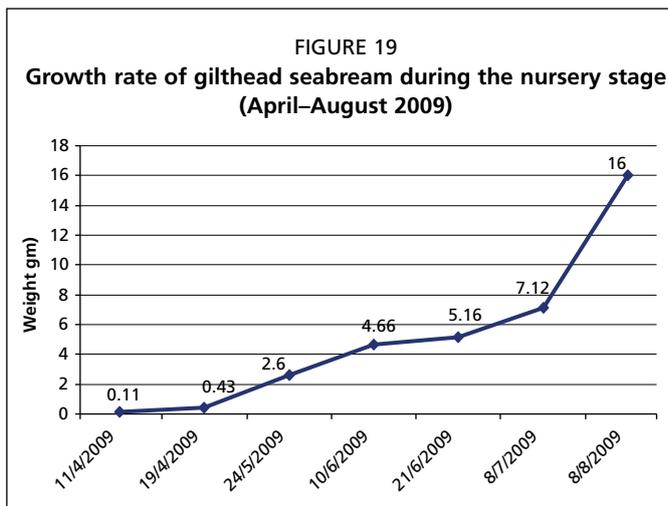
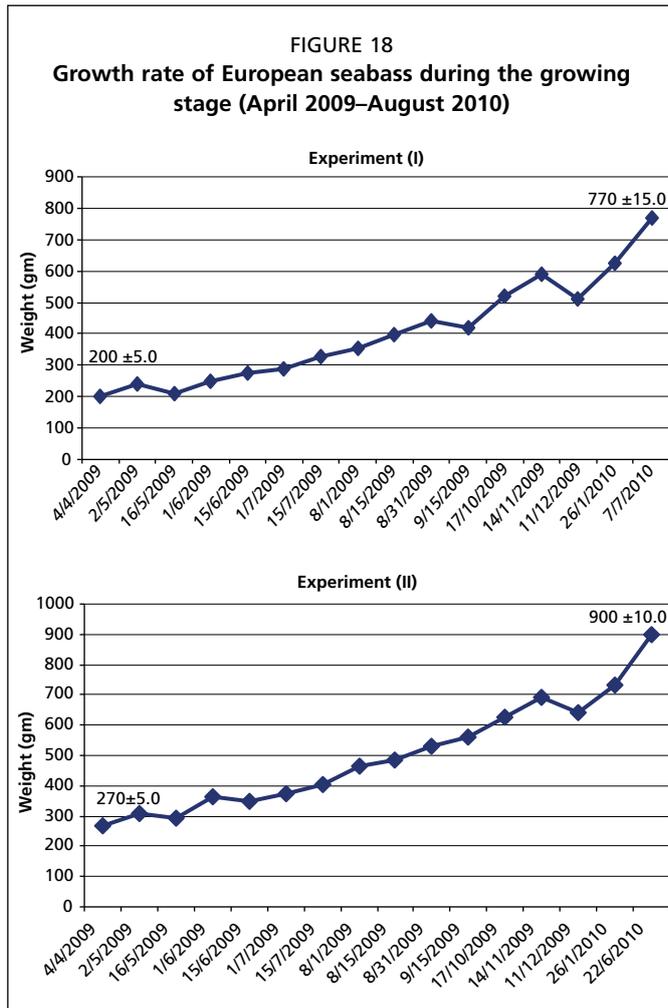
The FCR of gilthead seabream during the two growing phases were calculated to be 1.75:1 and 1.85:1 respectively (Figure 24). The overall FCR was 1.84:1, during the whole 14-month period. These results indicate that FCR for the gilthead was good throughout both phases.

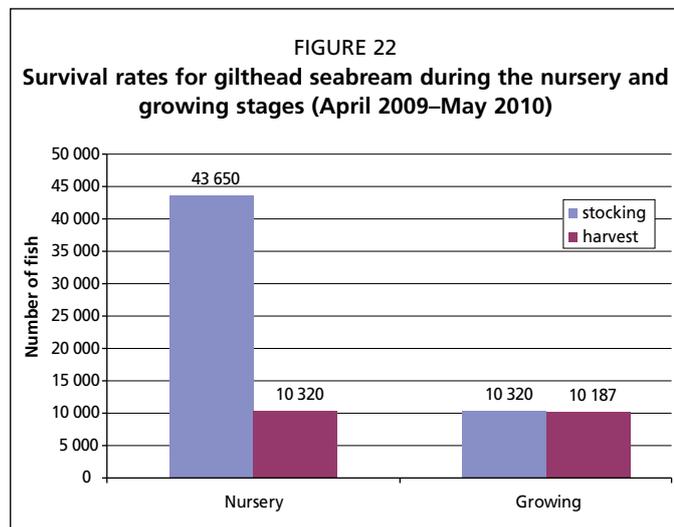
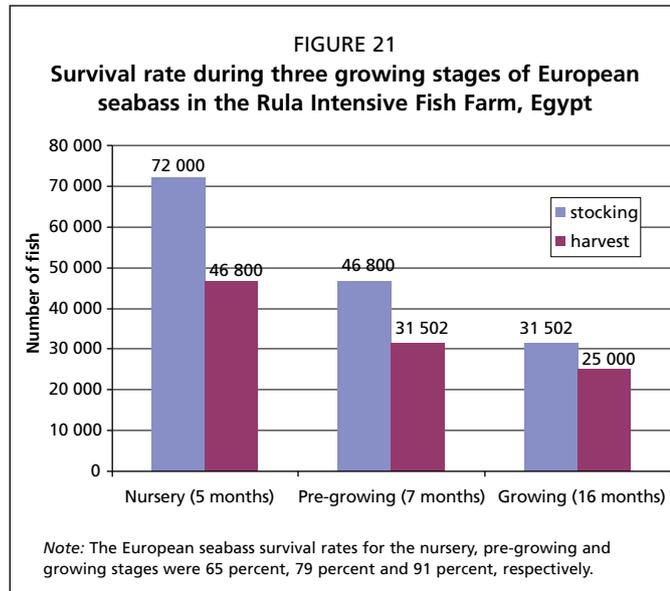
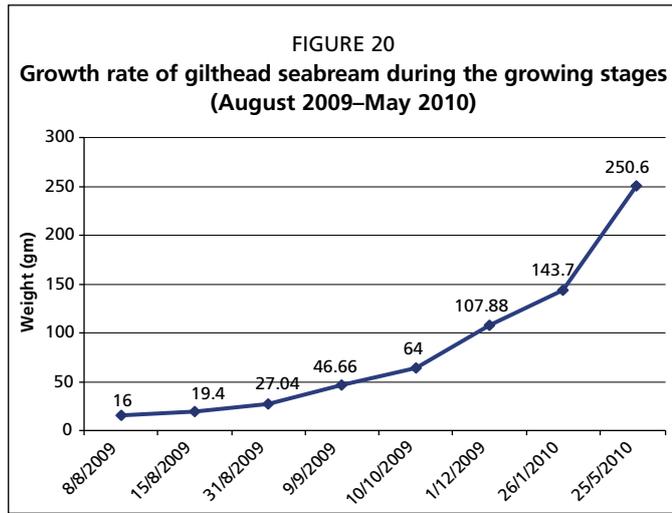
Harvest – Approximately 50 percent of the European seabass harvested weighed 700–800 g, while 25 percent were 400–600 g and 15 percent 200–300 g. The remaining 10 percent weighed 1 kg, which suits an existing niche market.

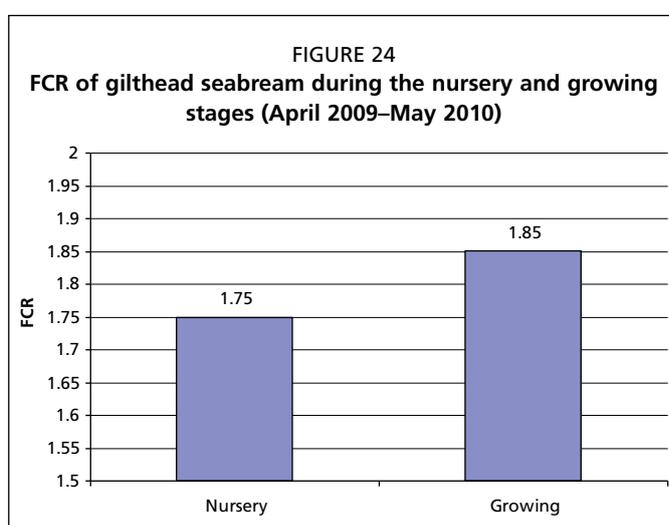
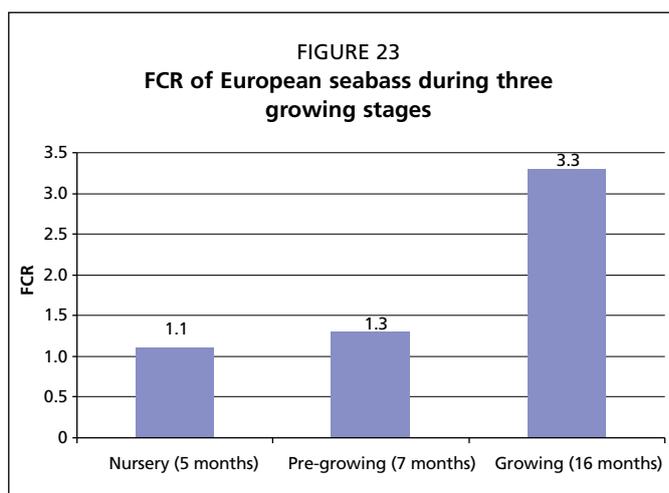
Around 66 percent of the gilthead seabream harvested weighed 200–300 g, while 19 percent weighed >300 g, and 15 percent weighed <200 g.

Production costs – The total production costs for the European seabass over the 29-month period were calculated to be USD6.20. Depreciation was taken on a straight line basis, over a period of 15 years. The total production cost break shows feed to be the highest at 40 percent. The other costs consisted of water consumption (16 percent), fish seed (14.4 percent), depreciation (13.6 percent), labour (8 percent), energy (5.6 percent) and animal health maintenance (2.4 percent). The net return for European seabass production was USD3.5/kg and the cost-benefit ratio was 0.56.

The total production cost for gilthead seabream over the 14-month period was calculated to be USD4.20/kg. Depreciation is taken on a straight line basis, over a period of 15 years. Feed and fish seed both shared the same proportion of costs (40.0 percent each), followed by water consumption (5 percent), energy (5 percent), labour (4 percent), depreciation (3.6 percent), and animal health maintenance (2.4 percent). The net return for gilthead seabream production was USD5.5/kg and the cost-benefit ratio was 1.3.







WAY FORWARD

Desert aquaculture in Egypt is a potential alternative to other food production activities where opportunities for agriculture are limited. It may be useful to recall the triple “F” message: 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 suggestions are provided in order to assist in achieving durable arid aquaculture developments in Egypt:

- Carry out environmental, social and economic assessments on the potential use of fresh and brackish groundwater for desert-based production systems.
- Estimate the water requirements and salinity tolerance of common Egyptian crops (fish, crustaceans, cloves, animal production).
- Encourage the use of RAS in feasible desert aquaculture projects.
- Evaluate specific research projects that have studied the integration of aquaculture with crop irrigation and animal production.
- Conduct research to identify non-conventional crops that will tolerate the use of brackish water.
- Study the characteristics of water and effluent use in integrated aquaculture in other countries.
- 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 Bedouins in the Central Sinai Area may be beneficial).

- Examine the opportunities for aquaponics.
- Provide credit facilities for artisanal and commercial desert aquaculture.
- Develop regulations for water use through an interministerial task force.

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An overview on desert aquaculture in the United States of America

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Treece, G. 2011. An overview on desert aquaculture in the United States of America. In V. Crespi & A. Lovatelli, eds. *Aquaculture in desert and arid lands: development constraints and opportunities*. FAO Technical Workshop. 6–9 July 2010, Hermosillo, Mexico. FAO Fisheries and Aquaculture Proceedings No. 20. Rome, FAO. 2011. pp. 159–185.

SUMMARY

This document provides a summary of aquaculture production and trends in the desert and arid regions (receiving <250 mm annual rainfall) in the United States of America. These areas are mainly located in the western states of Arizona, California, Idaho, New Mexico, Nevada and Texas and, to a smaller extent, in the states of Colorado, Oregon, Utah and Wyoming (Figure 1). Arizona, California, Idaho, New Mexico, Nevada and Texas had an aquaculture production of 22 700 tonnes in 2007 (USDA, 2009), valued at USD169 million. The production of the whole country, from 6 409 aquaculture farms, was 406 802 tonnes worth USD1.4 billion. These six states were, therefore, responsible for about 5.6 percent of total United States of America aquaculture production in 2007 and 12 percent of its value. However, the portion originating from the desert areas of those states is smaller. There are currently approximately 40 aquaculture farms located in the desert regions of the United States of America, producing about one percent of total annual national production, or about 4 000 tonnes per year. Most of the freshwater aquaculture production in the southern states near the Gulf of Mexico (Mississippi, Alabama, Louisiana, Texas and Arkansas) consists of channel catfish (*Ictalurus punctatus*). All of the desert and arid aquaculture facilities are located inland and use both freshwater and brackish water to produce a variety of species such as striped bass (*Morone saxatilis*), hybrid striped bass (*Morone chrysops* × *M. saxatilis*), a number of species of tilapia, the marine shrimp (*Litopenaeus vannamei*), channel catfish, grass carp (*Ctenopharyngodon idellus*) and algae (both *Spirulina* and other algae for biofuels and fat extracts). Commercial scale production of tilapia (mainly Nile tilapia, *Oreochromis niloticus*) has taken place in the desert regions of Arizona's Gila Bend, New Mexico and California's Imperial Valley, and has expanded at about the same rate as the other sections of finfish aquaculture in the United States of America. Tilapia production from one farm in Arizona has consistently been around 454 tonnes per year. Farms in Arizona, California and New Mexico contribute to a relatively large proportion of the tilapia produced in desert and arid regions. This document also provides a summary of constraints affecting the development of aquaculture in the desert and arid lands of the United States of America, including low farm-gate prices, competitive markets, high and increasing feed and other operating costs, as well as water quality problems with trace metal imbalances and toxic algal problems. There are four main desert regions in

the United States of America. Three of these deserts, the Chihuahuan, the Sonoran and the Mojave, are called “hot deserts” because of their high temperatures during the long summer and because the evolutionary affinities of their plant life are largely similar to the subtropical plant communities to the south. The fourth desert, the Great Basin Desert, is called a “cold desert” because it is generally cooler and its dominant plant life is not subtropical in origin. Chihuahuan Desert: a small area in southeastern New Mexico and extreme western Texas, extending south into a vast area of Mexico. Great Basin Desert: the northern three-quarters of Nevada, western and southern Utah, to the southern third of Idaho and the southeastern corner of Oregon. It also includes small portions of western Colorado and southwestern Wyoming and is bordered on the south by the Mojave and Sonoran Deserts. Mojave Desert: a portion of southern Nevada, extreme southwestern Utah and of eastern California, north of the Sonoran Desert. Sonoran Desert: a relatively small region of extreme south-central California and most of the southern half of Arizona, east to almost the New Mexico line.

RÉSUMÉ

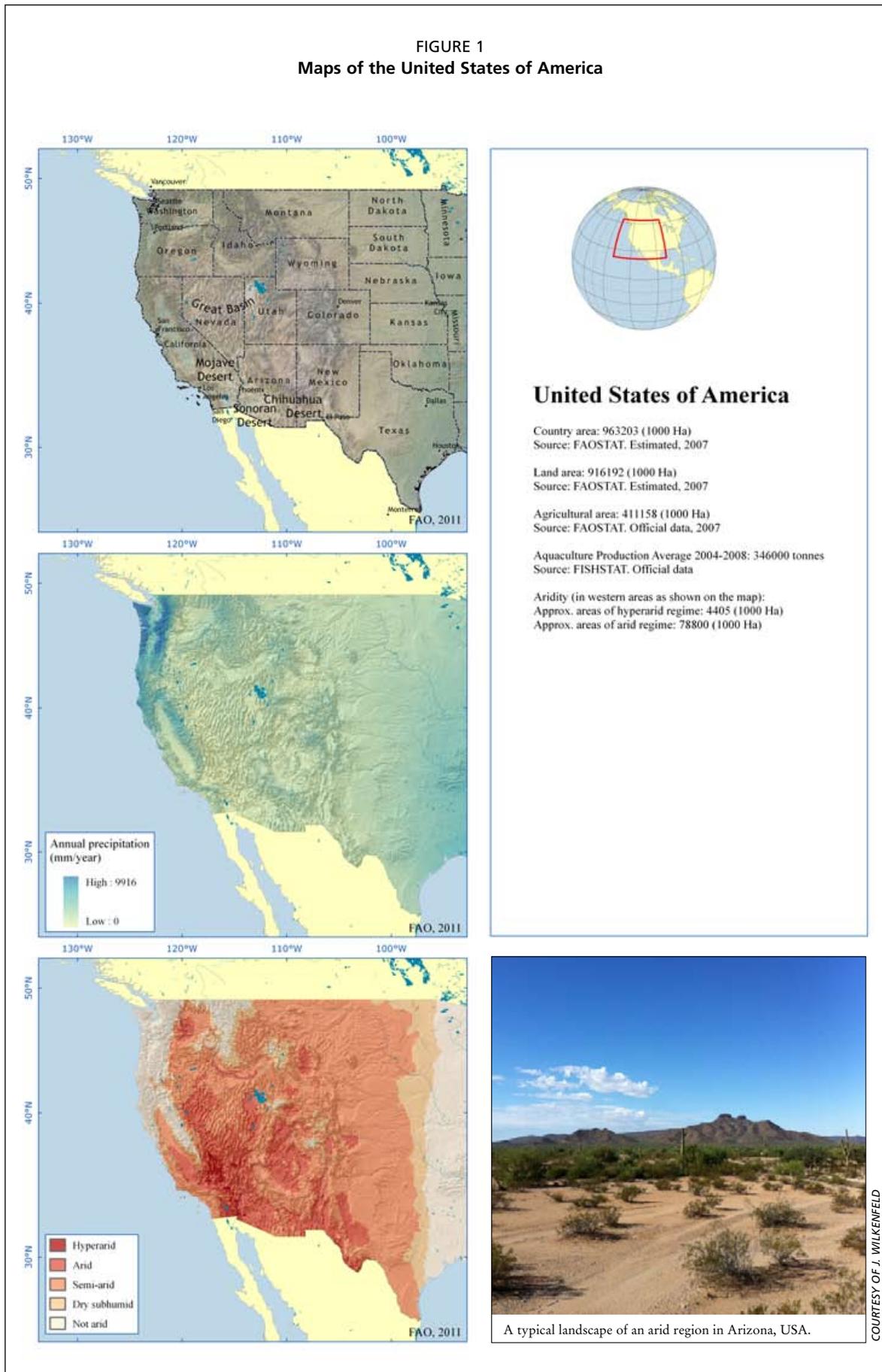
Ce document fournit un résumé de la production aquacole et des tendances de ce secteur dans les régions désertiques et arides des États-Unis d'Amérique (dont les précipitations annuelles sont inférieures à 250 mm). Ces régions se trouvent principalement dans six États de l'ouest et du sud du pays : l'Arizona, la Californie, l'Idaho, le Nouveau-Mexique, le Nevada et le Texas. Elles couvrent aussi, dans une moindre mesure, les États du Colorado, de l'Oregon, de l'Utah et du Wyoming (Figure 1). La production aquacole des premiers s'élevait à 22 700 tonnes en 2007 (USDA, 2009), pour une valeur de 169 millions d'USD. Celle de l'ensemble des 6 409 exploitations aquacoles des États-Unis d'Amérique atteignait alors 406 802 tonnes, évaluées à 1,4 milliards d'USD. Ces six États représentaient par conséquent en 2007 environ 5,6 pour cent de la production aquacole totale des États-Unis d'Amérique et 12 pour cent de sa valeur. La part de cette production provenant des régions désertiques est cependant plus petite. À l'heure actuelle, plus ou moins 40 exploitations aquacoles se trouvent dans des zones désertiques aux États-Unis d'Amérique. Elles produisent environ 1 pour cent de la production aquacole annuelle totale du pays, c'est-à-dire environ 4 000 tonnes. Dans les États du sud proches du Golfe du Mexique (Mississippi, Alabama, Louisiane, Texas et Arkansas), le poisson-chat ou barbe d'Amérique (*Ictalurus punctatus*) est la principale espèce élevée en eau douce. Toutes les structures aquacoles des zones désertiques et arides se trouvent à l'intérieur des terres et utilisent de l'eau douce ou saumâtre pour produire des bars d'Amérique (*Morone saxatilis*), des bars d'Amérique hybride (*Morone chrysops* × *M. saxatilis*), plusieurs espèces de tilapias, des crevettes marines (*Litopenaeus vannamei*), des barbes d'Amérique, des carpes herbivores (*Ctenopharyngodon idellus*) et plusieurs algues (les deux *Spirulina* et d'autres types d'algues pour les biocarburants et les extraits de matières grasses). La production de tilapias à une échelle commerciale (principalement de tilapia du Nil, *Oreochromis niloticus*) a tout d'abord été lancée dans les zones désertiques de la région de Gila Bend en Arizona, du Nouveau-Mexique et de la vallée impériale en Californie, pour ensuite se développer plus ou moins au même rythme que les autres formes de pisciculture du pays. En Arizona, la production d'une exploitation s'est maintenue à environ 454 tonnes par an. Les exploitations situées en Arizona, en Californie et au Nouveau-Mexique contribuent pour une bonne part à la production de tilapias réalisée dans les zones désertiques et arides. Ce document propose aussi un résumé des obstacles qui nuisent au développement de l'aquaculture dans les régions désertiques et arides des États-Unis d'Amérique, notamment les prix bas à la sortie de l'exploitation, les marchés concurrentiels, le coût élevé et croissant de l'alimentation et des autres charges d'exploitation ou encore la qualité de l'eau, avec des traces de métaux lourds ou la présence d'algues toxiques. Les États-Unis d'Amérique

comptent quatre grandes régions désertiques. Trois d'entre elles sont des « déserts chauds » : le Chihuahua, le Sonora et le Mojave. Les températures y sont élevées au cours des longs étés et les végétaux y sont d'un type très similaire à celui des communautés de plantes subtropicales. Le quatrième désert, le désert du Grand Bassin, est quant à lui qualifié de « désert froid ». Les températures y sont généralement plus froides et la vie végétale n'y est pas d'origine subtropicale. Le désert de Chihuahua couvre une partie du sud-est du Nouveau-Mexique, l'extrême ouest du Texas et s'étend plus au sud sur une vaste portion du territoire mexicain. Le désert du Grand Bassin couvre les trois-quarts du nord du Nevada, l'ouest et le sud de l'Utah, le tiers sud de l'Idaho et l'extrême sud-est de l'Oregon. Il couvre aussi de petites portions de l'ouest du Colorado et du sud-ouest du Wyoming. Il est bordé au sud par les déserts de Mojave et de Sonora. Le désert de Mojave couvre une partie du sud du Nevada, l'extrême sud-ouest de l'Utah et l'est de la Californie, au nord du désert de Sonora. Ce dernier, relativement petit, couvre l'extrême sud-est de la Californie, la plus grande partie de la moitié sud de l'Arizona et s'étend plus au sud sur une bonne part de la façade est du Mexique.

ملخص

توفر هذه الوثيقة ملخصاً حول إنتاج تربية الأحياء المائية واتجاهاتها في المناطق الصحراوية والجافة (التي تستقبل > 250 ملم كمعدل سنوي لسقوط الأمطار) في الولايات المتحدة الأمريكية. وتقع هذه المناطق بشكل أساسي في الولايات الغربية أريزونا، وكاليفورنيا، وايدهو، ونيو مكسيكو، ونييفادا وتكساس والى مدى أقل في ولايات كولارادو، وأوريجون، ويوتا و ايومنغ. ان ولايات اريزونا، وكاليفورنيا، وايدهو، ونيو مكسيكو، ونييفادا وتكساس كان لديها إنتاج تربية الأحياء مائية وصل الى 700 22 طن في عام 2007 (USDA, 200) بقيمة وصلت الى 169 مليون دولار أمريكي. والإنتاج الكلي لتربية الأحياء المائية في البلد من 6 409 مزرعة كان 406 802 طن بقيمة 1.4 مليار دولار أمريكي. وبالتالي فان هذه الولايات الست كانت مسؤولة عن 5.6 في المائة من إنتاج تربية الأحياء المائية في الولايات المتحدة الأمريكية في عام 2007 و 12 في المائة من قيمة هذا الإنتاج. ومع ذلك، فان نصيب المناطق الصحراوية من إنتاج هذه الولايات يعتبر صغيراً. وحالياً، هناك تقريباً اربعون مزرعة لتربية الأحياء المائية في المناطق الصحراوية في الولايات المتحدة الأمريكية، وتنتج حوالي 1 في المائة من الإنتاج الكلي السنوي للولايات المتحدة الأمريكية، او ما يعادل 4 000 طن في السنة. ومعظم إنتاج تربية الأحياء المائية في المياه العذبة في الولايات الغربية بالقرب من خليج المكسيك (المسيبي، والاباما، ولويزيانا، وتكساس واركنساس) يتألف من اسماك قرموط القنوات (*Ictalurus punctatus*). وجميع تسهيلات تربية الأحياء المائية في الصحراء والأراضي الجافة تقع في الأراضي الداخلية وتستخدم كل من المياه العذبة والمياه شبه المالحة لإنتاج تشكيلات متنوعة من الأنواع السمكية مثل القاروص المقطع (*Morone saxatilis*)، والقاروص المخطط الهجين (*Morone chrysops x M. saxatilis*)، عدد من أنواع البلطي، والربيان البحري (*Litopenaeus vannamei*) واسماك قرموت القنوات، والكارب العشبي او الشبوط العشبي (*Ctenopharyngodon idellus*) والطحالب (كل من سيربولينا و الطحالب الأخرى للوقود الحيوي ومستخلصات الدهون). وقد حدث إنتاج تجاري للبلطي (وبشكل أساسي البلطي النيلي، *Oreochromis niloticus*) في المناطق الصحراوية من جيبلا بيند في اريزونا، ونيو مكسيكو والوادي الإمبراطوري في كاليفورنيا، وقد توسع بنفس معدل توسع الأقسام الأخرى في تربية الأحياء المائية للأسماك الزعفرانية في الولايات المتحدة الأمريكية. ان إنتاج البلطي من مزرعة واحدة في اريزونا كان وبشكل ثابت عند مستوى 454 طن في السنة. ان المزارع في اريزونا، وكاليفورنيا ونيومكسيكو تساهم بجزء كبير نسبياً في إنتاج البلطي من المناطق الصحراوية والجافة. كما توفر هذه الوثيقة أيضاً ملخصاً للعوائق التي تواجه تنمية تربية الأحياء المائية في الأراضي الصحراوية والأراضي الجافة في الولايات المتحدة الأمريكية، وتتضمن المستويات المنخفضة لسعر باب المزرعة، والأسواق التنافسية، والتكاليف العالية والمتزايدة للغذاء والجوانب التشغيلية الأخرى، بالإضافة الى مشاكل جودة المياه المتعلقة بعدم التوازن في العناصر الدقيقة ومشاكل الطحالب السامة. هناك أربع مناطق صحراوية رئيسية في الولايات المتحدة الأمريكية. ثلاث من هذه المناطق الصحراوية، تشيهواهاوا، وسونوران وموهافي تسمى "الصحاري الحارة" بسبب درجات حرارتها العالية خلال فصل الصيف الطويل وبسبب الصلابة التطورية لنباتاتها الشبيهة كثيراً بالمجمعات النباتية الشبه استوائية في الجنوب. والصحراء الرابعة، صحراء الحوض الكبير تسمى "الصحراء الباردة" بسبب أنها بشكل عام باردة وحيات نباتاتها السائدة ليست شبه استوائية من حيث المنشأ. صحراء تشيهواهاوا: منطقة صغيرة في جنوب شرق نيومكسيكو وأقصى الغرب من تكساس، وتمتد جنوباً في منطقة واسعة من المكسيك. صحراء الحوض الكبير: ثلاثة ارباع

FIGURE 1
Maps of the United States of America



COURTESY OF J. WILKENFELD

شمال نيفادا، وغرب وجنوب يوتا، الى الجنوب الثالث من ايداهو والزاوية الجنوب شرقية من اريجون. كما انها تتضمن أجزاء صغيرة من غرب كولورادو وجنوب غرب ابومنج ويحدها من الجنوب صحاري موهافي وسونوران. صحراء موهافي: جزء من جنوب نيفادا، أقصى الجنوب الغربي من يوتا وشرق كاليفورنيا، وشمال صحراء سونوران. صحراء سونوران: منطقة صغيرة نسبيا في أقصى جنوب شرق كاليفورنيا ومعظم النصف الجنوبي من ولاية أريزونا، وتمتد جنوبا على الى تقريبا خط نيومكسيكو.

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

Marine shrimp production – Marine shrimp production from these arid regions started in Texas in 1972 on a trial basis, and commercial level production peaked in Arizona and Texas in 2002 and 2003 and then began to decline. There were approximately 11 marine shrimp farms in southern Arizona and desert west Texas during the period from 2000 to 2003. However, this has declined to only one desert shrimp farm in Texas and one in Arizona in 2011, and production in 2009 and 2010 was very low. At one point, there were 90

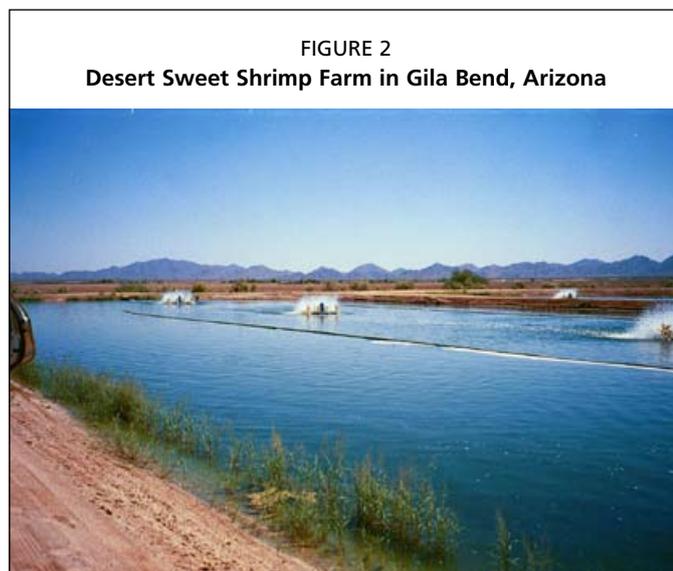
hectares of ponds in desert west Texas with seven producing commercial farms (Treece, 2002) and there were over 131 hectares of desert shrimp on four farms in Arizona (Figure 2). California also had one shrimp farm in the desert, which is now producing finfish.

Total United States of America whiteleg shrimp (*Litopenaeus vannamei*) aquaculture production has progressively fallen since 2003; this is true of the desert farms, for similar reasons (imports lowering prices and increasing feed and fuel costs).

Aquaculture production from the desert and arid lands of the United States of America has declined in Texas, Arizona and California, specifically in shrimp production in Texas and Arizona and hybrid striped bass in California. Kent Sea Farm in California was the largest producer of hybrid striped bass in the United States of America, but ceased producing fish so it could raise algae for biofuels. The low farm-gate prices of shrimp due to a tremendous increase in imported shrimp that began in 2004 contributed to the closing of all but two farms, one in Arizona and one in desert west Texas. Therefore, shrimp production from arid regions in the United States of America was only four tonnes in 2009. In 2008, the last farm in Arizona stocked 2.6 million post-larvae (PLs) of *L. vannamei* and harvested 25 tonnes. In 2009, it stocked 750 000 PLs and harvested 4 tonnes of eight-gram animals; the farm closed in 2010 but re-opened in 2011. The one remaining shrimp farm in the arid lands of Texas stocked 400 000 PLs in 1.6 hectares in 2008 and harvested 4 tonnes. That farm did not stock in 2009, but did so in 2010 and harvested 2.7 tonnes.

Finfish production in desert and arid ecosystems of Arizona – There are several types of finfish desert and arid ecosystems with varying degrees of integration: earth ponds, lined ponds and cement raceways (open and covered). All sustainable production systems are intensive culture systems:

- Finfish farms that practice monoculture and are built to stand alone.
- Mixed farming systems in which fish or shrimp are grown intensively and effluent is used on a terrestrial crop such as winter wheat, salt tolerant wheat, alfalfa, olive trees, *Salicornia* or other salt tolerant vegetation.



COURTESY OF G. TREECE

FIGURE 3
Flood irrigation from shrimp effluent to table olives in Arizona



COURTESY OF G. TREECE

FIGURE 4
Table olive nursery in Arizona



COURTESY OF G. TREECE

A specific example of shrimp and table olive integration is found in Arizona. The Woods Bros. Shrimp Farm (Desert Sweet Shrimp) is located in Gila, Arizona (Figures 3 and 4).

HUMAN RESOURCES

It is estimated using past data from the University of Arizona (K. Fitzsimmons, personal communication, 2010) that about 50 people are employed in commercial aquaculture facilities in Arizona; this figure does not include the aquaculture permitted schools and irrigation and drainage district that is government controlled. It is estimated that 11 commercial facilities operate in the desert and arid region of Arizona and 10 commercial operations employ about the same number of personnel in desert and arid regions of California. Idaho has 12 facilities using geothermal water, but it is not known how many personnel are employed. New Mexico, Nevada and Texas have few operations and employ only a small number of workers in desert regions.

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

Arizona – Some of the facilities in Arizona use geothermal wells to produce water ranging between 30–40 °C. Sitting over a large geothermal aquifer, Hyder Valley in southwest Arizona is a centre

for warmwater fish farming. Because of its close proximity to markets in Tucson, Phoenix and Southern California and its access to geothermal springs, Hyder Valley is considered a centre of aquaculture in the State. Other warmwater operations rely on pumped groundwater or surface water and are located mainly in the southern, warmer part of Arizona, at lower elevations. The irrigation water that flows in the canals in the desert regions of the State is especially suitable for warmwater fish farming. The desert climate warms the water above 22 °C. Warmwater fish include tilapia, catfish, hybrid striped bass and largemouth black bass (*Micropterus salmoides*). About 40 percent of the fish are produced to stock various facilities, with 60 percent being sold as food or table fish. Tilapia and catfish are generally sold for human consumption in the Tucson and Phoenix metropolitan areas. However, fish farmers also sell at the farm-gate or from the back of a truck. Much of the striped bass and largemouth black bass are sold for stocking. Fish farming in Arizona mainly consists of family operations and many people view this activity as fitting within the celebrated agricultural tradition of the independently owned and operated family farm (Table 1).

In some ways, Arizona is very favourable to aquaculture. For example, its climate is beneficial, especially in the southern part of the State with its abundance of sunny days, which are “growth days” for fish. Furthermore, fish do not have to be sheltered

TABLE 1
Arizona aquaculture production 1994–2009 (Tonnes/Thousand Dollars)

	1994	1995	1996	1997	1998	1999	2000	2001
Bass-striped largemouth	99	108	108	90	68	54	54	45
Catfish	\$610	\$660	\$660	\$500	\$400	\$420	\$420	\$400
Tilapia	172	181	195	204	181	181	185	190
Shrimp	\$380	\$410	\$430	\$450	\$440	\$440	\$492	\$525
Other	181	190	188	204	192	181	199	199
	\$440	\$462	\$450	\$562	\$531	\$500	\$550	\$550
	<1	<1	<1	2.7	84	98	76	146
	<1	<1	<1	\$30	\$935	\$1,085	\$840	\$1,296
	4.5	5.4	5.4	5.4	5.4	5.4	5.4	5.4
	\$300	\$302	\$302	\$300	\$300	\$300	\$300	\$300
TOTAL (tonnes)	457	485	497	506	530	519	519	585
(000 \$)	2 281	2 423	2 442	2 442	3 206	3 345	3 282	3 771

Arizona aquaculture production 1994–2009 (Tonnes/Thousand Dollars)

	2002	2003	2004	2005	2006	2007	2008	2009
Bass-striped largemouth	45	36	27	22	18	18	18	18
Catfish	\$400	\$320	\$240	\$200	\$180	\$180	\$180	\$180
Tilapia	199	181	181	158	158	158	158	158
Shrimp	\$550	\$500	\$500	\$500	\$550	\$550	\$550	\$550
Other	204	181	181	181	226	454	454	454
	\$562	\$500	\$600	\$700	\$800	\$2 000	\$2 000	\$2 000
	246	141	136	19	22	22	22.7	3.6
	\$2 176	\$1 300	\$1 200	\$147	\$150	\$150	\$155	\$25
	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
	\$300	\$300	\$300	\$300	\$300	\$300	\$300	\$300
TOTAL (tonnes)	699	544	530	385	429	657	658	639
(000 \$)	4 688	3 620	3 540	2 547	2 710	3 180	3 185	3 055

Source: Kevin Fitzsimmons, Univ., AZ and USDA, 2009.

against severe weather conditions. In other states with a less favourable climate, little or no growth occurs for two to four months out of the year and fish also need to be sheltered. Fish farming advocates even interpret Arizona's aridity, the very condition that might seem to disfavour aquaculture, as a factor to justify its practice. Water must be used wisely in the desert, and a wise policy is to use limited supplies more intensely and productively. Every drop of water must count and aquaculture represents a multiple and more productive use of water. The link between aquaculture and agriculture is a central characteristic of Arizona aquaculture. More than a convenient strategy, this arrangement is also necessary because Arizona does not have the large ponds that characterize aquaculture in other, more temperate parts of the country. Instead, much of Arizona's water flows through irrigation canals and ditches; these can also serve as fish farms. In general, water used to irrigate plants will support fish production. Thus, perhaps rather unexpectedly, Arizona has ample water that is suitably contained to support a fish farming industry. Furthermore, farmers already have various types of equipment that can also be used for aquaculture, e.g. tractors, back hoes, welding equipment, trucks and cold storage. It therefore, follows that the

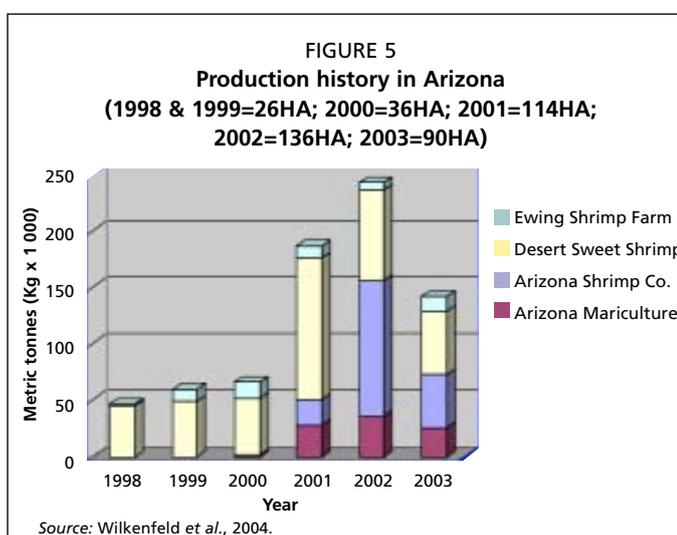


TABLE 2
Production results of two shrimp companies in Arizona (Desert Sweet Shrimp and Arizona Shrimp Company)

System performance		
Farm	Des. Sweet (Intensive)	AZ Shrimp (Extensive)
Total Area - Hectares	9.70	37.00
Number of Ponds	18	5
Mean Pond Size (ha)	0.5	7.4
Stocking Date	7/5	16/6
Most Harvests Finished	15/10	12/10
Mean Days of Culture	155	115
Stocking Density (No./m ²)	57	8
Stocking Weight (g)	0.10	0.10
Harvest Density (No./m ²)	32	5
Survival	56%	58%
Harvest Weight (g)	18.0	28.0
Weekly Growth (g)	0.81	1.70
Kg/ha Harvested	5 717	1 265
Total Harvest (kg)	55 455	46 818
Feed Conversion	1.80	2.00

Source: J. Wilkenfeld *et al.*, 2004.

TABLE 3
Financial performance of Desert Sweet Shrimp vs. Arizona Shrimp Company

Financial performance		
Farm	Des. Sweet (Intensive)	AZ Shrimp (Extensive)
Total Hectares	9.7	37.0
Total Harvest (kg)	55,455	46,818
Kg/ha Harvested	5,717	1,265
Harvest Weight (g)	18.0	28.0
Assume Tail Recovery	63%	63%
Fulton Fish Price (\$/kg)	\$7.04	\$8.80
Crop Value/ha	\$25 356	\$7 015
Total Crop Value	\$245 954	\$259 559
Production Costs/kg	\$6.73	\$3.74
Total Production Cost	\$373 212	\$175 099
Net Income/ha	-\$13 119	\$2 283
Total Net Income	-\$127 258	\$84 460

Source: J. Wilkenfeld *et al.*, 2004.

ceased operations in 2010, but began again in 2011), worked hard from 1998 onwards on a strategy to market shrimp under its own brand name at premium prices in Phoenix. Establishing a specialty niche is a long, difficult and expensive process. Assuming the mean wholesale price of USD14.08/kg, which is double the Fulton Seafood market price, and adding a USD2.20/kg production cost to cover the overhead of their significant marketing effort, Desert Sweet Shrimp would have barely broke even. It is amazing that the farm continued to operate under such economic conditions for so long, and diversification seems to have been the key. Had it not produced other crops along with the shrimp, the farm would have closed its aquaculture operations years ago. With funds running low, Desert Sweet Shrimp only stocked 2.83 hectares of shrimp

extensive agricultural industry in the State, with its reliance on irrigation, offers a significant advantage for aquaculture development.

Arizona's history in desert shrimp farm production from its inception to its decline (1998–2003) is shown in Figure 5. Until 2002, there had been annual increases, both in area and production. In 2002, the farmers expected production in 2003 to increase to 400 tonnes. What happened was quite different. Changes in the shrimp market and financial constraints caused a contraction in the area farmed and a reduction in stocking densities. Thus, production actually decreased by 100 tonnes from the previous year to 142 tonnes in 2003. Production levels in 2004 were expected to rise again to 250 tonnes, but because of the fall in shrimp prices in 2004, the farms never returned to their peak 2002 production.

The production results shown in Table 2 represent two Arizona desert shrimp farms (Desert Sweet Shrimp, which is an intensive farm, and Arizona Shrimp Company, which was extensive; J. Wilkenfeld *et al.*, 2004). Neither of these farms had any significant production problems that year. The key operating and performance parameters highlighted in green are typical of what one would expect from these two systems. The smaller intensive farm actually produced about 19 percent more shrimp volume than the larger extensive farm, but this is only part of the story, as described below.

Table 3 illustrates that, using the shrimp prices from Fulton Seafood Market, the crop value per hectare in the more intensive system is more than three times that of the extensive system. However, the estimated production costs (including processing) were about 80 percent greater in the intensive system.

If the farms had sold their production at the market price taken from Fulton Seafood Market, the intensive farm would have lost USD127 000, while the extensive farm would have cleared a profit of about USD85 000.

The intensive farm, Desert Sweet Shrimp (which

in 2009 and when its feed supply ran out it allowed the shrimp to feed on natural productivity for the rest of the production cycle. Only 3.6 tonnes of eight-gram shrimp were harvested in 2009, compared to 2008 when it was 22.7 tonnes from 17.29 hectares. Their production costs were USD4.40 to USD5.50 per kilogram of shrimp. Desert Sweet Shrimp even had its own shrimp retail stores and restaurants in the larger metropolitan areas to retail its product, but its operation was still having problems with sustainability. However, after reopening in 2011, the management believe that they can be successful this time.

California – The Imperial Valley of California is in the desert southwest of the United States of America. There are a number of producing farms there growing mainly catfish, tilapia, algae and triploid grass carp (Figure 6). A number of these farms are discussed below.

One of the oldest farms is Earthrise Nutritionals (113 E. Hooper Road, Calipatria, California 92233). The farm produces *Spirulina* algae for the health food industry and will be discussed in the paragraph “Success stories” of this review. The Imperial Catfish farm and hatchery is also discussed in the same paragraph. Another farm is SunEco Farm’s “Rock and Fish Ranch” (605 Beal Road, Niland, California 92257). This farm raises catfish for food fish and algae for extracts of oils, fats and biofuels.

In the unique area of the Imperial Valley era the Salton Sea, the Salton Trough and San Andreas fault system. Many geothermal wells are located in the Imperial Valley and ten geothermal power generation plants circle the Salton Sea, which is far below sea level (e.g. Calipatria is 56 meters below sea level). White plumes of steam can be seen rising from some of the older plants. The Colorado River, about 160 km to the east, is the major water source, and the irrigation district operates 2 253 km of canals, 1 700 km of pipelines and supplies 182 186 hectares of irrigated desert land, which is where a large part of the vegetables grown in the United States of America are produced. One geothermal power generation station in California is located next to a triploid grass carp hatchery operated by the Imperial Irrigation District in El Centro. The Irrigation District stocks grass carp into the irrigation canals to keep clear of vegetation; apparently this is very effective.

Aquaponics Earth (56925 Yucca Trail, Suite #303, Yucca Valley, California 92284; Tel. 760 2983755; E-mail: advisor@aquaponicsearth.com; Web site: www.aquaponicsearth.com/Aquaponics_Earth_Home.html) has recently started an aquaponics project in the lower desert of southern California near Palm Springs. This area was chosen because it is ideal for aquaponics even though it is in the severe climate of the Mojave Desert, where daytime temperatures can reach 65 °C in the summer and 4.5 °C in the winter. However, these arid desert weather conditions – low humidity coupled with high temperatures – combine to create ideal growing conditions for aquaponics systems.

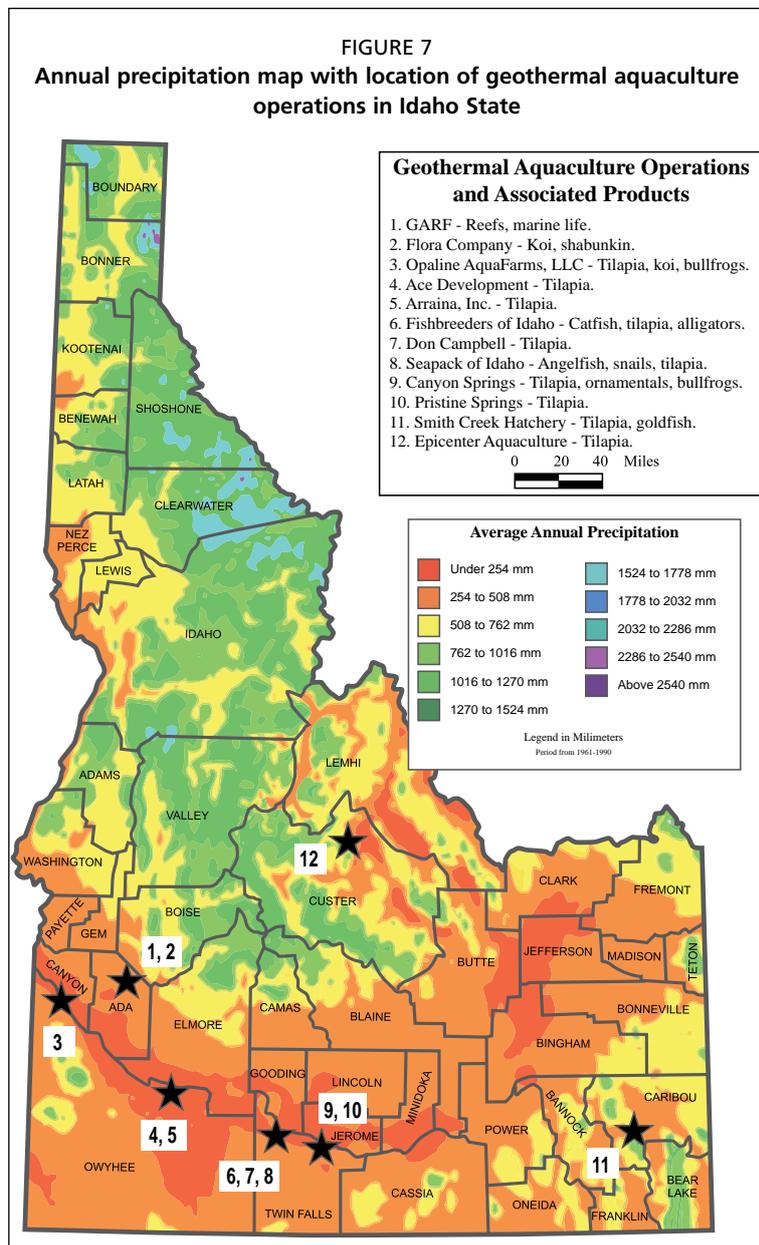
Kent Sea Tech (Mike Massingale) was in operation for more than twenty years as the largest producer of hybrid striped bass in the United States of America until it closed the fish part of its operation in late 2008. It has now switched its focus entirely to the production of algal biomass for biofuels and is still trying to raise funding.



Pacific Aquafarms (Bill Engler, 10468 Hot Mineral Spa Road, Niland, California 92557; Tel. 760 3541533; Fax. 760 3541068) has been in operation for twenty years. The owner attended the Texas Sea Grant Shrimp Farming course in 1987 and grew shrimp originally, but now primarily rears tilapia.

Blue Beyond Fisheries LLC (Mark Eglington, PO Box 399, Desert Hot Springs, California 92240; Tel. 760 2750762) rears channel catfish, giant river prawns (*Macrobrachium rosenbergii*), largemouth black bass, smallmouth bass (*Micropterus dolomieu*), striped bass, striped bass hybrids and Mozambique tilapia (*Oreochromis mossambicus*).

The California Aquaculture Association does not compile aquaculture production information, but at least some information can be found through the Department of Fish and Game in California (CFGC), where those operations that have aquaculture permits that agree to be listed are provided, together with their addresses and products on the Internet at www.dfg.ca.gov. Detailed aquaculture information in California is very hard to obtain. The CFGC states that the total number of freshwater aquaculture facilities in the state in 2010 was 192. It is estimated that the ex-farm value of aquaculture in the state is USD100 million per year.



Idaho – Geothermal aquaculture is big business in Idaho, where catfish, tilapia, ornamental fish, coral, aquatic plants and alligators are all being raised. People have used the natural hot water there since 1973 for aquaculture businesses and research (see Figure 7 with black stars showing the locations of 12 facilities). Some of these are in desert and arid lands and some on its borders.

Mr Leo Ray (Fish Processors, Inc. Hagerman) was the first person in Idaho to use geothermal water to raise aquatic life. Catfish, alligators and tilapia (the latter species is the most commonly raised aquaculture product in Idaho) are raised in 35 °C water. His alligators have multiple uses as food, to eliminate byproducts from his processing operations, and as hides for quality leather goods. Mr Ray raises tilapia in raceways using geothermal water and was the first producer to realize that there was a market for redbelly tilapia (*Tilapia zilli*) to clean aquatic vegetation from water impoundments. He developed production technology to supply large numbers of reproductive

age *T. zilli* for early spring stockings. Problems incurred in producing tilapia during the winter included timing, predation, grading and transportation. Mr. Ray also realized a second market potential for tilapia, namely for food.

By 2010, ten of the 12 Idaho geothermal aquaculture businesses were raising tilapia, but the industry has faced financial challenges from overseas producers. To overcome these challenges, Bob Williams ([Arraina Inc. and Ace Development](#)) modified his aquaculture operation in the Owyhee County desert in order to deliver live tilapia to Vancouver, British Columbia, Canada, where its Asian residents prefer

live seafood, and are willing to pay extra for it. Other Idaho aquaculture operations followed Mr Williams' lucrative approach to tilapia farming. Six Idaho businesses use geothermal water to raise ornamental aquaculture products: angelfish, goldfish and other ornamentals. In Ada County, the [Flora Company](#) raises koi (domesticated varieties of the common carp, *Cyprinus carpio*) and goldfish (*Carassius auratus*) in a cascading application that is downstream from their geothermal greenhouses. Also in Ada County, the [Geothermal Aquaculture Research Foundation](#) raises fish and reef animals and aquatic plants to stimulate interest in, appreciation for and understanding of marine life. It began 20 years ago as a wetlands project, the plant operation includes valuable aquatic species collected from around the world to enhance the study of algae control and the balance of nature. These plants thrive and reproduce rapidly due to the continued availability of geothermal water in the Boise warm springs water district.

New Mexico – [AmeriCulture Inc. Geothermal Aquaculture](#) (Damon Seawright, 25 Tilapia Trail, Animas, New Mexico 88020; Tel. 575 5482328; Web site: www.americulture.com) is among the largest domestic suppliers of tilapia fingerlings and has a capacity of four to seven million fingerlings annually. AmeriCulture raises a genetically improved Nile tilapia (*Oreochromis niloticus*) in tanks situated under a greenhouse roof to protect them from weather conditions, natural predators such as birds and from the introduction of pathogens. Great care is taken to optimize rearing conditions for disease-free tilapia, using strict protocols, standards, and regular inspections by an aquatic disease diagnostic laboratory. Photos of their operation are available on their Web site. Figure 8 is an example of a tilapia farm in New Mexico.

Nevada – According to the United States Department of Agriculture (USDA, 2009), the state has four aquaculture farms with 325 tonnes of annual production, but no other information is currently available from that source.

A large recirculation system farm for Pacific whiteleg shrimp, *Litopenaeus vannamei*, has recently been built in an industrial park in the Nevada desert just north of Las Vegas by [Ganix Bio-Technologies Inc.](#) This development is geared initially to produce ~225 tonnes per year of shrimp, using on-site well water owned by the city authorities (Dodd, 2011).

Texas – Early experiments in desert west Texas in 1972 were crude and few data were recorded, other than survival that indicated the biological feasibility of shrimp and fish cultivation there. Stocking continued, and gradually a body of information

FIGURE 8
Tilapia farm near the University of New Mexico at
Las Cruces which uses geothermal water



COURTESY OF G. TREECE

FIGURE 9
Saline shrimp culture ponds (Permian Sea Organics)



accumulated supporting commercial aquaculture there. A detailed history of the development of aquaculture in the desert and arid region of west Texas has been published (Treece, 2002). The aquifer used by shrimp farms in the Imperial area is the cenozoic alluvium, water remaining from the Permian Sea. All farms had the same well water or aquifer source. Salinity varied from 10–15 ppt. There are no freshwater zones in that area, and no discharge water was allowed to leave any farm. This water is not used in any other form of agriculture on a large-scale. In the past, some of the farms maintained reservoirs and some had created wetlands that received the effluent and provided a habitat for the

endangered desert pupfish. There are four different species of pupfish in the Permian Sea Basin, but the species that the operating shrimp farm, Permian Sea Organics (Figure 9), works with is *Cyprinodon pecoensis*. Almost any permanent desert pool of water has a species of pupfish; all are at risk. The surface water seeps back into the aquifer through porous, sandy soils. Red clay soils can be found in the Pecos river basin for making ponds. Outside the river basin, the soils do not hold water.

Seven separate inland shrimp farms were built in desert west Texas, but only one has been sustainable. The remaining 26-hectare inland saline shrimp culture facility, Permian Sea Organics, built 16 ponds, each 1.62 hectares in size. Multiple ponds utilize a common drain and harvest area. The white spots shown on the photo in each pond are the result of paddlewheel aerators.

Permian Sea Organics also utilizes water from the Pecos County Water District No. 3, which is 2–5 ppt, mixed with the higher salinity aquifer water (10–15 ppt). This farm is utilizing “organic culture” to better utilize niche markets. The University of Texas Marine Science Institute and Nicholls State University have formed the Organic Aquaculture Institute, Inc. (OAI) (B. Reid, personal communication, 2011), a non-profit organization that conducts research in organic marine fish and shrimp aquaculture at the Imperial farm, Texas. OAI is also involved in extension and education. OAI has partnered with the International Initiative for Sustainable and Biosecure Aquafarming (IISBA) which fosters academic and industrial collaborations to establish new seafood manufacturing entities (M. Schwarz, personal communication, 2010). This initiative encourages sustained production of safe and wholesome seafood products. Initially, it was an open collaboration between the Association Réunionnaise de Développement de l’Aquaculture (France), Virginia Tech Aquaculture Centre, Blue Ridge Aquaculture Inc. (VA), the OAI (TX), Institut français de recherche pour l’exploration de la mer (IFREMER, France), INVE Aquaculture (Belgium) and the Virginia Seafood Agricultural Research and Extension Centre (Virginia, USA). IISBA merges international programmes of excellence in aquaculture research, extension and industrial application for comprehensive identification, prioritization and implementation of research from scientific validation to industrial realization.

Permian Sea Organics has strived to meet the United States of America standards for organic certification. Mainly, the use of chemicals, antibiotics and over-stocking is avoided, and organic feed is used. Shrimp from the farm have been certified as “USDA organic” by the accredited group Florida Organic Growers (M. Mesh, personal communication, 2010), and it is thought that this label might help his products

compete with foreign shrimp flooding into the United States of America from Asia and South America. It is claimed that the wholesale value of organic shrimp is USD11/kg, compared with USD4.4/kg for shrimp on the US commodity market.

The quantity of groundwater available in desert west Texas is still unknown; this creates uncertainty for existing farms or new projects. The composition of Permian Sea water is highly variable and not necessarily satisfactory for shrimp growth without some kind of manipulation (e.g. its potassium level may be low in comparison with normal seawater).

Marketing the farmed shrimp is another challenge. Some can be sold fresh to a local market, but that market is easily saturated and very seasonal. The organic certification of the shrimp opens up new markets, mainly in California, where the majority of the shrimp can be sold at a higher price. Permian Sea Organics has also taken additional steps to open other markets. Shrimp can be purchased from them over the Internet; however, their shrimp store and restaurant in Imperial, Texas, was not sustainable and closed in 2005.

Permian Sea Organics has found that desert aquaculture is more expensive than coastal aquaculture (B. Reid, personal communication, 2010), due to poor availability of goods and services. Feed, equipment and processing plants are on the coast, so desert operations have to pay more to utilize these. Although local markets are much smaller, as there are not many large metropolitan areas in the desert and seafood is not a main staple, they are lucrative because those that do eat it will pay more than for coastal seafood. Skilled labour is less available in the desert because of low population density. Financing is difficult since desert area banks have no experience with the fish and shrimp aquaculture sector. Desert soils are less able than coastal clays to retain water, thus, requiring greater construction effort and expense. Water availability is lower so, for example, mistakes like overfeeding cannot easily be solved by flushing; farm managers have to be alert to potential problems at all times.

Despite the problems outlined above, there are some plus factors. For example, regulations are less strict and land costs are lower in the desert. There are fewer disease problems in the desert. For example, when Taura syndrome virus (TSV) was sweeping coastal farms in 1995 and 1996, there was no virus in the desert. The desert farms out-produced the coastal farms at that time but stocked shrimp from the same hatcheries without seeing any disease (B. Reid, personal communication, 2011). Yellowhead virus (YHV), white spot syndrome virus (WSSV) or TSV are unknown in the desert farms of the United States of America; however, WSSV has recently been reported in Saudi Arabia (R. Rosenberry, personal communication, 2011). Desert farms also find that mechanical draining (pumping) is much better than gravity draining into nets during harvesting as is more often used by coastal farms (more convenient for farm workers and results in better quality product).

The technologies developed thus far in inland saline ecosystems in southern Arizona and west Texas indicate that the ratio of some of the ions in brackish water is just as important as the level of the ions. Research in Australia on the use of underground brackish water for aquaculture (Fielder, Bardsley and Allan, 2001) demonstrated a key relationship between the amount of potassium and chloride that affects fish and shrimp survival. These authors found that the K/Cl ratio had to be at least 0.0070, or the fish would not survive for long. Regardless of the actual levels of potassium and chloride (as long as the fish being reared were capable of living in various salinities), the minimum K/Cl *ratio* needed for survival remained the same (0.0070) regardless of salinity. Some inland saline shrimp farmers in the United States of America have successfully used a higher ratio (0.01). Boyd (2003) gave examples of inland saline ecosystem waters from China, Ecuador, Thailand and the United States of America and also provided an example of how ionic concentrations in an inland ecosystem can be manipulated.

CULTURED SPECIES

The following species contribute most of the production in desert and arid lands of the United States of America:

- **Tilapia** (*Oreochromis mossambicus*, *O. niloticus*, *T. zilli*) and channel catfish (*Ictalurus punctatus*) – 93 percent.
- **Algae** (*Arthrospira platensis* and *A. maxima*) – 3 percent.
- **Ornamentals** (including angelfish – genus *Pterophyllum*; snails in the family Thiariidae; koi – domesticated varieties of the common carp, *Cyprinus carpio*, and goldfish, *Carassius auratus*; grass carp, *Ctenopharyngodon idellus*; alligators, *Alligator mississippiensis*; bullfrogs, *Rana catesbeiana*; aquatic plants; corals; giant river prawns, *Macrobrachium rosenbergii*; largemouth black bass, *Micropterus salmoides*; smallmouth bass, *Micropterus dolomieu*; striped bass, *Morone saxatilis*; and striped bass hybrid, a hybrid between the striped bass *Morone saxatilis* and the white bass *M. chrysops*) – 3 percent.
- **Marine shrimp** (*Litopenaeus vannamei*) – <1 percent.
- **Other species** – <1 percent.

CULTURE PRACTICES

Intensive culture in outdoor ponds contributes 80 percent of the output, while 20 percent comes from intensive culture in greenhouses.

PRODUCTION

Arizona, California, Idaho, New Mexico, Nevada and Texas aquaculture production for 2002 can be seen in Table 4. The six states had an aquaculture production of 22 700 tonnes in 2007 (USDA, 2009), valued at USD169 million. The production of the whole country, from 6 409 aquaculture farms, was 406 802 tonnes worth USD1.4 billion. These six states were therefore, responsible for about 5.6 percent of total United States of America aquaculture production in 2007 and 12 percent of its value. However, the portion originating from the desert areas of those states is smaller. There are currently approximately 40 aquaculture farms located in the desert regions of the United States of America, producing about 1 percent of total annual United States of America production, or about 4 000 tonnes per year.

More recently, Arizona alone has produced over 454 tonnes of tilapia annually from one farm and over 600 tonnes of aquaculture products from other commercial operations but excluding trout farms. Arizona had 25 farms in 2002 (USDA, 2005) that produced 1 385 tonnes per year with a value of USD3 million. The desert and arid lands farms now produce over USD3 million of product annually. The increased tilapia production in Arizona has had a big impact in the state. New Mexico produces four million to seven million tilapia fingerlings annually. Idaho's total annual production is 1 572 tonnes, mostly of tilapia and catfish from geothermal waters. Texas only has one remaining marine shrimp operation in the western part of the state that produces about three tonnes per year. California has at least ten farms located in desert and arid regions. The total California aquaculture production for the state is estimated at USD100 million,

TABLE 4
Total aquaculture production (desert and otherwise)
from each of the six states

State	#Farms	Production t/yr	Estimated Value \$
Arizona	25	1 385	3 million
California	118	5 032	100 million
Idaho	35	1 572	3.5 million
New Mexico	3	1 401	3.4 million
Nevada	4	325	2.1 million
Texas	95	12 985	57 million

Source: USDA, 2005 using 2002 data.

but it is not known what proportion comes from the desert regions. USDA (2005) stated that California's total state production from aquaculture in 2002 was 5 032 tonnes from a total of 118 farms. The California Fish and Game Department (CFGD) states that there were 192 licenced freshwater aquaculture farms in California in 2010 (CFGD, personal communication, 2010).

Production from the Colorado, Oregon, Utah and Wyoming desert areas is very small and the output of coldwater species such as trout, which are produced in a cold wet climate, is not included here.

MARKET

Starting in the middle of the 2001 production cycle, Arizona Mariculture Associates (AMA) began to focus on the live shrimp market in Los Angeles, California. In 2003, that business strategy proved a disaster. Starting with the SARS (severe acute respiratory syndrome) virus scare, business in Chinese restaurants and supermarkets began to fall and never recovered, causing significant losses for the AMA farm. What had seemed a promising market for live *L. vannamei* could no longer be relied upon as the chief target for AMA production.

All four farms that existed at that time in Arizona sought a specialty niche, with Desert Sweet Shrimp Farm having the most complex business strategy. In 2003, three of the four Arizona shrimp farms were targeting large shrimp in the belief that these were less available from overseas. These three farms also lowered their stocking densities and tried to operate with lower costs. These tactics did not succeed, and even selling smaller shrimp to a specialty market at their own restaurants in nearby large cities did not help Desert Sweet Shrimp reach sustainability. When they could not get sufficient fruit from their olive trees, Desert Sweet Shrimp moved into supplying olive trees to the landscape industry. However, once Mexico found out about that lucrative market (landscape industry), competition caused the prices to drop, making it no longer feasible to sell to the landscape industry.

Much of the tilapia produced in desert regions of Arizona and California is sold live or fresh and about half is processed into fillets, individually quick frozen and packaged in plastic bags branded with company logos.

CONTRIBUTION TO THE ECONOMY

Being small, desert and arid lands aquaculture makes very little impact upon the social and economic development of the rest of the United States of America.

Arizona – Eleven farms (the annual payroll from four farms with five workers was USD90 000 in 2002 [USDA, 2005]). No large commercial operations are established in the state yet, although future ventures are likely. Exact aquaculture employment figures for Arizona are not readily available because most fish farms are family operated, with some use of occasional labour. Estimates indicate there are about 50 full-time positions.

California – One hundred and eighteen farms with 450 workers; 71 farms have an annual payroll of USD14.7 million. It is impossible to separate the desert operations from the total. Expenses in California are high no matter where the farm is located. Californian aquaculture is said to contribute USD100 million to the state economy annually (M. McCoy, personal communication, 2010).

Idaho – According to USDA (2005), Idaho had a total of 35 operations in 2002, with 129 workers and an annual payroll on 25 farms of USD3.9 million. Only 12 operations use geothermal water.

New Mexico – The state has one large tilapia hatchery and at least one other tilapia farm. Geothermal use by Burgett Geothermal Greenhouse and the AmeriCulture tilapia hatchery represent the largest boost to the economy in Hidalgo County, New Mexico. USDA (2005) listed three farms in 2002 but did not give production or annual payroll data.

Nevada – There was no information listed in the USDA 2005 census, but the 2009 census (USDA, 2009) shows that Nevada had four aquaculture farms in 2007 with a state production of 325 tonnes. Most of this state is desert.

Texas – One shrimp farm, with only one manager doing the work, does not make much of an impact on the local community of Imperial in Pecos County. The Pecos County Commissioners promoted aquaculture for many years as a potential way to raise revenues. However, the 90 hectares of farms were not sustainable. USDA (2005) listed 95 total farms, 153 total workers and an annual payroll from 55 farms at USD4.3 million in the state of Texas in 2002.

PROMOTION AND MANAGEMENT

Aquaculture in general is over-regulated in the United States of America. However, away from the areas considered sensitive such as coastal wetlands, permitting is claimed to be easier and less expensive in desert and arid lands by all operators. Remoteness makes some facilities expensive, but land is less expensive. It is also easier to obtain agriculture rates for electricity and taxes. The most important factor is water discharge. Most of the successful farms are integrated with effluent reuse for crop irrigation. This spreads the cost of water pumping, diversifies farm income, spreads labour and equipment between both operations and saves on fertilizer expenses. There is no promotion of desert aquaculture other than by private companies. The Texas Department of Agriculture sponsors a seafood marketing programme (“Go Texan” Program) but it is for all seafood in the state, whether it be harvested or farm-grown.

INSTITUTIONAL FRAMEWORK AND GOVERNING REGULATIONS

Arizona – Arizona Department of Agriculture. Aquaculture regulation pertains to the growing, transporting and processing of commercially raised fish and shrimp for human consumption. Average number of licences issued: transporters (20), processors (10), facilities (23), special facilities (11), and fee fishing (6).

California – California Department of Fish and Game (all regulations and licence requirements are posted on their Web site: www.dfg.ca.gov).

Idaho – Idaho Department of Water Resources (322 East Front Street, Boise, ID 83720; Tel. 208 2874800; Web site: www.idwr.state.id.us). This agency regulates the geothermal sites for direct use and aquaculture. The Office of Energy Resources (322 East Front Street, Suite 560, PO Box 83720 Boise, Idaho 83720-0199; Tel. 208 2874891) also plays a role in Idaho aquaculture regulation.

New Mexico – Aquaculture is regulated by New Mexico Game and Fish (Web site: www.wildlife.state.nm.us).

Nevada – The Nevada Division of Wildlife regulates and permits aquaculture projects in the state through the Fisheries Bureau. Nevada Division of Wildlife (1100 Valley Road, Reno, NV 89512; Tel. 775 6881500; Web site: www.ndow.org).

Texas – The role of the Texas Department of Agriculture (fish farming licence) is permitting and promoting aquaculture. The role of the Texas Commission on Environmental Quality (discharge permit) is environmental protection. The Texas Parks and Wildlife (exotic species permit) has its role in natural resources protection. A complete aquaculture permitting manual for Texas has been published by Texas Sea Grant (Treece, 2005).

General

The Arizona Department of Agriculture is chiefly responsible for regulating fish farming in the state. Initially, the Arizona Game and Fish Department was in charge, but after lobbying efforts by state aquaculture interests, legislative action relocated aquaculture within agriculture. Certain advantages accrued. Aquaculture gained financially by moving to agriculture. Fish farming then became regarded as an agribusiness and eligible for certain financial benefits. For example, fish farmers were now entitled to lower agricultural water rates. State officials also believed the change was warranted. It was believed that agriculture was in a better position to enforce rules and regulations. Agriculture maintains border stations and assigns inspectors to cover dairy and chicken farms.

These operations could readily be broadened to include fish farms. Agriculture is involved in the day-to-day operations of aquaculture facilities, including issuing licences for various activities such as fish farming, transportation, processing and fee fishing. The rules and regulations the agency enforces, cover everything from recordkeeping to fish health. An important regulatory concern shared between the departments of Agriculture and Game and Fish is the establishment of new or exotic species in the state. State wildlife rules include a listing of restricted wildlife, including various species of fish. Fish on the restricted list cannot be possessed or imported into Arizona without a special licence or an exemption from Game and Fish. Wildlife rules also include criteria for the issuance of a licence or an exemption. Restricted wildlife is “that wildlife which has been determined by the commission to be an actual or potential or significant threat to indigenous wildlife by competition, disease or parasite, habitat degradation, predation, or impact on population management or an actual or potential significant threat to public safety by disease, physical threat, property damage, or nuisance.” The restrictive list does not necessarily ban a species of fish, but requires a licence or an exemption to control its occurrence in the state. The white amur bream (*Parabramis pekinensis*) is a case in point. This species (which is exotic to Arizona) eats aquatic vegetation and is useful for controlling vegetation growth in canals and waterways and is therefore, valuable to the state. Some Arizona aquaculturists claim that the state’s regulatory agencies are unduly conservative, and their list of approved fish is overly restrictive, saying that Arizona has approved fewer fish species for aquaculture than most other states. This is regarded as unfair since Arizona is mostly desert, with little surface water to contaminate. Game and Fish officials claim that they are considering the broad environmental picture that is sometimes overlooked by individual fish farmers. Since 32 of the 36 native Arizona fishes are threatened or endangered, Game and Fish believe that caution is justified to prevent further threats to native fish. Arizona regulations pertaining to fish effluent are favourable to fish farmers. Aquaculture waste generally is classified either as an industrial or point source pollutant and the discharge of fish effluent must therefore, meet various and often strict state regulations. In Arizona, however, aquaculture interests worked with state regulatory agencies to simplify the permit process. The goal was to allow the use of aquaculture effluent for irrigation as an approved method of disposal. As a result, the Arizona Department of Environmental Quality included a new facility category for aquaculture that requires less information, with no monitoring requirements unless problems arise. In addition, no application or permit fees were established.

California and Texas both have restrictive laws governing aquaculture. Texas desert farms solve discharge restriction by not allowing any to leave the farms. Most of the water percolates back into the ground through sandy soils. Texas Parks and Wildlife Department has recently published a “white list” (aquatic species allowed in the state), instead of the “black list” that had been in use (a list of species not allowed in the state). Aquaculture regulations for all the desert and arid states are readily available on the Web sites of regulatory agencies.

APPLIED RESEARCH, EDUCATION AND TRAINING

Arizona

Shrimp Aquaculture and Olive Production – This research project has been funded by the International Arid Lands Consortium through a grant awarded to Kevin Fitzsimmons (Director of International Programs, Professor and Extension Specialist Department of Soil, Water and Environmental Science, College of Agriculture and Life Sciences, University of Arizona, 2601 E. Airport Drive, Tucson, Arizona, USA 85756; Tel. 520 6216574; E-mail: kevfitz@ag.arizona.edu; Web site: www.ag.arizona.edu/azaqua).

Shrimp Pathology Training Courses – Twenty-two courses have been held since 1989, training 563 people from 57 countries; these are partially funded by the USDA/US Marine Shrimp Farming Program (Dr Donald Lightner, University of Arizona, Dept. of Veterinary Science, Bldg. 90, Rm 202, Tuscon, Arizona, USA. 85721; Tel. 520 6212355. Note: The US Congress terminated funding for the US Marine Shrimp Farming Program in 2011, so it is not known if Dr Lightner will be able to continue these courses without this support).

Texas

Organic Aquaculture Institute, Inc. – Permian Sea Organics, the University of Texas Marine Science Institute and Nicholls State University formed this institute to provide training in desert organic aquaculture (E-mail: reid_bart@yahoo.com).

Marine Shrimp and Marine Finfish Culture Short Courses. These courses have been held for 25 years. (Texas A&M University. Sea Grant College Program. Contact: Granvil Treece, Mariculture Specialist, 2700 Earl Rudder Freeway, S. Suite 1800, College Station, Texas, USA 77845; Tel. 979 8457527; E-mail: g-treece@tamu.edu).

Regional

Western Regional Aquaculture Center (Web site: www.fish.washington.edu/wrac).

Southern Regional Aquaculture Center (Web site: www.srac.tamu.edu).

TRENDS, ISSUES AND DEVELOPMENT

The trend of aquaculture in the desert and arid lands of the United States of America mimics trends in United States of America aquaculture. Some businesses cease operations and others enter to try something different. Shrimp farming boomed in 2001 and 2002 in desert and arid regions, but has declined since. Tilapia production has replaced most of the shrimp production that has been lost. Diversification has been the key survival aspect of most sustainable farms, together with a combination of aquatic and terrestrial farming. Imports of shrimp and fish have definitely affected the marketing trends in the United States of America. Water availability has not played a great a role and does not appear inhibitory because the industry is currently small. However, if the industry expands, water availability (and its cost) will become more critically important. For example, when there were seven farms in desert west Texas, both water availability and marketing issues were already of concern. It is common knowledge that changing markets and prices at the farm-gate, coupled with increasing feed costs and other operating costs have contributed to the downward trends in production in shrimp and catfish operations in the United States of America.

Diseases have not been a major factor, but toxic algae have played a major role at some of the inland arid aquaculture farms in the United States of America. Blue-green (Cyanophyta) algae proliferate in inland saline ponds with high organic waste. Farmers have found that the blue-greens are not detrimental to all aquatic life, but they are generally regarded by producers in the United States of America as non-desirable

algae in ponds. According to Snyder, Goodwin and Freeman (2002), there are benefits of certain blue-green algae in nutrition and in triggering higher immune response activities. At least one genus, *Oscillatoria*, has been known to cause “off-flavour” problems. Farmers in Australia have found blue-green blooms to be a problem for the past 20 years. If *Oscillatoria* blooms in a pond it generally means that the shrimp or fish will become ill. Experience in farms in Texas and Belize has shown that herbicides with the active ingredient Atrazine can successfully knock out blue-green algae temporarily but, unless water with an alternative strong bloom is introduced into the pond, blue-greens will take over again.

Most shrimp pathologists agree that when blue-green algae are dominant species, shrimp may develop haemocytic enteritis (HE). It is also possible for juveniles to develop lesions within the gastrointestinal lining as a result of ingesting algal filaments. However, if shrimp are exposed early onto the toxins, the shrimp may develop immunity to the endotoxin and may not become infected with HE (D. Lightner, personal communication, 2010). Catfish in saline ponds in Arkansas have died from *Anacystis marina* according to Snyder, Goodwin and Freeman (2002). The sensitivity of fish and shrimp to microcystin is species-dependent and is probably influenced by the nature of the animal’s normal habits. Other fish kills in saline commercial catfish and red drum (*Sciaenops ocellatus*) operations have been linked to cyanobacterial toxins (J. Wilkenfeld, personal communication, 2010). *Microcystis* was also found in Arizona shrimp farms and caused heavy mortality at Arizona Mariculture Associates. This farm has dropped shrimp culture and now produces tilapia and terrestrial crops. Early research found that a single species of toxic alga dominated pond flora and toxins were released when competition for nutrients becomes intense, killing or inhibiting the growth of other algae (Herman and Meyer, 1992). As the toxic alga uses up available nutrients, the species competes with itself continuously releasing toxins. Eventually, the water becomes toxic to zooplankton, insects, shrimp and fish (and sometimes to animals that drink the water).

Certain constraints or obstacles exist in the development of aquaculture in the desert and arid regions of the United States of America. For example, Arizona fish farmers now have difficulty competing with fish farmers in other parts of the United States of America. Fish which are raised in Idaho and Colorado are sold in Arizona at lower cost. Raising fish is more costly in Arizona partly because aquaculture is a relatively small activity. Not enough fish farmers are buying fish and feed to ensure low costs and centralized processing to further reduce costs is unavailable. Cooperative purchasing activities among current fish farmers is one strategy to save money; however, more fish farmers are needed to ensure lower prices for aquaculture supplies and services. On the other hand, more fish farmers might cause farm-gate prices to fall. The lack of managerial talent also is a factor limiting desert aquaculture development. Many fish farmers enter the field from a background in cotton or cattle, which does not automatically qualify them as aquaculturists. Farmers need to learn fish farming using new methodologies and technologies; this can be a challenging task. Aquaculture sometimes attracts the wrong kind of interest. Some individuals approach fish farming as an alternative profession; to them, fish farming is simply tending fish – a clean, idyllic, undemanding way of life promising quick profits. Such people underestimate the amount of work required to raise shrimp or fish, and their eventual failure discredits the industry and complicates business for the more committed.

Appropriated water rights apply to land where rainfall is limited and water is scarce, such as found in the drier United States of America desert southwest. Appropriated water rights are similar to real property in that the water can be sold, transferred or mortgaged. In other words, the water is independent of the land. Because it is limited in supply, proper management by the state must occur (such as with the Colorado River) through priority administration. This form of state water distribution management

defines the water rights as “first in time is first in right” and senior *vs.* junior rights. Put simply, the first to acquire the right to the water has precedence over those that come after, at least in theory. Where there are problems, such as those of increasing concern to water users in the desert southwest, litigants can make a case for relief through the initial step of water delivery call which is followed by an administrative hearing to determine the extent of injury and confirm senior and junior water rights. This is often followed by an appeal to a district court and finally the State Supreme Court. The cost to the litigant to defend its water rights has been reported to be USD300 000 annually by one individual farm in 2010 (K. Fitzsimmons, personal communication, 2010). The effort by the company to defend its water rights has been successful but it has still not received the water that it is due. This farm now believes that working with the junior water right holders to create a “win-win” for both sides may be more fruitful. Freshwater is a resource that is limited in supply and over appropriated. It has, is and will be a source of “water wars” unless practical solutions to share the water and use it more efficiently are found.

The economics of integrating aquaculture with terrestrial crops looks good for some and marginal for others, but is very site-specific. Terrestrial crops that suit the locality and aquatic species that suit the water quality must be selected. Desert Sweet Shrimp got nine cuttings per year of alfalfa (C. Collins, personal communication, 2010), which was unique because most states only get three to four cuttings per year. The 2010 alfalfa price received by this farm was USD135 per tonne, but price decreases in the summer due to quality constraints. Olive trees might work very well at another location, but Desert Sweet Shrimp never had any significant production of olives. The olive trees grew rapidly, but did not ever produce much fruit. There are a growing number of people who are combining fish culture with raising various vegetables and using the waste water for fertilization of the hydroponic crops and then recycling the water back to the fish; thus, producing organic crops that command higher returns. This system would work better with shrimp if the farm grew various saltwater crops such as *Salicornia* or even seaweed.

The best way is to maximize the synergy and use economies of scale. If the operation is large enough and enough faecal material is produced, then it can use the waste material in anaerobic digesters to produce methane gas and produce power for the farm. There will always be waste products and farms need to find ways to utilize everything.

FIGURE 10
Desert Springs Tilapia fish farm



Source: Google Earth.

SUCCESS STORIES, A QUESTIONABLY SUSTAINABLE SHRIMP FARM IN ARIZONA AND A DESERT CASE STUDY

Desert Springs Tilapia (HCI Box 46A 50621 Agua Caliente Road, Dateland, Arizona, USA 85333; Tel. 928 4542360; E-mail: sales@desertspringstilapia.com).

Desert Springs Tilapia (formerly Arizona Mariculture Associates) was formerly a shrimp farm, but now produces 454 tonnes of tilapia annually (Figures 10 and 11).

The elevated nursery ponds that gravity fed to the grow-out ponds at the Arizona Mariculture Associates farm was a poor design for the desert (J. Wilkenfeld, personal communication,

2010). In 2000, it cost more than USD one million to construct (excavate and construct) twelve 400 m² nursery ponds situated above twelve 1 000 m² grow-out ponds. The original blueprints for the farm showed 500 pairs of nursery and grow-out ponds, but only these few were actually built. In theory, transferring juveniles by gravity from the nursery ponds through a 30 cm drain pipe directly into the grow-out ponds below seemed ideal. However, the water had to be pumped from 263 metres underground to the elevated nurseries, and then had to be pumped again in order to remove it from the grow-out pond harvest sumps for water exchange or harvesting. In addition, unsuitable water chemistry kept the shrimp in a continual state of stress, so that they could not handle the transfer from nursery to grow-out ponds. A whole array of other design and management problems were also encountered, so it was no wonder that the shrimp farm closed. However, under new management, the farm began to raise tilapia using intensive culture and it has been very successful. The management is now considering establishing a hybrid striped bass farm in the same area. The existing facility is agriculture integrated with olives and alfalfa fields utilizing the fish farm effluent (Figure 12). Up to 9 cuttings per year have been made at some farms (Figure 13).

Imperial Catfish farm and hatchery (Imperial Catfish Farm, 152 E. Harris Road, Imperial, California, USA 92251).

This is another successful farm and hatchery in the Imperial Valley desert area of California; its only crop is catfish (Figure 14).

Earthrise Nutritionals (113 E. Hooper Road, Calipatria, California, USA 92233).

This is one of the oldest producing farms and produces *Spirulina* algae for the health food industry (Figure 15).

FIGURE 11
Desert Springs Tilapia intensive lined ponds



COURTESY OF K. FITZSIMMONS

FIGURE 12
Alfalfa field at Desert Springs Tilapia

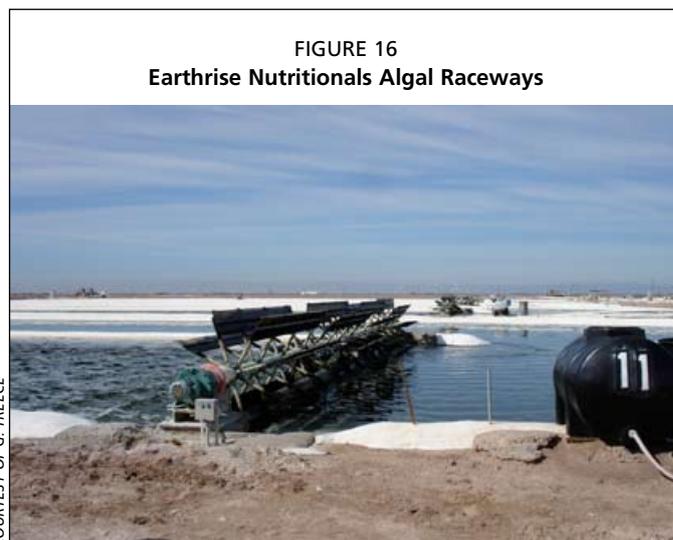
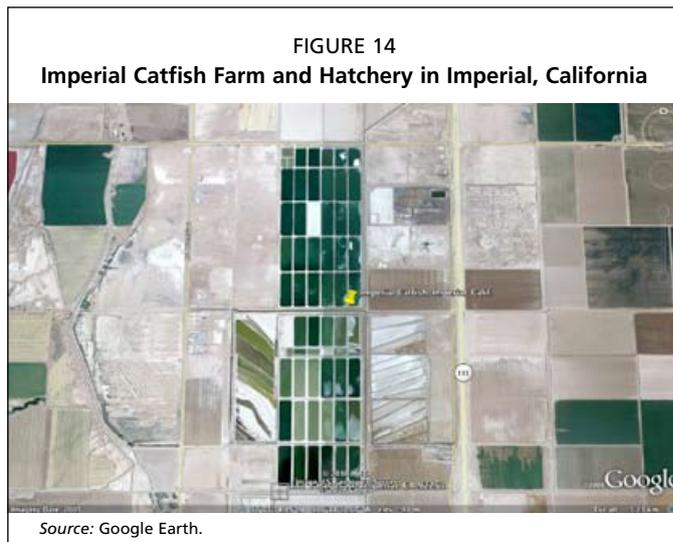


COURTESY OF K. FITZSIMMONS

FIGURE 13
Cut alfalfa at Desert Springs Tilapia



COURTESY OF K. FITZSIMMONS



In 1979, after years of research, Earthrise introduced *Spirulina*¹ to the natural foods market. Then, in 1982, the owners built the first United States of America *Spirulina* farm to grow this green superfood in the desert sun. Today, the Earthrise Farm is the world's largest *Spirulina* farm. Earthrise® products are marketed in the United States of America and in over 20 countries on six continents. *Spirulina* is a whole product of biological origin. It consists of the dried biomass of the cyanobacterium *Arthrospira*. *Arthrospira* are filamentous microscopic blue-green algae (cyanobacteria) that occur abundantly in an almost unialgal form in highly alkaline lakes with high pH. The high pH and alkalinity prevent other algae from growing and it is, therefore, grown outdoors virtually free of contamination by other algae. More information is available on www.earthrise.com/whatIsSpirulina.html.

A QUESTIONABLY SUSTAINABLE SHRIMP OPERATION IN ARIZONA

Shrimp farming has still not proven to be sustainable in the deserts of Arizona. In 2010, the last remaining shrimp farm in Arizona decided to cease shrimp culture and concentrate on the terrestrial agriculture. A seemingly sustainable shrimp farm in the Gila Bend, Arizona, until 2010 was the Woods Bros. Farm, later called Desert Sweet Shrimp before closing its shrimp operation. It had nursery ponds consisting of covered earthen ponds (Figure 17) and cement raceways covered with greenhouses and aerated with airlift pumps (Figure 18). The farm was agriculture-integrated with olives, wheat, alfalfa and other crops. The farm has a new investor and plans to stock shrimp again in 2011 (C. Collins, personal communication, 2011).

Shrimp production at the Desert Sweet Shrimp farm was related to an

¹ The true taxonomic name of *Spirulina* has been revised recently. The edible forms of *Spirulina* are now called *Arthrospira*. The common species under commercial cultivation are *Arthrospira platensis* and *Arthrospira maxima*. The name *Spirulina* is now retained to describe the product and not the algae.

aeration horsepower as well as to animal size at harvest. If the farm harvested smaller sizes then they got significantly higher survival rates than when rearing for the larger sizes of 26–28 g shrimp (C. Collins, personal communication, 2010). Productivity was good when they first began – consistently 5 000 to 10 000 kg/ha. When the management stopped investing in maintenance and horsepower capacity was reduced, productivity went down significantly. Production was only 2 000 to 3 000 kg/hectare if the shrimp were harvested between 16–17 g, and the farm did not try to get the larger sizes due to the prices in local markets.

CASE STUDY OF ARIZONA DESERT SALINE SHRIMP FARMS

This case study will review problems that were encountered by four Arizona shrimp farms. These included slow but continuous attrition, surges of shrimp mortality associated with moulting, stress-induced cramping of shrimp, and unstable blooms of predominantly unfavourable algal species. In effect (J. Wilkenfeld, personal communication, 2010), it seemed that with some variation from farm to farm, the shrimp seemed to be living on the edge of disaster, and any additional input of stress caused by handling, significant water exchanges, moulting and increases in temperature was likely to cause mortalities, especially at three of the farms.

Analyses of well water in Arizona were presented by Boyd, Thunjai and Boonyaratpalin (2002), who later showed that there were characteristic chemical differences between well water and what would be expected in seawater diluted to a similar salinity. The differences varied from farm to farm, but typically included low levels of potassium and magnesium, low alkalinity (which was specific to Arizona Mariculture Associates) and high levels of calcium. It was clear from other work done at Auburn University in Alabama (Boyd, 2003) that similar water chemistry issues were common to other inland culture sites, even beyond the desert environment. Green Prairie Aqua Farms, near Montgomery, Alabama, is one such farm that is still operating after solving its problem with low potassium. Some improvements in the industry included modifications in diet, operating procedures and the use of various pond additives such as dolomite and K/Cl. Arizona Mariculture Associates attempted to establish a logical protocol for the use of K/Cl to deal with a given potassium deficiency, as well as a fertilizer regime to modify and control algal blooms, which may provide a road map for future shrimp farming operations in the desert.

As shown in Table 5, all four farms had low levels of potassium, but the K/Cl ratio of K/Cl was satisfactory for Desert Sweet Shrimp, whose K/Cl ratio, indicated in

FIGURE 17
Desert Sweet Shrimp – A covered shrimp nursery



COURTESY OF G. TREECE

FIGURE 18
Desert Sweet Shrimp – Greenhouse covered shrimp raceways



COURTESY OF G. TREECE

TABLE 5
Deductive reasoning for focus on potassium

COMPONENT (mg/l)	SEA WATER	DILUTE SEA WATER (Calc.)	Arizona Mariculture (Lab & Boyd)	Arizona Shrimp Co. (Lab & Boyd)	Desert Sweet Shrimp (Lab & Boyd)	Ewing Shrimp Farm (Boyd)
Salinity (ppt)	35.0	4.5	4.6	7.4	1.5	4.6
pH	8.2	ND	7.3	7.6	7.8	7.9
Alkalinity	125.0	ND	55.0	220.0	137.0	174.4
Cl	19 400.0	2 494.3	1 800.0	3 223.0	530.0	2 339.0
Na	10 500.0	1 350.0	1 500.0	2 595.0	410.0	1 610.0
SO ₄	2 740.0	352.3	1 800.0	2 313.0	343.0	857.0
Mg	1 272.0	163.5	36.0	222.0	12.0	113.0
Ca	400.0	51.4	520.0	497.0	120.0	319.0
K	380.0	48.9	7.0	15.2	10.0	13.0
K/Cl Factor	0.0196	0.0196	0.0039	0.0047	0.0189	0.0055
For K/Cl factor of 0.0100, K should be	NA	NA	18.0	32.2	5.3	23.4
Additional mg of K/Cl required to reach K/Cl Factor of 0.0100	None	None	11.0	17.0	(4.7)	10.4
Grams of K/Cl to be added per 1 000 liters of new water	None	None	22.1	34.1	(9.4)	21.0

Source: Winklenfel et al., 2004.

Table 5 in green, was almost the ideal ratio of full strength seawater (0.0196). However, the other three farms were all below the 0.0070 minimum specified by Fielder, Bardsley and Allan (2001) and well below the target safety factor of 0.01, as discussed earlier in this review. Potassium deficiency seemed to be the key problem. So with a target of 0.01 in mind, it is possible from the formula of K/Cl to calculate that in the case of Arizona Mariculture Associates, they should have added 18 mg/litre of potassium, and should also have been adding 11 mg/litre of K to all new water entering their ponds. Armed with this information and the fact that potassium is roughly 50 percent of potash by weight, it was easy to set up a pond-by-pond spreadsheet that showed how much K/Cl should be added when first filling each pond, and how much should be added on a daily basis depending on percolation losses and water exchange. Using this method, Arizona Mariculture Associates did not experience attrition or moult related mortalities. The Arizona Shrimp Company and Ewing also used K/Cl to avoid the mortality problems that they had experienced but their application method made it difficult to quantify their data.

After fighting unstable blue-green algae blooms for two years, Arizona Mariculture Associates dropped their old fertilization protocol and decided to use a 20:1 ratio of nitrogen to phosphorus (J. Wilkenfeld, personal communication, 2010). After some trial and error, a basic dose rate of 11.5 kg of urea and 1.02 kg of phosphoric acid per hectare was decided. The farm manager started with two applications in the first week of rearing and then applied further doses as needed, to obtain and retain Secchi disc readings of 35–45 cm. Experience showed that it was important not to overreact by adding too much fertilizer or applying it too frequently, or the algae will become out of control. Using this regime, algae at this farm became dominated by diatoms, primarily *Synedra*, which is a pinnate diatom, and at least two species of *Chaetoceros*. In previous years, their blooms had been characterized by various blue-greens including *Oscillatoria*, *Spirulina*, *Merismopedia* and others.

It is important to note that Desert Sweet Shrimp had the most consistent production results and the fewest problems of the four Arizona farms, and survived longer than the

other farms in Arizona. Arizona Mariculture Associates consistently produced very low quantities of shrimp and it was believed that this was because of the water quality coming from its wells. Apparently, the water quality is satisfactory for tilapia but not for shrimp and this farm now rears tilapia.

WAY FORWARD

After more than ten years of commercial trials in the United States of America desert regions, it seems that tilapia, catfish and algae have the greatest potential; this is evident in looking at the species now under culture. Aquaponic or integrated aquaculture of the above species with wheat, olives, alfalfa and other terrestrial crops seem to offer the most return on investment and help spread the risks. If marine shrimp farming is to be attempted, then a super-intensive biofloc culture should be considered with lower operating costs and added culture of *Salicornia* or seaweed if the salinity is high enough. If the salinity is low then other terrestrial crops should be used. All of the shrimp farms in the United States of America are very aware of and interested in the continuing efforts of various groups to develop super-intensive, indoor, recirculating (RAS) or zero water exchange heterotrophic culture systems, especially those using biofloc techniques. These systems hold considerable promise for the future of shrimp culture in North America and elsewhere. However, these systems are not yet proven commercially sustainable. It is believed that not breaking the cycle of bacteria (especially *Vibrio*) by drying out the systems between crops is the key factor contributing to failure. Most research facilities do break the cycle by drying, but commercial facilities have not been doing this. Research facilities are still plagued with *Vibrio*. The USDA/US Marine Shrimp Farming Program had planned to continue research on RAS and the problems associated with high-density culture, but funding was cut in 2011. Researchers at Nicolls State University are also working on quick identification methods for the various species of *Vibrio* but, without the USDA/US Marine Shrimp Farming Program, they have no extension funding to spread the results of their work.

Given the specific conditions described earlier in this review it appears that, at least for the time being, the best strategy in the Arizona desert is tilapia farming or the culture of other finfish, such as hybrid striped bass, involving simple operating methods. The objective should be to produce fish in high density at low cost, and to remain diversified with the production of other terrestrial or aquatic plant crops. Only a few sites in Arizona were trouble-free from toxic algal blooms. A fertilizer regime of 20N:1P should be the first step with any outdoor pond. Even though there is no research that proves this practice to be necessary, many farmers that have grown crops in ponds for years in the desert attest to it being necessary to avoid toxic algal blooms.

Aquaculture has many positive impacts on the environment, but it also can have negative impacts, which often occur when there is overexploitation. The more intensive the operation, the greater the demands on the environment. Any operation in the deserts of the United States of America should follow the Best Aquaculture Practices². Koonse (2003) described the United States of America Federal Drug Administration (FDA) "Good Aquaculture Practices" guidelines, which should also be followed, along with the guidelines for sustainable aquaculture suggested by FAO and the World Wildlife Fund. In October 2010, the first global guidelines for aquaculture certification were adopted by FAO³. Given the rapid growth of aquaculture globally, it is important for academic institutions to define the curricula (undergraduate and graduate level) and research facilities required for further education and basic research in sustainable aquaculture to ensure human resource development and capacity building.

² Additional information can be viewed at www.aquaculturecertification.org

³ www.fao.org/news/story/en/item/45834/icode

One important environmental issue in desert aquaculture is the potential salination of soil and freshwater wells as salt intrudes into groundwater in inland areas after it is transported and added into the ponds. Another environmental issue is the loss of groundwater. Good practices to protect groundwater resources during pond aquaculture in saline areas include:

- adopting a switch over strategy to culture high saline tolerant species in high saline areas;
- not using low saline tolerant species in areas where high salinity prevails;
- assessing the groundwater availability before extracting it for aquaculture; and
- not using groundwater in large quantities to dilute saline water without assessing the availability of the resource, and the impacts it may cause.

The introduction of non-native fish species into the wild through aquaculture may eventually lead to serious problems. These are less likely to occur in desert environments, but are still possible. Strategies associated with the use of exotics and genetically modified organism (GMO) for aquaculture should be reviewed and practical codes for risk assessment and management should be developed, as emphasized in the FAO Code of Conduct for Responsible Fisheries. Attention should be focused on implementation of the strategies/actions of the signatories to the Convention on Biological Diversity. The prohibited or restricted list of species should be checked; do not culture or introduce prohibited or restricted species.

Some claim that it is more expensive to operate aquaculture farms in desert locations because they are so remote (B. Reid, personal communication, 2010). Diseases do not seem to be a significant issue inland. Finfish seem to have been more sustainable than shrimp in these desert environments. Water composition (trace metals) seems to be more important for shrimp than fish and toxic blue-green algae are problematic at some farms. Expenses are high in the whole of California. Remoteness is expensive for some items but land is cheaper and it is easier to get agriculture rates for electricity and taxes. The most critical factor of all is water discharge. Most of the successful farms are integrated with the reuse of effluent for crop irrigation. This spreads the cost of water pumping, diversifies farm income, spreads labour and equipment between each operation and saves fertilizer expenses.

As a non-consumptive sharer of irrigation water, aquaculture represents a strategy to help crop farmers pay their water bills. Currently, desert and arid lands aquaculture in the United States of America is being explored further, after many years of commercial trials. Much work needs to be done. For example, research needs to continue to identify new species that are more suitable for culture within the arid regions and that will bring a greater return on investment than tilapia and provide more human nutritional benefits. Although they recognize this, some aquaculturists also realize that identifying new species does not ensure that the public will buy them. Consumers are wary of products they are not familiar with. This raises another important aquaculture need, which is market research. What kind of fish do people buy and how much of it? How much are people willing to pay for fish? What proportion is purchased fresh or frozen? What variables affect the purchase of fish products? Such information is needed to plan fish farming activities in the arid regions of the United States of America. The availability of such information would also help in planning a market strategy, another necessity. Other requirements include more lenient terms from lending institutions. Money is not readily available at present to support aquaculture. There have been many failures and the business is considered as a very high risk. Other research is needed on how to deal with the increases in total dissolved solids that occur through high evaporation levels in heavily recirculating systems, and in nutrient modelling. In the long term, it is thought (K. Fitzsimmons, personal communication, 2010) that soil texture analyses are needed to address the question “do infiltration rates increase or decrease?” and “are there problems with salination or sodicity?”. Other important research is required

on fertilizer values, cost-benefits, enterprise budgets and the further development of heterotrophic biofloc suspended culture techniques in the culture water, and terrestrial crops or salt tolerant crops suitable to accompany it. More educational opportunities for persons engaged in fish farming also are important.

A promising development is the integrated multi-trophic aquaculture approach, where species of complementing trophic levels are grown together. Such ecologically-integrated systems have been shown to be able to sustain themselves economically in both developed and developing countries. Pond systems that minimize water exchange appear most compatible with the concept of sustainability. This appears to be true for those systems that can show a positive energy use advantage. Most Chinese aquaculture occurs in extensive (as opposed to intensive) ponds with little water exchange and little expense on power for aeration, carbon dioxide stripping, clarification and biofiltration. Farmers there use the sun and a mixture of fish with different feeding habits to maintain water quality. While much of current efforts in industry and research address the reduction in the use of fishmeal and fish oil in aquafeeds, and in the use of energy in the aquaculture production process, there are additional aspects that are also important (A. Neori, personal communication, 2010).

Working out the above matters will help refine aquaculture in arid regions of the United States of America, its characteristics and its potential.

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An overview on desert aquaculture in Mexico

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SUMMARY

In the United Mexican States, aquaculture began as a complementary social activity to improve the nutritional status of the population in the rural areas (Juárez-Palacios, 1987). Since then, aquaculture in Mexico has consisted of: (i) rural aquaculture which is extensive and mostly at subsistence level (mainly carp and tilapia); (ii) capture-based aquaculture (the stocking of large reservoirs, dams and other natural water bodies with tilapia, carps, catfish and bass; and (iii) commercial aquaculture of trout, catfish, shrimp and tilapia (Ramírez-Martínez and Sánchez, 1998). In Mexico, even though fisheries and aquaculture activities have been primarily promoted by the state, diverse political, economical and social factors have shaped and sized their development. From 1950 to 1970, state aquaculture policies were oriented towards the development of extensive aquaculture. From the mid-1960s and into the 1970s, efforts were concentrated on building hatcheries to provide seed, fingerlings and post-larvae for social and commercial production. The 1980s were characterized by a profound economic crisis caused by devaluation and an almost uncontrolled inflation. The 1990s became a benchmark because from the economical crisis, a renewed fisheries and aquaculture industry appeared where their development was closely related to the opening of the state to the international market. Also, in this decade, a decrease in landings and a new ecological awareness began to shift the state policies towards promoting the development of the aquaculture industry. In this new century, aquaculture has begun to develop in all 32 federal entities. In the year 2000, the 1 402 936 tonnes of capture fisheries total production outweighed the 188 158 tonnes of aquaculture total production. By 2008, the output of both sectors had increased, more pronouncedly in the case of aquaculture. Aquaculture production in 2008 (283 625 tonnes) was a 50 percent increase on 2000; on the other hand, fisheries total production in 2008 (1 745 424 tonnes) was only 25 percent higher than in 2000 (SAGARPA, 2009). Data obtained from the last census accounts for a total of 967 production units involved in fish aquaculture. Of these, 817 used ponds or tanks, 29 lakes or lagoons and 20 estuaries. In 2008, a total of 520 ponds (742 hectares) were devoted to tilapia production, 37 ponds (123 hectares) to channel catfish (*Ictalurus punctatus*), 107 ponds (46 hectares) to carp (*Cyprinus* spp.) and 7 ponds (4 hectares) to largemouth black bass (*Micropterus salmoides*). Production of commercial aquaculture and capture-based aquaculture in 2008 was

comprised of: tilapia – 3 789 and 67 229 tonnes (USD3 793 625 and USD67 311 055), respectively, with a total value of USD71 104 780; catfish – 970 and 2 070 tonnes (USD1 801 762 and 3 844 998) with a total value of USD5 646 760; carp – 570 and 23 588 tonnes (USD320 540 and 13 264 750) for a total value of USD13 585 290; and largemouth bass – 1 and 1 220 tonnes (USD1 491 and 1 818 509) with a total value of USD1 820 000. From 2002 to 2008, an increase in the number of ponds and their area also occurred. This period was also characterized by an increased governmental interest (diverse federal and state sector support programmes were provided for both rural and private aquaculture enterprises).

RÉSUMÉ

Aux États-Unis du Mexique, l'aquaculture a démarré en tant qu'activité sociale complémentaire pour améliorer l'état nutritionnel de la population dans les zones rurales. Elle s'est ensuite développée sous les trois formes suivantes : i) une aquaculture rurale extensive qui est essentiellement de subsistance (avec un élevage principalement de carpes et de tilapias) ; ii) une aquaculture fondée sur les captures (mise en charge de grands réservoirs, de barrages et d'autres pièces d'eau naturelles avec des tilapias, des carpes, des poissons-chats et des perches truitées) ; et iii) une aquaculture commerciale de truites, de poissons-chats, de crevettes et de tilapias. Au Mexique, même si les activités halieutiques et aquacoles ont été encouragées dans un premier temps par l'État, divers facteurs politiques, économiques et sociaux ont caractérisé et déterminé leur développement. De 1950 à 1970, les politiques nationales en matière d'aquaculture visaient le développement de l'aquaculture extensive. À partir du milieu des années 1960 et au cours des années 1970, les efforts se sont concentrés sur la construction d'écloseries pour fournir des semences, des postlarves, des alevins, etc. destinés à la production sociale et commerciale. Les années 1980 se sont caractérisées par une profonde crise économique due à la dévaluation du peso et à une inflation pratiquement incontrôlée. À cause de la crise économique, les années 1990 sont devenues un modèle, caractérisé par un renouvellement de l'industrie halieutique et aquacole dont le développement était étroitement lié à l'ouverture de l'État au marché international. Au cours de cette décennie, la baisse des débarquements de poissons et une nouvelle prise de conscience écologique ont en effet amené l'État à élaborer des politiques encourageant le développement de l'industrie aquacole. En ce début du XXI^e siècle, l'aquaculture commence à se développer dans les 32 États fédérés du pays. En 2000, la pêche de capture s'élevait au total à 1 402 936 tonnes alors que la production aquacole totale n'était que de 188 158 tonnes. En 2008, les deux secteurs avaient progressé, mais de façon plus prononcée pour le second : la production aquacole a ainsi augmenté de 50 pour cent entre 2000 et 2008 (pour atteindre 283 625 tonnes), alors que celle de la pêche de capture n'a progressé que de 25 pour cent dans le même temps (à 1 745 424 tonnes) (SAGARPA, 2009). Les données du dernier recensement faisaient état d'un total de 967 unités de production aquacoles ayant recours à 817 étangs ou bassins, à 29 lacs ou lagons et à 20 estuaires. En 2008, 520 étangs (742 hectares) étaient utilisés pour la production de tilapias, 37 étangs (123 hectares) étaient consacrés à celle de poissons-chats (*Ictalurus punctatus*), 107 étangs (46 hectares) servaient à l'élevage de carpes (*Cyprinus* spp.) et 7 étangs (4 hectares) étaient destinés à celui de perches truitées (*Micropterus salmoides*). En 2008, la production de l'aquaculture commerciale et celle de l'aquaculture fondée sur les captures présentaient respectivement les résultats suivants : 3 789 et 67 229 tonnes de tilapias (3 793 625 USD et 67 311 055 USD), pour une valeur totale de 71 104 780 USD ; 970 et 2 070 tonnes de poissons-chats (1 801 762 USD et 3 844 998 USD) pour une valeur totale de 5 646 760 USD ; 570 et 23 588 tonnes de carpes (320 540 USD et 13 264 750 USD) pour une valeur totale de 13 585 290 USD ; et enfin 1 et 1 220 tonnes de perches truitées (1 491 USD et 1 818 509 USD) pour une valeur totale de 1 820 000 USD. De 2000 à 2008, on a constaté une augmentation du nombre et de la

surface des étangs. Cette période s'est aussi caractérisée par un accroissement de l'intérêt des autorités fédérales pour l'aquaculture (plusieurs programmes fédéraux et nationaux au secteur ont été mis en œuvre en vue d'appuyer les entreprises aquacoles aussi bien rurales que privées).

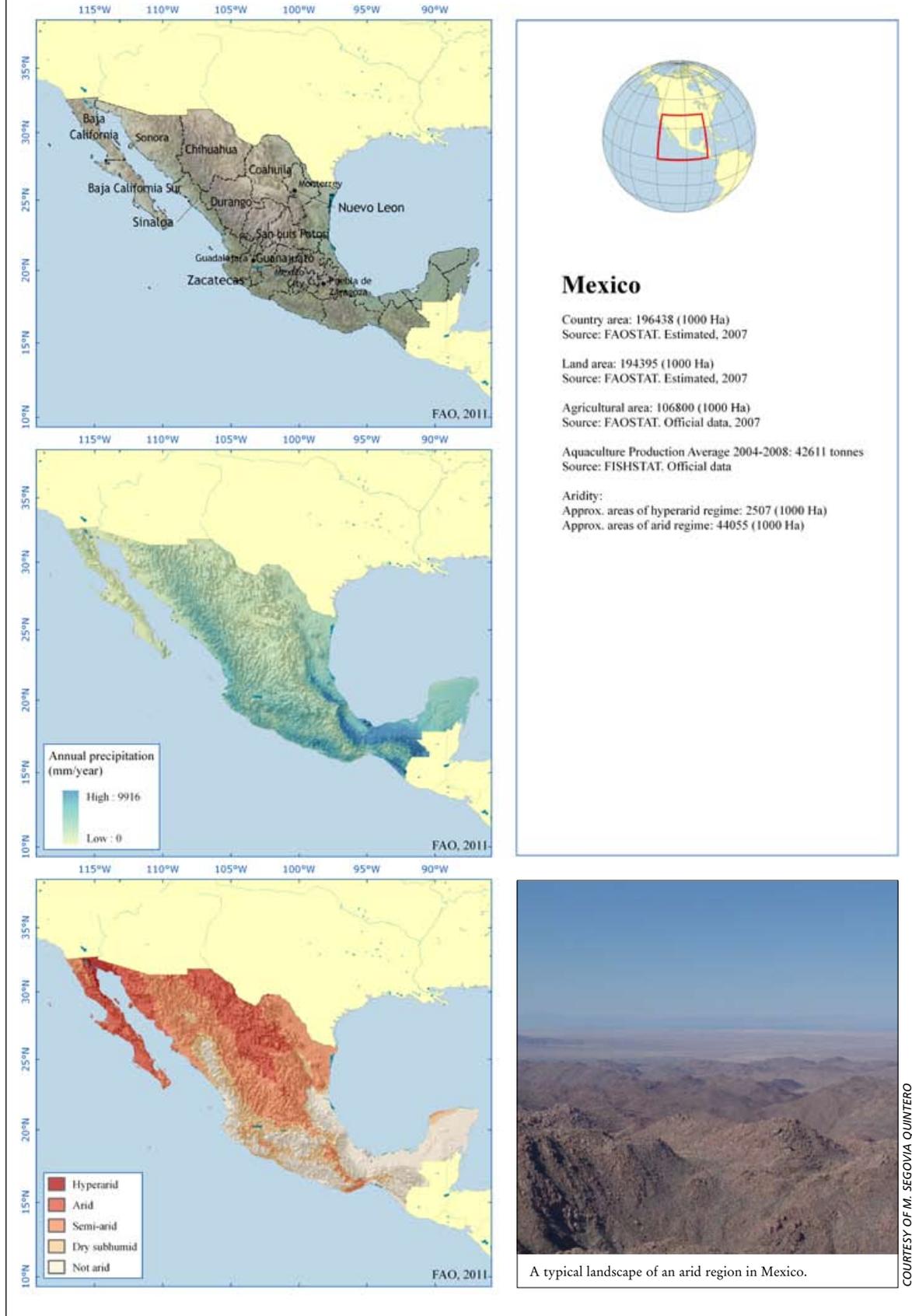
ملخص

في الولايات المتحدة المكسيكية، بدأت تربية الأحياء المائية كمنشآت اجتماعية مكملة لتحسين الحالة الغذائية للسكان في المناطق الريفية. ومنذ ذلك الوقت، فإن تربية الأحياء المائية في المكسيك تألفت من: (i) تربية الأحياء المائية بنظام الاستزراع الموسع وهي في الغالب على مستوى الكثافة (وبشكل أساسي الشبوط والبلطي)؛ (ii) تربية الأحياء المائية القائمة على المصايد السمكية (التخزين في الخزانات الكبيرة، والسدود والمساحات المائية الطبيعية الأخرى للبلطي، والشتبوط، والقرموط والقاروص)؛ (iii) الاستزراع التجاري للتراوت، والقرموط، والريبان والبلطي. وفي المكسيك، وبالرغم من أن أنشطة المصايد السمكية وتربية الأحياء المائية قد تم الترويج لهما أساساً من قبل البلد، إلا أن عوامل متنوعة سياسية، واقتصادية واجتماعية قد صاغت وشكلت تنمية هذا القطاع. ومن 1950 إلى 1970، تم توجيه سياسات البلد فيما يخص تربية الأحياء المائية نحو تنمية تربية الأحياء المائية بنظام التربية الموسعة. ومن منتصف الستينيات من القرن الماضي وفي السبعينات من نفس القرن، تم تركيز الجهود على بناء مفرخات لتوفير الزريعة، والاصبعيات ومرحلة ما بعد البرقات للإنتاج التجاري والاجتماعي. وتميزت مرحلة الثمانينات من نفس القرن بالأزمة الاقتصادية العميقة بسبب انخفاض قيمة العملة وتقريباً بسبب التضخم غير المتحكم فيه. أما فترة التسعينات فقد كانت علامة بارزة وذلك بسبب انه من الأزمة الاقتصادية ظهرت المصايد السمكية وتربية الأحياء المائية المتجددة حيث تنميتها كانت قريبة جداً من افتتاح البلد أمام الأسواق الدولية. وأيضاً، وخلال هذا العقد فإن النقص في الإنزال والوعي البيئي الجديد قد بدأ بتحويل البلد نحو السياسات التي تشجع تنمية صناعة تربية الأحياء المائية. وفي هذا القرن الجديد، بدأت تربية الأحياء المائية بالتطور في جميع الكيانات الفيدرالية البالغ عددها 32. وفي عام 2000، فإن الإنتاج السمكي الكلي من المصايد التقليدية والذي وصل إلى 1 402 936 طن زاد بشكل كبير عن إنتاج تربية الأحياء المائية والذي وصل إلى 188 158 طن. وبحلول عام 2008، فإن الإنتاج من كلا القطاعين قد ازداد، وبشكل أكثر وضوحاً في قطاع تربية الأحياء المائية. إن إنتاج تربية الأحياء المائية في عام 2008 (283 625 طن) ازداد بمعدل 50 في المائة عن إنتاج عام 2000؛ ومن ناحية أخرى، فإن الإنتاج الكلي من المصايد السمكية في عام 2008 (1 745 424 طن) كان أكبر بمعدل 25 في المائة فقط عن إنتاج عام 2000. والبيانات التي تم الحصول عليها من التعداد الأخير تشير إلى وجود 967 وحدة إنتاج تعمل في استزراع الأسماك. ومنها، 817 تستخدم البرك أو الأحواض، 29 بحيرة أو خور و 20 مصب نهر. وفي عام 2008، تم تخصيص ما مجموعه 520 حوض (742 هكتار) لإنتاج البلطي، 37 حوض (123 هكتار) لسماك القرموط (*Ictalurus punctatus*)، 107 حوض (46 هكتار) لأسماك الشبوط (*Cyprinus spp.*) و سبعة أحواض (4 هكتار) للقاروص (*Micropterus salmoides*). إن إنتاج الاستزراع التجاري وتربية الأحياء المائية القائمة على المصايد في عام 2008 تتألف من: البلطي 3789 طن و 76 229 طن (793 625 دولار أمريكي و 67 311 055 دولار أمريكي) على التوالي، مع قيمة إجمالية تصل 71 104 780 دولار أمريكي؛ وأسماك القرموط 970 و 207 طن (801 762 و 1 844 998 دولار أمريكي) مع قيمة إجمالية تصل إلى 5 646 760 دولار أمريكي؛ و الشبوط 570 و 23 588 طن (320 540 و 13 264 750 دولار أمريكي) بقيمة إجمالية عند 13 585 290 دولار أمريكي؛ والقاروص ذو الفم الكبير 1 و 1 220 طن (1 491 و 1 818 509 دولار أمريكي) بقيمة إجمالية 1 820 000 دولار أمريكي. ومن 2002 إلى 2008، حدثت أيضاً زيادة في أعداد الأحواض ومساحاتها. كما تميزت هذه الفترة كذلك بزيادة الاهتمام الحكومي (تم توفير برامج دعم متنوعة للقطاع على مستوى الولاية والكيان الفيدرالي لكل من مشاريع تربية الأحياء المائية الريفية والخاصة).

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

Mexico covers an area of 1 959 248 km², and its topography ranges from tropical coastal plains to deserts and mountains (Figure 1). The arid and semi-arid lands with annual rainfall lower than 250 mm are located mainly in the northern part of Mexico. This area extends over 604 048 km², which is equivalent to approximately one third of the total surface area of Mexico, and includes 11 states. The area of desert and arid lands as a proportion of total area in each of these states is as follows: Zacatecas (35.3 percent), San Luis Potosi (52.1 percent), Guanajuato (6.6 percent), Nuevo Leon (20.9 percent),

FIGURE 1
Maps of Mexico



Coahuila (73.0 percent), Durango (20.3 percent), Chihuahua (56.5 percent), Sonora (55.3 percent), Sinaloa (13.6 percent), Baja California (97.4 percent) and Baja California Sur (99.7 percent).

The contribution of each of these States to total aquaculture production in 2008 was as follows: Zacatecas (0.72 percent), San Luis Potosi (0.13 percent), Guanajuato (1.06 percent), Nuevo Leon (0.04 percent), Coahuila (0.33 percent), Durango (1.36 percent), Chihuahua (0.26 percent), Sonora (29.19 percent), Sinaloa (16.19 percent), Baja California (1.63 percent) and Baja California Sur (1.24 percent).

HUMAN RESOURCES

The lack of trained specialists in aquaculture is a problem for both federal and state programmes. Technical training programmes are necessary for both rural and commercial farmers, so that they can operate sustainably. Many important subjects need to be included in these programmes, including tank engineering, feeding, carrying capacity, water quality management, disease monitoring and control, and the introduction of new and improved aquaculture techniques.

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

There are a total of 521 aquaculture production units (including commercial aquaculture and capture-based aquaculture) in the 11 states with arid and desert lands. These units, which constitute 53.8 percent of the 967 that existed in the whole of Mexico, employed a total of 11 078 persons (INEGI, 2004).

Fish culture in the arid states is generally characterized by low investment and capitalization. Baja California is an exception because of the development of tuna farming. Even though aquaculture began almost 60 years ago in the inland states, such as Zacatecas, San Luis Potosi, Guanajuato, Coahuila, Durango and Chihuahua, it can still be regarded as a fairly new activity, with less than 10 years of true development.

Nowadays, aquaculture in Mexico is focused on two different strategies: rural and commercial aquaculture. Rural aquaculture produces fish at a subsistence level for local consumption (Juárez, de la Luz Flores and Luna, 2007). From its inception, tilapia and carp culture have been characterized by low yields, difficult access to regional markets and price fluctuation. Meanwhile, commercial aquaculture is focused on high volume output, either for national or international markets with better financing programmes. In 2006, rural aquaculture accounted for only 1.89 percent of the total production, while it was highest in 2007, at 4.89 percent. Rural aquaculture generally involves social organizations such as cooperatives, growers associations, civil societies, anonymous societies, family groups and private micro-industries. Those associated

TABLE 1

Aquaculture production units in the desert and arid lands of Mexico, including employment

State	Aquaculture production units	People employed in the aquaculture industry		
		Total	Male	Female
1) Zacatecas	139	323	301	22
2) San Luis Potosi	n/a	46	31	15
3) Guanajuato	46	5	5	0
4) Tamaulipas	13	169	150	19
5) Nuevo Leon	n/a	27	22	5
6) Coahuila	n/a	269	182	87
7) Durango	32	30	29	1
8) Chihuahua	10	269	182	87
9) Sonora	87	4 040	3 570	470
10) Sinaloa	162	5 494	5 147	347
11) Baja California	25	475	408	67
12) Baja California Sur	7	190	158	32

Source: INEGI, 2004.



with family groups were involved in trout production (56 percent), while cooperatives preferred carp production, and anonymous societies concentrated on tilapia production (30 percent). Rural aquaculture is promoted by federal and state programmes for self subsistence, mainly as a complementary activity (Torres, Martínez and Mendoza, 1999). Sonora and Sinaloa are the states with the highest commercial aquaculture production in Mexico (mainly shrimp culture), accounting for a total of 130 049 tonnes in 2008. In contrast, 5 328 tonnes of tilapia, catfish and carp were produced in

commercial aquaculture (together with 92 888 tonnes from capture-based aquaculture). The contribution of tilapia, catfish and carp to total aquaculture production was 3.6 percent.

In 2008, the total production (commercial aquaculture plus capture-base fisheries) of catfish, carp, largemouth bass, tilapia and rainbow trout from the arid/desert lands of Mexico was 23 886 tonnes or 25.8 percent of the overall national aquaculture production. Even though tilapia is the main species cultured in both commercial aquaculture and capture-based aquaculture, the contribution of the former to total tilapia production is insignificant. In fact, production decreased from 5.6 percent to 2.3 percent from 2002 to 2008.

The main species cultured in each of the desert and arid states are listed in Table 2.

In Mexico, shrimp farming is the most important sector of the aquaculture industry in terms of volume and value (Figure 2). In 2008, the total value of fisheries exports was USD401 557 000, of which shrimp formed 88.1 percent (35 962 tonnes with a value of USD353 784 000). Because of their differing importance for Mexico, the financing available for shrimp and fish aquaculture differs significantly. The Agriculture Related Trusts and Foreign Trade Mexican Bank (BANCOMEXT) finance, through diverse loans schemes, as much as 94.4 percent of the USD78 662 452 in shrimp culture related activities for the private and social sector (loans related to production, equipment, processing, for example) (CONAPESCA, 2008a, 2008b).

TABLE 2

Volume of aquaculture production (tonnes) in 2008 in the arid/desert States of Mexico produced in commercial and capture-based aquaculture

State	Catfish	Carps	Bass	Tilapia	Rainbow trout
1) Zacatecas	22	419	12	1 586	-
2) San Luis Potosi	68	67	-	243	-
3) Guanajuato	6	1 370	10	1 130	-
4) Tamaulipas	470	-	91	4 221	-
5) Nuevo Leon	17	32	16	44	-
6) Coahuila	78	651	2	123	-
7) Durango	717	897	588	890	213
8) Chihuahua	83	320	12	143	176
9) Sonora	268	244	1	753	-
10) Sinaloa	757	244	1	6 901	-
11) Baja California	-	-	-	-	-
12) Baja California Sur	-	-	-	-	-

Source: SAGARPA, 2009.

SECTOR PERFORMANCE

Aquaculture in the desert and arid lands of Mexico faces several problems that have to be solved in order to become viable. These are detailed in this section of the review.

PRODUCTION

Mexico has a total of eight reference hatcheries, and 17 support hatcheries managed by the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA – Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). The main species produced by these hatcheries are: largemouth black bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*), wuchang bream (*Megalobrama amblycephala*), common carp (*Cyprinus carpio*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), rainbow trout (*Oncorhynchus mykiss*), and garpique alligator (*Atractosteus spatula*). The species produced by these hatcheries are used to stock dams and lakes for capture-based aquaculture and/or aquaculture through federal, state and municipal programmes either for commercial or rural aquaculture. Breeding and genetics programmes within these hatcheries need to be implemented for the benefit of national aquaculture development.

The first challenge faced by producers is the high price of commercial pelleted feeds for tilapia, catfish and carp. Beyond the traditional states where commercial aquaculture is practised, access to fish feeds and other aquaculture supplies is difficult. Availability of feed and other supplies has to be improved to support aquaculture development in non-traditional aquaculture states.

New or improved culture technologies for inland aquatic species need to be promoted. These have to focus on pond design, construction and management throughout the production cycle. Proper water quality protocols that are specific for the region, producer, initial and final stocking densities, species and stage. Management must include feeding strategies throughout the cold and hot months, stocking and harvesting calendars, and transport and processing protocols. The same incentive must drive the development of new (or improved) processing equipment, as well as more competitive production lines.

In Mexico, there are several sanitary programmes that are oriented to monitor, control or eradicate diseases in several crustacean species such as white shrimp (*Litopenaeus vannamei*) and blue shrimp (*L. stylirostris*), as well as in finfish (carp, tilapia, rainbow trout) and molluscs (e.g. oysters and clams). For example, the Service of Food and Agriculture Health and Quality promotes sanitary programmes through extension services and training for aquaculture producers focusing on the application of good management practices in rainbow trout, tilapia, shrimp and oyster production. However, it is necessary to formalize a sanitary certification programme to be applied in all 32 federal entities, as this would result in a more competitive product on the market.

MARKET

In aquaculture, as in any other economic activity, the market is of extreme importance. In accessing all markets (regional, national and international), the commercialization of aquatic products has faced several difficulties in Mexico. Farm logistics, marketing and retailing, equipment, packaging, and quality certification are the main issues to be solved to ensure a successful aquaculture programme in Mexico.

Farm logistics – The lack of transportation (moving the product from the farm to the market) is one of the issues to be solved. This can be done by acquiring or developing transport routes to facilitate the distribution of aquaculture products.

Local retailing – Generally, aquaculture products are sold locally. Large wholesale companies and fish farms with the ability to market their own products are very few. One of the biggest constraints faced by rural and small commercial producers is the middleman. For example, the farm-gate price paid by the middleman in the case of eviscerated tilapia from capture-based aquaculture fluctuates between USD1.21 and 1.61/kg, while tilapia from farms fluctuates between USD1.45 and 1.77/kg. The final consumer normally pays (for whole eviscerated fish) between USD1.61 and 2.01/kg. The middleman sets the market price to maximize his profit margin. To solve this issue, it is important to create an organization that can regulate the interaction between the producer and the middleman. Usually, producers lack knowledge on sales and marketing, and it is becoming more important to develop specific technical training courses focused on techniques and simple models to access markets and market their production bypassing the middleman.

Regional marketing – The main issue for aquaculture producers is the absence of a developed local market that ensures a stable demand for their products. There is also a negative perception of aquaculture products that needs to be confronted. It is necessary to develop chains of supply and distribution between producers and retailers to create a constant demand for aquaculture products, as well developing an educational programme to promote the advantages of aquaculture products as a steady source of healthy, value for money food.

Three main wholesale distributors or groups share the market for aquatic products in Mexico: La Nueva Viga (51 percent of the market), a wholesale market situated in Mexico City; local farms (3 percent); and local retailers throughout the country (46 percent).

Mexican supreme quality certification – Although Mexico is the eighth largest producer of tilapia in the world, there is still a national unsatisfied demand of >30 000 tonnes of fish per year. The demand that is not satisfied by national production includes whole frozen fish (19 500 tonnes), fresh fish (5 000 tonnes) and fresh fillets (4 500 tonnes). A massive supply of imported cheap tilapia, possibly subsidized from China, Viet Nam and Taiwan Province of China, is well-established on the local market. Therefore suitable strategies need to be developed to increase productivity within the Mexican aquaculture industry, ultimately satisfying the existing deficit.

It is also important to develop an anti-dumping policy to focus on protecting national producers, as well as integrating complete production chains that will supply a product fulfilling premium quality standards, achieving quality aquatic products with a competitive edge that are suitable for international markets.

Good management practices – Besides the factors mentioned above, it is necessary to establish an operational framework that guarantees the safety of aquatic products for human consumption by implementing a risk reduction system at production and processing units. In 2001, SAGARPA and the National Health Service, Food Safety and Food Quality (SENASICA – Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria) began to establish policies, criteria, systems, strategies, programmes, procedures and services oriented to improve the quality of aquatic products destined for human consumption. Some of the health risks that derive from aquaculture practices are still not comprehended or envisioned; they are complex and can cause short- and medium-term impacts on human health, other aquatic organisms and the environment. To achieve sustainable aquaculture in terms of both environment and economy, it is necessary to adopt viable technology and good management practices, such as those drafted by SENASICA.

Good management practices include the following specific criteria:

- Careful site selection to ensure freedom from contamination.
- Decreasing the risk of biological and chemical contamination.
- Introducing general hygienic practices for farming systems and staff.
- Providing proper infrastructure (including sanitary facilities) and equipment. The production areas need to be properly designed with the appropriate space, and the functional layout must be considered for optimum overall performance. The number of sanitary facilities will depend on the number of workers in the farm.
- Establishing appropriate cleaning and disinfection programmes for all aquaculture facilities and equipment. This should include a written plan that must be in place in each facility and include pre-cleaning, pre-rinsing, cleaning, rinsing, disinfection, post-rinsing, storage and cleaning verification.
- Managing disposal including everyday activities such as garbage disposal, sanitary cleaning and disinfection, strategic provision of garbage cans, and protocols for the disposal of dead fish.
- Developing control systems to decrease disease problems by using appropriate infectious vector protocol prevention.
- Providing adequate water supplies, together with the production of potable ice.
- Ensuring proper sanitary criteria (a) to avoid the introduction of pathogens into the farms and (b) to improve the farming environment. These measures must include the acquisition of pathogen-free organisms, good ponds and tank maintenance during farming and down time, the control of wildlife to avoid the spread of diseases, and the control of domestic animals.

CONTRIBUTION TO THE ECONOMY

The contribution of aquaculture to food security, employment and poverty alleviation is extremely important in Mexico. Aquaculture has a substantial economic and social impact in this country; it generates direct employment for 350 000 individuals, and indirect employment for more than two million (INEGI, 2004). Even though the contribution of fisheries and aquaculture to the GDP of Mexico was a meagre 4 percent from the period 1999 to 2004, the importance it plays in the social role aspect is extremely important. In 2011, 18.2 percent of the Mexican population live in conditions of extreme poverty; because of this, the role of rural aquaculture is growing in importance as a viable mean of increasing employment opportunities. However, the low levels of consumption of fish and other aquatic organisms, due to cultural preferences, is the most limiting factor in developing this industry (Ramírez-Martínez and Sánchez, 1997).

Table 3 shows the status and trends of rural and commercial aquaculture production from 1994 to 2006. The objective of Mexico's National Programme for the Support of Rural Aquaculture (PRONAR) is to promote the development of aquaculture in marginal areas through fingerling supply, technical support provided by national institutions, economic resources to rehabilitate or construct facilities, equipment acquisition, and the provision of specialized technical assistance (FAO, 2006).

INSTITUTIONAL FRAMEWORK AND GOVERNING REGULATIONS

Information on the promotion and management of the sector, which includes the institutional framework, governing regulations, applied research, education and training, can be obtained by consulting the FAO National Aquaculture Sector Overview (NASO): www.fao.org/fishery/countrysector/naso_mexico/en

The agency in charge of Mexican aquaculture is the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA). Within SAGARPA, the National Commission on Aquaculture and Fisheries (CONAPESCA), being an administrative entity of SAGARPA, is responsible for management, coordination and policy development regarding the sustainable use and exploitation of fisheries and

TABLE 3
Rural, commercial and capture-based fisheries production in tonnes

Year	Total Aquaculture production	Rural aquaculture ^a			Commercial aquaculture			Capture based aquaculture ^c
		Production (Tonnes)	Coverage		Production (Tonnes)	Surface open for culture (ha)	Production units	Production (Tonnes)
			Communities (number)	Municipalities ^b (number)				
1994	171 389	2 630	–	219	19 874	–	–	148 885
1995	157 574	3 424	397	192	22 657	16 973	828	131 493
1996	169 211	5 915	1 314	295	20 069	20 112	1 135	143 227
1997	173 878	6 011	2 265	648	23 338	20 265	1 504	144 529
1998	159 781	8 897	2 255	560	29 713	20 437	1 618	121 171
1999	166 366	9 642	2 343	576	36 005	28 561	1 885	120 689
2000	188 158	9 515	2 334	558	40 834	31 460	1 898	137 809
2001	196 723	5 881	1 712	510	57 766	47 648	1 963	133 076
2002	187 485	4 068	1 451	429	53 298	51 869	2 445	130 119
2003	207 776	1 848	273	126	74 039	60 644	2 665	131 889
2004	220 359	7 230	629	389	81 705	60 981	2 849	131 424
2005	238 081	11 646	847	418	95 243	62 723	2 941	131 192
2006	249 050	4 727	369	201	113 354	64 464	3 033	130 959

^a Includes all production units in poor areas in all 32 states covered by the Rural Aquaculture Programme.

^b Each one of the 32 states is politically divided into Municipalities.

^c Mainly carps, trout, tilapia and shrimp.

aquatic resources. The commission has the support of the National Fisheries Institute (Instituto Nacional de la Pesca, INAPESCA), which is another administrative entity of SAGARPA. Through SAGARPA, the Rural Aquaculture National Programme was created. The role of this programme is to provide rural communities with technical assistance, training and technology transfer to improve aquaculture production. It is within this programme that special attention will be provided for the creation of rural supply chains, brand creation, traceability follow up, disease control and final product quality control. A legal framework has been devised to regulate aquaculture activities.

APPLIED RESEARCH, EDUCATION AND TRAINING

Aquaculture research is becoming more important for the development of the aquaculture industry. Several universities and research centres offer graduate programmes (Masters and PhD degrees), the most important being the Instituto Tecnológico del Mar No. 1 in Veracruz; the Centro de Investigaciones Biológicas del Noroeste (CIBNOR); the Centro de Investigación en Alimentación y Desarrollo (CIAD); and the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE).

Aquaculture research by INAPESCA has increased the interaction between producers and the academic sector through the National Network for Research in Aquaculture. This network consists of a total of 760 members belonging to 120 institutions from all over the country. Research topics include sanitary aspects on the handling of the white spot syndrome viral disease in shrimp and disease prevention and sanitary control in oysters and clams. Regarding nutrition, research projects have focused on the digestibility of commercial feeds, with the aim of diminishing their impact on the environment

TRENDS, ISSUES AND DEVELOPMENT

Aquaculture in the desert and arid lands of Mexico occurs in two different areas: (i) inland states (Zacatecas, San Luis Potosi, Guanajuato, Nuevo Leon, Coahuila, Durango and Chihuahua), where 58.24 percent of the total area is desert and arid lands; and (ii) coastland states (Sonora, Sinaloa, Baja California and Baja California Sur),

where 41.75 percent of the total area is desert and arid lands. The contribution of both inland and coastal states to the total aquaculture production in 2008 was 52 percent (4 percent inland states; 48 percent coastland states).

In all eleven states with desert and arid lands, aquaculture was mainly focused on fresh water species such as tilapia, instead of native species, until developments with marine and brackishwater species occurred; the production value of these has since surpassed freshwater aquaculture. Today, 18.78 percent of total tuna production comes from aquaculture (with a net value of USD17 295 916). Crustacean aquaculture plays an important role in the economy of the northwestern Pacific Region of Mexico. Unlike other aquatic species, shrimp farming has undergone significant technological development and has become a high quality food item of major importance as an export product (Álvarez and Avilés, 1995). The farming of molluscs has also made some progress, particularly of oysters (*Crassostrea gigas*, *C. corteziensis*), mussels (*Mytilus edulis*) and abalone (*Haliotis rufescens*). Research on improved technological practices has recently widened interest in other species such as clams, native scallops (pen shells *Pinna rugosa* and *Atrina maura* and lion's paws *Liropecten subnudus*), pearl oysters (*Pinctada mazatlanica*) and wing oysters (*Pteria sterna*) (SEMARNAP, 1995). The most widely cultured fish are the tilapias, which have been stocked in reservoirs and water bodies in various regions of the country enabled by the hatchery production of fingerlings. Tilapia culture contributes over 60 percent of the total farmed fish production.

For the desert and arid inland and coastal states, there are specific and common issues that have to be addressed. In the inland states, the three main issues that have an effect on aquaculture development are diseases, low product prices and high costs of production.

Fish diseases of bacterial, parasitic and viral origin, even when detected on time, they usually kill the fish due to the lack of proper medication and/or treatments. Proper disease screening programmes are still in development and new diseases are appearing in the freshwater aquaculture industry in Mexico such as *Streptococcus iniae* and *Flexibacter columnaris*.

The low prices of the main freshwater species cultured such as tilapia, carp, catfish and largemouth bass usually make aquaculture unattractive for the private investor and it has become a social activity funded by federal and state programmes. Social aquaculture in inland states is characterized by production units that usually consist of one to six 28–79 m³ circular liner tanks with or without a greenhouse. Aquaculture social programmes usually provide a specific short-term benefit (immediate working opportunity) without addressing economies of scale or investment in the production chain. In the medium term, this will eventually translate for the farmer (programme beneficiary) into poor prices, little or no access to markets (local, regional or national). In addition, once the programme ends, farmers without an education in administration usually find it difficult to continue producing fish at a competitive price. In recent years in Mexico, the growth rate of the fish feed industry has been higher than the rate at which ingredients (corn, wheat, soybean and cottonseed meal) can be produced (CONAPESCA, 2008a). The variable price of fishmeal and the uncertainty in its supply, directly affect the small-scale farmers or the beneficiaries of social aquaculture programme because they cannot afford purchasing of fish feed without subsidy or support of State or Federal Funds.

For the coastal states, biosecurity, breeding and genetic improvement programmes, sanitary certification and better quality of seed (fish, several bivalve species and shrimp) are the main issues to address (in coastal states shrimp – and more recently molluscs – are the main species cultured). Molluscan sanitary culture problems are serious issues for oyster producers, as are juvenile mortality due to low genetic diversity and the presence of *Perkinsus marinus*, *Vibrio cholera*, *V. parahaemolyticus* and *Salmonella* spp.

in oyster culture all along the coastal states. Early diagnostic and routine detection programmes *in situ* need to be improved to develop an effective control of diseases. For fish, the sanitary issues are similar to those present in the desert and arid inland states. Shrimp are by far the main aquaculture product for the desert and arid coastal states. However, in recent years this industry has experienced several setbacks where white spot syndrome virus (WSSV), Taura syndrome virus (TSV) and the yellowhead virus (YHV) have played a key role, translating into important economical losses for the region. The most common bacterial infection is related to *Vibrio* spp. and the necrotizing hepatopancreatitis bacterium (NHPB).

For both inland and coastal states with arid and desert lands, water quality and effluent management, the availability of commercial diets, environmental, social and economic sustainability are common issues that need to be addressed and solved, as noted below.

Apart from balanced commercial shrimp diets, feeds for finfish present several challenges to be solved, including:

- developing new and effective means of incorporating free amino acids, enzymes, chemoattractants, probiotics and immunostimulants;
- improving fish feed formulations and manufacturing processes to increase shelf life; and
- improving integration between fish feed manufacturing plants, distributors and farmers.

The development of good management practices at the farm level is also important, including:

- improved culture techniques;
- better pond fertilization protocols; and
- the selection of fish that are in low trophic levels.

Environmental sustainability issues related to desert and arid land states that need to be addressed are:

- developing specific programmes that focus on the carrying capacity of water reservoirs;
- the legal regulation of water usage and effluent disposal; and
- the development of state aquaculture zonification programmes.

Social sustainability issues related to desert and arid land states that need to be addressed are:

- new programmes that will provide training in the organization of production units;
- the creation of Value Networks Strengthening and Establishment Programmes (state and national) that will strengthen the producer by selling directly to the market avoiding the middleman; and
- the implementation of specific extension programmes for arid and desert aquaculture.

Economic sustainability issues related to desert and arid land states include:

- the creation of federal support programmes (firstly for tilapia and catfish) similar to those used by the poultry industry;
- implementing the formation of trusts with liquid funds and seed capital for desert aquaculture programmes;
- developing programmes focused on aquaculture economics and administration; and
- providing risk capital special funds (for social aquaculture).

Aquaculture represents 16.25 percent of the total fisheries production, although it is estimated that aquaculture has the potential to represent up to 40 percent within 10 to 15 years. However, its development has been slow, as a result of a variety of factors, including:

- poorly oriented aquaculture development policies;

- loans with high interest rates;
- low profit margins;
- high cost of fingerlings and feed;
- periodic changes within government and its related institutions;
- lack of information;
- lack of technical assistance;
- little or no access to potential markets;
- difficult access to new production technologies;
- lack of private investment;
- lack of market studies;
- lack of interest in aquaculture research;
- lack of infrastructure;
- poor use of basic scientific and technical knowledge;
- deficiencies in the availability of funds for development; and
- lack of a legal framework for guaranteed legal land tenure to facilitate the provision of services from banks and other financial institutions, especially in coastal areas.

Despite positive contributions to society and the economy, aquaculture development in Mexico is still far below its actual potential. Mexico has great opportunities to contribute to food security and rural development throughout the country through aquaculture. Aquaculture expansion should be carefully promoted, considering the beneficial impact it could have on the environment. Particular attention should be paid to global strategies and guidelines such as the FAO Code of Conduct for Responsible Fisheries (FAO, 1995).

The diverse climate of Mexico contributes to a variety of climatic conditions and ecosystems which aid the development of a diversified aquaculture sector. The current aquaculture development plan foresees different levels of actions to achieve better performance for small-scale subsistence aquaculture, stock enhancement activities and commercial aquaculture, all of which are consistently linked with socio-economic and environmental aspects.

Aquaculture products must first meet regional, national and specific international standards related to environmental protection of natural resources, and also including post-harvest processing and handling. To achieve these diverse standards, an increase in production costs will occur; in some cases this may inhibit the commercial market potential because a lack of funding to fulfil these standards.

The contribution of aquaculture to economic and social development depends on adequate plans within the context of environmental management. Of particular concern are the uncontrolled use of inland water resources and the rapid environmental degradation of the coast (Álvarez, 1996).

The PRONAR main objective is to encourage investment in small-scale projects through the distribution of financial support to rural producers for the creation of efficient production units capable of integrating and competing within aquaculture and fisheries chains. The programme is coordinated with the actions of state governments to fulfil the needs of poor producers with such issues as technical assistance, training, studies, infrastructure (new buildings and rehabilitation), equipment, input acquisitions, establishment of demonstration or pilot scale units, and the development of productive projects as an alternative to inland fisheries. Up to 2011, 343 rural production units have received support of various kinds, including the rehabilitation of impoundments and ponds; the construction of earthen ponds and floating cages for tilapia culture; construction of four demonstration units for the cultivation of marine fish and molluscs; acquisition for the monitoring of physical and chemical parameters, scales, water pumps, freezers, etc.; provision of technical assistance and training, etc. The former actions have benefited a total of 4 129 rural producers located in 369 communities belonging to 201 municipalities of the country (SAGARPA, 2006).

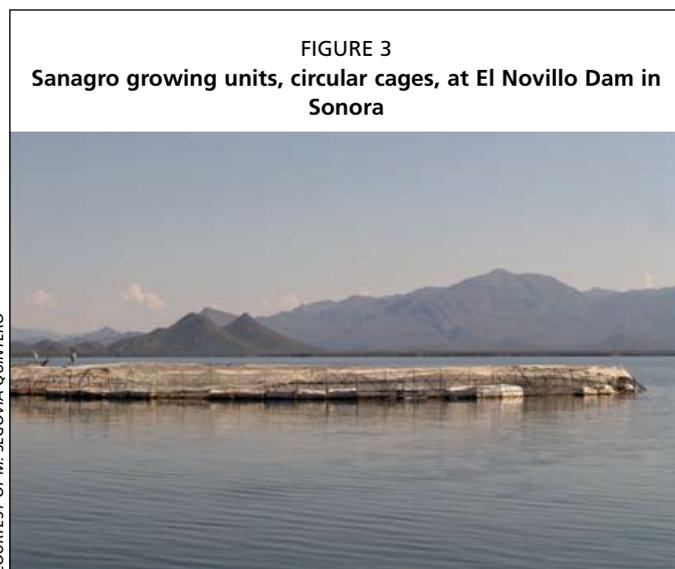
With regard to aquatic health, the System of Information on Diagnostic Results of the Laboratory Network has been established to provide information to CONAPESCA and SENASICA on high-risk diseases in aquaculture. Also, state Aquaculture Health Committees have been established as auxiliary entities for the prevention, diagnosis and control of aquaculture diseases; these committees also promote sanitation campaigns (SAGARPA, 2004). At present, there are 17 Aquaculture Health Committees belonging to the States of Aguascalientes, Baja California, Baja California Sur, Chihuahua, Mexico, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Sinaloa, Sonora, Tabasco, Tamaulipas, Tlaxcala, Puebla and Veracruz.

The Aquaculture and Fishing Programme (Alianza Contigo) of CONAPESCA provides subsidies to benefit the fisheries and aquaculture sectors of the country with the intention of promoting the competitiveness of the production units and ensuring the sustainable and rational use of resources. In 2003, a total of 243 projects were approved, with a total investment value of 122 million pesos (USD11 million), benefiting 25 000 people. In 2004, a total of 63 projects were approved, with a total investment value of 85 million pesos (USD7.17 million) distributed throughout 12 States. With this programme, fisheries and aquaculture production chains are being consolidated, moving the sector towards the cultivation of species with greater development potential and helping low income social groups to access profitable productive activities. In response to deficiencies shown in the applications submitted to the Alianza Contigo in 2003, technical assistance and training was provided to fisheries and aquaculture producers in project feasibility. Emphasis has also been made on subject areas ranging from managerial and administrative abilities to quality, health and safety of products.

In Mexico, fishing and aquaculture production chains have been initiated by the Value Networks Strengthening and Establishment Programme with the main objective of consolidating fishing and aquaculture productive units in value networks coordinated through the Productive Systems Committees. These committees aim to improve the organizational and productive skills of the producers, creating high aggregated value products that can compete in national and international markets (SAGARPA, 2004).

SUCCESS STORIES

Four reference or main federal hatcheries and one private hatchery are located in the desert and arid lands of Mexico.



Sanagro, a private hatchery, is by far the largest fingerling producer in Mexico, producing 12 million fry/year. Sanagro is located in the State of Sonora and is subdivided into three production units. The hatchery is 18 km from the capital of Sonora, Hermosillo (average precipitation rate 200 mm). The tilapia grow-out production units are the Sanagro Coastal Unit and the Novillo Dam Unit (Figure 3). At the Sanagro Coastal Unit, tilapia are reared in earthen ponds in a 14-month production cycle, while at the Novillo Dam Unit a 12-month cycle is obtained. At the Novillo Dam, besides the tilapia produced by Sanagro, a capture-based

fishery for tilapia and catfish (325 tonnes and 114 tonnes, respectively) is operated by local cooperatives. The merits of Sanagro derive from its aquaculture operation and stocking programmes, which have provided both direct and indirect employment in the region.

Acuicultura del Desierto, a small business operated by its owner in the state of Baja California, is the only farm in the region that operates an aquaponics operation. This small operation annually produces 7.5 tonnes of tilapia, 13 tonnes of cherry tomatoes, 20 tonnes of gourmet zucchinis and almost one tonne of lettuce and basil. Acuicultura del Desierto has been able to operate successfully and prosper through using aquaponics technology; it is becoming a model for other aquaculture enterprises in the region.

WAY FORWARD

Further development of aquaculture in Mexico depends on the successful application of efficient technologies, innovation, modernization and conversion processes. Although there have been several recent research projects conducted by academic institutions aimed at developing techniques for the farming of native species, there is a clear need for the creation of a national coordination mechanism to take advantage of the current national research capacity and available infrastructure in order to obtain beneficial results for the culture of native species.

In coastal states with desert and arid lands, aquaculture will follow three different trends, namely oyster, shrimp and marine fish farming. Freshwater aquaculture is expected to remain focused on social aquaculture in these coastal states. In the inland states, tilapia culture will be the major focus for federal, state and university research. New genetic programmes with new tilapia strains are being developed by a research centre (CIBNOR) that have improved growth rates and yields. Biofloc technology will be tested; among the advantages of this new technique are lower unit tilapia production costs, all year production, and an improved control of water quality. In Mexico, there is an unsatisfied annual demand for 35 000 tonnes of tilapia. A National Tilapia Value Network has been formed to address specific problems within the production chain such as the application of tariffs for Chinese tilapia imports and the development of a Mexican quality brand.

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Aquaculture in desert and arid lands Development constraints and opportunities

FAO Technical Workshop
6–9 July 2010
Hermosillo, Mexico

Modern technologies and alternative energy sources have allowed the expansion of aquaculture in deserts and arid regions over the last decade. The current status of desert aquaculture, developmental constraints and opportunities, were discussed at the FAO technical workshop held in Hermosillo, Mexico, in July 2010. The organization of this workshop resulted from the growing interest of numerous countries with vast desert areas to develop this food production sector and the desire to make better use of the limited water resources available in these harsh environments. This publication presents the recent experiences of desert and arid land aquaculture in seven countries and regions across the globe (Australia, Egypt, Israel, Mexico, Southern Africa, the United States of America, and Central Asia) describing the achievements of a number of farming operations, and the potential of using geothermal, surface and underground fresh and brackish waters. Furthermore, the global overview on desert aquaculture illustrates, with the use of maps and tables, those countries with vast extensions of arid territories that have the potential of further develop this industry. The document also provides recommendations on how to promote and expand this aquaculture subsector. Limited water supply remains the single largest developmental constraint, however, where the resource is available, the development of integrated aqua-agriculture systems may provide economic output opportunities from such resource-limited regions.

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