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.

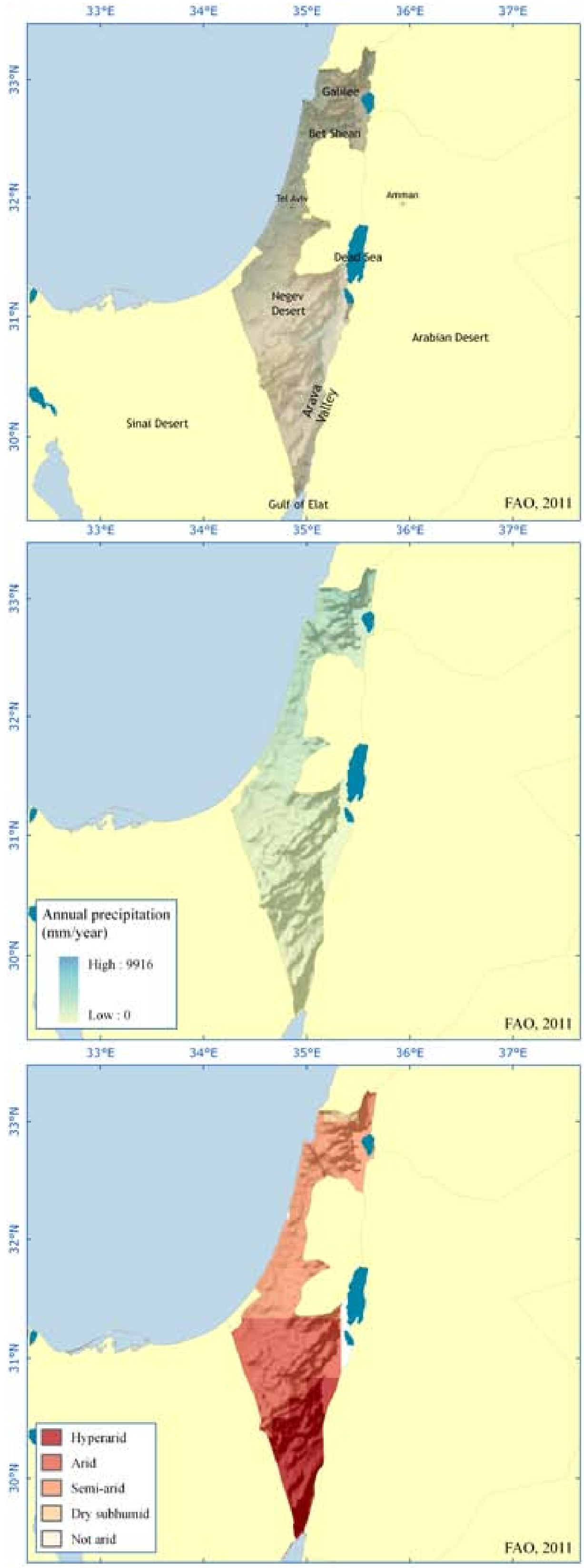
RÉSUMÉ

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 عرفة؛ 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، فان 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 لابد من تخفيض حصص المياه للقطاع بشكل كبير مما سبب خفض في الإنتاجية الزراعية. وبالرغم من القيود المناخية الواضحة والنقص العام في المياه، فان 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 اسماك طازجة صالحة للأكل، وتتضمن: (i) خزانات لتخزين مياه الامطار 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 الصلبه؛ (iii) أنظمة التدوير عالية الكثافة والتي تتضمن أنظمة فلترة المياه، مثل مرشحات البرميل، والمرشحات البيولوجية، ومزيلة 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



Israel

Country area: 2207 (1000 Ha)
Source: FAOSTAT. Estimated, 2007

Land area: 2164 (1000 Ha)
Source: FAOSTAT. Estimated, 2007

Agricultural area: 501 (1000 Ha)
Source: FAOSTAT. Official data, 2007

Aquaculture Production Average 2004-2008: 19225 tonnes
Source: FISHSTAT. Official data

Aridity:
Approx. areas of hyperarid regime: 474 (1000 Ha)
Approx. areas of arid regime: 859 (1000 Ha)

A typical landscape of an arid region in Israel

COURTESY OF A. CNAANI

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. ان فكرة استخدام المياه الجوفية الساخنة في تربية الأحياء المائية عالية التكثيف، 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. ان مناطق بيسان ووادي الأردن وجبل جلبوع تقوم بزراعة 60 في المائة من الكارب العام او الشبوط الشائع (*Cyprinus carpio*) 82 في المائة من البلطي و 78 في المائة من البوري مفلطح الرأس (*Mugil cephalus*) المنتج في اسرائيل، وسوية تمثل 3 في المائة من إجمالي إنتاج تربية الأحياء المائية. وتقوم النقب بتربية جميع اسماك القاروص `*Lates calcarifer*) والكوفر ذهبي الرأس او ما يسمى بالقجاج (*Sparus aurata*) المستزرع في المياه شبه المالحة ونصف القاروص المقلم (*Morone chrysops* x *M. saxatilis*)، ويمثل ما نسبته أقل من 3 في المائة من إجمالي إنتاج تربية الأحياء المائية. وخلال العقد الأخير، فان 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، فان أسباب الفشل كانت أخطاء إدارية قام بها المالكون او 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 لاتوجد مشاريع جديدة تظهر اهتماما في البدء بمزارع جديدة، او تنعش التي تم إغلاقها حديثا. وقد تم تطوير قطاع بديل لتربية اسماك الزينة والذي يزدهر ولديه الإمكانية الكبيرة للتوسع. ان تربية الأسماك في المنطقة الجافة تزدهر حيث تكون التنمية أكثر على الأرجح، مع ان حتى في هذه الحالة، فان 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 km^2. 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 PROBLEM[1]

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 m^3, 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 m^3, 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 m^3), the Coastal Aquifer – along the coastal plain of the Mediterranean Sea (320 million m^3), and the Mountain Aquifer – under the central north-south (Carmel) mountain range (370 million m^3). 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 m^3.

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 m^3 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 m^3 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							
		Water sources					
Year	Population (Million)	Surface water	Ground water	Brackish	Treated effluents	Desalination	Total
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						
		Water sources				
Year	Urban sector	Natural	Brackish	Waste water effluents	Total	Total
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.

FIGURE 2
Israel national water supply system

Source: Mekorot Water Company.

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 m^3 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).

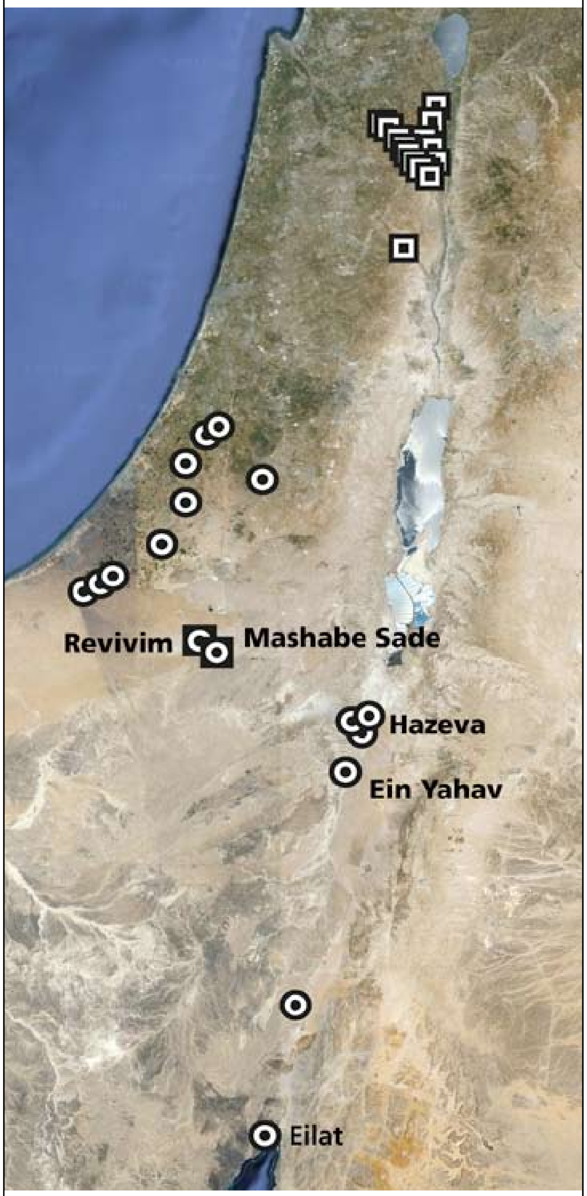
The southern (desert) half of the country is sparsely inhabited – only around 15 percent of the population live there at a population density of 76/km^2 (compared to national density of nearly 330/km^2, and to 7 425/km^2 in the dense urban area of Tel Aviv district). Unemployment in 2010 was a little 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).

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



Note: Data inserted in a Google Earth image.

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 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/m^3 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 m^2 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

FIGURE 4
A fish farm reservoir (low water level) in the arid Bet Shean Valley

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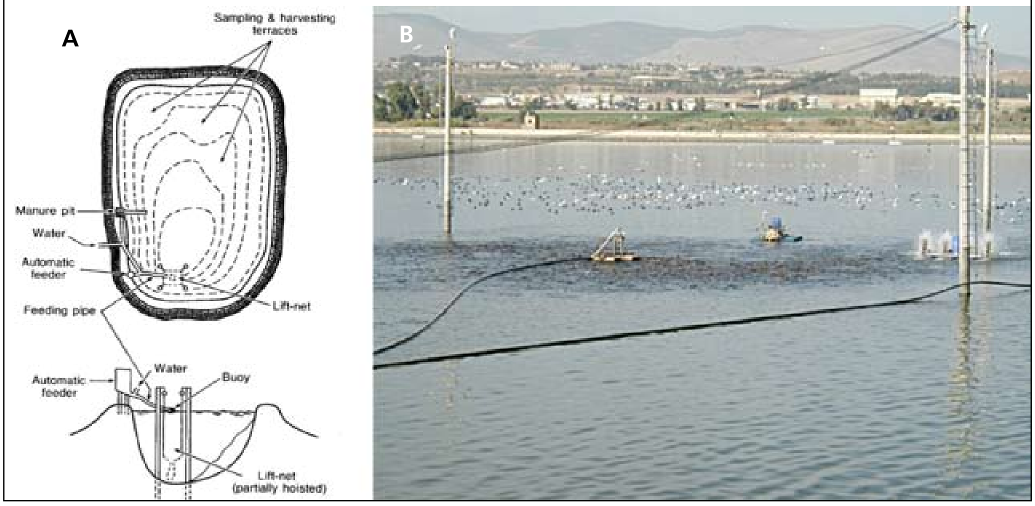
FIGURE 5
(A) Diagram of an integrated irrigation and fish farming reservoir with feeding and harvesting installations, from Hepher (1985). (B) Photo of a reservoir with installations



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.

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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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 m^3 are used when cultured in reservoirs, compared to 7.4 m^3 in conventional earthen ponds, and 4.6 m^3 in intensive concrete ponds, though only 1.4 m^3 in an industrial, indoors super-intensive culture system. A detailed breakdown of production costs of fish in dual-purpose reservoirs is presented in Table 3.

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

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.

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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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 m^3 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 m^3 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/m^3.

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 *Dunalliela* species) and fish ponds has also been successfully trialled, but did not prove to be economically valid.

For both economic (cost of one m^3 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 m^3 will, therefore, use about 200 m^3 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 × 300 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 Floc 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 m^3. 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 maculates*); 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*; anglefish – 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.

REFERENCES

Arlosoroff, S. 2007. Wastewater management, treatment, and reuse in Israel. *In* M.K. Zaidi, ed. *Wastewater reuse–risk assessment, decision-making and environmental security*, pp. 55–64. NATO Security through Science Series. Netherlands, Springer.

Avnimelech, Y. 1998. Minimal discharge from intensive fish ponds. *World Aquacult*., 21: 32–37.

Avnimelech, Y. 2009. *Biofloc technology – a practical guide book*. Baton Rouge, USA, World Aquaculture Society.

Avnimelech, Y., Kochva, M. & Diab, S. 1994. Development of controlled intensive aquaculture systems with a limited water exchange and adjusted carbon to nitrogen ratio. *Isr. J. Aquacult. – Bamidgeh*, 46: 119–131.

Avnimelech, Y., Mokady, S. & Schroeder, G.L. 1989. Circulated ponds as efficient bioreactors for single-cell protein production. *Isr. J. Aquacult. – Bamidgeh*, 41: 58–66.

Avnimelech, Y., Verdegem, M.C.J., Kurup, M. & Keshavanath, P. 2008. Sustainable land-based aquaculture: rational utilization of water, land and feed resources. *Mediterr. Aquacult. J*., 1: 45–55.

Central Bureau of Statistics (CBS), 2010. *Central Bureau of Statistics* (Israel) [online]. www.cbs.gov.il/reader/

Hepher, B. 1985. Aquaculture intensification under land and water limitations. *GeoJournal*, 10: 253–259.

Hepher, B. & Pruginin, Y. 1981. *Commercial fish farming*. New York, USA, Wiley-Interscience, John Wiley and Sons. 261 pp.

Issar A.S. 1994. Fossil water under the deserts of the Middle East: a safeguard against strife. *Stud. Environ. Sci.*, 58: 351–361.

Issar, A.S. 2008. Progressive development in arid environments: adapting the concept of sustainable development to a changing world. *Hydrogeol. J.*, 16: 1431–2174.

Issar, A.S. 2008. Progressive development to sustain food supply in the arid and semi-arid regions (ASAR). *J. Arid Environ.*, 73: 396–397.

Issar, A.S. 2011. Development of water resources of Israel and Palestine with the impact of global warming. *In* H.G. Brauch, Ú. Oswald Spring, C. Mesjasz, J. Grin, P. Kameri-Mbote, B. Chourou, P. Dunay & J. Birkmann, eds. *Coping with global environmental change, disasters and security*. Hexagon Series on Human and Environmental Security and Peace. Springer. (in press)

Issar, A.S. & Adar E. 2010. The Negev Desert of Israel – a conceptual plan of a progressive development project for an arid region. *Progressive Development; Environmental Science and Engineering*, Part 2: 57–69.

Issar, A.S. & Oron, G. 1982. Water from fossil aquifers as a potential supply source for solar desalination plants on a regional scale. *Desalination*, 40: 25–32.

Kolkovski, S., Hulata, G. & Simon Y. 2011. Desert aquaculture: inland. *In* J.S. Lucas & P.C. Southgate, eds. *Aquaculture: farming aquatic animals and plants*, Chapter 5. 2nd edition. Chichester, UK, Wiley Blackwell. (in press)

Milstein, A. & Zoran, M. 2001. Effect of water withdrawal from the epilimnion on thermal stratification in dual purpose reservoirs for fish culture and field irrigation. *Aquaculture International*, 9: 81–86.

Milstein, A., Krambeck, H.-J. & Zoran, M. 2000. Stratification interference practice and modeling as a management tool in fish culture reservoirs. *Verhand. Int. verein. Limnol.*, 27: 200–205.

Milstein, A., Zoran, M. & Krambeck, H.-J. 1995. Seasonal stratification in fish culture and irrigation reservoirs: potential dangers for fish culture. *Aquacult. Internat.*, 3: 1–7.

Milstein, A., Zoran, M. & Krambeck, H.-J. 2001. Destratification as a tool for fish culture improvement in deep water reservoirs. *Aquacult. Internat.*, 9: 3–15.

Mires, D. 2000. Development of inland aquaculture in arid climates: water utilization strategies applied in Israel. *Fish. Manage. Ecol.*, 7: 189–195.

Nativ, R., Bachmat, Y. & Issar A.S. 1987. Potential use of the deep aquifers in the Negev desert, Israel: a conceptual model. *J. Hydrol.*, 94: 237–265.

Rana, K.J. 2007. *Regional review on aquaculture development. 6. Western-European region – 2005*. FAO Fisheries Circular No. 1017/6. Rome, FAO. 56 pp. Contains a CD–ROM.

Sarig, S. 1988. The development of polyculture in Israel: a model of intensification. *In* C.J. Shepherd & N.R. Bromage, eds. *Intensive fish farming*, pp. 302–332. Oxford, UK, BSP Professional Books.

Shapiro, J. 2011. *The Fisheries and Aquaculture of Israel 2009*. Department of Fisheries, Ministry of Agriculture and Rural Development, Israel. (in preparation)

Zoran, M. & Milstein, A. 1998. A device for gradual breaking of stratification in deep fish culture reservoirs. *Internat. Rev. Hydrobiol.*, 83: 673–80.

Zoran, M., Milstein, A. & Krambeck, H.-J. 1994. Limnology of dual purpose reservoirs in the coastal area and Jordan Valley of Israel. *Isr. J. Aquacult. – Bamidgeh*, 46: 64–75.

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°471E	–	–	–	–	–
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	antignus1@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 Banim - 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°471E	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@betalfa.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)	omri@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-ruppin.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_sergi@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
Shluhot	32°27'N 35°28'E	60	550	Carp, tilapia, mullet (polyculture)	midgea@shluhot.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