Contributed papers

Global desert aquaculture at a glance

Valerio Crespi
Department of Fisheries and Aquaculture
Food and Agriculture Organization of the United Nations. Rome, Italy
E-mail: Valerio.Crespi@fao.org

Alessandro Lovatelli
Department of Fisheries and Aquaculture
Food and Agriculture Organization of the United Nations. Rome, Italy
E-mail: Alessandro.Lovatelli@fao.org

Crespi, V. & Lovatelli, A. 2011. Global desert aquaculture at a glance. *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. 25–37.

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

INTRODUCTION

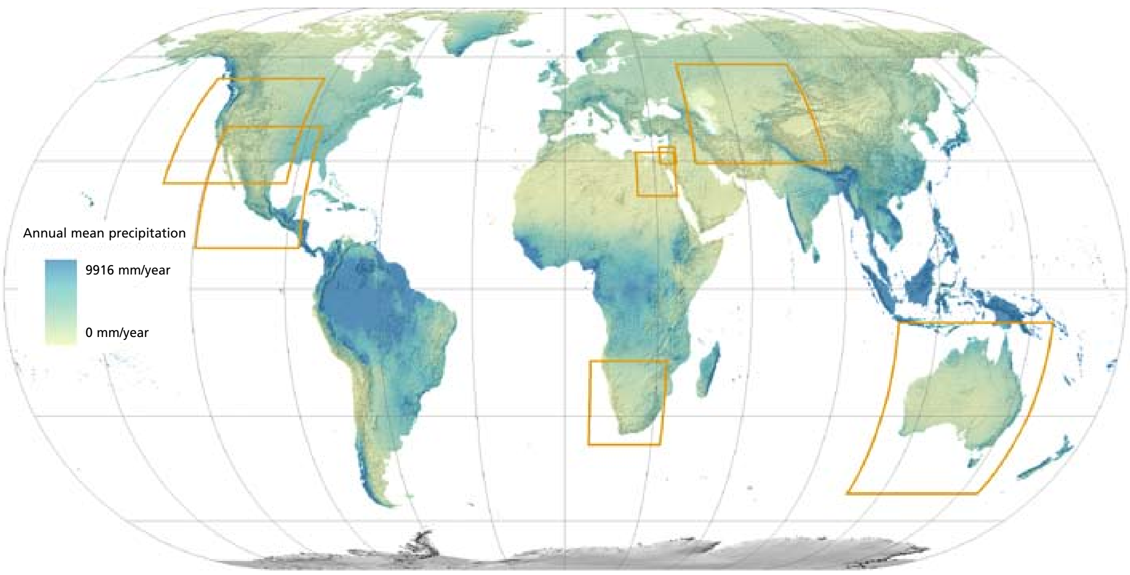
This paper provides a brief introduction on desert and arid land aquaculture highlighting the main physical characteristics of this environment and identifying the foremost limiting factors hampering the development of this industry subsector. Furthermore, this chapter is an introduction to the review 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.

FIGURE 1
Annual mean precipitation levels across the globe. The seven desert and arid land regions covered in the FAO review delimited by orange frames



Source: Data provided by www.worldclim.org. Web site accessed on June 2011.

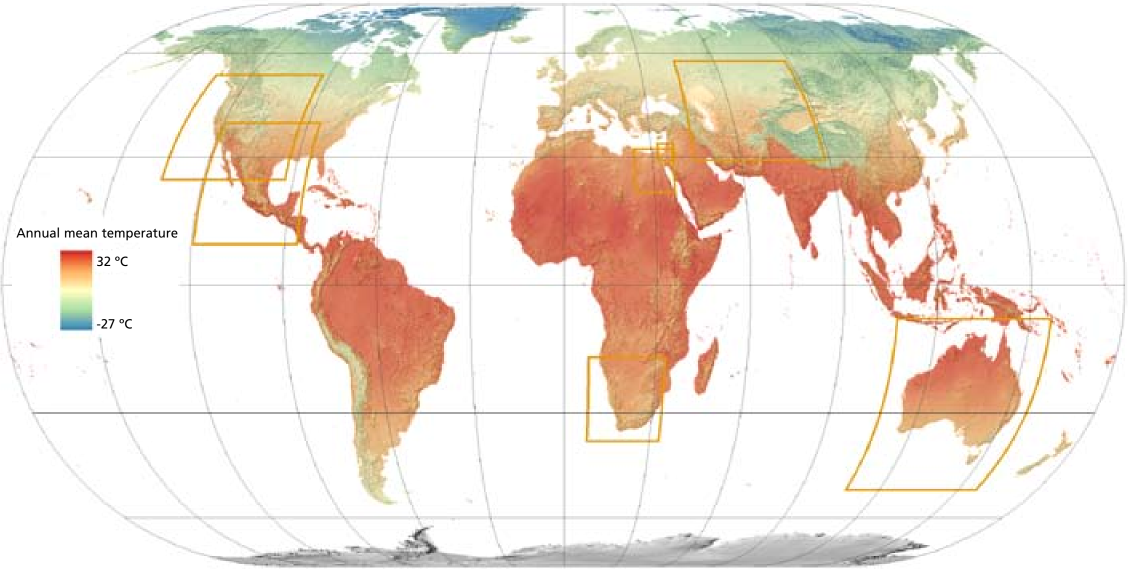
The global population growth and increase in food demand is driving the rapid expansion and intensification of cultivated lands. This, along with increasing evapotransportation and the decrease in rainfall, possibly also as a result of global climate changes, are certainly contributing to the desertification 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 km^2 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).

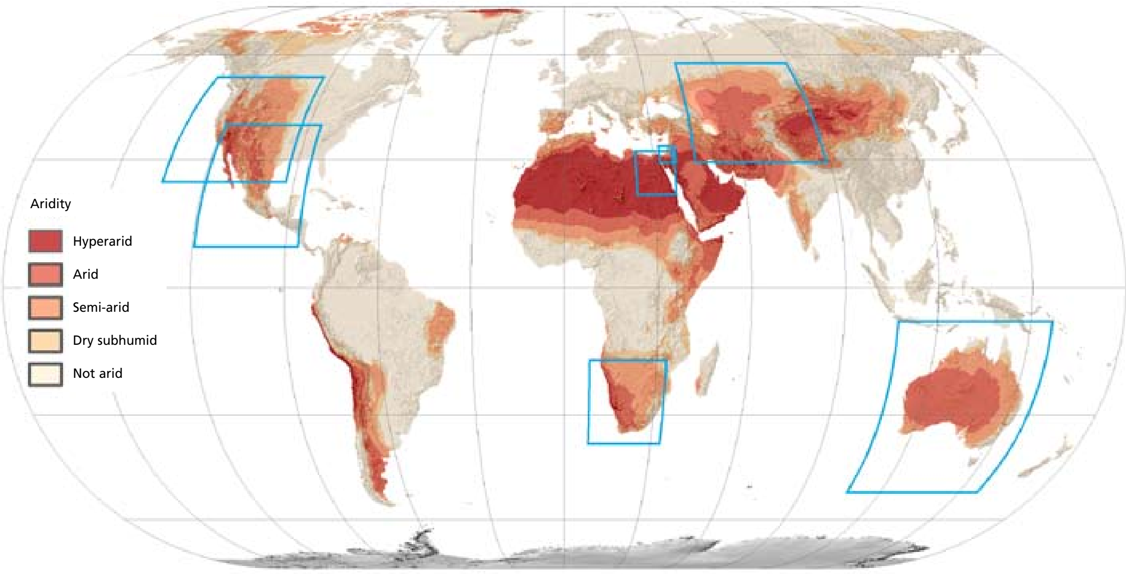
Current and future developments of inland aquaculture in such areas will rely greatly on the appropriate use of subsurface waters using farming technologies which ensure the conservative use of this limited resource. The constant growth of the human population and the continuous exploitation for land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

FIGURE 2
Annual mean temperature levels across the globe. The seven desert and arid land regions covered in the FAO review delimited by orange frames



Source: Data provided by www.worldclim.org. Web site accessed on June 2011.

FIGURE 3
Map of the world drylands



Hyperarid = areas that have very limited and highly variable rainfall amounts, both interannually and on a monthly basis; **Arid** = areas that have mean annual precipitation up to about 200 mm in winter rainfall areas and 300 mm in summer rainfall areas; interannual variability in the 50–100 percent range; **Semi-arid** = areas with highly seasonal rainfall regimes and mean annual values up to about 800 mm in summer rainfall areas and about 500 mm in winter rainfall areas; high (25–50) percent interannual variability.

Source: Adapted from Smith *et al.*, 2008.

Source: New *et al.*, 2002; data available from www.fao.org/geonetwork/srv/en/main.home. Data accessed on June 2011.

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
Middle East	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	–
	Gurbantünggüt	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	–

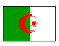
For comparison, below is the surface area in km² of selected countries:

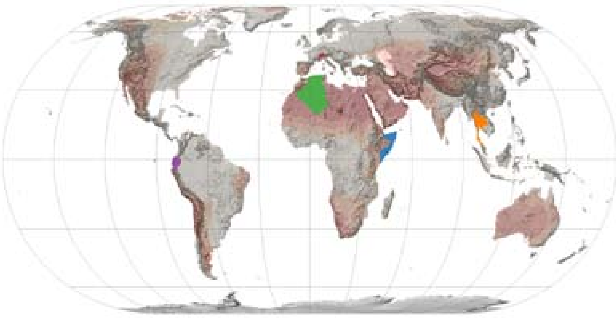
Switzerland  = 41 293 km²

Ecuador  = 272 045 km²

Thailand  = 513 115 km²

Somalia  = 637 657 km²

Algeria  = 2 381 741 km²



[1] *Source:* From different Internet sources.
[2] *Source:* FAO. www.fao.org/nr/land/information-resources/terrastat/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/m^3 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 mulloway (*Argyrosomus japonicus*) and the rainbow trout (*Oncorynchus 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 ß-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 (Rakocy, 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

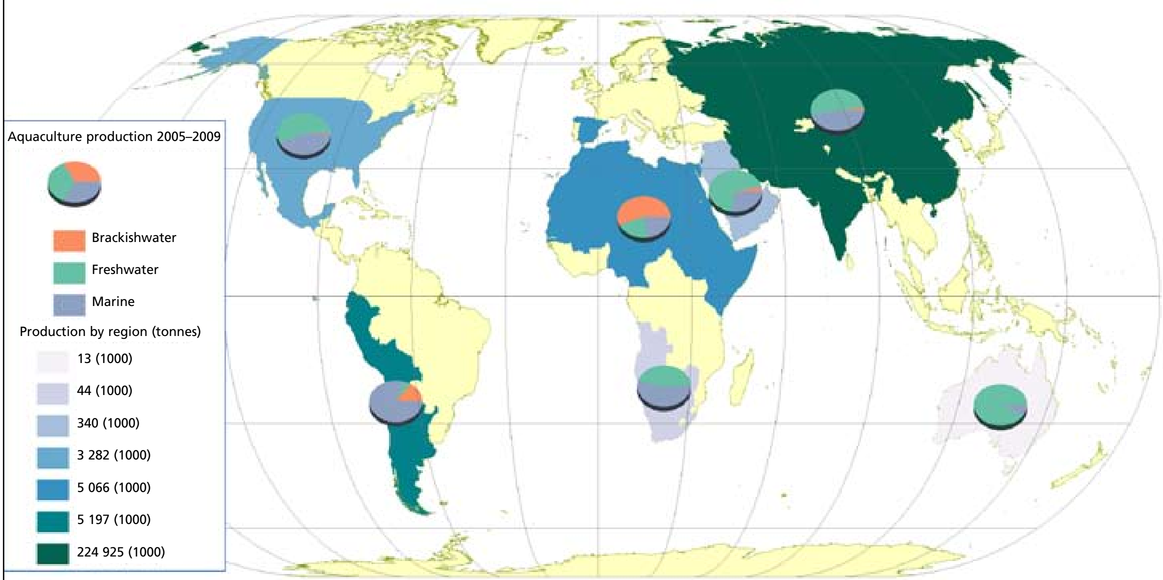
The FAO aquaculture production statistics are currently available for a large number of farmed species and can easily be sorted by the production environment, i.e. whether the species has been produced in the marine, brackish water or the freshwater environment. Unfortunately, it is not possible to extrapolate 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 (*Penaues indicus*) in high salinity waters. The success of shrimp production has lead 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

FIGURE 4
Global map with aquaculture production by environment and production levels by region



Source: Map prepared by the authors and based on data from FAO, Aquaculture Production (Quantities and values) 1950–2009 (Release date: March 2011).

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	• High temperatures, solar radiation and scarce precipitation • Low water exchange rate • Risks of water salinization	• 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	• High evaporation rates • High temperature variations	• 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	• High cost of water • Competition in the use of limited water resources	• 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	• Exceeded aquaculture production	• 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)	• Increasing soil salinization • Low oxygen level	• 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)	• Construction costs	• Use of existing ponds and reservoirs • Involvement of local farmer communities
Abundant inexpensive land	• Limited surface and subsurface water supplies	• Closed recirculation aquaculture system • Integrated aquaculture-agriculture systems • Desalinization • Mariculture
Integration of aquaculture with agriculture	• Reluctance of farmers to use recycled water from fish ponds • Poor technical capacity and trained personnel	• 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	• Low promotion and limited private and governmental funds	• 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.

REFERENCES

Ayala, F. & Vargas, T. 1987. *Experiments on* Spirulina *culture on waste-effluent media and at the pilot plant*. Twelfth International Seaweed Symposium. M.A. Ragan & C.J. Bird (eds.). Hydrobiologia, 151/152: 91–93.

Benemann, J.R. 2008. *Opportunities and challenges in algae biofuels production.* [online]. Position paper by Dr. John R. Benemann in line with Algae World 2008. 15 pp. [cited 14 October 2011]. www.futureenergyevents.com/algae/whitepaper/algae_positionpaper.pdf

Crespi, V. 2009. *Support to the development of desert aquaculture and management of the brackish water lakes in Algeria*. FAO Aquaculture Newsletters 43. pp. 20–22. FAO. Rome.

FAO. 1996. *Precautionary approach to capture fisheries and species introduction*. FAO Technical Guidelines for Responsible Fisheries. No. 2. Rome. 54 pp. (also available at ftp://ftp.fao.org/docrep/fao/003/W3592e/W3592e00.pdf).

FAO. 2007. Aq*uaculture development. 2. Health management for responsible movement of live aquatic animals*. FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 2. Rome. 31 pp. (also available at www.fao.org/docrep/010/a1108e/a1108e00.htm).

FAO. 2010. *The state of world fisheries and aquaculture 2010*. Rome. 197 pp. (also available at www.fao.org/docrep/013/i1820e/i1820e.pdf).

FAO. 2011. *Global map of aridity – 10 arc minutes* [online]. Rome [Cited 14 October 2011]. www.fao.org/geonetwork/srv/en/metadata.show?id=37040

FAO Fisheries Department. 2011. *World aquaculture 2010*. FAO Fisheries and Aquaculture Technical Paper. No. 500/1. Rome. 105 pp.

Fishelson, L. & Loya, Y. 1969. *Experiments on rearing Tilapia-hybrids in brackish water pond near the Dead Sea*. Limnology, 17: 602–610.

Goodin, J.R. & Northington, D.K. (eds.). 1985. *Plant resources of arid and semiarid lands. A global perspective.* Academic Press, Inc., Orlando, Florida. 338 pp.

Habib, M.A.B., Parvin, M., Huntington, T.C. & Hasan, M.R. 2008. *A review on culture, production and use of Spirulina as food for humans and feeds for domestic animals and fish*. FAO Fisheries and Aquaculture Circular. No. 1034. Rome. 33 pp.

Hochman, E. & Brill, E. 1994. *Fish production in a super-intensive controlled system in the Israeli Desert*. *In* Y.C. Shang, P.S. Leung, C.S. Lee, M.S. Su & I.C. Liao (eds.) Socio-economics of aquaculture. Tungkang Marine Laboratory Conference Proceedings, 4: 281–295.

Kolkovski, S., Simon, Y., Hulata, G. & Ayaril, N. 2011. *Desert aquaculture.* pp. 107–125. *In* Aquaculture: Farming Aquatic Animals and Plants. Second Edition. J.S. Lucas & P.C. Southgate (eds.) Paperback Wiley-Blackwell 648 pp.

McMurtry, M.R., Sanders, D.C., Cure, J.D., Hodson, R.G., Haning, B.C. & St. Amand, P.C. 1997. *Efficiency of water use of an integrated fish/vegetable co-culture system*. Journal of the World Aquaculture Society, 28: 4.

Mires, D. 2000. *Development of inland aquaculture in arid climates: water utilization strategies applied in Israel*. Fisheries Management and Ecology, 7: 189–195.

New, M., Lister, D., Hulme, M. & Makin, I. 2002. *A high-resolution data set of surface climate over global land areas*. Climate Research, 21: 1–25.

Pruginin, Y., Fishelson, L. & Koren, A. 1988. *Intensive tilapia farming in brackishwater from an Israeli desert aquifer*. pp. 75–81. *In* R.S.V. Pullin, T. Bhukaswan, K. Tonguthai & J.L. Maclean (eds). The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15, 623 pp. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Rakocy, J.E. 1989. *Vegetable hydroponics and fish culture: a productive interface*. World Aquaculture Society, 20: 42–47.

Richmond, A. & Preiss, K. 1980. *The biotechnology of alga culture*. Interdisciplinary Science Reviews, 5(1): 60–70.

Sadek, S., Sabry, M. & El-Samadony, E. 2011. *Fish and shrimp culture in salt ground water of Rula Land Reclamation Land Company, Wadi-Group, Egypt: lessons of the first three years (2008–2011)*. *In* Integrated aquaculture – agriculture in Egypt towards more efficient use of water resources workshop, 21 April 2011, Cairo, Egypt. The Netherlands, Wageningen University, Centre for Development Innovation, and Cairo, Egyptian Fish Council. 9 pp.

Smith, M., Veth, P., Hiscock, P. & Wallis, L.A. 2008. *Global desert in perspective*. pp. 1–14. *In* Desert peoples: archaeological perspectives. Smith, M., Veth, P. & Hiscock, P. (eds.). Blackwell Publishing. 320 pp.

Suloma, A. & Ogata, H.Y. 2006. *Future of rice-fish culture, desert aquaculture and feed development in Africa: the case of Egypt as the leading country in Africa*. JARQ, 40(4): 351–360.

United Nations Convention to Combat Desertification (UNCCD). 2007. *Desertification, exacerbated by climate change, represents one of the greatest environmental challenges of our times*. [online]. UNCCD thematic fact sheet series No. 1. Climate change and desertification. [cited 14 October 2011]. www.unccd.int/documents/Desertificationandclimatechange.pdf.