

An overview on desert aquaculture in Mexico

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SUMMARY

In the United Mexican States, aquaculture began as a complementary social activity to improve the nutritional status of the population in the rural areas (Juárez-Palacios, 1987). Since then, aquaculture in Mexico has consisted of: (i) rural aquaculture which is extensive and mostly at subsistence level (mainly carp and tilapia); (ii) capture-based aquaculture (the stocking of large reservoirs, dams and other natural water bodies with tilapia, carps, catfish and bass; and (iii) commercial aquaculture of trout, catfish, shrimp and tilapia (Ramírez-Martínez and Sánchez, 1998). In Mexico, even though fisheries and aquaculture activities have been primarily promoted by the state, diverse political, economical and social factors have shaped and sized their development. From 1950 to 1970, state aquaculture policies were oriented towards the development of extensive aquaculture. From the mid-1960s and into the 1970s, efforts were concentrated on building hatcheries to provide seed, fingerlings and post-larvae for social and commercial production. The 1980s were characterized by a profound economic crisis caused by devaluation and an almost uncontrolled inflation. The 1990s became a benchmark because from the economical crisis, a renewed fisheries and aquaculture industry appeared where their development was closely related to the opening of the state to the international market. Also, in this decade, a decrease in landings and a new ecological awareness began to shift the state policies towards promoting the development of the aquaculture industry. In this new century, aquaculture has begun to develop in all 32 federal entities. In the year 2000, the 1 402 936 tonnes of capture fisheries total production outweighed the 188 158 tonnes of aquaculture total production. By 2008, the output of both sectors had increased, more pronouncedly in the case of aquaculture. Aquaculture production in 2008 (283 625 tonnes) was a 50 percent increase on 2000; on the other hand, fisheries total production in 2008 (1 745 424 tonnes) was only 25 percent higher than in 2000 (SAGARPA, 2009). Data obtained from the last census accounts for a total of 967 production units involved in fish aquaculture. Of these, 817 used ponds or tanks, 29 lakes or lagoons and 20 estuaries. In 2008, a total of 520 ponds (742 hectares) were devoted to tilapia production, 37 ponds (123 hectares) to channel catfish (*Ictalurus punctatus*), 107 ponds (46 hectares) to carp (*Cyprinus* spp.) and 7 ponds (4 hectares) to largemouth black bass (*Micropterus salmoides*). Production of commercial aquaculture and capture-based aquaculture in 2008 was

comprised of: tilapia – 3 789 and 67 229 tonnes (USD3 793 625 and USD67 311 055), respectively, with a total value of USD71 104 780; catfish – 970 and 2 070 tonnes (USD1 801 762 and 3 844 998) with a total value of USD5 646 760; carp – 570 and 23 588 tonnes (USD320 540 and 13 264 750) for a total value of USD13 585 290; and largemouth bass – 1 and 1 220 tonnes (USD1 491 and 1 818 509) with a total value of USD1 820 000. From 2002 to 2008, an increase in the number of ponds and their area also occurred. This period was also characterized by an increased governmental interest (diverse federal and state sector support programmes were provided for both rural and private aquaculture enterprises).

RÉSUMÉ

Aux États-Unis du Mexique, l'aquaculture a démarré en tant qu'activité sociale complémentaire pour améliorer l'état nutritionnel de la population dans les zones rurales. Elle s'est ensuite développée sous les trois formes suivantes : i) une aquaculture rurale extensive qui est essentiellement de subsistance (avec un élevage principalement de carpes et de tilapias) ; ii) une aquaculture fondée sur les captures (mise en charge de grands réservoirs, de barrages et d'autres pièces d'eau naturelles avec des tilapias, des carpes, des poissons-chats et des perches truitées) ; et iii) une aquaculture commerciale de truites, de poissons-chats, de crevettes et de tilapias. Au Mexique, même si les activités halieutiques et aquacoles ont été encouragées dans un premier temps par l'État, divers facteurs politiques, économiques et sociaux ont caractérisé et déterminé leur développement. De 1950 à 1970, les politiques nationales en matière d'aquaculture visaient le développement de l'aquaculture extensive. À partir du milieu des années 1960 et au cours des années 1970, les efforts se sont concentrés sur la construction d'écloseries pour fournir des semences, des postlarves, des alevins, etc. destinés à la production sociale et commerciale. Les années 1980 se sont caractérisées par une profonde crise économique due à la dévaluation du peso et à une inflation pratiquement incontrôlée. À cause de la crise économique, les années 1990 sont devenues un modèle, caractérisé par un renouvellement de l'industrie halieutique et aquacole dont le développement était étroitement lié à l'ouverture de l'État au marché international. Au cours de cette décennie, la baisse des débarquements de poissons et une nouvelle prise de conscience écologique ont en effet amené l'État à élaborer des politiques encourageant le développement de l'industrie aquacole. En ce début du XXI^e siècle, l'aquaculture commence à se développer dans les 32 États fédérés du pays. En 2000, la pêche de capture s'élevait au total à 1 402 936 tonnes alors que la production aquacole totale n'était que de 188 158 tonnes. En 2008, les deux secteurs avaient progressé, mais de façon plus prononcée pour le second : la production aquacole a ainsi augmenté de 50 pour cent entre 2000 et 2008 (pour atteindre 283 625 tonnes), alors que celle de la pêche de capture n'a progressé que de 25 pour cent dans le même temps (à 1 745 424 tonnes) (SAGARPA, 2009). Les données du dernier recensement faisaient état d'un total de 967 unités de production aquacoles ayant recours à 817 étangs ou bassins, à 29 lacs ou lagons et à 20 estuaires. En 2008, 520 étangs (742 hectares) étaient utilisés pour la production de tilapias, 37 étangs (123 hectares) étaient consacrés à celle de poissons-chats (*Ictalurus punctatus*), 107 étangs (46 hectares) servaient à l'élevage de carpes (*Cyprinus* spp.) et 7 étangs (4 hectares) étaient destinés à celui de perches truitées (*Micropterus salmoides*). En 2008, la production de l'aquaculture commerciale et celle de l'aquaculture fondée sur les captures présentaient respectivement les résultats suivants : 3 789 et 67 229 tonnes de tilapias (3 793 625 USD et 67 311 055 USD), pour une valeur totale de 71 104 780 USD ; 970 et 2 070 tonnes de poissons-chats (1 801 762 USD et 3 844 998 USD) pour une valeur totale de 5 646 760 USD ; 570 et 23 588 tonnes de carpes (320 540 USD et 13 264 750 USD) pour une valeur totale de 13 585 290 USD ; et enfin 1 et 1 220 tonnes de perches truitées (1 491 USD et 1 818 509 USD) pour une valeur totale de 1 820 000 USD. De 2000 à 2008, on a constaté une augmentation du nombre et de la

surface des étangs. Cette période s'est aussi caractérisée par un accroissement de l'intérêt des autorités fédérales pour l'aquaculture (plusieurs programmes fédéraux et nationaux au secteur ont été mis en œuvre en vue d'appuyer les entreprises aquacoles aussi bien rurales que privées).

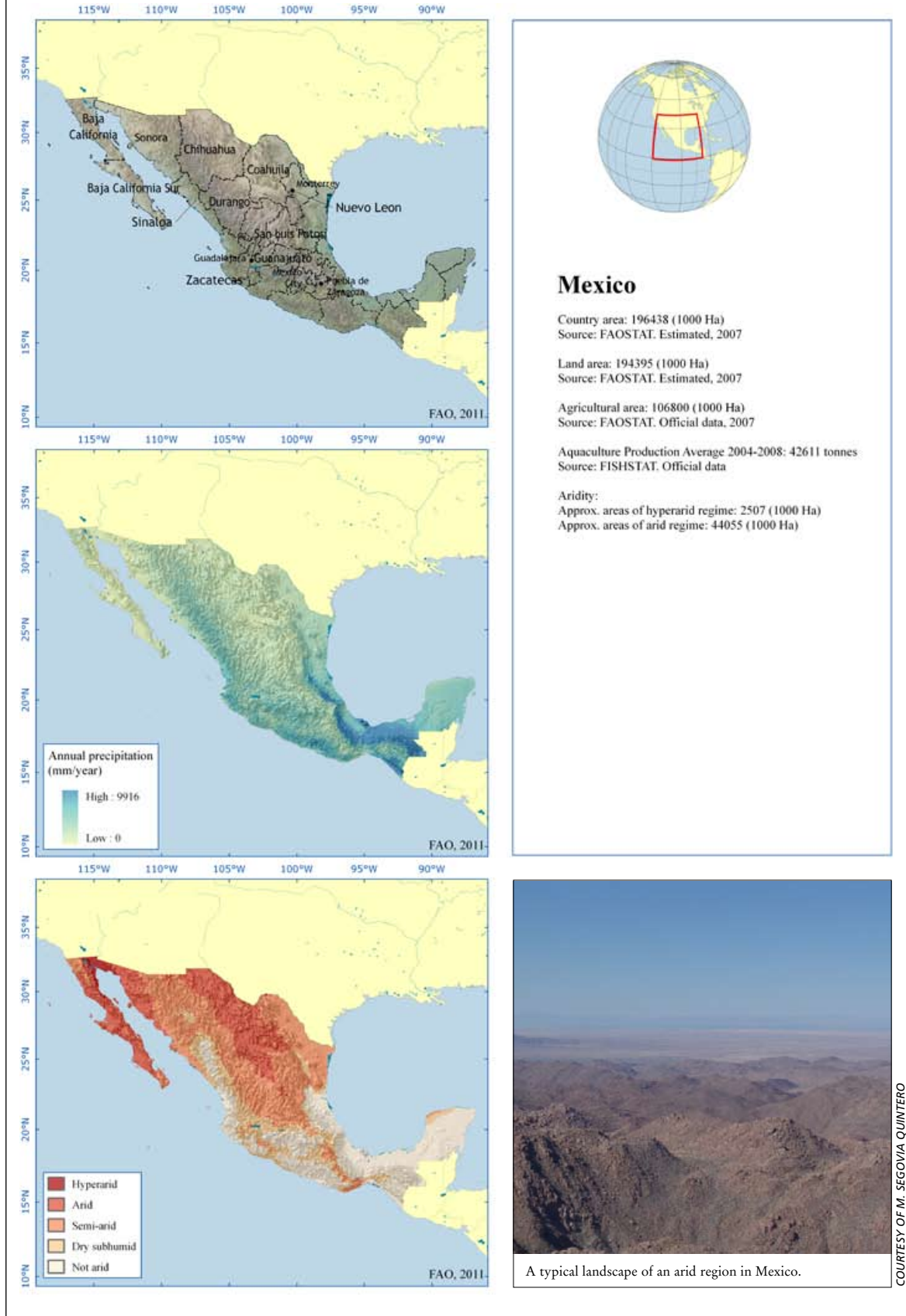
ملخص

في الولايات المتحدة المكسيكية، بدأت تربية الأحياء المائية كمنشآت اجتماعية مكملة لتحسين الحالة الغذائية للسكان في المناطق الريفية. ومنذ ذلك الوقت، فإن تربية الأحياء المائية في المكسيك تألفت من: (i) تربية الأحياء المائية بنظام الاستزراع الموسع وهي في الغالب على مستوى الكفاف (وبشكل أساسي الشبوط والبلطي)؛ (ii) تربية الأحياء المائية القائمة على المصايد السمكية (التخزين في الخزانات الكبيرة، والسدود والمساحات المائية الطبيعية الأخرى للبلطي، والشتبوط، والقرموط والقاروص)؛ (iii) الاستزراع التجاري للتراوت، والقرموط، والريبان والبلطي. وفي المكسيك، وبالرغم من أن أنشطة المصايد السمكية وتربية الأحياء المائية قد تم الترويج لهما أساساً من قبل البلد، إلا أن عوامل متنوعة سياسية، واقتصادية واجتماعية قد صاغت وشكلت تنمية هذا القطاع. ومن 1950 إلى 1970، تم توجيه سياسات البلد فيما يخص تربية الأحياء المائية نحو تنمية تربية الأحياء المائية بنظام التربية الموسعة. ومن منتصف الستينيات من القرن الماضي وفي السبعينات من نفس القرن، تم تركيز الجهود على بناء مفرخات لتوفير الزريعة، والاصبعيات ومرحلة ما بعد البرقات للإنتاج التجاري والاجتماعي. وتميزت مرحلة الثمانينات من نفس القرن بالأزمة الاقتصادية العميقة بسبب انخفاض قيمة العملة وتقريباً بسبب التضخم غير المتحكم فيه. أما فترة التسعينات فقد كانت علامة بارزة وذلك بسبب انه من الأزمة الاقتصادية ظهرت المصايد السمكية وتربية الأحياء المائية المتجددة حيث تنميتها كانت قريبة جداً من افتتاح البلد أمام الأسواق الدولية. وأيضاً، وخلال هذا العقد فإن النقص في الإنزال والوعي البيئي الجديد قد بدأ بتحويل البلد نحو السياسات التي تشجع تنمية صناعة تربية الأحياء المائية. وفي هذا القرن الجديد، بدأت تربية الأحياء المائية بالتطور في جميع الكيانات الفيدرالية البالغ عددها 32. وفي عام 2000، فإن الإنتاج السمكي الكلي من المصايد التقليدية والذي وصل إلى 1 402 936 طن زاد بشكل كبير عن إنتاج تربية الأحياء المائية والذي وصل إلى 188 158 طن. وبحلول عام 2008، فإن الإنتاج من كلا القطاعين قد ازداد، وبشكل أكثر وضوحاً في قطاع تربية الأحياء المائية. إن إنتاج تربية الأحياء المائية في عام 2008 (283 625 طن) ازداد بمعدل 50 في المائة عن إنتاج عام 2000؛ ومن ناحية أخرى، فإن الإنتاج الكلي من المصايد السمكية في عام 2008 (1 745 424 طن) كان أكبر بمعدل 25 في المائة فقط عن إنتاج عام 2000. والبيانات التي تم الحصول عليها من التعداد الأخير تشير إلى وجود 967 وحدة إنتاج تعمل في استزراع الأسماك. ومنها، 817 تستخدم البرك أو الأحواض، 29 بحيرة أو خور و 20 مصب نهر. وفي عام 2008، تم تخصيص ما مجموعه 520 حوض (742 هكتار) لإنتاج البلطي، 37 حوض (123 هكتار) لسماك القرموط (*Ictalurus punctatus*)، 107 حوض (46 هكتار) لأسماك الشبوط (*Cyprinus spp.*) و سبعة أحواض (4 هكتار) للقاروص (*Micropterus salmoides*). إن إنتاج الاستزراع التجاري وتربية الأحياء المائية القائمة على المصايد في عام 2008 تتألف من: البلطي 3789 طن و 76 229 طن (793 625 دولار أمريكي و 67 311 055 دولار أمريكي) على التوالي، مع قيمة إجمالية تصل 71 104 780 دولار أمريكي؛ وأسماك القرموط 970 و 207 طن (801 762 و 1 844 998 دولار أمريكي) مع قيمة إجمالية تصل إلى 5 646 760 دولار أمريكي؛ و الشبوط 570 و 23 588 طن (320 540 و 13 264 750 دولار أمريكي) بقيمة إجمالية عند 13 585 290 دولار أمريكي؛ والقاروص ذو الفم الكبير 1 و 1 220 طن (1 491 و 1 818 509 دولار أمريكي) بقيمة إجمالية 1 820 000 دولار أمريكي. ومن 2002 إلى 2008، حدثت أيضاً زيادة في أعداد الأحواض ومساحاتها. كما تميزت هذه الفترة كذلك بزيادة الاهتمام الحكومي (تم توفير برامج دعم متنوعة للقطاع على مستوى الولاية والكيان الفيدرالي لكل من مشاريع تربية الأحياء المائية الريفية والخاصة).

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

Mexico covers an area of 1 959 248 km², and its topography ranges from tropical coastal plains to deserts and mountains (Figure 1). The arid and semi-arid lands with annual rainfall lower than 250 mm are located mainly in the northern part of Mexico. This area extends over 604 048 km², which is equivalent to approximately one third of the total surface area of Mexico, and includes 11 states. The area of desert and arid lands as a proportion of total area in each of these states is as follows: Zacatecas (35.3 percent), San Luis Potosi (52.1 percent), Guanajuato (6.6 percent), Nuevo Leon (20.9 percent),

FIGURE 1
Maps of Mexico



Coahuila (73.0 percent), Durango (20.3 percent), Chihuahua (56.5 percent), Sonora (55.3 percent), Sinaloa (13.6 percent), Baja California (97.4 percent) and Baja California Sur (99.7 percent).

The contribution of each of these States to total aquaculture production in 2008 was as follows: Zacatecas (0.72 percent), San Luis Potosi (0.13 percent), Guanajuato (1.06 percent), Nuevo Leon (0.04 percent), Coahuila (0.33 percent), Durango (1.36 percent), Chihuahua (0.26 percent), Sonora (29.19 percent), Sinaloa (16.19 percent), Baja California (1.63 percent) and Baja California Sur (1.24 percent).

HUMAN RESOURCES

The lack of trained specialists in aquaculture is a problem for both federal and state programmes. Technical training programmes are necessary for both rural and commercial farmers, so that they can operate sustainably. Many important subjects need to be included in these programmes, including tank engineering, feeding, carrying capacity, water quality management, disease monitoring and control, and the introduction of new and improved aquaculture techniques.

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

There are a total of 521 aquaculture production units (including commercial aquaculture and capture-based aquaculture) in the 11 states with arid and desert lands. These units, which constitute 53.8 percent of the 967 that existed in the whole of Mexico, employed a total of 11 078 persons (INEGI, 2004).

Fish culture in the arid states is generally characterized by low investment and capitalization. Baja California is an exception because of the development of tuna farming. Even though aquaculture began almost 60 years ago in the inland states, such as Zacatecas, San Luis Potosi, Guanajuato, Coahuila, Durango and Chihuahua, it can still be regarded as a fairly new activity, with less than 10 years of true development.

Nowadays, aquaculture in Mexico is focused on two different strategies: rural and commercial aquaculture. Rural aquaculture produces fish at a subsistence level for local consumption (Juárez, de la Luz Flores and Luna, 2007). From its inception, tilapia and carp culture have been characterized by low yields, difficult access to regional markets and price fluctuation. Meanwhile, commercial aquaculture is focused on high volume output, either for national or international markets with better financing programmes. In 2006, rural aquaculture accounted for only 1.89 percent of the total production, while it was highest in 2007, at 4.89 percent. Rural aquaculture generally involves social organizations such as cooperatives, growers associations, civil societies, anonymous societies, family groups and private micro-industries. Those associated

TABLE 1

Aquaculture production units in the desert and arid lands of Mexico, including employment

State	Aquaculture production units	People employed in the aquaculture industry		
		Total	Male	Female
1) Zacatecas	139	323	301	22
2) San Luis Potosi	n/a	46	31	15
3) Guanajuato	46	5	5	0
4) Tamaulipas	13	169	150	19
5) Nuevo Leon	n/a	27	22	5
6) Coahuila	n/a	269	182	87
7) Durango	32	30	29	1
8) Chihuahua	10	269	182	87
9) Sonora	87	4 040	3 570	470
10) Sinaloa	162	5 494	5 147	347
11) Baja California	25	475	408	67
12) Baja California Sur	7	190	158	32

Source: INEGI, 2004.



with family groups were involved in trout production (56 percent), while cooperatives preferred carp production, and anonymous societies concentrated on tilapia production (30 percent). Rural aquaculture is promoted by federal and state programmes for self subsistence, mainly as a complementary activity (Torres, Martínez and Mendoza, 1999). Sonora and Sinaloa are the states with the highest commercial aquaculture production in Mexico (mainly shrimp culture), accounting for a total of 130 049 tonnes in 2008. In contrast, 5 328 tonnes of tilapia, catfish and carp were produced in

commercial aquaculture (together with 92 888 tonnes from capture-based aquaculture). The contribution of tilapia, catfish and carp to total aquaculture production was 3.6 percent.

In 2008, the total production (commercial aquaculture plus capture-base fisheries) of catfish, carp, largemouth bass, tilapia and rainbow trout from the arid/desert lands of Mexico was 23 886 tonnes or 25.8 percent of the overall national aquaculture production. Even though tilapia is the main species cultured in both commercial aquaculture and capture-based aquaculture, the contribution of the former to total tilapia production is insignificant. In fact, production decreased from 5.6 percent to 2.3 percent from 2002 to 2008.

The main species cultured in each of the desert and arid states are listed in Table 2.

In Mexico, shrimp farming is the most important sector of the aquaculture industry in terms of volume and value (Figure 2). In 2008, the total value of fisheries exports was USD401 557 000, of which shrimp formed 88.1 percent (35 962 tonnes with a value of USD353 784 000). Because of their differing importance for Mexico, the financing available for shrimp and fish aquaculture differs significantly. The Agriculture Related Trusts and Foreign Trade Mexican Bank (BANCOMEXT) finance, through diverse loans schemes, as much as 94.4 percent of the USD78 662 452 in shrimp culture related activities for the private and social sector (loans related to production, equipment, processing, for example) (CONAPESCA, 2008a, 2008b).

TABLE 2

Volume of aquaculture production (tonnes) in 2008 in the arid/desert States of Mexico produced in commercial and capture-based aquaculture

State	Catfish	Carps	Bass	Tilapia	Rainbow trout
1) Zacatecas	22	419	12	1 586	-
2) San Luis Potosi	68	67	-	243	-
3) Guanajuato	6	1 370	10	1 130	-
4) Tamaulipas	470	-	91	4 221	-
5) Nuevo Leon	17	32	16	44	-
6) Coahuila	78	651	2	123	-
7) Durango	717	897	588	890	213
8) Chihuahua	83	320	12	143	176
9) Sonora	268	244	1	753	-
10) Sinaloa	757	244	1	6 901	-
11) Baja California	-	-	-	-	-
12) Baja California Sur	-	-	-	-	-

Source: SAGARPA, 2009.

SECTOR PERFORMANCE

Aquaculture in the desert and arid lands of Mexico faces several problems that have to be solved in order to become viable. These are detailed in this section of the review.

PRODUCTION

Mexico has a total of eight reference hatcheries, and 17 support hatcheries managed by the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA – Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). The main species produced by these hatcheries are: largemouth black bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*), wuchang bream (*Megalobrama amblycephala*), common carp (*Cyprinus carpio*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), rainbow trout (*Oncorhynchus mykiss*), and garpique alligator (*Atractosteus spatula*). The species produced by these hatcheries are used to stock dams and lakes for capture-based aquaculture and/or aquaculture through federal, state and municipal programmes either for commercial or rural aquaculture. Breeding and genetics programmes within these hatcheries need to be implemented for the benefit of national aquaculture development.

The first challenge faced by producers is the high price of commercial pelleted feeds for tilapia, catfish and carp. Beyond the traditional states where commercial aquaculture is practised, access to fish feeds and other aquaculture supplies is difficult. Availability of feed and other supplies has to be improved to support aquaculture development in non-traditional aquaculture states.

New or improved culture technologies for inland aquatic species need to be promoted. These have to focus on pond design, construction and management throughout the production cycle. Proper water quality protocols that are specific for the region, producer, initial and final stocking densities, species and stage. Management must include feeding strategies throughout the cold and hot months, stocking and harvesting calendars, and transport and processing protocols. The same incentive must drive the development of new (or improved) processing equipment, as well as more competitive production lines.

In Mexico, there are several sanitary programmes that are oriented to monitor, control or eradicate diseases in several crustacean species such as white shrimp (*Litopenaeus vannamei*) and blue shrimp (*L. stylirostris*), as well as in finfish (carp, tilapia, rainbow trout) and molluscs (e.g. oysters and clams). For example, the Service of Food and Agriculture Health and Quality promotes sanitary programmes through extension services and training for aquaculture producers focusing on the application of good management practices in rainbow trout, tilapia, shrimp and oyster production. However, it is necessary to formalize a sanitary certification programme to be applied in all 32 federal entities, as this would result in a more competitive product on the market.

MARKET

In aquaculture, as in any other economic activity, the market is of extreme importance. In accessing all markets (regional, national and international), the commercialization of aquatic products has faced several difficulties in Mexico. Farm logistics, marketing and retailing, equipment, packaging, and quality certification are the main issues to be solved to ensure a successful aquaculture programme in Mexico.

Farm logistics – The lack of transportation (moving the product from the farm to the market) is one of the issues to be solved. This can be done by acquiring or developing transport routes to facilitate the distribution of aquaculture products.

Local retailing – Generally, aquaculture products are sold locally. Large wholesale companies and fish farms with the ability to market their own products are very few. One of the biggest constraints faced by rural and small commercial producers is the middleman. For example, the farm-gate price paid by the middleman in the case of eviscerated tilapia from capture-based aquaculture fluctuates between USD1.21 and 1.61/kg, while tilapia from farms fluctuates between USD1.45 and 1.77/kg. The final consumer normally pays (for whole eviscerated fish) between USD1.61 and 2.01/kg. The middleman sets the market price to maximize his profit margin. To solve this issue, it is important to create an organization that can regulate the interaction between the producer and the middleman. Usually, producers lack knowledge on sales and marketing, and it is becoming more important to develop specific technical training courses focused on techniques and simple models to access markets and market their production bypassing the middleman.

Regional marketing – The main issue for aquaculture producers is the absence of a developed local market that ensures a stable demand for their products. There is also a negative perception of aquaculture products that needs to be confronted. It is necessary to develop chains of supply and distribution between producers and retailers to create a constant demand for aquaculture products, as well developing an educational programme to promote the advantages of aquaculture products as a steady source of healthy, value for money food.

Three main wholesale distributors or groups share the market for aquatic products in Mexico: La Nueva Viga (51 percent of the market), a wholesale market situated in Mexico City; local farms (3 percent); and local retailers throughout the country (46 percent).

Mexican supreme quality certification – Although Mexico is the eighth largest producer of tilapia in the world, there is still a national unsatisfied demand of >30 000 tonnes of fish per year. The demand that is not satisfied by national production includes whole frozen fish (19 500 tonnes), fresh fish (5 000 tonnes) and fresh fillets (4 500 tonnes). A massive supply of imported cheap tilapia, possibly subsidized from China, Viet Nam and Taiwan Province of China, is well-established on the local market. Therefore suitable strategies need to be developed to increase productivity within the Mexican aquaculture industry, ultimately satisfying the existing deficit.

It is also important to develop an anti-dumping policy to focus on protecting national producers, as well as integrating complete production chains that will supply a product fulfilling premium quality standards, achieving quality aquatic products with a competitive edge that are suitable for international markets.

Good management practices – Besides the factors mentioned above, it is necessary to establish an operational framework that guarantees the safety of aquatic products for human consumption by implementing a risk reduction system at production and processing units. In 2001, SAGARPA and the National Health Service, Food Safety and Food Quality (SENASICA – Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria) began to establish policies, criteria, systems, strategies, programmes, procedures and services oriented to improve the quality of aquatic products destined for human consumption. Some of the health risks that derive from aquaculture practices are still not comprehended or envisioned; they are complex and can cause short- and medium-term impacts on human health, other aquatic organisms and the environment. To achieve sustainable aquaculture in terms of both environment and economy, it is necessary to adopt viable technology and good management practices, such as those drafted by SENASICA.

Good management practices include the following specific criteria:

- Careful site selection to ensure freedom from contamination.
- Decreasing the risk of biological and chemical contamination.
- Introducing general hygienic practices for farming systems and staff.
- Providing proper infrastructure (including sanitary facilities) and equipment. The production areas need to be properly designed with the appropriate space, and the functional layout must be considered for optimum overall performance. The number of sanitary facilities will depend on the number of workers in the farm.
- Establishing appropriate cleaning and disinfection programmes for all aquaculture facilities and equipment. This should include a written plan that must be in place in each facility and include pre-cleaning, pre-rinsing, cleaning, rinsing, disinfection, post-rinsing, storage and cleaning verification.
- Managing disposal including everyday activities such as garbage disposal, sanitary cleaning and disinfection, strategic provision of garbage cans, and protocols for the disposal of dead fish.
- Developing control systems to decrease disease problems by using appropriate infectious vector protocol prevention.
- Providing adequate water supplies, together with the production of potable ice.
- Ensuring proper sanitary criteria (a) to avoid the introduction of pathogens into the farms and (b) to improve the farming environment. These measures must include the acquisition of pathogen-free organisms, good ponds and tank maintenance during farming and down time, the control of wildlife to avoid the spread of diseases, and the control of domestic animals.

CONTRIBUTION TO THE ECONOMY

The contribution of aquaculture to food security, employment and poverty alleviation is extremely important in Mexico. Aquaculture has a substantial economic and social impact in this country; it generates direct employment for 350 000 individuals, and indirect employment for more than two million (INEGI, 2004). Even though the contribution of fisheries and aquaculture to the GDP of Mexico was a meagre 4 percent from the period 1999 to 2004, the importance it plays in the social role aspect is extremely important. In 2011, 18.2 percent of the Mexican population live in conditions of extreme poverty; because of this, the role of rural aquaculture is growing in importance as a viable mean of increasing employment opportunities. However, the low levels of consumption of fish and other aquatic organisms, due to cultural preferences, is the most limiting factor in developing this industry (Ramírez-Martínez and Sánchez, 1997).

Table 3 shows the status and trends of rural and commercial aquaculture production from 1994 to 2006. The objective of Mexico's National Programme for the Support of Rural Aquaculture (PRONAR) is to promote the development of aquaculture in marginal areas through fingerling supply, technical support provided by national institutions, economic resources to rehabilitate or construct facilities, equipment acquisition, and the provision of specialized technical assistance (FAO, 2006).

INSTITUTIONAL FRAMEWORK AND GOVERNING REGULATIONS

Information on the promotion and management of the sector, which includes the institutional framework, governing regulations, applied research, education and training, can be obtained by consulting the FAO National Aquaculture Sector Overview (NASO): www.fao.org/fishery/countrysector/naso_mexico/en

The agency in charge of Mexican aquaculture is the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA). Within SAGARPA, the National Commission on Aquaculture and Fisheries (CONAPESCA), being an administrative entity of SAGARPA, is responsible for management, coordination and policy development regarding the sustainable use and exploitation of fisheries and

TABLE 3
Rural, commercial and capture-based fisheries production in tonnes

Year	Total Aquaculture production	Rural aquaculture ^a			Commercial aquaculture			Capture based aquaculture ^c
		Production (Tonnes)	Coverage		Production (Tonnes)	Surface open for culture (ha)	Production units	Production (Tonnes)
			Communities (number)	Municipalities ^b (number)				
1994	171 389	2 630	–	219	19 874	–	–	148 885
1995	157 574	3 424	397	192	22 657	16 973	828	131 493
1996	169 211	5 915	1 314	295	20 069	20 112	1 135	143 227
1997	173 878	6 011	2 265	648	23 338	20 265	1 504	144 529
1998	159 781	8 897	2 255	560	29 713	20 437	1 618	121 171
1999	166 366	9 642	2 343	576	36 005	28 561	1 885	120 689
2000	188 158	9 515	2 334	558	40 834	31 460	1 898	137 809
2001	196 723	5 881	1 712	510	57 766	47 648	1 963	133 076
2002	187 485	4 068	1 451	429	53 298	51 869	2 445	130 119
2003	207 776	1 848	273	126	74 039	60 644	2 665	131 889
2004	220 359	7 230	629	389	81 705	60 981	2 849	131 424
2005	238 081	11 646	847	418	95 243	62 723	2 941	131 192
2006	249 050	4 727	369	201	113 354	64 464	3 033	130 959

^a Includes all production units in poor areas in all 32 states covered by the Rural Aquaculture Programme.

^b Each one of the 32 states is politically divided into Municipalities.

^c Mainly carps, trout, tilapia and shrimp.

aquatic resources. The commission has the support of the National Fisheries Institute (Instituto Nacional de la Pesca, INAPESCA), which is another administrative entity of SAGARPA. Through SAGARPA, the Rural Aquaculture National Programme was created. The role of this programme is to provide rural communities with technical assistance, training and technology transfer to improve aquaculture production. It is within this programme that special attention will be provided for the creation of rural supply chains, brand creation, traceability follow up, disease control and final product quality control. A legal framework has been devised to regulate aquaculture activities.

APPLIED RESEARCH, EDUCATION AND TRAINING

Aquaculture research is becoming more important for the development of the aquaculture industry. Several universities and research centres offer graduate programmes (Masters and PhD degrees), the most important being the Instituto Tecnológico del Mar No. 1 in Veracruz; the Centro de Investigaciones Biológicas del Noroeste (CIBNOR); the Centro de Investigación en Alimentación y Desarrollo (CIAD); and the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE).

Aquaculture research by INAPESCA has increased the interaction between producers and the academic sector through the National Network for Research in Aquaculture. This network consists of a total of 760 members belonging to 120 institutions from all over the country. Research topics include sanitary aspects on the handling of the white spot syndrome viral disease in shrimp and disease prevention and sanitary control in oysters and clams. Regarding nutrition, research projects have focused on the digestibility of commercial feeds, with the aim of diminishing their impact on the environment

TRENDS, ISSUES AND DEVELOPMENT

Aquaculture in the desert and arid lands of Mexico occurs in two different areas: (i) inland states (Zacatecas, San Luis Potosi, Guanajuato, Nuevo Leon, Coahuila, Durango and Chihuahua), where 58.24 percent of the total area is desert and arid lands; and (ii) coastland states (Sonora, Sinaloa, Baja California and Baja California Sur),

where 41.75 percent of the total area is desert and arid lands. The contribution of both inland and coastal states to the total aquaculture production in 2008 was 52 percent (4 percent inland states; 48 percent coastland states).

In all eleven states with desert and arid lands, aquaculture was mainly focused on fresh water species such as tilapia, instead of native species, until developments with marine and brackishwater species occurred; the production value of these has since surpassed freshwater aquaculture. Today, 18.78 percent of total tuna production comes from aquaculture (with a net value of USD17 295 916). Crustacean aquaculture plays an important role in the economy of the northwestern Pacific Region of Mexico. Unlike other aquatic species, shrimp farming has undergone significant technological development and has become a high quality food item of major importance as an export product (Álvarez and Avilés, 1995). The farming of molluscs has also made some progress, particularly of oysters (*Crassostrea gigas*, *C. corteziensis*), mussels (*Mytilus edulis*) and abalone (*Haliotis rufescens*). Research on improved technological practices has recently widened interest in other species such as clams, native scallops (pen shells *Pinna rugosa* and *Atrina maura* and lion's paws *Liropecten subnudus*), pearl oysters (*Pinctada mazatlanica*) and wing oysters (*Pteria sterna*) (SEMARNAP, 1995). The most widely cultured fish are the tilapias, which have been stocked in reservoirs and water bodies in various regions of the country enabled by the hatchery production of fingerlings. Tilapia culture contributes over 60 percent of the total farmed fish production.

For the desert and arid inland and coastal states, there are specific and common issues that have to be addressed. In the inland states, the three main issues that have an effect on aquaculture development are diseases, low product prices and high costs of production.

Fish diseases of bacterial, parasitic and viral origin, even when detected on time, they usually kill the fish due to the lack of proper medication and/or treatments. Proper disease screening programmes are still in development and new diseases are appearing in the freshwater aquaculture industry in Mexico such as *Streptococcus iniae* and *Flexibacter columnaris*.

The low prices of the main freshwater species cultured such as tilapia, carp, catfish and largemouth bass usually make aquaculture unattractive for the private investor and it has become a social activity funded by federal and state programmes. Social aquaculture in inland states is characterized by production units that usually consist of one to six 28–79 m³ circular liner tanks with or without a greenhouse. Aquaculture social programmes usually provide a specific short-term benefit (immediate working opportunity) without addressing economies of scale or investment in the production chain. In the medium term, this will eventually translate for the farmer (programme beneficiary) into poor prices, little or no access to markets (local, regional or national). In addition, once the programme ends, farmers without an education in administration usually find it difficult to continue producing fish at a competitive price. In recent years in Mexico, the growth rate of the fish feed industry has been higher than the rate at which ingredients (corn, wheat, soybean and cottonseed meal) can be produced (CONAPESCA, 2008a). The variable price of fishmeal and the uncertainty in its supply, directly affect the small-scale farmers or the beneficiaries of social aquaculture programme because they cannot afford purchasing of fish feed without subsidy or support of State or Federal Funds.

For the coastal states, biosecurity, breeding and genetic improvement programmes, sanitary certification and better quality of seed (fish, several bivalve species and shrimp) are the main issues to address (in coastal states shrimp – and more recently molluscs – are the main species cultured). Molluscan sanitary culture problems are serious issues for oyster producers, as are juvenile mortality due to low genetic diversity and the presence of *Perkinsus marinus*, *Vibrio cholera*, *V. parahaemolyticus* and *Salmonella* spp.

in oyster culture all along the coastal states. Early diagnostic and routine detection programmes *in situ* need to be improved to develop an effective control of diseases. For fish, the sanitary issues are similar to those present in the desert and arid inland states. Shrimp are by far the main aquaculture product for the desert and arid coastal states. However, in recent years this industry has experienced several setbacks where white spot syndrome virus (WSSV), Taura syndrome virus (TSV) and the yellowhead virus (YHV) have played a key role, translating into important economical losses for the region. The most common bacterial infection is related to *Vibrio* spp. and the necrotizing hepatopancreatitis bacterium (NHPB).

For both inland and coastal states with arid and desert lands, water quality and effluent management, the availability of commercial diets, environmental, social and economic sustainability are common issues that need to be addressed and solved, as noted below.

Apart from balanced commercial shrimp diets, feeds for finfish present several challenges to be solved, including:

- developing new and effective means of incorporating free amino acids, enzymes, chemoattractants, probiotics and immunostimulants;
- improving fish feed formulations and manufacturing processes to increase shelf life; and
- improving integration between fish feed manufacturing plants, distributors and farmers.

The development of good management practices at the farm level is also important, including:

- improved culture techniques;
- better pond fertilization protocols; and
- the selection of fish that are in low trophic levels.

Environmental sustainability issues related to desert and arid land states that need to be addressed are:

- developing specific programmes that focus on the carrying capacity of water reservoirs;
- the legal regulation of water usage and effluent disposal; and
- the development of state aquaculture zonification programmes.

Social sustainability issues related to desert and arid land states that need to be addressed are:

- new programmes that will provide training in the organization of production units;
- the creation of Value Networks Strengthening and Establishment Programmes (state and national) that will strengthen the producer by selling directly to the market avoiding the middleman; and
- the implementation of specific extension programmes for arid and desert aquaculture.

Economic sustainability issues related to desert and arid land states include:

- the creation of federal support programmes (firstly for tilapia and catfish) similar to those used by the poultry industry;
- implementing the formation of trusts with liquid funds and seed capital for desert aquaculture programmes;
- developing programmes focused on aquaculture economics and administration; and
- providing risk capital special funds (for social aquaculture).

Aquaculture represents 16.25 percent of the total fisheries production, although it is estimated that aquaculture has the potential to represent up to 40 percent within 10 to 15 years. However, its development has been slow, as a result of a variety of factors, including:

- poorly oriented aquaculture development policies;

- loans with high interest rates;
- low profit margins;
- high cost of fingerlings and feed;
- periodic changes within government and its related institutions;
- lack of information;
- lack of technical assistance;
- little or no access to potential markets;
- difficult access to new production technologies;
- lack of private investment;
- lack of market studies;
- lack of interest in aquaculture research;
- lack of infrastructure;
- poor use of basic scientific and technical knowledge;
- deficiencies in the availability of funds for development; and
- lack of a legal framework for guaranteed legal land tenure to facilitate the provision of services from banks and other financial institutions, especially in coastal areas.

Despite positive contributions to society and the economy, aquaculture development in Mexico is still far below its actual potential. Mexico has great opportunities to contribute to food security and rural development throughout the country through aquaculture. Aquaculture expansion should be carefully promoted, considering the beneficial impact it could have on the environment. Particular attention should be paid to global strategies and guidelines such as the FAO Code of Conduct for Responsible Fisheries (FAO, 1995).

The diverse climate of Mexico contributes to a variety of climatic conditions and ecosystems which aid the development of a diversified aquaculture sector. The current aquaculture development plan foresees different levels of actions to achieve better performance for small-scale subsistence aquaculture, stock enhancement activities and commercial aquaculture, all of which are consistently linked with socio-economic and environmental aspects.

Aquaculture products must first meet regional, national and specific international standards related to environmental protection of natural resources, and also including post-harvest processing and handling. To achieve these diverse standards, an increase in production costs will occur; in some cases this may inhibit the commercial market potential because a lack of funding to fulfil these standards.

The contribution of aquaculture to economic and social development depends on adequate plans within the context of environmental management. Of particular concern are the uncontrolled use of inland water resources and the rapid environmental degradation of the coast (Álvarez, 1996).

The PRONAR main objective is to encourage investment in small-scale projects through the distribution of financial support to rural producers for the creation of efficient production units capable of integrating and competing within aquaculture and fisheries chains. The programme is coordinated with the actions of state governments to fulfil the needs of poor producers with such issues as technical assistance, training, studies, infrastructure (new buildings and rehabilitation), equipment, input acquisitions, establishment of demonstration or pilot scale units, and the development of productive projects as an alternative to inland fisheries. Up to 2011, 343 rural production units have received support of various kinds, including the rehabilitation of impoundments and ponds; the construction of earthen ponds and floating cages for tilapia culture; construction of four demonstration units for the cultivation of marine fish and molluscs; acquisition for the monitoring of physical and chemical parameters, scales, water pumps, freezers, etc.; provision of technical assistance and training, etc. The former actions have benefited a total of 4 129 rural producers located in 369 communities belonging to 201 municipalities of the country (SAGARPA, 2006).

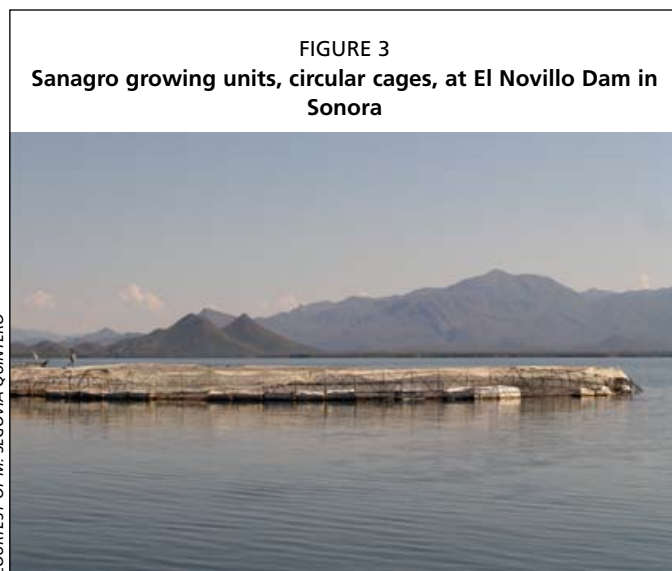
With regard to aquatic health, the System of Information on Diagnostic Results of the Laboratory Network has been established to provide information to CONAPESCA and SENASICA on high-risk diseases in aquaculture. Also, state Aquaculture Health Committees have been established as auxiliary entities for the prevention, diagnosis and control of aquaculture diseases; these committees also promote sanitation campaigns (SAGARPA, 2004). At present, there are 17 Aquaculture Health Committees belonging to the States of Aguascalientes, Baja California, Baja California Sur, Chihuahua, Mexico, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Sinaloa, Sonora, Tabasco, Tamaulipas, Tlaxcala, Puebla and Veracruz.

The Aquaculture and Fishing Programme (Alianza Contigo) of CONAPESCA provides subsidies to benefit the fisheries and aquaculture sectors of the country with the intention of promoting the competitiveness of the production units and ensuring the sustainable and rational use of resources. In 2003, a total of 243 projects were approved, with a total investment value of 122 million pesos (USD11 million), benefiting 25 000 people. In 2004, a total of 63 projects were approved, with a total investment value of 85 million pesos (USD7.17 million) distributed throughout 12 States. With this programme, fisheries and aquaculture production chains are being consolidated, moving the sector towards the cultivation of species with greater development potential and helping low income social groups to access profitable productive activities. In response to deficiencies shown in the applications submitted to the Alianza Contigo in 2003, technical assistance and training was provided to fisheries and aquaculture producers in project feasibility. Emphasis has also been made on subject areas ranging from managerial and administrative abilities to quality, health and safety of products.

In Mexico, fishing and aquaculture production chains have been initiated by the Value Networks Strengthening and Establishment Programme with the main objective of consolidating fishing and aquaculture productive units in value networks coordinated through the Productive Systems Committees. These committees aim to improve the organizational and productive skills of the producers, creating high aggregated value products that can compete in national and international markets (SAGARPA, 2004).

SUCCESS STORIES

Four reference or main federal hatcheries and one private hatchery are located in the desert and arid lands of Mexico.



Sanagro, a private hatchery, is by far the largest fingerling producer in Mexico, producing 12 million fry/year. Sanagro is located in the State of Sonora and is subdivided into three production units. The hatchery is 18 km from the capital of Sonora, Hermosillo (average precipitation rate 200 mm). The tilapia grow-out production units are the Sanagro Coastal Unit and the Novillo Dam Unit (Figure 3). At the Sanagro Coastal Unit, tilapia are reared in earthen ponds in a 14-month production cycle, while at the Novillo Dam Unit a 12-month cycle is obtained. At the Novillo Dam, besides the tilapia produced by Sanagro, a capture-based

fishery for tilapia and catfish (325 tonnes and 114 tonnes, respectively) is operated by local cooperatives. The merits of Sanagro derive from its aquaculture operation and stocking programmes, which have provided both direct and indirect employment in the region.

Acuicultura del Desierto, a small business operated by its owner in the state of Baja California, is the only farm in the region that operates an aquaponics operation. This small operation annually produces 7.5 tonnes of tilapia, 13 tonnes of cherry tomatoes, 20 tonnes of gourmet zucchinis and almost one tonne of lettuce and basil. Acuicultura del Desierto has been able to operate successfully and prosper through using aquaponics technology; it is becoming a model for other aquaculture enterprises in the region.

WAY FORWARD

Further development of aquaculture in Mexico depends on the successful application of efficient technologies, innovation, modernization and conversion processes. Although there have been several recent research projects conducted by academic institutions aimed at developing techniques for the farming of native species, there is a clear need for the creation of a national coordination mechanism to take advantage of the current national research capacity and available infrastructure in order to obtain beneficial results for the culture of native species.

In coastal states with desert and arid lands, aquaculture will follow three different trends, namely oyster, shrimp and marine fish farming. Freshwater aquaculture is expected to remain focused on social aquaculture in these coastal states. In the inland states, tilapia culture will be the major focus for federal, state and university research. New genetic programmes with new tilapia strains are being developed by a research centre (CIBNOR) that have improved growth rates and yields. Biofloc technology will be tested; among the advantages of this new technique are lower unit tilapia production costs, all year production, and an improved control of water quality. In Mexico, there is an unsatisfied annual demand for 35 000 tonnes of tilapia. A National Tilapia Value Network has been formed to address specific problems within the production chain such as the application of tariffs for Chinese tilapia imports and the development of a Mexican quality brand.

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Aquaculture in desert and arid lands Development constraints and opportunities

FAO Technical Workshop
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Hermosillo, Mexico

Modern technologies and alternative energy sources have allowed the expansion of aquaculture in deserts and arid regions over the last decade. The current status of desert aquaculture, developmental constraints and opportunities, were discussed at the FAO technical workshop held in Hermosillo, Mexico, in July 2010. The organization of this workshop resulted from the growing interest of numerous countries with vast desert areas to develop this food production sector and the desire to make better use of the limited water resources available in these harsh environments. This publication presents the recent experiences of desert and arid land aquaculture in seven countries and regions across the globe (Australia, Egypt, Israel, Mexico, Southern Africa, the United States of America, and Central Asia) describing the achievements of a number of farming operations, and the potential of using geothermal, surface and underground fresh and brackish waters. Furthermore, the global overview on desert aquaculture illustrates, with the use of maps and tables, those countries with vast extensions of arid territories that have the potential of further develop this industry. The document also provides recommendations on how to promote and expand this aquaculture subsector. Limited water supply remains the single largest developmental constraint, however, where the resource is available, the development of integrated aqua-agriculture systems may provide economic output opportunities from such resource-limited regions.

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