An overview on desert aquaculture in the United States of America

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SUMMARY

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

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

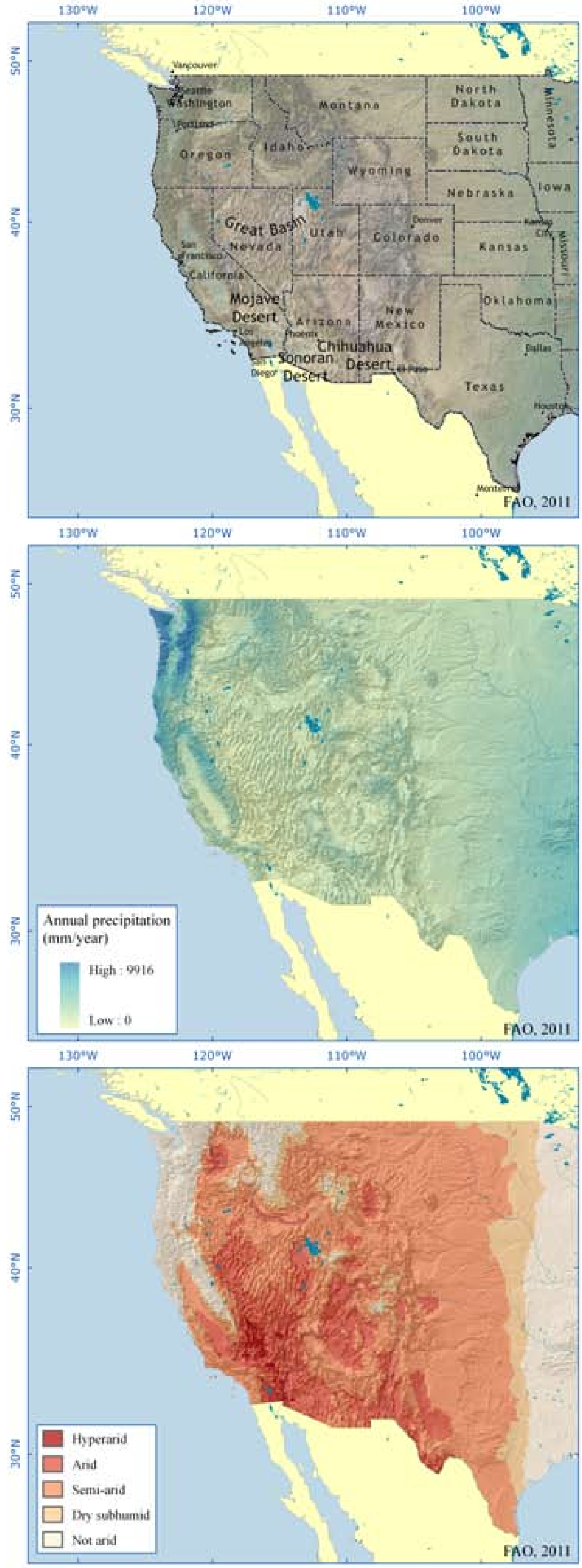
RÉSUMÉ

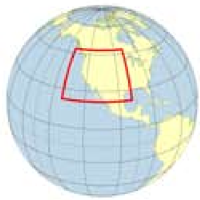
Ce document fournit un résumé de la production aquacole et des tendances de ce secteur dans les régions désertiques et arides des États-Unis d'Amérique (dont les précipitations annuelles sont inférieures à 250 mm). Ces régions se trouvent principalement dans six États de l'ouest et du sud du pays : l'Arizona, la Californie, l'Idaho, le Nouveau-Mexique, le Nevada et le Texas. Elles couvrent aussi, dans une moindre mesure, les États du Colorado, de l'Oregon, de l'Utah et du Wyoming (Figure 1). La production aquacole des premiers s'élevait à 22 700 tonnes en 2007 (USDA, 2009), pour une valeur de 169 millions d'USD. Celle de l'ensemble des 6 409 exploitations aquacoles des États-Unis d'Amérique atteignait alors 406 802 tonnes, évaluées à 1,4 milliards d'USD. Ces six États représentaient par conséquent en 2007 environ 5,6 pour cent de la production aquacole totale des États-Unis d'Amérique et 12 pour cent de sa valeur. La part de cette production provenant des régions désertiques est cependant plus petite. À l'heure actuelle, plus ou moins 40 exploitations aquacoles se trouvent dans des zones désertiques aux États-Unis d'Amérique. Elles produisent environ 1 pour cent de la production aquacole annuelle totale du pays, c'est-à-dire environ 4 000 tonnes. Dans les États du sud proches du Golfe du Mexique (Mississippi, Alabama, Louisiane, Texas et Arkansas), le poisson-chat ou barbue d'Amérique (*Ictalurus punctatus*) est la principale espèce élevé en eau douce. Toutes les structures aquacoles des zones désertiques et arides se trouvent à l'intérieur des terres et utilisent de l'eau douce ou saumâtre pour produire des bars d'Amérique (*Morone saxatilis*), des bars d'Amérique hybride (*Morone chrysops* x *M. saxatilis*), plusieurs espèces de tilapias, des crevettes marines (*Litopenaeus vannamei*), des barbues d'Amérique, des carpes herbivores (*Ctenopharyngodon idellus*) et plusieurs algues (les deux *Spirulina* et d'autres types d'algues pour les biocarburants et les extraits de matières grasses). La production de tilapias à une échelle commerciale (principalement de tilapia du Nil, *Oreochromis niloticus*) a tout d'abord été lancée dans les zones désertiques de la région de Gila Bend en Arizona, du Nouveau-Mexique et de la vallée impériale en Californie, pour ensuite se développer plus ou moins au même rythme que les autres formes de pisciculture du pays. En Arizona, la production d'une exploitation s'est maintenue à environ 454 tonnes par an. Les exploitations situées en Arizona, en Californie et au Nouveau-Mexique contribuent pour une bonne part à la production de tilapias réalisée dans les zones désertiques et arides. Ce document propose aussi un résumé des obstacles qui nuisent au développement de l'aquaculture dans les régions désertiques et arides des États-Unis d'Amérique, notamment les prix bas à la sortie de l'exploitation, les marchés concurrentiels, le coût élevé et croissant de l'alimentation et des autres charges d'exploitation ou encore la qualité de l'eau, avec des traces de métaux lourds ou la présence d'algues toxiques. Les États-Unis d'Amérique comptent quatre grandes régions désertiques. Trois d'entre elles sont des « déserts chauds » : le Chihuahua, le Sonora et le Mojave. Les températures y sont élevées au cours des longs étés et les végétaux y sont d'un type très similaire à celui des communautés de plantes subtropicales. Le quatrième désert, le désert du Grand Bassin, est quant à lui qualifié de « désert froid ». Les températures y sont généralement plus froides et la vie végétale n'y est pas d'origine subtropicale. Le désert de Chihuahua couvre une partie du sud-est du Nouveau-Mexique, l'extrême ouest du Texas et s'étend plus au sud sur une vaste portion du territoire mexicain. Le désert du Grand Bassin couvre les trois-quarts du nord du Nevada, l'ouest et le sud de l'Utah, le tiers sud de l'Idaho et l'extrême sud-est de l'Oregon. Il couvre aussi de petites portions de l'ouest du Colorado et du sud-ouest du Wyoming. Il est bordé au sud par les déserts de Mojave et de Sonora. Le désert de Mojave couvre une partie du sud du Nevada, l'extrême sud-ouest de l'Utah et l'est de la Californie, au nord du désert de Sonora. Ce dernier, relativement petit, couvre l'extrême sud-est de la Californie, la plus grande partie de la moitié sud de l'Arizona et s'étend plus au sud sur une bonne part de la façade est du Mexique.

ملخص

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

FIGURE 1
Maps of the United States of America





United States of America

Country area: 963203 (1000 Ha)
Source: FAOSTAT. Estimated, 2007

Land area: 916192 (1000 Ha)
Source: FAOSTAT. Estimated, 2007

Agricultural area: 411158 (1000 Ha)
Source: FAOSTAT. Official data, 2007

Aquaculture Production Average 2004-2008: 346000 tonnes
Source: FISHSTAT. Official data

Aridity (in western areas as shown on the map):
Approx. areas of hyperarid regime: 4405 (1000 Ha)
Approx. areas of arid regime: 78800 (1000 Ha)

A typical landscape of an arid region in Arizona, USA.

COURTESY OF J. WILKENFELD

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

GENERAL OVERVIEW OF DESERT AND ARID LANDS AQUACULTURE DEVELOPMENT

FIGURE 2
Desert Sweet Shrimp Farm in Gila Bend, Arizona

COURTESY OF G. TREECE

Marine shrimp production – Marine shrimp production from these arid regions started in Texas in 1972 on a trial basis, and commercial level production peaked in Arizona and Texas in 2002 and 2003 and then began to decline. There were approximately 11 marine shrimp farms in southern Arizona and desert west Texas during the period from 2000 to 2003. However, this has declined to only one desert shrimp farm in Texas and one in Arizona in 2011, and production in 2009 and 2010 was very low. At one point, there were 90 hectares of ponds in desert west Texas with seven producing commercial farms (Treece, 2002) and there were over 131 hectares of desert shrimp on four farms in Arizona (Figure 2). California also had one shrimp farm in the desert, which is now producing finfish.

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

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

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

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

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

COURTESY OF G. TREECE

FIGURE 4
Table olive nursery in Arizona

COURTESY OF G. TREECE

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

HUMAN RESOURCES

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

FARMING SYSTEMS DISTRIBUTION AND CHARACTERISTICS

Arizona – Some of the facilities in Arizona use geothermal wells to produce water ranging between 30–40 °C. Sitting over a large geothermal aquifer, Hyder Valley in southwest Arizona is a centre for warmwater fish farming. Because of its close proximity to markets in Tuscon, Phoenix and Southern California and its access to geothermal springs, Hyder Valley is considered a centre of aquaculture in the State. Other warmwater operations rely on pumped groundwater or surface water and are located mainly in the southern, warmer part of Arizona, at lower elevations. The irrigation water that flows in the canals in the desert regions of the State is especially suitable for warmwater fish farming. The desert climate warms the water above 22 °C. Warmwater fish include tilapia, catfish, hybrid striped bass and largemouth black bass (*Micropterus salmoides*). About 40 percent of the fish are produced to stock various facilities, with 60 percent being sold as food or table fish. Tilapia and catfish are generally sold for human consumption in the Tucson and Phoenix metropolitan areas. However, fish farmers also sell at the farm-gate or from the back of a truck. Much of the striped bass and largemouth black bass are sold for stocking. Fish farming in Arizona mainly consists of family operations and many people view this activity as fitting within the celebrated agricultural tradition of the independently owned and operated family farm (Table 1).

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

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

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

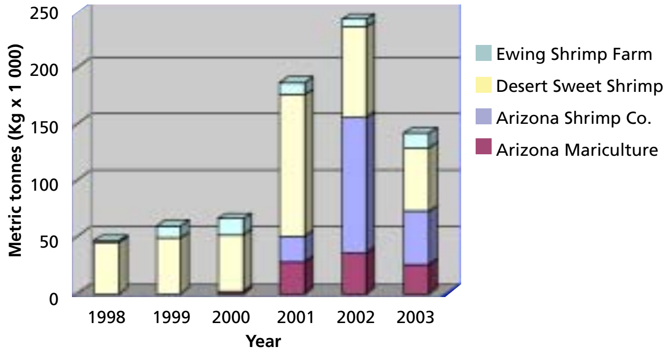
Arizona aquaculture production 1994–2009 (Tonnes/Thousand Dollars)

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

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

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

FIGURE 5
Production history in Arizona
(1998 & 1999=26HA; 2000=36HA; 2001=114HA; 2002=136HA; 2003=90HA)



Source: Wilkenfeld *et al.*, 2004.

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

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

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

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

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

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

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

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

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

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

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

The intensive farm, Desert Sweet Shrimp (which ceased operations in 2010, but began again in 2011), worked hard from 1998 onwards on a strategy to market shrimp under its own brand name at premium prices in Phoenix. Establishing a specialty niche is a long, difficult and expensive process. Assuming the mean wholesale price of USD14.08/kg, which is double the Fulton Seafood market price, and adding a USD2.20/kg production cost to cover the overhead of their significant marketing effort, Desert Sweet Shrimp would have barely broke even. It is amazing that the farm continued to operate under such economic conditions for so long, and diversification seems to have been the key. Had it not produced other crops along with the shrimp, the farm would have closed its aquaculture operations years ago. With funds running low, Desert Sweet Shrimp only stocked 2.83 hectares of shrimp in 2009 and when its feed supply ran out it allowed the shrimp to feed on natural productivity for the rest of the production cycle. Only 3.6 tonnes of eight-gram shrimp were harvested in 2009, compared to 2008 when it was 22.7 tonnes from 17.29 hectares. Their production costs were USD4.40 to USD5.50 per kilogram of shrimp. Desert Sweet Shrimp even had its own shrimp retail stores and restaurants in the larger metropolitan areas to retail its product, but its operation was still having problems with sustainability. However, after reopening in 2011, the management believe that they can be successful this time.

FIGURE 6
Tilapia farms in the California Desert: F&B Fisheries in Desert Centre has round ponds

Photos of tilapia farms in California can also be found at http://ag.arizona.edu/azaqua/aquaculture_images/cal2002/cal2.html

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

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

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

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

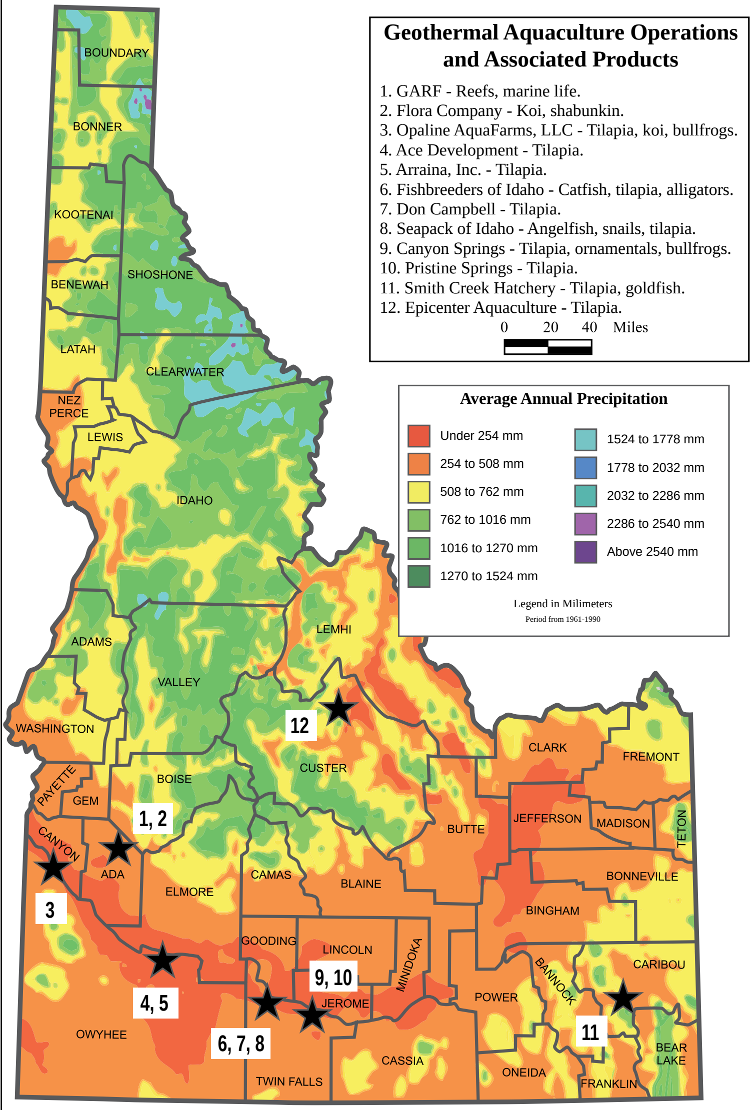
Kent Sea Tech (Mike Massingale) was in operation for more than twenty years as the largest producer of hybrid striped bass in the United States of America until it closed the fish part of its operation in late 2008. It has now switched its focus entirely to the production of algal biomass for biofuels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

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

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

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

FIGURE 7
Annual precipitation map with location of geothermal aquaculture operations in Idaho State



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

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

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

COURTESY OF G. TREECE

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

By 2010, ten of the 12 Idaho geothermal aquaculture businesses were raising tilapia, but the industry has faced financial challenges from overseas producers. To overcome these challenges, Bob Williams (Arraina Inc. and Ace Development) modified his aquaculture operation in the Owyhee County desert in order to deliver live tilapia to Vancouver, British Columbia, Canada, where its Asian residents prefer live seafood, and are willing to pay extra for it. Other Idaho aquaculture operations followed Mr Williams' lucrative approach to tilapia farming. Six Idaho businesses use geothermal water to raise ornamental aquaculture products: angelfish, goldfish and other ornamentals. In Ada County, the Flora Company raises koi (domesticated varieties of the common carp, *Cyprinus carpio*) and goldfish (*Carassius auratus*) in a cascading application that is downstream from their geothermal greenhouses. Also in Ada County, the Geothermal Aquaculture Research Foundation raises fish and reef animals and aquatic plants to stimulate interest in, appreciation for and understanding of marine life. It began 20 years ago as a wetlands project, the plant operation includes valuable aquatic species collected from around the world to enhance the study of algae control and the balance of nature. These plants thrive and reproduce rapidly due to the continued availability of geothermal water in the Boise warm springs water district.

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

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

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

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

FIGURE 9
Saline shrimp culture ponds (Permian Sea Organics)

COURTESY OF B. REID

accumulated supporting commercial aquaculture there. A detailed history of the development of aquaculture in the desert and arid region of west Texas has been published (Treece, 2002). The aquifer used by shrimp farms in the Imperial area is the cenozoic alluvium, water remaining from the Permian Sea. All farms had the same well water or aquifer source. Salinity varied from 10–15 ppt. There are no freshwater zones in that area, and no discharge water was allowed to leave any farm. This water is not used in any other form of agriculture on a large-scale. In the past, some of the farms maintained reservoirs and some had created wetlands that received the effluent and provided a habitat for the endangered desert pupfish. There are four different species of pupfish in the Permian Sea Basin, but the species that the operating shrimp farm, Permian Sea Organics (Figure 9), works with is *Cyprinodon pecoenis.* Almost any permanent desert pool of water has a species of pupfish; all are at risk. The surface water seeps back into the aquifer through porous, sandy soils. Red clay soils can be found in the Pecos river basin for making ponds. Outside the river basin, the soils do not hold water.

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

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

Permian Sea Organics has strived to meet the United States of America standards for organic certification. Mainly, the use of chemicals, antibiotics and over-stocking is avoided, and organic feed is used. Shrimp from the farm have been certified as "USDA organic" by the accredited group Florida Organic Growers (M. Mesh, personal communication, 2010), and it is thought that this label might help his products compete with foreign shrimp flooding into the United States of America from Asia and South America. It is claimed that the wholesale value of organic shrimp is USD11/kg, compared with USD4.4/kg for shrimp on the US commodity market.

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

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

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

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

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

CULTURED SPECIES

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

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

CULTURE PRACTICES

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

PRODUCTION

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

More recently, Arizona alone has produced over 454 tonnes of tilapia annually from one farm and over 600 tonnes of aquaculture products from other commercial operations but excluding trout farms. Arizona had 25 farms in 2002 (USDA, 2005) that produced 1 385 tonnes per year with a value of USD3 million. The desert and arid lands farms now produce over USD3 million of product annually. The increased tilapia production in Arizona has had a big impact in the state. New Mexico produces four million to seven million tilapia fingerlings annually. Idaho's total annual production is 1 572 tonnes, mostly of tilapia and catfish from geothermal waters. Texas only has one remaining marine shrimp operation in the western part of the state that produces about three tonnes per year. California has at least ten farms located in desert and arid regions. The total California aquaculture production for the state is estimated at USD100 million, but it is not known what proportion comes from the desert regions. USDA (2005) stated that California's total state production from aquaculture in 2002 was 5 032 tonnes from a total of 118 farms. The California Fish and Game Department (CFGD) states that there were 192 licenced freshwater aquaculture farms in California in 2010 (CFGD, personal communication, 2010).

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

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

Source: USDA, 2005 using 2002 data.

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

MARKET

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

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

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

CONTRIBUTION TO THE ECONOMY

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

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

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

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

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

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

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

PROMOTION AND MANAGEMENT

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

INSTITUTIONAL FRAMEWORK AND GOVERNING REGULATIONS

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

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

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

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

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

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

General

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

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

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

APPLIED RESEARCH, EDUCATION AND TRAINING

Arizona

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

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

Texas

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

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

Regional

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

TRENDS, ISSUES AND DEVELOPMENT

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

Diseases have not been a major factor, but toxic algae have played a major role at some of the inland arid aquaculture farms in the United States of America. Blue-green (Cyanophyta) algae proliferate in inland saline ponds with high organic waste. Farmers have found that the blue-greens are not detrimental to all aquatic life, but they are generally regarded by producers in the United States of America as non-desirable algae in ponds. According to Snyder, Goodwin and Freeman (2002), there are benefits of certain blue-green algae in nutrition and in triggering higher immune response activities. At least one genus, *Oscillatoria*, has been known to cause "off-flavour" problems. Farmers in Australia have found blue-green blooms to be a problem for the past 20 years. If *Oscillatoria* blooms in a pond it generally means that the shrimp or fish will become ill. Experience in farms in Texas and Belize has shown that herbicides with the active ingredient Atrizine can successfully knock out blue-green algae temporarily but, unless water with an alternative strong bloom is introduced into the pond, blue-greens will take over again.

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

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

Appropriated water rights apply to land where rainfall is limited and water is scarce, such as found in the drier United States of America desert southwest. Appropriated water rights are similar to real property in that the water can be sold, transferred or mortgaged. In other words, the water is independent of the land. Because it is limited in supply, proper management by the state must occur (such as with the Colorado River) through priority administration. This form of state water distribution management defines the water rights as "first in time is first in right" and senior *vs.* junior rights. Put simply, the first to acquire the right to the water has precedence over those that come after, at least in theory. Where there are problems, such as those of increasing concern to water users in the desert southwest, litigants can make a case for relief through the initial step of water delivery call which is followed by an administrative hearing to determine the extent of injury and confirm senior and junior water rights. This is often followed by an appeal to a district court and finally the State Supreme Court. The cost to the litigant to defend its water rights has been reported to be USD300 000 annually by one individual farm in 2010 (K. Fitzsimmons, personal communication, 2010). The effort by the company to defend its water rights has been successful but it has still not received the water that it is due. This farm now believes that working with the junior water right holders to create a "win-win" for both sides may be more fruitful. Freshwater is a resource that is limited in supply and over appropriated. It has, is and will be a source of "water wars" unless practical solutions to share the water and use it more efficiently are found.

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

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

FIGURE 10
Desert Springs Tilapia fish farm

Source: Google Earth.

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

Desert Springs Tilapia (HCI Box 46A 50621 Agua Caliente Road, Dateland, Arizona, USA 85333; Tel. 928 4542360; E-mail: sales@desertspringstilapia.com).

Desert Springs Tilapia (formerly Arizona Mariculture Associates) was formerly a shrimp farm, but now produces 454 tonnes of tilapia annually (Figures 10 and 11).

The elevated nursery ponds that gravity fed to the grow-out ponds at the Arizona Mariculture Associates farm was a poor design for the desert (J. Wilkenfeld, personal communication, 2010). In 2000, it cost more than USD one million to construct (excavate and construct) twelve 400 m^2 nursery ponds situated above twelve 1 000 m^2 grow-out ponds. The original blueprints for the farm showed 500 pairs of nursery and grow-out ponds, but only these few were actually built. In theory, transferring juveniles by gravity from the nursery ponds through a 30 cm drain pipe directly into the grow-out ponds below seemed ideal. However, the water had to be pumped from 263 metres underground to the elevated nurseries, and then had to be pumped again in order to remove it from the grow-out pond harvest sumps for water exchange or harvesting. In addition, unsuitable water chemistry kept the shrimp in a continual state of stress, so that they could not handle the transfer from nursery to grow-out ponds. A whole array of other design and management problems were also encountered, so it was no wonder that the shrimp farm closed. However, under new management, the farm began to raise tilapia using intensive culture and it has been very successful. The management is now considering establishing a hybrid striped bass farm in the same area. The existing facility is agriculture integrated with olives and alfalfa fields utilizing the fish farm effluent (Figure 12). Up to 9 cuttings per year have been made at some farms (Figure 13).

Imperial Catfish farm and hatchery (Imperial Catfish Farm, 152 E. Harris Road, Imperial, California, USA 92251).

This is another successful farm and hatchery in the Imperial Valley desert area of California; its only crop is catfish (Figure 14).

Earthrise Nutritionals (113 E. Hoober Road, Calipatria, California, USA 92233).

This is one of the oldest producing farms and produces *Spirulina* algae for the health food industry (Figure 15).

FIGURE 11
Desert Springs Tilapia intensive lined ponds

COURTESY OF K. FITZSIMMONS

FIGURE 12
Alfalfa field at Desert Springs Tilapia

COURTESY OF K. FITZSIMMONS

FIGURE 13
Cut alfalfa at Desert Springs Tilapia

COURTESY OF K. FITZSIMMONS

FIGURE 14
Imperial Catfish Farm and Hatchery in Imperial, California

Source: Google Earth.

FIGURE 15
Earthrise Nutritionals Farm from Google Earth

Source: Google Earth.

FIGURE 16
Earthrise Nutritionals Algal Raceways

COURTESY OF G. TREECE

In 1979, after years of research, Earthrise introduced *Spirulina*[1] to the natural foods market. Then, in 1982, the owners built the first United States of America *Spirulina* farm to grow this green superfood in the desert sun. Today, the Earthrise Farm is the world's largest *Spirulina* farm. Earthrise® products are marketed in the United States of America and in over 20 countries on six continents. *Spirulina* is a whole product of biological origin. It consists of the dried biomass of the cyanobacterium *Arthrospira*. *Arthrospira* are filamentous microscopic blue-green algae (cyanobacteria) that occur abundantly in an almost unialgal form in highly alkaline lakes with high pH. The high pH and alkalinity prevent other algae from growing and it is, therefore, grown outdoors virtually free of contamination by other algae. More information is available on www.earthrise.com/whatIsSpirulina.html.

A QUESTIONABLY SUSTAINABLE SHRIMP OPERATION IN ARIZONA

Shrimp farming has still not proven to be sustainable in the deserts of Arizona. In 2010, the last remaining shrimp farm in Arizona decided to cease shrimp culture and concentrate on the terrestrial agriculture. A seemingly sustainable shrimp farm in the Gila Bend, Arizona, until 2010 was the Woods Bros. Farm, later called Desert Sweet Shrimp before closing its shrimp operation. It had nursery ponds consisting of covered earthen ponds (Figure 17) and cement raceways covered with greenhouses and aerated with airlift pumps (Figure 18). The farm was agriculture-integrated with olives, wheat, alfalfa and other crops. The farm has a new investor and plans to stock shrimp again in 2011 (C. Collins, personal communication, 2011).

Shrimp production at the Desert Sweet Shrimp farm was related to an

[1] The true taxonomic name of *Spirulina* has been revised recently. The edible forms of *Spirulina* are now called *Arthrospira*. The common species under commercial cultivation are *Arthrospira platensis* and *Arthrospira maxima*. The name *Spirulina* is now retained to describe the product and not the algae.

aeration horsepower as well as to animal size at harvest. If the farm harvested smaller sizes then they got significantly higher survival rates than when rearing for the larger sizes of 26–28 g shrimp (C. Collins, personal communication, 2010). Productivity was good when they first began – consistently 5 000 to 10 000 kg/ha. When the management stopped investing in maintenance and horsepower capacity was reduced, productivity went down significantly. Production was only 2 000 to 3 000 kg/hectare if the shrimp were harvested between 16–17 g, and the farm did not try to get the larger sizes due to the prices in local markets.

FIGURE 17
Desert Sweet Shrimp – A covered shrimp nursery

COURTESY OF G. TREECE

FIGURE 18
Desert Sweet Shrimp – Greenhouse covered shrimp raceways

COURTESY OF G. TREECE

CASE STUDY OF ARIZONA DESERT SALINE SHRIMP FARMS

This case study will review problems that were encountered by four Arizona shrimp farms. These included slow but continuous attrition, surges of shrimp mortality associated with moulting, stress-induced cramping of shrimp, and unstable blooms of predominantly unfavourable algal species. In effect (J. Wilkenfeld, personal communication, 2010), it seemed that with some variation from farm to farm, the shrimp seemed to be living on the edge of disaster, and any additional input of stress caused by handling, significant water exchanges, moulting and increases in temperature was likely to cause mortalities, especially at three of the farms.

Analyses of well water in Arizona were presented by Boyd, Thunjai and Boonyaratpalin (2002), who later showed that there were characteristic chemical differences between well water and what would be expected in seawater diluted to a similar salinity. The differences varied from farm to farm, but typically included low levels of potassium and magnesium, low alkalinity (which was specific to Arizona Mariculture Associates) and high levels of calcium. It was clear from other work done at Auburn University in Alabama (Boyd, 2003) that similar water chemistry issues were common to other inland culture sites, even beyond the desert environment. Green Prairie Aqua Farms, near Montgomery, Alabama, is one such farm that is still operating after solving its problem with low potassium. Some improvements in the industry included modifications in diet, operating procedures and the use of various pond additives such as dolomite and K/Cl. Arizona Mariculture Associates attempted to establish a logical protocol for the use of K/Cl to deal with a given potassium deficiency, as well as a fertilizer regime to modify and control algal blooms, which may provide a road map for future shrimp farming operations in the desert.

As shown in Table 5, all four farms had low levels of potassium, but the K/Cl ratio of K/Cl was satisfactory for Desert Sweet Shrimp, whose K/Cl ratio, indicated in

TABLE 5
Deductive reasoning for focus on potassium

COMPONENT (mg/l)	SEA WATER	DILUTE SEA WATER (Calc.)	Arizona Mariculture (Lab & Boyd)	Arizona Shrimp Co. (Lab & Boyd)	Desert Sweet Shrimp (Lab & Boyd)	Ewing Shrimp Farm (Boyd)
Salinity (ppt)	35.0	4.5	4.6	7.4	1.5	4.6
pH	8.2	ND	7.3	7.6	7.8	7.9
Alkalinity	125.0	ND	55.0	220.0	137.0	174.4
Cl	19 400.0	2 494.3	1 800.0	3 223.0	530.0	2 339.0
Na	10 500.0	1 350.0	1 500.0	2 595.0	410.0	1 610.0
SO_4	2 740.0	352.3	1 800.0	2 313.0	343.0	857.0
Mg	1 272.0	163.5	36.0	222.0	12.0	113.0
Ca	400.0	51.4	520.0	497.0	120.0	319.0
K	380.0	48.9	7.0	15.2	10.0	13.0
K/Cl Factor	0.0196	0.0196	0.0039	0.0047	0.0189	0.0055
For K/Cl factor of 0.0100, K should be	NA	NA	18.0	32.2	5.3	23.4
Additional mg of K/Cl required to reach K/Cl Factor of 0.0100	None	None	11.0	17.0	(4.7)	10.4
Grams of K/Cl to be added per 1 000 liters of new water	None	None	22.1	34.1	(9.4)	21.0

Source: Winkenfel *et al.*, 2004.

Table 5 in green, was almost the ideal ratio of full strength seawater (0.0196). However, the other three farms were all below the 0.0070 minimum specified by Fielder, Bardsley and Allan (2001) and well below the target safety factor of 0.01, as discussed earlier in this review. Potassium deficiency seemed to be the key problem. So with a target of 0.01 in mind, it is possible from the formula of K/Cl to calculate that in the case of Arizona Mariculture Associates, they should have added 18 mg/litre of potassium, and should also have been adding 11 mg/litre of K to all new water entering their ponds. Armed with this information and the fact that potassium is roughly 50 percent of potash by weight, it was easy to set up a pond-by-pond spreadsheet that showed how much K/Cl should be added when first filling each pond, and how much should be added on a daily basis depending on percolation losses and water exchange. Using this method, Arizona Mariculture Associates did not experience attrition or moult related mortalities. The Arizona Shrimp Company and Ewing also used K/Cl to avoid the mortality problems that they had experienced but their application method made it difficult to quantify their data.

After fighting unstable blue-green algae blooms for two years, Arizona Mariculture Associates dropped their old fertilization protocol and decided to use a 20:1 ratio of nitrogen to phosphorus (J. Wilkenfeld, personal communication, 2010). After some trial and error, a basic dose rate of 11.5 kg of urea and 1.02 kg of phosphoric acid per hectare was decided. The farm manager started with two applications in the first week of rearing and then applied further doses as needed, to obtain and retain Secchi disc readings of 35–45 cm. Experience showed that it was important not to overreact by adding too much fertilizer or applying it too frequently, or the algae will become out of control. Using this regime, algae at this farm became dominated by diatoms, primarily *Synedra*, which is a pinnate diatom, and at least two species of *Chaetoceros*. In previous years, their blooms had been characterized by various blue-greens including *Oscillatoria*, *Spirulina*, *Merismopedia* and others.

It is important to note that Desert Sweet Shrimp had the most consistent production results and the fewest problems of the four Arizona farms, and survived longer than the other farms in Arizona. Arizona Mariculture Associates consistently produced very low quantities of shrimp and it was believed that this was because of the water quality coming from its wells. Apparently, the water quality is satisfactory for tilapia but not for shrimp and this farm now rears tilapia.

WAY FORWARD

After more than ten years of commercial trials in the United States of America desert regions, it seems that tilapia, catfish and algae have the greatest potential; this is evident in looking at the species now under culture. Aquaponic or integrated aquaculture of the above species with wheat, olives, alfalfa and other terrestrial crops seem to offer the most return on investment and help spread the risks. If marine shrimp farming is to be attempted, then a super-intensive biofloc culture should be considered with lower operating costs and added culture of *Salicornia* or seaweed if the salinity is high enough. If the salinity is low then other terrestrial crops should be used. All of the shrimp farms in the United States of America are very aware of and interested in the continuing efforts of various groups to develop super-intensive, indoor, recirculating (RAS) or zero water exchange heterotrophic culture systems, especially those using biofloc techniques. These systems hold considerable promise for the future of shrimp culture in North America and elsewhere. However, these systems are not yet proven commercially sustainable. It is believed that not breaking the cycle of bacteria (especially *Vibrio*) by drying out the systems between crops is the key factor contributing to failure. Most research facilities do break the cycle by drying, but commercial facilities have not been doing this. Research facilities are still plagued with *Vibrio.* The USDA/US Marine Shrimp Farming Program had planned to continue research on RAS and the problems associated with high-density culture, but funding was cut in 2011. Researchers at Nicolls State University are also working on quick identification methods for the various species of *Vibrio* but, without the USDA/US Marine Shrimp Farming Program, they have no extension funding to spread the results of their work.

Given the specific conditions described earlier in this review it appears that, at least for the time being, the best strategy in the Arizona desert is tilapia farming or the culture of other finfish, such as hybrid striped bass, involving simple operating methods. The objective should be to produce fish in high density at low cost, and to remain diversified with the production of other terrestrial or aquatic plant crops. Only a few sites in Arizona were trouble-free from toxic algal blooms. A fertilizer regime of 20N:1P should be the first step with any outdoor pond. Even though there is no research that proves this practice to be necessary, many farmers that have grown crops in ponds for years in the desert attest to it being necessary to avoid toxic algal blooms.

Aquaculture has many positive impacts on the environment, but it also can have negative impacts, which often occur when there is overexploitation. The more intensive the operation, the greater the demands on the environment. Any operation in the deserts of the United States of America should follow the Best Aquaculture Practices[2]. Koonse (2003) described the United States of America Federal Drug Administration (FDA) "Good Aquaculture Practices" guidelines, which should also be followed, along with the guidelines for sustainable aquaculture suggested by FAO and the World Wildlife Fund. In October 2010, the first global guidelines for aquaculture certification were adopted by FAO[3]. Given the rapid growth of aquaculture globally, it is important for academic institutions to define the curricula (undergraduate and graduate level) and research facilities required for further education and basic research in sustainable aquaculture to ensure human resource development and capacity building.

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[2] Additional information can be viewed at www.aquaculturecertification.org

[3] www.fao.org/news/story/en/item/45834/icode

One important environmental issue in desert aquaculture is the potential salination of soil and freshwater wells as salt intrudes into groundwater in inland areas after it is transported and added into the ponds. Another environmental issue is the loss of groundwater. Good practices to protect groundwater resources during pond aquaculture in saline areas include:

- adopting a switch over strategy to culture high saline tolerant species in high saline areas;
- not using low saline tolerant species in areas where high salinity prevails;
- assessing the groundwater availability before extracting it for aquaculture; and
- not using groundwater in large quantities to dilute saline water without assessing the availability of the resource, and the impacts it may cause.

The introduction of non-native fish species into the wild through aquaculture may eventually lead to serious problems. These are less likely to occur in desert environments, but are still possible. Strategies associated with the use of exotics and genetically modified organism (GMO) for aquaculture should be reviewed and practical codes for risk assessment and management should be developed, as emphasized in the FAO Code of Conduct for Responsible Fisheries. Attention should be focused on implementation of the strategies/actions of the signatories to the Convention on Biological Diversity. The prohibited or restricted list of species should be checked; do not culture or introduce prohibited or restricted species.

Some claim that it is more expensive to operate aquaculture farms in desert locations because they are so remote (B. Reid, personal communication, 2010). Diseases do not seem to be a significant issue inland. Finfish seem to have been more sustainable than shrimp in these desert environments. Water composition (trace metals) seems to be more important for shrimp than fish and toxic blue-green algae are problematic at some farms. Expenses are high in the whole of California. Remoteness is expensive for some items but land is cheaper and it is easier to get agriculture rates for electricity and taxes. The most critical factor of all is water discharge. Most of the successful farms are integrated with the reuse of effluent for crop irrigation. This spreads the cost of water pumping, diversifies farm income, spreads labour and equipment between each operation and saves fertilizer expenses.

As a non-consumptive sharer of irrigation water, aquaculture represents a strategy to help crop farmers pay their water bills. Currently, desert and arid lands aquaculture in the United States of America is being explored further, after many years of commercial trials. Much work needs to be done. For example, research needs to continue to identify new species that are more suitable for culture within the arid regions and that will bring a greater return on investment than tilapia and provide more human nutritional benefits. Although they recognize this, some aquaculturists also realize that identifying new species does not ensure that the public will buy them. Consumers are wary of products they are not familiar with. This raises another important aquaculture need, which is market research. What kind of fish do people buy and how much of it? How much are people willing to pay for fish? What proportion is purchased fresh or frozen? What variables affect the purchase of fish products? Such information is needed to plan fish farming activities in the arid regions of the United States of America. The availability of such information would also help in planning a market strategy, another necessity. Other requirements include more lenient terms from lending institutions. Money is not readily available at present to support aquaculture. There have been many failures and the business is considered as a very high risk. Other research is needed on how to deal with the increases in total dissolved solids that occur through high evaporation levels in heavily recirculating systems, and in nutrient modelling. In the long term, it is thought (K. Fitzsimmons, personal communication, 2010) that soil texture analyses are needed to address the question "do infiltration rates increase or decrease?" and "are there problems with salination or sodicity?". Other important research is required on fertilizer values, cost-benefits, enterprise budgets and the further development of heterotrophic biofloc suspended culture techniques in the culture water, and terrestrial crops or salt tolerant crops suitable to accompany it. More educational opportunities for persons engaged in fish farming also are important.

A promising development is the integrated multi-trophic aquaculture approach, where species of complementing trophic levels are grown together. Such ecologically-integrated systems have been shown to be able to sustain themselves economically in both developed and developing countries. Pond systems that minimize water exchange appear most compatible with the concept of sustainability. This appears to be true for those systems that can show a positive energy use advantage. Most Chinese aquaculture occurs in extensive (as opposed to intensive) ponds with little water exchange and little expense on power for aeration, carbon dioxide stripping, clarification and biofiltration. Farmers there use the sun and a mixture of fish with different feeding habits to maintain water quality. While much of current efforts in industry and research address the reduction in the use of fishmeal and fish oil in aquafeeds, and in the use of energy in the aquaculture production process, there are additional aspects that are also important (A. Neori, personal communication, 2010).

Working out the above matters will help refine aquaculture in arid regions of the United States of America, its characteristics and its potential.

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