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Cover: The Melbourne Convention and Exhibition Centre is the site of AUSTRALASIAN AQUACULTURE 2012. *See page 18.*

WORLD AQUACULTURE Magazine

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Editor's note — Freezing the footprint of aquafood

Jason Clay is well-known to many in WAS. He was the plenary speaker at the triennial conference in 2007 and has been actively engaged with the Society and a broad spectrum of stakeholders to improve the environmental performance of aquaculture. Jason has been involved with the development of aquaculture Best Management Practices (although he prefers the adjective "better") and environmental certification programs, especially with his long-term employer, the World Wildlife Federation, where he is now a Vice-President of Market Transformation.

Last year, Jason authored an article published in Science (475:287-289) titled "Freezing the Footprint of Food," which is premised on the necessity of doing more with less as an approach to feed 2-3 billion more people (than the 9 billion already here) by 2050. Jason calls for a freeze on inputs to agriculture and offers a suggestions ranging from low-hanging fruit to long-term structural change.

In his article, Jason identifies eight strategies—what he calls "food wedges"—to achieve the freeze. The strategies are discussed broadly with respect to global agriculture and he does not single out aquaculture. Nonetheless, some strategies have relevance to aquaculture and these are discussed here. At the top of the list is genetic improvement. The combination of traditional selection techniques, aided by molecular markers, and a range of modern biotechnologies offers the promise of improved performance, particularly in growth rate, feed conversion, and disease resistance. Broadly speaking and with some notable exceptions, aquaculture lags far behind other forms of animal agriculture when it comes to genetic improvement. Given the generally superior growth performance in terms of nutrient and energy conversion of feeds by aquatic animals as compared to terrestrial livestock, freezing the footprint of food can be aided by shifting resources for breeding programs from poultry, swine, and cattle to fish and shrimp.

Better practices are identified as another food wedge in Jason's article. He argues for raising the level of the lowest-performing producers because the scope for increasing their productivity and income is greatest and they make a disproportionately large contribution to environmental impacts. He calls for new thinking about ways to transmit information to farmers. Weak governments, especially in lesser developed countries, means that traditional extension services are ineffective. Using master farmers or hatchery owners to deliver better practices to low-performing producers might be a more effective approach. Ecolabeling programs that have better practices at their core could also provide an incentive for more producers to improve practices and performance. The proliferation of such programs

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Society

Erratum

Dr. Stickney takes full responsibility for the misspelling of Nepal on the cover and photo credit in the December 2010 issue of **World Aquaculture** and expresses his regret for missing the error during review of the proof."

President's column

The World Aquaculture Society has a well-organized and decentralized system to promote and achieve the goals of the Society. This system consists of and is operationalized by committees, working groups, and chapters. I would like to take this opportunity to have a short discussion about the chapters of WAS.

The idea of chapter formation was launched about three decades ago with the main goal of increasing global participation in WAS. At present there are five chapters within the Society: the United States Chapter (USAS), the Asian Pacific Chapter (APC), the Latin American and Caribbean Chapter (LACC), the Korean Chapter, and the Japan Chapter. Each represents a specific geographic area of influence and is an essential mechanism to promote WAS in that area. Chapters with more than 200 members are entitled to send one voting delegate to the meeting of the Board of Directors of the World Aquaculture Society (Bylaw 10, Section 2).

It is expected that chapters become administratively and independently self-sustaining within a short time of their establishment. It is also expected that chapters organize scientific meetings for their members and actively participate in the development of aquaculture in their geographic area.

Since their establishment, chapters have been supporting the goals of the parent society in various ways. Most have been very active in editing and publishing books, organizing scientific meetings, and organizing sessions at WAS annual conferences. As evidence of this, the two major upcoming events are WAS chapter conferences. The first one is the Annual Conference and Exhibition of the US Chapter that will be held in Las Vegas, Nevada from February 29 to March 2. The mid-year meeting of the WAS Board of Directors will be held immediately after that conference. I will provide my impressions about the US Chapter conference in the next issue of **World Aquaculture** magazine.

Another upcoming conference will be held in Melbourne, Australia from May 1-4. The conference and trade exposition has been organized by the Asian Pacific Chapter and a large audience is being expected. There were more than 1,500 participants at the APC meeting held in Kochi, India last year.

Any individual can join a chapter; however, it is a pre-requisite to be an active member of WAS. To join a chapter it is also necessary to pay an additional modest membership fee of US$ 5.00 per year. Society members can join as many chapters as they like, as long as they are willing to pay for the privilege. I encourage all members to join at least one chapter.

During the meeting of the WAS Board of Directors in Natal, Brazil last June, there was some discussion about the current situation with some chapters. Over the years the Board of Directors has been very careful to approve a petition for establishment of a new chapter. The Board must judge that the chapter has a reasonably good probability that it will achieve administrative and financial independence. This is to prevent the undesirable situation that a chapter would have to be closed because of the lack of activities, which could cause losses to WAS and its members.

Therefore, despite the decentralized organization of the Society, chapters are governed by the WAS Bylaws and rules for the establishment of a chapter are provided in Bylaw 10 (www.was.org). Chapters must submit reports to the WAS Board of Directors, which in turn will support the chapters and ensure that their activities will continue to promote benefits to WAS members and to the development of aquaculture in each chapter's geographic area.

— *Ricardo C. Martino*
President

Book Review

Aquaculture and Fisheries Biotechnology: Genetics Approaches, 2nd edition by Rex Dunham

CHRISTOPHER C. GREEN[1]

Integration of genetics with aquaculture and fisheries, specifically through the application of technology, and an understanding of recent advances in genetics are critical for the development of high-performance culture species. There is often difficulty understanding how new genetic approaches and advances will benefit or be integrated in an aquaculture framework and this book attempts to address that issue. Rex A. Dunham is an Alumni Professor in the Department of Fisheries and Allied Aquacultures at Auburn University and is uniquely poised to relate his own work in aquaculture and genetics as well as draw from other research in this rapidly developing field. Channel catfish are featured to a perhaps excessive degree as the example organism for the wide array of topics covered in this volume as the author

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WAS Board adopts and operationalizes a new strategic plan

Graham C. Mair

I recently completed a three-year term as a Director on the WAS Board, an enjoyable and rewarding experience. I believe it is important when in such a position to actively contribute to the Society by taking responsibility or ownership of one or more specific activities focused on delivering a concrete and achievable output within the time frame of the directorship. Through my membership on the Finance and Long Range Planning Committee, I found myself driving a process, fully supported by the Board, to upgrade the WAS Strategic Plan. From the outset I was keen that this be more than simply updating a document that will then sit on a shelf in the WAS Home Office until a future board member gets the task to update it again. The goal from the beginning was to produce **and** operationalize the Strategic Plan as a management tool that would be used routinely by the Board as a living and evolving document, guiding its actions and providing continuity over time.

In developing this Strategic Plan the Board has gone through a systematic process, first by streamlining its strategies (from a previous list of nine to a new list of six - see Box 1). Under each of these strategies we then identified a number of key target outcomes we would like to achieve for the Society over the five-year life span of the Plan. Under each outcome we then identified a series of key outputs that the Board could achieve within a defined timetable that would deliver or contribute to the delivery of outcomes in the longer term. Lastly, under each output, we identified activities, the measure by which achievement of the output would be determined, and the committee that would be primarily responsible for delivering each output.

This was no trivial exercise, with the plan being developed over three Board meetings with active participation of the whole Board. The key principle underlying the plan is that the Board should be working towards the achievement of tangible outputs. We followed the SMART maxim for our outputs, ensuring that each was specific, measurable, attainable, relevant and timely. The measurable achievement of these outputs will move the Society forward in an agreed direction as defined by strategies and target outcomes within each Strategy.

However, it was not sufficient merely to produce a comprehensive Strategic Plan, and there is no doubt that the developed plan is comprehensive! It was vital that the plan be operationalized, that it becomes central to the functioning of the Board and that it evolves during the five-year term of the plan to take into account changes in priorities and contributions of new Board members. At its post-conference Board meeting in Natal, Brazil, the Board agreed not only to adopt the Strategic Plan but to operationalize it through each Board committee being assigned responsibility for delivering a series of outputs within the plan and reporting against progress towards these outputs at each Board meeting. During its review of progress at each Board meeting any changes or updates to the Strategic Plan can be identified and an updated version of the plan produced after the meeting such that the plan will evolve. The plan would then be more comprehensively reviewed after five years prior to issuing a new five-year plan. A copy of the Strategic Plan can be found on the WAS website.

The Board found the Strategic Plan development process to be a worthwhile exercise that focused the Board on the key strategies, outputs and associated activities that will move the Society forward in the right direction. Effective operationalization of the plan should ensure that current and future Boards, including the Executive Director, have a common and clear vision of the development of the society and a continuity in the progress toward key targets over time, even as the composition and membership of the Board changes.

Key strategies in the WAS strategic plan

1. Deliver quality services that meet the needs of our membership within the global aquaculture community.
2. Improve global representation within the society (membership and leadership), especially from underrepresented groups.
3. Improve the visibility, recognition and outreach of WAS in the global community.
4. Develop linkages and alliances with aquaculture and related organizations.
5. Recognize and reward excellence in aquaculture service, technology and innovation.
6. Ensure commitment to excellence in management and a sustainable business model.

Editor's Note

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in aquaculture is a testimony to the now widespread interest in the role of better practices.

Jason calls for an across-the-board doubling of efficiency in the use of every production input, including water, feed, fertilizer, and energy. This is a very high bar. Certainly the scope for doubling the efficiency of some inputs is better than others, but there is always room for improvement. Aquaculture faces limiting factors everywhere it is practiced. Once explicitly identified, producers have strong economic incentives to develop creative approaches to increase efficiency of limiting inputs. Occasionally policies such as subsidies can distort or mask the limitation, so policy reform may be necessary to enable improvement in input efficiency.

Jason also calls for more use of degraded lands. Certainly aquaculture ponds can be built using saline soils and on marginal or unproductive land and managed effectively, assuming water is available, thereby reserving land with good soils for staple grains or other terrestrial crops. Aquaculture can also make increased use of degraded water, such as irrigation drainage, wastewater, or high-salinity groundwater. I am not convinced that using degraded lands is the best approach. One can also argue that degraded or unproductive land should be allowed to revert to nature and that more effort should be dedicated toward the responsible and ethical intensification of agriculture where production potential is greatest.

Jason also included consideration of a social factor, the need for clear property rights and land tenure, especially in Africa. He sees this as a huge impediment to freezing the footprint of food. Landless or tenant farmers have little incentive to invest in improvements of their land. These investments could improve environmental performance, reduce waste, increase the efficiency of inputs, and improve farm income. This is clearly true with respect to converting land to fish ponds, which requires a substantial capital investment. Improving title to land would open the door for more potential fish farmers and improving practices on those farms that already exist.

Jason identifies the huge losses that occur after crops are harvested as an area that needs attention. Obviously the products of aquaculture are highly perishable and maintaining product quality (and safety) has always been a primary concern in marketing. Given that most fish in aquaculture are low-value species marketed within the countries where they are produced, attention to preserving freshness after harvest will increase the availability of fish to low-income consumers.

Although the focus of Jason's article is on the major cereal crops, his suggestions have specific application to aquaculture. In the context of global agriculture, aquaculture production is a minor player. Nonetheless, the kinds of changes he suggests are relevant and will allow farmers to be more productive and less wasteful and will allow aquaculture to make a contribution to freezing the footprint of food. Before resources become limiting, we can slowly and deliberately work towards doing more with what we have now, while the broadest range of options remains open to us.

— *John Hargreaves*
Editor-in-Chief

U.S. Aquaculture Society Chapter Update

In my final column as president of the United States Aquaculture Society, I want to reinforce the subject of WAS President Dr. Ricardo Martino's column in this same issue on the importance of chapters to the WAS parent society.

As aquaculture continues its expansion in the USA and globally, the potential role and importance of WAS and its chapters increases as well. With regards to the USAS, our mission is to provide a national forum for the timely exchange of information among aquaculture researchers, students and industry members in the United States. The USAS serves this mission through sponsoring workshops and meetings, fostering educational opportunities, and publishing aquaculture-related materials important to U.S. aquaculture development. Our membership fluctuates between 800 and 900 members per year, representing the broad spectrum of public and private organizations such as academia, government, industry, education, and other individuals either engaged or interested in aquaculture.

While we have a mandate to advance aquaculture, our effectiveness is only as good as our leadership is strong. In that regard, I wish to review briefly the organization of the USAS and opportunities for members to serve the society either in an official or unofficial capacity. Within the elected leadership of the society are the officers and the Executive Board. Officers are represented by the President, President-Elect, Vice President, and Secretary/Treasurer. The Executive Board consists of the officers, along with four Members-at-Large who are elected to 2-year terms, the Immediate Past-President, and the Student Liaison (a 2-year ex-officio member of the Executive Board).

The activities of the USAS are conducted through Committees, which are chaired by officers and executive board members, but may be comprised of members of the society in good standing. Standing committees include the Election Committee, Finance Committee, Conference Committee, Awards Committee, Publication Committee, Student Activities Committee, Student Subunit Committee, Strategic Planning Committee, Rules and Regulations Committee, Promotion and Membership Committee, and Presidents Committee. There are also ad hoc committees that are established and dissolved as needed to address specific activities or agendas as deemed appropriate to achieve society initiatives.

There are numerous opportunities for members of the USAS to engage in leadership and service to the society. I urge each of you to consider service to the society at some point during your career and engagement with USAS. An engaged membership makes a strong society. I'm extremely fortunate and appreciative of our membership and the opportunity to serve you as President in 2011 and look forward to continued service as Immediate Past-President and beyond. I am further appreciative of all the service and support towards advancement of the society by the 2011 USAS Officers, Executive Board, committee members, and of course our Home Office staff and Executive Director and thankful for their hard work and diligence as they balance service to the society with their daily jobs, family, and other commitments in life. Hoping everyone has a wonderful meeting this year in Las Vegas at "Bringing All Players to the Table" Aquaculture America 2012 and I look forward to seeing all of you there.

— Michael H. Schwarz
U.S. Aquaculture Society President

New FAO Technical Report

A new FAO Fisheries and Aquaculture Technical Paper (564) on "Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects" has been released. The authors are internationally renowned nutritionists Albert Tacon, Mohammad Hasan, and Marc Metian. Some of the findings highlighted in the Executive Summary include:

- About 46 percent of total global aquaculture production is dependent on the supply of feeds.
- Compound aquafeed production grew three-fold from 1995 to 2008 or about 11% per year.
- Aquafeeds represent only 4 percent of global animal feed production.
- About 29 million tons of compound aquafeeds are produced annually, along with 19 to 31 million tons of farm-made aquafeeds, and more than 8 tons of low-value fish used directly as feed.
- The aquaculture sector uses more than 68 percent of global fishmeal supplies and 81 percent of global fish oil supplies.
- The total use of fishmeal has been declining and is expected to decline further.
- In contrast, the use of fish oil is expected to increase slowly.
- There is considerable scope to increase the use of meals and oils from terrestrial animal by-products in compound aquafeeds.
- On average, compound aquafeeds contain 25 percent soybeans by weight.
- The sustainability of the aquaculture sector is more likely linked to the sustainability of terrestrial animals and plants for feed resources than to that of marine products.

Asian Pacific Chapter Update

It has been about a year since the last WAS-APC event, the Asian-Pacific Aquaculture Conference held in Kochi, India. We are now gearing up for the next big event, Australasian Aquaculture 2012, which will take place from May 1-4 in Melbourne, Australia. Here are some quick updates on the state of the Chapter since the last meeting.

After discussions between representatives of Asian Pacific and Japan Chapters, a decision was made to begin to merge these two chapters together to strengthen the Asian region overall. We hope to complete this process later in 2012.

We have a new president elect, Dr. Amrit Bart, who is currently Director of the Asian Institute of Technology Center in Vietnam. He has already been taking part in Chapter activities, including helping to plan the next APA meeting.

Plans have been moving forward to hold the next Asian-Pacific Aquaculture meeting in 2013 in Ho Chi Minh City and to support this effort John Cooksey and Mario Stael visited Vietnam in December 2011. It is expected that this event will occur in the last quarter of 2013. This location was chosen because of Vietnam's strong aquaculture sector, third in the world after China and India, and Ho Chi Minh City in particular because of its close proximity to prominent aquaculture production areas. This event will be held in conjunction with the International Oyster Symposium (IOS5).

The Asian-Pacific Chapter Executive Committee has been working on some ideas for regional symposia, as outlined in the Kochi meeting. The goal is to have smaller, targeted events to bring knowledge to areas that need more focused attention. Some possible targets are arid aquaculture in the Middle East, post-tsunami/high value aquaculture in Japan, and national aquaculture development in Myanmar.

As president, I have been giving presentations about WAS in various venues, including Myanmar, Philippines, and Indonesia. I will be moderating at the 3rd Annual AquaTech Conference in the Philippines in April 2012 where the Asian-Pacific Chapter is a named supporter of the event.

We continue to work on the idea of an expanded role for others in our Chapter through an Executive Advisory Council and Country Ambassadors Program. If you are a member of the WAS-APC we encourage you to contact the Board member in charge of this effort, Dr. Ram Bhujel, by emailing the WAS-APC (apcwas@was.org).

This is only a short update of our Chapter activities. If you are in the Asian region and not yet a member of the WAS or APC, please feel free to contact us via our email above. We are looking forward to an eventful and exciting 2012 for WAS and the Asian-Pacific Chapter!

—*Lukas Manomaitis*
Asian Pacific Chapter President

Korean Chapter Update

A technical seminar on recirculating aquaculture systems was held on May 12, 2011 in Seoul, Korea. This international seminar was co-organized by the Korean Chapter of the World Aquaculture Society (KC-WAS) and the Aquaculture Chapter of Korean Society of Fisheries and Aquatic Sciences (AqC-KOSFAS), and supported by the Organizing Committee of the International Exposition Yeosu Korea 2012 (EXPO 2012 Yeosu). EXPO 2012 Yeosu will be open on May 12 and run for three months in Yeosu, Korea (eng.expo2012.kr). The main theme is "The Living Ocean and Coast," conceptualizing the most desirable future for the ocean whose sound preservation and well-being is essentially linked with the survival of humankind. As the KC-WAS and AqC-KOSFAS have been supporting this event since its inception in 2007, we enthusiastically welcome all WAS members. We expect to see all of you in Yeosu soon.

On June 24-25, 2012, the KC-WAS and the AqC-KOSFAS will join together at the annual conference in Kangnung, Korea. At the last joint meeting, about 100 members registered and delivered oral and poster presentations. During the last AqC-KOSFAS annual business meeting the election committee identified the new chapter president, Seok-Joong Kang, professor at Gyeongsang National University. Ik Kyo Chung, President-Elect of the KC-WAS, professor at Pusan National University acceded to his presidency for the 2012-13 term. New members of the Board of Directors are Gun Wook Baeck of Gyeongsang National University as Secretary and Joo Myun Park of Chonnam National University as Treasurer.

— *Ik Kyo Chung*
Korean Chapter President

Bioeconomic analysis of the area impacted by a sea bream farm in Gran Canaria, Spain

Rabassó-Krohnert[1], Miguel and Hernández, Juan M.

In last decades, global aquaculture production has increased, diversified, intensified and technologically improved. Current and forecast production figures (FAO 2010) show its huge potential as an income-generating activity and its essential role in food security and poverty mitigation. Nevertheless, aquaculture production includes some negative effects on the surrounding area where the farm is located, such as effluents (e.g., food discards, nutrients, metals, other chemical products), escapes or attraction of foreign species, competition with other activities, and visual impact to the local population. In some instances, the combined effects—exacerbated by inadequate farm management—may result in serious ecological and socioeconomic consequences (e.g., destruction of natural habitats or disease epidemics). These externalities or undesirable effects have led to increased concern or distrust about the sustainability of marine aquaculture in net pens in technologically advanced societies.

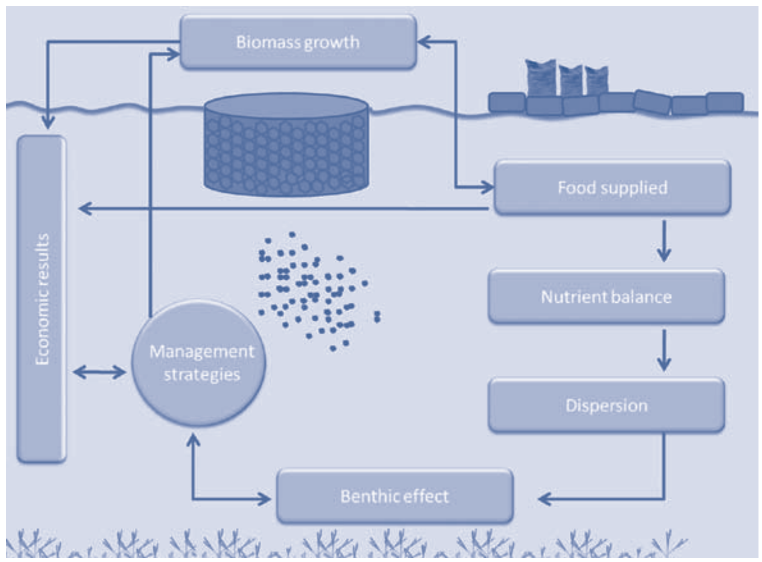

Fig. 1. A bioeconomic model for a marine net-pen system.

Enrichment of organic matter in the environment derived from emissions from marine net-pens has attracted the interest of researchers. Many such studies use models to quantify biophysical mechanisms regulating material releases, such as metabolic processes related to the emissions of organic matter and other nutrients, dispersion of these materials, and impacts on the natural environment. The farm is normally considered to be a static system. Proposed models do not consider changes in management strategies that may influence the ecological impact of emissions.

Fish Production and Material Emissions Model

The research team of aquaculture economics and management of the University of Las Palmas de Gran Canaria (Spain) has developed a bioeconomic model based on simple biological and physical relationships. The model estimates the mass of emissions from a marine fish farm, the dispersion of those emissions, and their effect on the surrounding area. Annual production, harvesting size, and other management factors are included as variables in the model. This methodology allows estimation of the economic results and environmental impacts derived from alternative management decisions on the farm and may help farm owners, government regulators, and local citizens consider the economic and environmental effects of production.

The bioeconomic model is assembled from separate modules that integrate biological, physical, economic, and managerial elements in the production and environmental impact from a marine aquaculture farm (Fig. 1). Biophysical components of the model are represented in modules located on the right side of Figure 1. The *biomass growth* module provides information on fish size throughout the culture period, depending on fish weight and water temperature. The amount of food supplied during the growth period is estimated in the *food supplied* module, which is also determined by fish size and water temperature. The *nutrient balance* module estimates the flow of nitrogen, phosphorus, and organic matter produced during fish culture. This is the input for the *dispersion* module, which calculates the impacted area depending on particle settling velocity, water depth, velocity and direction of current. Finally, interaction between discharges and the seabed are analyzed in the *benthic effect* module. Formal relationships among variables (i.e., model coefficients) in modules were extracted from published theoretical and empirical studies. If specific information on commercial growth of the species and physical conditions of the environment is available, functional expressions and parameters included in the model can be adapted to particular species and production strategies.

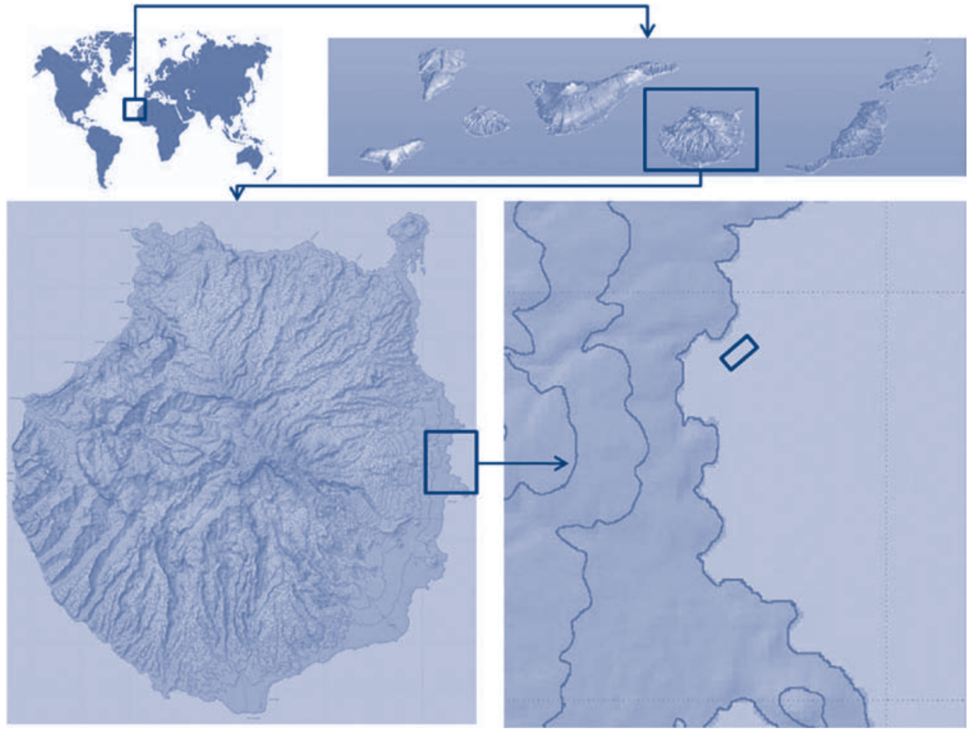

Fig. 2. Location of the case study farm site on Gran Canaria, Spain.

Economic and management components of the model are represented on the left side of Figure 1. Specifically the *economic results* module calculates the financial results of the farm (profits, net present value, and internal rate of return) obtained from the commercial activity. Production is planned in the *management strategy* module, which includes some management choices in the farm, e.g. annual production, harvest size, or time span for the investment. Thus, economic and environmental consequences of different production alternatives can be estimated.

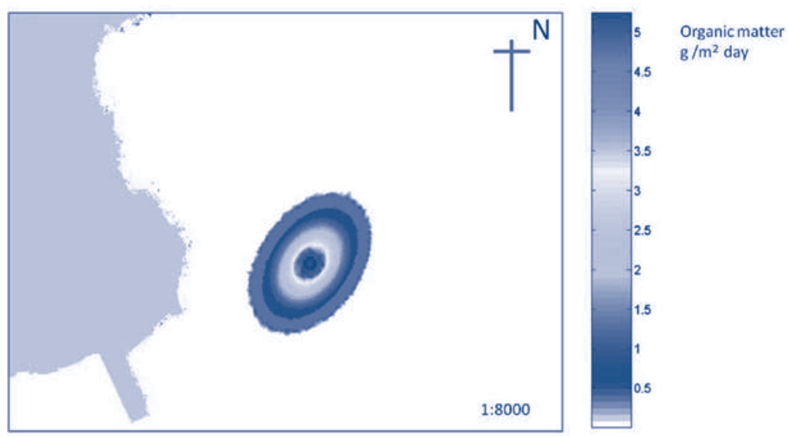

Fig. 3. Simulation of the impacted area in Melenara Bay derived from a facility with annual sea bream production of 600 t and harvest size of 450 g.

Case Study: Sea Bream Net Pens in Melenara Bay

The model was fitted to sea bream (*Sparus aurata*) culture conditions in Melenara Bay (Gran Canaria Island, Spain) (Fig. 2). Water temperature in this region ranges between 17.3 ºC in summer and 18-22 ºC in winter. The seagrass *Cymodocea nodosa* is the predominant plant in the soft sediment of the bay. It exerts an important ecological and physical role in the coastal ecosystem (stabilization of marine substrates, detritus generation, and nutrient provision). Accordingly this species is considered a bioindicator of human activities on the seabed.

There are currently 12 net pens in Melenara Bay for sea bream and sea bass culture, each ranging from 13.2 to 16 m in diameter, 8 m high, and bound with a steel cable enclosing a surface area of 4848 m^2. The annual production is around 1200 t, monthly production fluctuates between 25 and 225 t, and harvest size ranges between 450 and 1000 g. Extruded commercial feed is commonly provided to fish, although sometimes pelleted feed is used.

To fit the bioeconomic model, a data set of sea bream growth in 12 separate cages was considered. The monthly number of individuals in a cage and the amount and composition of feed supplied were used to calculate the feed conversion ratio for the culture period. Other information needed to fit the model (metabolic parameters, settling velocity of particles, current direction and velocity, depth, degradation coefficients, and economic data) were collected from technical reports and specialized bibliographies. A daily organic matter sedimentation rate of 5 g/m^2 was used to indicate complete degradation of the seabed (Díaz-Almela *et al*. 2008).

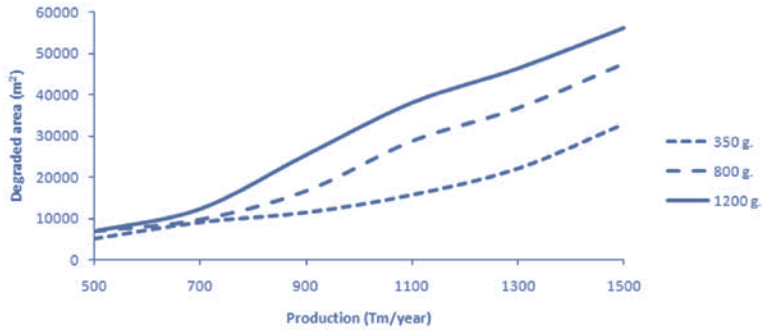

Fig. 4. Degraded area as a function of annual production of sea bream harvested at three sizes.

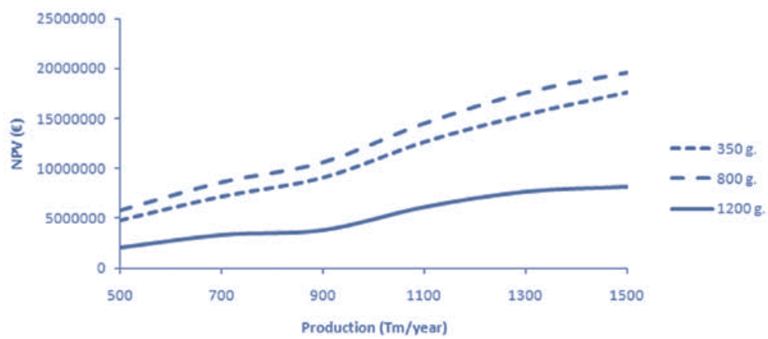

Fig. 5. Net present value as a function of annual production of sea bream harvested at three sizes.

Figure 3 illustrates the impacted area from the sea bream farm, assuming an annual production of 600 t and a harvest size of 450 g. The surface occupied by net pens is concentrated in a central circular area of the represented spot. Emitted particles fall to the seabed at a certain distance from this central area, depending on particle settling velocity, depth, and direction of currents, which is mainly determined by tide in Melanara Bay. Thus, solids accumulate on the seabed in an ellipsoidal pattern (Fig. 3).

To find the best management strategy that integrates economic and environmental perspectives, 18 production scenarios of sea bream farming were analyzed: three harvest sizes (350, 800 and 1200 g) and six annual production levels (from 500 to 1500 t), divided into four lots annually. Figure 4 shows changes in the impacted area resulting from emissions from net pens for different annual production levels and harvest sizes. As expected, the area of environmental impact increases with scale of production and harvest size, although the impact area increases substantially when production exceeds 700 t/year.

Figure 5 shows the economic performance (net present value in 20 years) resulting from different management strategies. Economic returns increase with annual production. However, the influence of harvest size is not straightforward. The most profitable harvest size is 800 g and the final size of 1200 g is suboptimal. Managers have economic and environmental information (Figs. 4 and 5) on the effects of different management strategies.

The Value of a Broad Modeling Approach

Recently, marine aquaculture in net pens has been facing an image problem because of real or perceived negative environmental effects, which calls into question the sustainability of fish farming in net pens. With the purpose of centering this debate on reasonable terms, it is useful to apply methodologies that rigorously assess the net social benefits of the activity, including monetary returns and ecological costs. In addition, these methodologies should be dynamic, that is, alternative management strategies and their effect on obtained social benefits should be included in their hypotheses.

The bioeconomic model described here points the way because it provides producers and managers a simple quantitative tool for decision making on farm management, taking into account financial returns and environmental impacts derived from marine aquaculture.

Notes

[1]University of Las Palmas de Gran Canaria, Spain.

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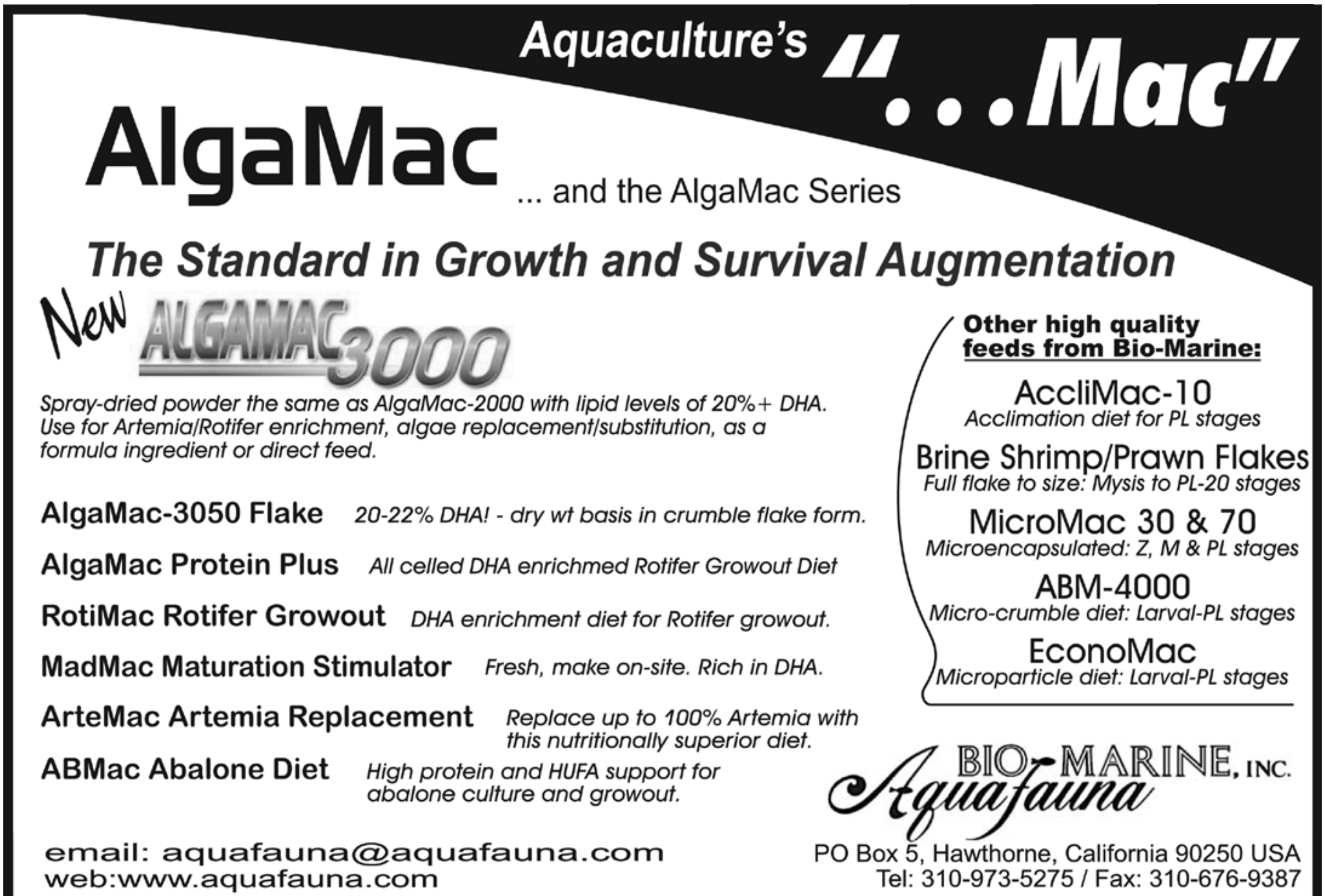
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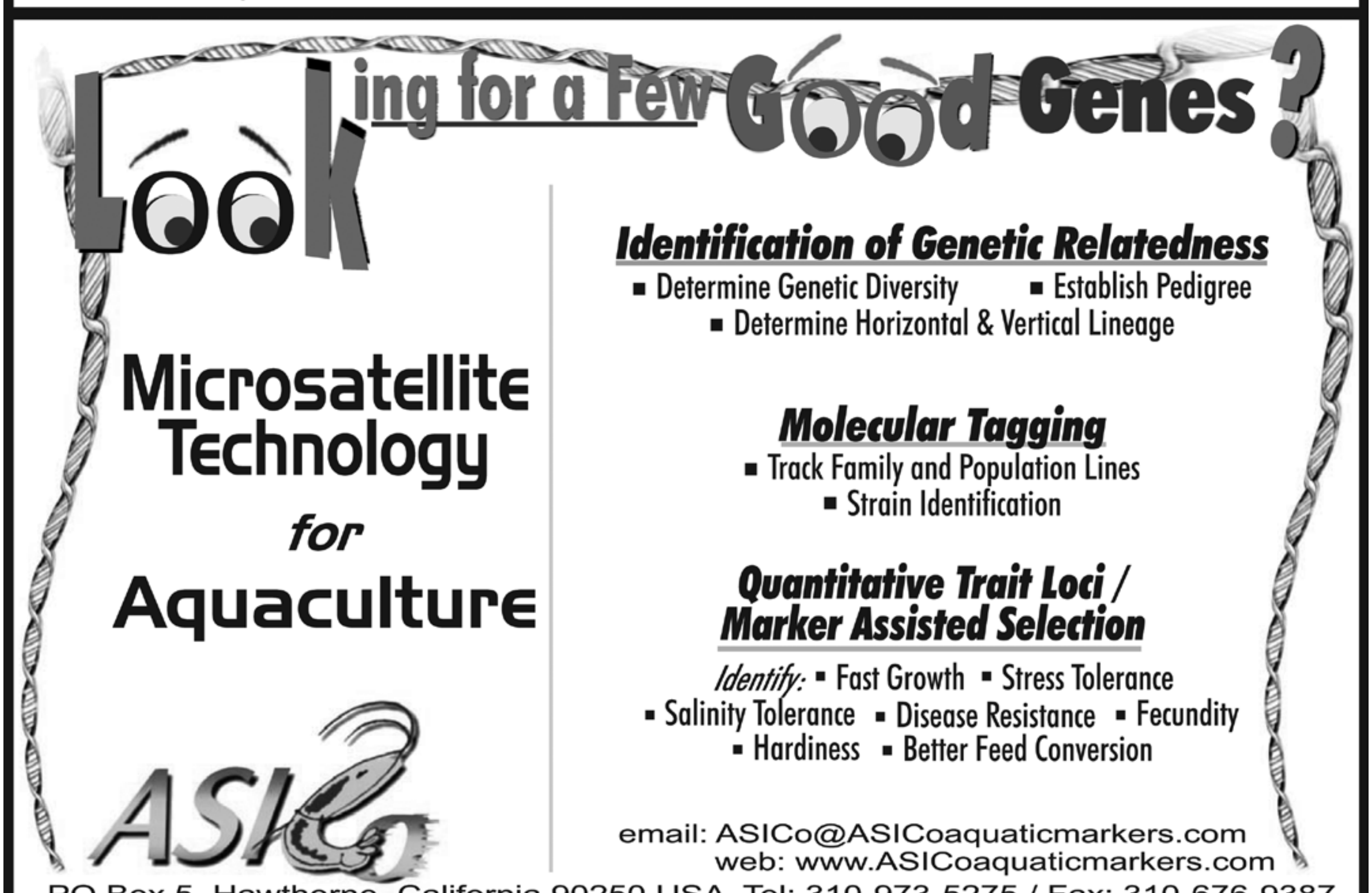
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Mangrove forests and aquaculture farmers: Aspects of climate change adaptation on the central coast of Bangladesh

M. Mizanur Rahman[*1] and M. Shahadat Hossain[1]

Aquaculture production and its share of the seafood market are predicted to expand and play an increasingly important role in meeting global fish demands. The success of the sector, therefore, has important implications for food security and as a source of income for a growing number of producers. Consequently, any potential direct or indirect effects of climate change on aquaculture must be taken seriously.

The major consequences of climate change include ice melting, sea-level rise, irregular drought and rain, cyclonic storms, coastal erosion, inundation of low-lying areas, salinity intrusion and groundwater contamination. Sea-level rise will have gradual impacts because of the loss of land from inundation and erosion. Salinization of groundwater may reduce the availability of freshwater for aquaculture, agriculture, domestic and industrial uses. Similar problems may arise with increasing the frequency of droughts. Severe droughts may lead to water shortages and massive forest fires. Forest fires release millions of tons of carbon into the atmosphere, creating a dangerous feedback loop that further accelerates global warming. The severity and frequency of storm surges increase from the effects of mean sea-level rise and the loss of natural defenses, such as mangrove forests. High winds and waves destroy structures used for coastal aquaculture such as embankments, pond dikes, sluice gates, hatcheries, electricity poles and cage materials, resulting in loss of stock and damage to equipment and facilities. Damage to farm infrastructure can also cause saline water intrusion in the culture pond (FAO 2008). The financial impacts of cyclonic storms on aquaculture may be severe because coastal aquaculture species are often of high value. Climate change can also increase physiological stress on cultured stock. This would reduce productivity and increase vulnerability to diseases and consequently impose higher risks and reduce returns to farmers.

Bangladesh, a very low-lying country with a substantial aquaculture industry, typically experiences storm surges between 3 and 6 m, with theoretical predictions up to 7.5 m (Salam and Beveridge 2003). Future predictions for Bangladesh, in association with increased sea surface temperature of 2 °C and 4 °C, suggest maximum storm surge heights of 9.2 and 11.3 m, depending on the extent of sea level rise (Ali 1996). Annual total rainfall over Bangladesh is predicted to increase 296 mm by 2050 and 543 mm by 2100 (Karmakar and Shrestha 2000). Singh *et al.* (2000) showed that mean tidal level at Hiron Point (21° 48′ N, 89° 28′ E), Hatyia (22°08′ N, 91°06′ E) and Cox's Bazar (21° 26′ N, 91° 59′ E) increased 4.0, 6.0 and 7.8 mm/year, respectively. Torrential rainfall leads to flooding and paralyzes the affected area, inundating houses, displacing and killing people, destroying infrastructure, and damaging crops, causing massive economic loss.

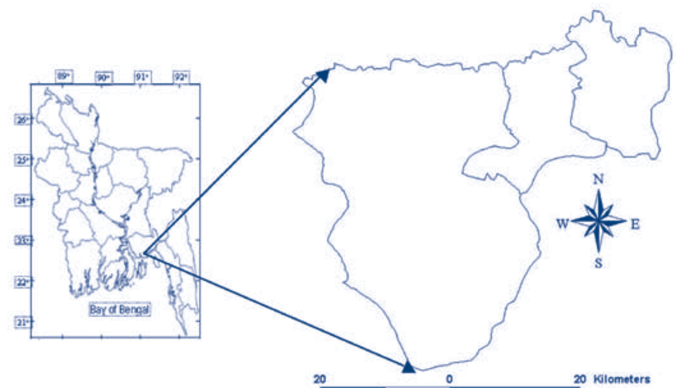

Fig. 1. Geographical location of the study area.

A study was conducted in the Feni-Noakhali area, which is a centrally exposed part of coastal Bangladesh. The geographical location and geomorphological conditions of this region have made it one of the most vulnerable areas in the world to natural disasters (Fig. 1). The objectives of the study were to measure the area in aquaculture, measure the spatial distribution of mangrove forest, identify the causes and impacts of climate change on coastal aquaculture, and analyze the role of mangrove forests in mitigating climate change vulnerability.

The region is a flat, low-lying delta, mostly comprising the floodplain of three large and converging rivers. The Big Feni River flows on the southeast and the Meghna River flows on the western side of the study area. The study area was divided into three zones under three thana (sub-districts) on the basis of a road network and availability of water sources, *khas* land (i.e., government-owned accreted coastal land), aquaculture farms, mangrove forest, cyclone-affected area, embankment, culture species, and fry sources.

Table 1. Significance ratings and weights of the relevant criteria in connection to perceived value of mangrove forest.

Parameter	Ranking	Temporary weight	Final weight W_i
House building materials	1.4	0.571	0.106
Fuel wood	1.0	0.800	0.148
Grazing land	1.2	0.667	0.123
Foot bridge	1.0	0.800	0.148
Fishing pole	1.5	0.533	0.099
Fencing	1.5	0.533	0.099
Furniture	0.8	1.000	0.185
Cyclone protector	1.6	0.500	0.093
Sum		5.405	

Table 2. Total fishery production from aquaculture and contribution in local demand at the study area.

Production	Noakhali Sadar	Companigonj	Sonagazi
Fish (mt)	7927	2610	3480
Indian carp (%)		40	
Chinese carp (%)		25	
Tilapia (%)		20	
Pangus (%)		10	
Other (%)		5	
Prawn (mt)	233	41	1020
Total production (mt)	8160	2651	4500
Total fish demand (mt)	13177	3851	9420

Aquaculture in the Study Area

The area in aquaculture ponds was assessed using GIS. The topographic map published by the survey of Bangladesh in 1999 at a scale of 1:10,000 and the 2006 topographic map of Noler Char and Char Langulia were used to develop thematic maps. The base map with the union boundary of Noakhali Sadar, Com panigonj and Sonagazi thana were demarcated using ArcView GIS software. Thematic maps were marked as union boundaries, water areas, road network, embankments, and land use. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery of the study area acquired in 2007 was used to identify geographical features. The image processing software for the analysis was ENVI. ArcView software was used to digitize all classified and other necessary maps.

Aquaculture activities were identified in 1694 ha of the study area (Fig. 2), similar to previous observations (Shahid *et al*. 1992, Venkataratnam *et al*. 1997).Water bodies that support aquaculture production, such as rivers, canals, and tributaries of the study area are shown in Figure 3. Greater aquaculture production from every water body type (such as pond, *gheer*, *khal*, and waterlogged areas) came from Noakhali Sadar region than from the two other zones in the study (Table 2).

Aquaculture has increased rapidly since 1990 in the Feni-Noakhali coastal region as a result of government *khas* land leasing. Availability of land and water resources—such as rivers, canals, and tributaries—make this area suitable for aquaculture. There are also various value chain facilities, including fry sources, hatchery, labor, and market, that are located in this zone to support aquaculture development. The large areas of intertidal land in Bangladesh are especially suitable for prawn production (Fleming 2003) and growth in the industry is being encouraged through a number of aid programs and government initiatives. Carp species, native and exotic, represent

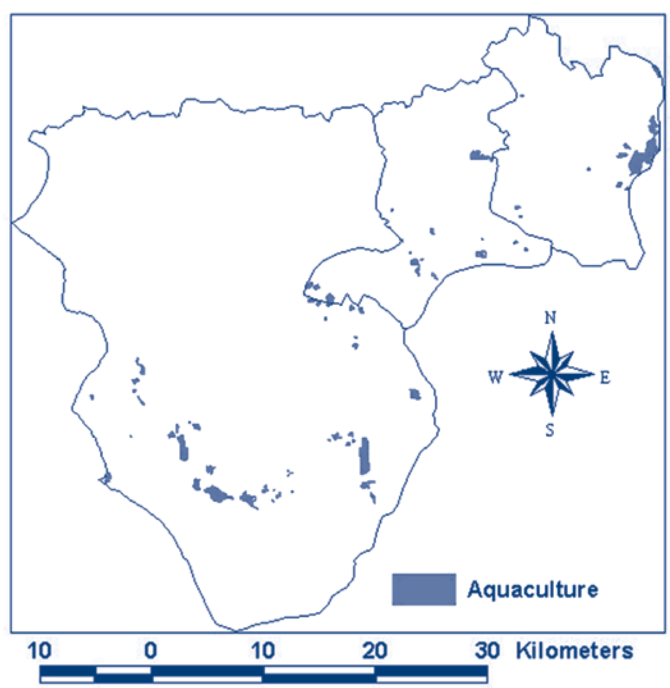

Fig. 2. Aquaculture areas of the Feni-Noakhali coastal region.

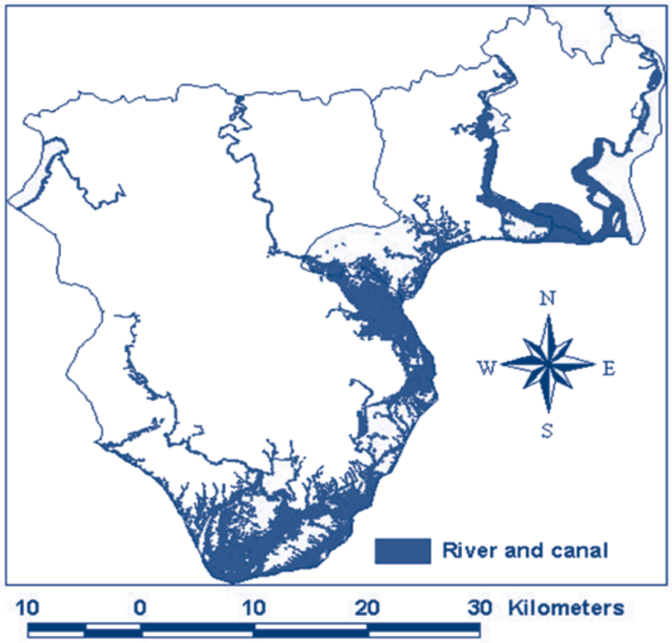

Fig. 3. Water areas of the Feni-Noakhali coast.

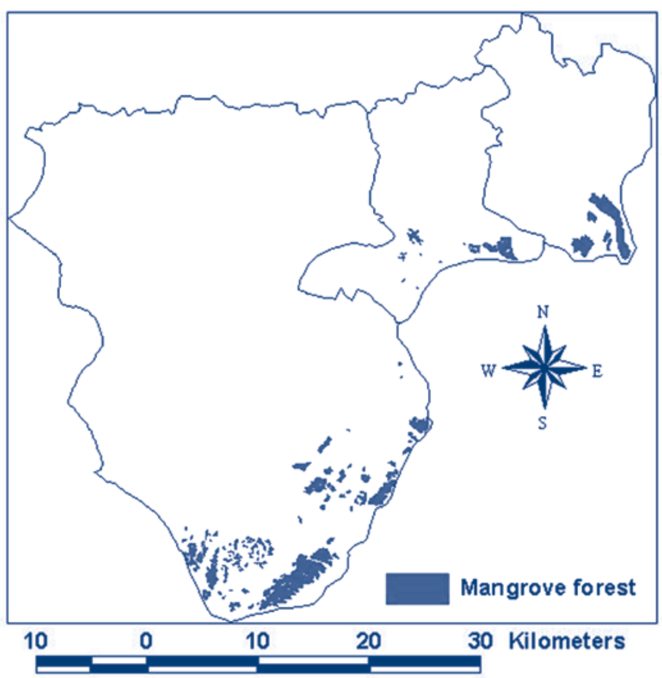

Fig. 4. Spatial distribution of mangrove forests on the Feni-Noakhali coast.

a large portion of total production, although tilapia, snakeheads, *Clarias* and *Pangasius* catfish, and small indigenous species are also cultured. Extensive and semi-intensive culture systems are used. Bangladesh is undergoing a gradual intensification of aquaculture but, while more sophisticated techniques are being employed, production per unit area is similar to that of many Asian countries (Salam 2000).

Mangrove Forest

There are 3,455 ha of mangrove forest in the Feni-Noakahali coastal area. Most of the mangrove forest in the study area is in Noakhali Sadar zone and the least is in Companigonj zone (Fig. 4). A similar estimate of the extent of mangrove forest was made by Syed *et al*. (2001). Local people provided reasons for what is seen as a degraded mangrove forest. Sixty percent of respondents indicated that timber banditry was the responsible factor for mangrove destruction. Criminals form gangs and become timber bandits later. They either sold forest resources or burned them to damage the land. Afterwards, forest lands were sold and handed over to others. The cycle of transferring land from one owner to another was the main source of their income. This was identified as the most severe problem by most of the respondents of the study area.

River erosion is a common phenomenon in coastal areas. Many people become landless because of river erosion. These people encroach on comparatively raised forest land with the help of bandits. During field visits, respondents identified the lack of guidelines as a cause of mangrove forest destruction.

Local community respondents reported forest resources were destroyed because of the lack of proper action taken by law enforcement agencies from 1997 to 2000. The Forest Department filed cases to the court against forest offences, but these cases were not decided which encouraged further forest offences. Different stakeholders, such as rickshaw pullers and agricultural farmers, complain that corrupt forest officials and staff at the territory level were responsible for forest resource destruction.

Fifty-eight percent responded that the fuel wood crisis was a serious problem causing mangrove destruction and 60 percent responded that they use mangrove as fuel wood. A similar observation was made by Sajjaduzzaman *et al*. (2005).

Stakeholder perceptions of climate change

Perceptions regarding climate change and effects on aquaculture, causes of forest encroachment, consequences, and suggestive measures were collected from five groups of respondents: land-owning aquaculture farmer, integrated agriculture-aquaculture farmer, landless aquaculture farmer, fisher, and other. Forty respondents from three zones were selected by stratified random sampling. Eight stations were selected randomly from each zone for a social survey to investigate the root causes of deforestation and encroachment of mangrove forest areas, aqua-

Table 3. Individual quality rating (q_i) on the basis of measured and optimum values for the selected respondents group.

Criteria	Landless aqua farmer		Agri cum aqua farmers		Land owning aqua farmer		Fish catcher		Others	
	Measured value	Individual quality	Measured value	Individual quality	Measured value	Individual quality	Measured value	Individual quality	Measured value	Individual quality
House building materials	5	89.3	4	71.4	3	53.6	3	53.6	10	178.6
Fuel wood	10	250.0	5	125.0	4	100.0	6	150.0	5	125.0
Grazing land	8	166.7	3	62.5	2	41.7	5	104.2	3	62.5
Foot Bridge	2	50.0	1	25.0	3	75.0	2	50.0	4	100.0
Fishing Pole	4	66.7	2	33.3	5	83.3	6	100.0	2	33.3
Fencing	4	66.7	4	66.7	2	33.3	4	66.7	1	16.7
Furniture	3	93.8	1	31.3	1	31.3	3	93.8	8	250.0
Cyclone protector	7	109.4	5	78.1	4	62.5	5	78.1	6	93.8

Table 4. Adaptation index (W_i q_i) of selected respondent groups.

Parameter	Landless aquafarmer	Agri cum aqua farmers	Land-owning	Fish Catcher	Others
House building materials	9.4	7.6	5.7	5.7	18.9
Fuel wood	37.0	18.5	14.8	22.2	18.5
Grazing land	20.6	7.7	5.1	12.8	7.7
Foot bridge	7.4	3.7	11.1	7.4	14.8
Fishing pole	6.6	3.3	8.2	9.9	3.3
Fencing	6.6	6.6	3.3	6.6	1.6
Furniture	17.3	5.8	5.8	17.3	46.3
Cyclone protector	10.1	7.2	5.8	7.2	8.7
$\sum$ Wi.qi	115.0	60.3	59.8	89.1	119.8
Score card	2	4	5	3	1

culture status and area, climatic hazards, and options for mitigation. Information was collected with a structured questionnaire, formal and informal interviews, and field observations. Moreover, group meetings with landless people and encroachers (squatters) were conducted in each area to assess their views and perceptions.

For the public at large, the most important concerns about the effects of climate change were cyclones (cited by 75 percent of respondents), irregular rainfall (55 percent), and tidal height change (50 percent) (Fig. 5). Aquaculture farmers cited various concerns about the consequences of climate change on their farms. These included dike erosion (60 percent of respondents), infrastructure damage (50 percent), and economic losses (45 percent).

An applied approach to understand the adaptation index by considering all criteria relevant to climate change allotted a ranking value of ten. Temporary weights were obtained by dividing the highest rating by each individual mean rating. Each temporary weight was then divided by the sum of all the temporary weights to arrive at the final weight of each parameter (Table 1). The sum of the product of each final weight (w_i) and quality rating (q_i) for each parameter was used to provide a quantitative adaptation index.

Individual quality ratings presented in Table 3 reflect the congenial environment in almost all the criteria assessed among the five groups of respondents. Variation of individual quality ratings has influenced the adaptation index (Table 4) of the selected respondents group. Score cards of the adaptation index, prepared on the basis of the adaptation index, indicates the order of adaptation in the sequence of others> landless aquaculture farmer> fish catcher> agriculture-aquaculture farmer> land owning aquaculture farmer.

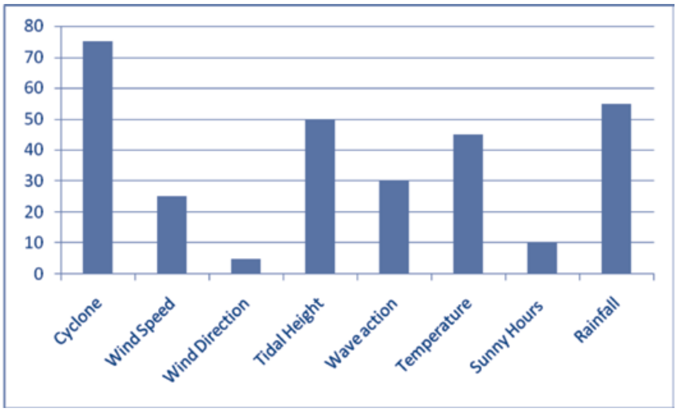

Fig. 5. Perceived importance of various impacts of climate change on aquaculture (n=40 respondents).

Mangroves are Essential for Adaptation to Climate Change

Mangroves have tremendous ecological and social value. The mangrove ecosystem provides income from the collection of mollusks, crustaceans and fish that live there. Mangroves are harvested for fuelwood, charcoal, timber, and wood chips. Ecological services include the role of mangroves as nurseries for economically important fisheries, especially for shrimp. Mangroves also provide habitats for a large number of mollusks, crustaceans, birds, insects, monkeys and reptiles (Wells *et al*. 2006).

Mangrove forests play at least two critical but contrasting roles in mitigating the effects of climate change; one is as a sink for greenhouse gases, especially carbon dioxide, and the other is as a physical buffer of climate change impacts. Mangroves play a major role in moderating the physical challenges of climate change, such as increasing frequency of storms, changing rainfall patterns, rising sea-levels and rising sea surface temperatures. Mangrove vegetation can slow down the runoff of floods and invasion of seawater without the need for similar and expensive engineered infrastructure (Bartlett *et al*. 1993).

The area is subject to high tidal variation, monsoon flooding and tropical cyclones, the larger of which tend to damage infrastructure and cause extreme loss of life. Three cyclones (1970, 1974, and 1991) had storm surge heights of at least 8 m. As a consequence, about 500,000 people lost their lives (Islam 2002). Mangroves save lives and property in the coastal area. For example, 10,117 ha of mangrove forest in Chakaria was converted completely into shrimp farms in ten years (1985-1995). In the 1970s this area was covered with mangrove forest and people were protected from storm surge. After conversion to shrimp ponds, the absence of mangrove forests in the area could not adequately buffer storm surge, resulting in deaths following cyclones in 1991 and 1994.

Climate change impacts such as floods, cyclonic storms, erosion, and the length or irregularity of the dry season, and thus water supply for relatively quick draining soils will be important factors when considering potential aquaculture development in these areas. Adaptation of aquaculture to climate change in Bangladesh will vary depending on the stakeholders involved, their level of financial capital, location and the type and scale of aquaculture taking place. Appropriate policy making, species diversification, improved culture practices, and mangrove planting should be promoted in the changing environment.

Notes

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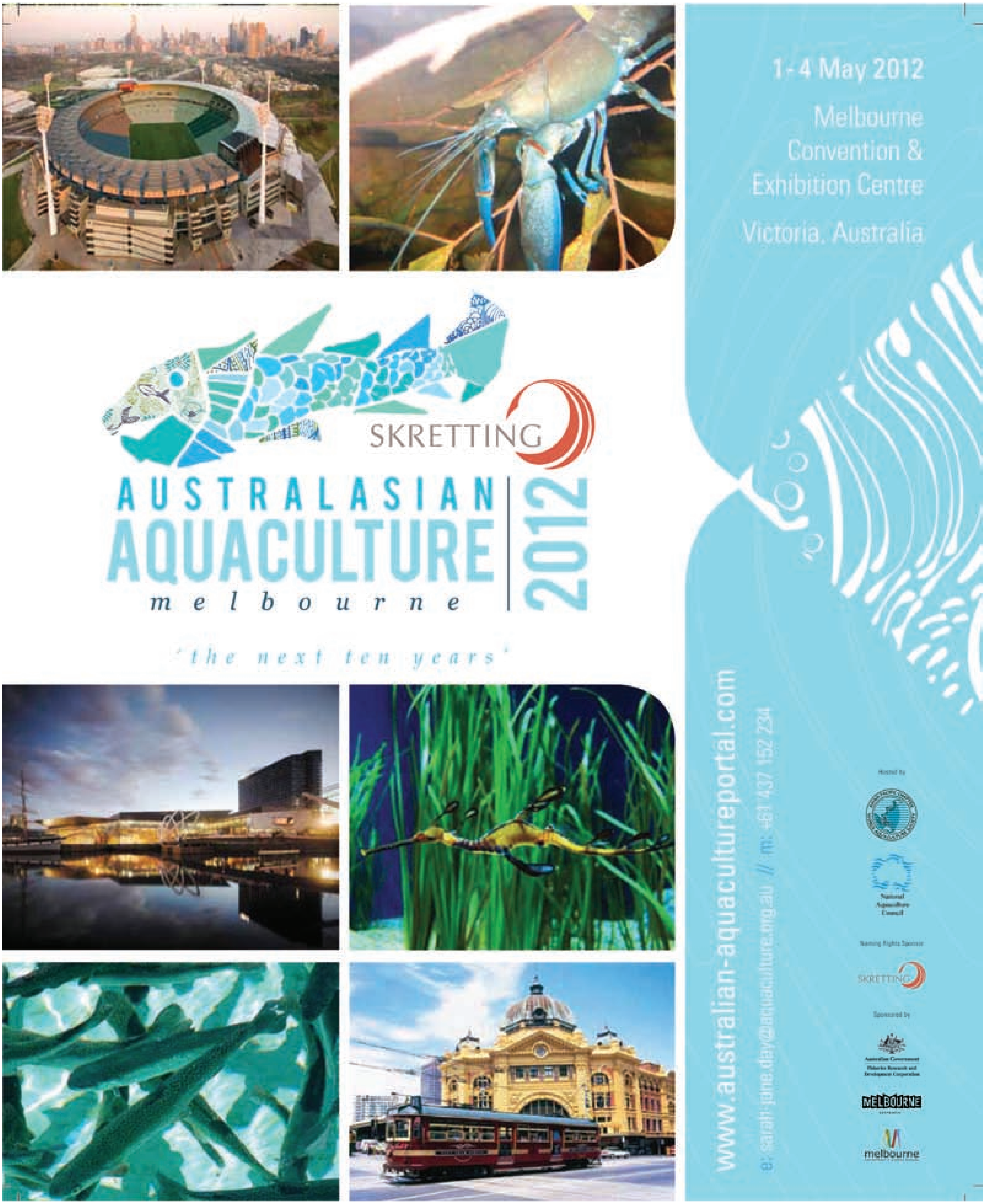

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AUSTRALASIAN AQUACULTURE 2012: The next ten years

Roy Palmer[1] and Graham Mair[2]

Melbourne is the capital city of the Australian state of Victoria, where arguably aquaculture was first practiced in the country. Melbourne is playing host to the next Australasian Aquaculture Conference and International Trade Show, taking place May 1-4, 2012. The theme of the conference and the whole week's activities is "The Next Ten Years."

Before we look forward, let us look back. In southwestern Victoria, specifically at the Budj Bim National Heritage Landscape at Lake Condah, there is evidence of a large, settled aboriginal community (Gunditjmara) from thousands of years ago, systematically farming eels for food and trade. This activity is considered to be Australia's and possibly the region's earliest and largest aquaculture venture. This complex enterprise took place in a rugged landscape carved out by natural forces and full of meaning to the people living there. They built stone dams to hold water, creating ponds and wetlands where they grew southern shortfin eel (*Anguilla australis*) and other fish. They also created channels linking wetlands that contained weirs with large woven baskets to harvest mature eels. The trees close by were hollowed out and used as smoking 'ovens' to cook the eels. The modified and engineered wetlands and eel traps provided an economic basis for the development of a settled society with villages. With European settlement in the area in the 1830s came conflict. When this conflict came to an end in the 1860s, many aboriginal people were displaced. However, land was eventually returned to the people of Gunditjmara in 1987.

Nowadays aquaculture in the area is managed under the Fisheries Act (Victoria) 1995. The Act provides for the management, development and promotion of an ecologically sustainable and viable aquaculture industry. Over the years there have been major efforts to support aquaculture development, with both government and industry investing in a range of projects. The production value (farm gate) of Victoria's aquaculture sector increased by 60 percent between 1998 and 2006, from $13.7 million to $21.9 million, or approximately 6 percent per year. The new vision (the Victorian Aquaculture Strategy) is to "grow the value of the Victorian aquaculture industry from $22 million to $60 million by 2015 in a sustainable manner."

Victorian aquaculture is undertaken in a variety of offshore, coastal and inland facilities and includes the production of rainbow trout, Atlantic salmon (including hand-milked caviar), abalone, blue mussel, aquarium finfish, eel, Murray cod, barramundi, silver perch, golden perch and yabby.

However, the aquaculture sector in Victoria is confronted with a number of challenges that affect competitiveness. The abalone industry is recovering from the impact of a virus outbreak and the trout and eel industries have major production problems associated with frequent drought. There is an urgent need to attract investment to the sector to achieve economies of scale, and the conference is seen by locals as a means to this end. Future challenges include adapting to climate change with associated water shortages and biosecurity risks, increasing competition in local and global markets, declining terms of trade, and meeting consumer demands (including the sustainability of production systems and integrity of seafood products). There is little doubt that key challenges must be addressed for the Victorian aquaculture sector to capitalize on opportunities associated with the pristine environment and the increasing global demand for seafood, and to be part of global aquaculture, now valued at more than $70 billion per year.

The strong mussel farming industry has struggled for years with an unreliable supply of wild spat for seed-stock, a situation that has now been resolved through a collaborative hatchery project between the state government and a mussel industry group. The hatchery will be part of one of the conference tours. Benefits to the mussel industry have included a doubling of hatchery output to almost 6000 spat ropes per season, a competitive advantage through the production of spat outside its usual seasonal availability. At least 20 percent of hatchery production will be made available to industry members not directly involved in the hatchery, increasing employment opportunities for regional Victoria. Technology transfer to industry will facilitate potential development of a larger, commercial-scale hatchery. This development has the potential to add a further 1700 tonnes annually to the sector.

Since their inception, the biennial Australasian Aquaculture conferences have been organized as a joint venture between the Australian National Aquaculture Council and the WAS-Asian Pacific Chapter. This relationship has prospered over the years and the conference series has been extremely successful. The establishment of this strong relationship recently secured the World Aquaculture Conference and Trade Show to be held in Adelaide 7-11 June 2014. Both Melbourne and Adelaide conferences will have lots of additional activities besides bringing all that comes with such conferences and trade shows.

For the upcoming conference in Melbourne there are events every day from 28 April right through to 6 May (see table) so, whatever your connection to aquaculture, you should be able to find an interesting aspect to engage you. Furthermore, there will be many networking opportunities and some events—including the inaugural Australasian Aquaculture Awards—that will be held as part of the 'Articulture' function at the National Gallery of Victoria.

The naming rights sponsor, Skretting Australia (the leading supplier of fish feed in Australasia), and other important sponsors – Fisheries Research & Development Corporation and Australian Seafood Cooperative Research Centre – have joined with the State Government of Victoria to ensure that there will be much to remember from the occasion of the conference. Northern Melbourne Institute of TAFE is sponsoring the venues for the Recirculation Aquaculture System Workshop and the AquaEd event. Agrifood Skills Australia is the key sponsor for AquaEd along with Victorian Department of Education and Early Childhood Development. The Global Aquaculture Alliance is sponsoring the awards program, which is an exciting new initiative for the industry. Intrafish is coming on board as the media sponsor for the first time, as they look to expand their coverage of our industry. We welcome all sponsors' involvement as we work together to develop a strong aquaculture industry.

Aquaculture field trips organized through Department of Primary Industry (Aquaculture section) will be held before and after the conference. These are full-day tours, including lunch. The first covers inland aquaculture and the second marine aquaculture. Both promise to be good opportunities to see industry and government activities, and provide opportunities for discussion and networking.

The home of the Conference and Trade Show is the Melbourne Convention & Exhibition Centre (MCEC), the centerpiece of a new world-class $1.4 billion conference and events precinct, which includes a new convention center as an extension to the current award-winning exhibition center, hotels, restaurants, retail and residential establishments. This is located in central Melbourne, on the banks of the Yarra River in the developing South Wharf area, a vibrant riverside precinct, easily accessed by public transport and within walking distance to accommodations and more restaurants. The MCEC sets a new benchmark through its advanced applications of presentation technology and its '6 Star, Green Star' building environmental rating. Combined with innovative design and new operational features, organizations and guests will be assured of a high level of event delivery, in a comfortable and exciting environment. It is one of the 'greenest' convention centers in the world. What better place to present the world's most environmentally friendly food source, aquaculture?

National Gallery of Victoria

An excellent array of plenary speakers has been organized for the conference, all focusing on different aspects of the main theme. The opening will include Dr. Alex Obach, Managing Director of Skretting Aquaculture Research Centre, Norway and Chen Wen, Director of Fisheries Division of Guangdong Provincial Oceanic and Fisheries Administration, China. From those two speakers we will get a great understanding of two major global issues in aquaculture today: technology development and sustainability in aquaculture feeds and the direction of China's largest region with respect to supply and demand of seafood products.

The plenary on the second day will feature two commu-

Table of Activities at AA12

Date	Event	Where	How
Saturday April 28	Recrculation Workshop	NMIT	Booking required
Sunday April 29	Recirculation Workshop	NMIT	Booking required
Monday April 30	All Day Tour – Inland Aquaculture	Alexandra, Snobbs Creek	Booking required
Tuesdat May 1	Exhibition - IN	MCEC	Exhibitors
	Seafood Emergency Response Plan Workshop	MCEC	Invite only
	Australian Aquaculture Committee (sub-comm AFMF)	MCEC	Invite only
	Welcome reception	MCEC	Booking required
Wednesday May 2	AA12 Conference – Day one		Booking required
	Articulture – Awards Networking night	NGV	Booking required
	GAA GOAL Breakfast	MCEC	Invite only
Thursday May 3	AA12 Conference – Day two	MCEC	Booking required
Friday May 4	AA12 Conference – Day three	MCEC	Booking required
	Exhibtion – OUT (pm)	MCEC	Exhibitors
	Footy or Rugger	Etihad or AAMI	Invited or self
Saturday May 5	AquaEd	NMIT	Booking required
	All Day Tour – Marine Aquaculture	Portarligton, Queenscliff	Booking required
Sunday May 6	AquaEd	NMIT	Booking required

nication experts and will focus on food security with Julian Cribb, and how the industry will need to adapt with Paul McCarthy. This will be followed on the third day with the Seafood CRC bringing focus to two widely disparate but vitally important areas of research. This first will focus on technology by describing the role that the incredibly rapidly evolving molecular sciences and genomics will play on the future of aquaculture. The second plenary will focus on opportunities in seafood marketing.

An Australasian Aquaculture event without Tom Losordo running an expert Recirculation Workshop (28-29 April) would not meet expectations. Clearly, from the interest being shown, the demand for such information is greater than ever.

The organizers have encouraged Seafood Services Australia to arrange the Seafood Incident Response Workshop on 1 May. This will be an interesting activity: a mock food safety crisis will be created and all people attending will be engaged in understanding how to manage such an event.

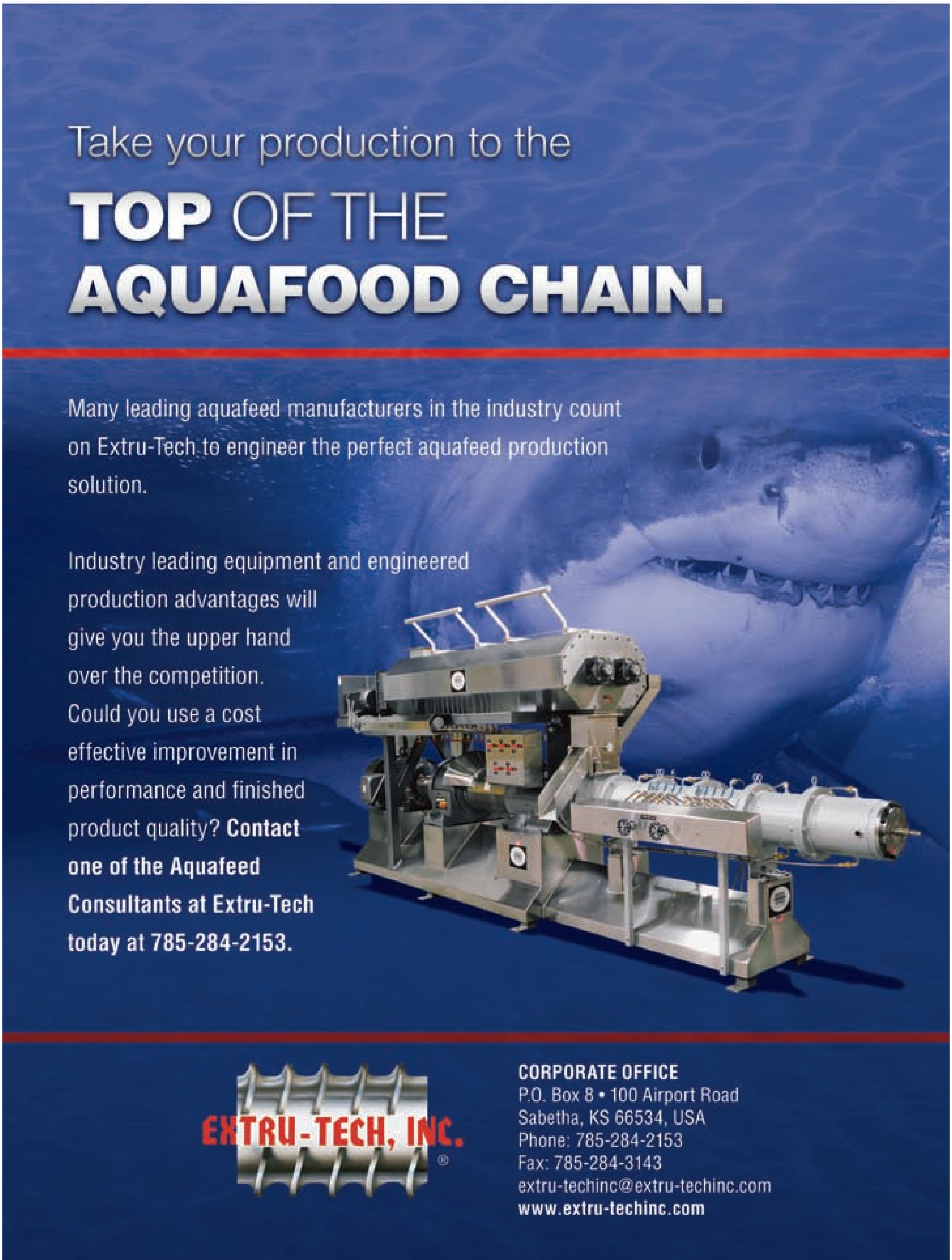
For those interested in Training, Education and Workforce Development, an AquaEd event will be taking place after the conference on 5 and 6 May. The small extra fee for this includes coach transfers, lunch and dinner and will be an important event as we will have speakers from China, New Zealand, Texas, and Alaska, as well as from all around Australia, focusing minds on the key challenges in delivering appropriate education and training in aquaculture to meet the specific demands of an expanding industry.

For the first time an Australasian Aquaculture event is being held mid-week to allow participants the chance to engage with Melbourne's main events at this time of the year including football of all codes. Activities and how to get involved will be lodged on the website www.aquaculture.org.au. Of course, aside from the attractions of Melbourne itself, Victoria and Australia beyond offers numerous opportunities for tourists including wide-open spaces, fabulous wildlife, and multiple adventure options. This truly is a jam-packed week so get in for the early-bird concessions as soon as you can and start thinking "Melbourne in May" and let this be the beginning of your own Ten-Year Plan.

Notes:

[1]Roy Palmer has been involved the seafood industry since 1972. He has been engaged in the majority of Australasian Aquaculture events but took a greater involvement since 2008. He was Chairman of the 2010 event in Hobart, has played a strong role in the Melbourne event, and hopes to continue through to Adelaide. As WAS-APC Past President he is still very keen on developing the Chapter for the Society. His expertise lies in marketing, food safety, trade and training/education. Currently Roy has a number of roles within the industry and recently became the Australia/New Zealand Business Development Manager for the Global Aquaculture Alliance.

[2]Graham Mair has been involved in aquaculture and seafood research in the region for well over two decades and has lived and worked in Southeast Asian aquaculture for 16 of those years. He has been heavily involved with APC-WAS (having served as its President in 2007-2008) and WAS (as a Board member from 2008-2011) and has played significant roles in the organization of a number of successful regional conferences. Graham currently works as Program Manager for Production Innovation as part of the Australian Seafood Cooperative Research Centre (the Seafood CRC) and is thus actively engaged with a large part of the Australian aquaculture research community. The Seafood CRC is a major sponsor of Australasian Aquaculture 2012 including the coordination of a number of special sessions.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The first record of cubera snapper *Lutjanus cyanopterus* culture in Brazil

Eduardo Gomes Sanches*[1], Wanessa de Melo Costa[2], Felipe Gomes Vilani[2], Daniel Medeiros Krueger[2], Gabriel Passini[2] and Vinicius Ronzani Cerqueira[2]

The Brazilian marine fish culture probably began in the seventeenth century, during the Dutch government of Maurice of Nassau, in Pernambuco, when the activity was introduced in the region. At that time, snook (*Centropomus* sp), mullet´s (*Mugil* sp) and "carapebas" (*Eugerres* sp and *Diapterus* sp) were cultivated extensively inside tide ponds (Cavalli and Hamilton 2007).

According to Brugger (1995) the first research on marine fishes in Brazil started in the mid 70's by researchers at Universidade Federal de Pernambuco, studying about mullets. It is worth mentioning the pioneering studies on real-grouper, initiated in 1980 by the researchers Eduardo Fagundes Netto and Daniel Benetti at the Navy Research Office, Instituto de Pesquisas da Marinha, in Arraial do Cabo/RJ (Fagundes Netto and Benetti, 1984). Currently, many research centers, including Instituto de Pesca/SP, Universidade Federal de Santa Catarina/SC, Fundação Universidade do Rio Grande/RS, Universidade Federal do Ceará/CE, have groups dedicated to the study of marine fish with potential to be cultured. The most studied specimens in Brazil are snooks (*Centropomus parallelus* e *C. undecimalis*), flounders (*Paralichthys orbignyanus*), dusky grouper *(Epinephelus marginatus)* and snappers *(Lutjanus synagris* e *Lutjanus analis)*.

The Lutjanidae is a family composed of 17 genera and approximately 103 species of mostly reef-dwelling marine fishes, collectively known as snappers (Allen 1985). Within this family, 64 species compose the genus *Lutjanus* (Figueiredo and Menezes 2000). It is

*Cubera snapper (*Lutjanus cyanopterus*): the giant member of Lutjanidae family in Brazil.*

considered a high-value fish in the market and, according to Magalhães *et al.* (2003), fish of the Lutjanidae family are highly vulnerable to overfishing because they have slow growth ($K < 1.5$) and high longevity (20 to 30 years).

Watanabe *et al*. (2001) asserted that, in opposition to what happens in nature, fish of the genus *Lutjanus* grow faster in cultured conditions and, therefore, can be considered for aquaculture because of their productive performance as well as the high demand and high price for them in the market. Riley *et al.* (2004) also highlighted the culture potential of snapper species and, according to Sanches (2007), the cultivation of snappers and the consequent reduction of fishing pressure on natural stocks could be a way to preserve this important group of reef fish.

The cubera snapper, *Lutjanus cyanopterus,* is the largest species of the genus and may reach up to 57 kg in weight and 1600 mm in length (Allen 1985). Three reports, Allen (1985), Araujo *et al.* (2008) and Claro and Lindeman (2008), describe the geographic distribution of this species from the north of Florida (USA) to the northeast and southeast of Brazil. This species is listed as vulnerable on the International Union for Conservation of Nature and Natural Resources (IUCN 2010) and overfishing at reproductive aggregation sites has exacerbated this situation (Kadison *et al*. 2006).

To date, there are no records of the culture of this species, despite their large size and high tolerance for changing environmental conditions. The goal of this study is to record the first culture of *L. cyanopterus* in Brazil and to identify their potential for estuarine and marine aquaculture.

Study Methods

The study was conducted during the autumn of 2009 at the Marine Fish Laboratory (LAPMAR), Federal University of Santa Catarina, Florianópolis, Brazil, 27º 37' S and 48º 27'W. Seven specimens (average weight 456.29 g ± 289.08 and total length 32.57 cm ± 5.83) were caught in coastal areas of Lagoa da Conceição, Florianópolis, Brazil using fish traps, and stored in 8-m^3 multifilament nylon net cages with mesh of 13 mm.

At the beginning and end of the experiment, fish anesthetized with benzocaine, 1g/20L^{-1} water were individually measured using an ictiometer and weighed using a digital electronic scale (precise to 0.01 g). The fish were fed once daily until satiation with chopped bycatch obtained from local fishermen. Food consumption was measured by weighing the food provided daily. The study lasted 30 days.

Cubera snapper cultured in net cages in Brazil.

Results and Discussion

The limited literature on this species cites its distribution from the tropical western Atlantic to southeastern Brazil (Allen 1985, Moura and Lindeman 2007, Araujo *et al.* 2008 and Claro and Lindeman 2008). The occurrence of *L. cyanopterus* on the coast of Santa Catarina, southern Brazil, observed in this study, shows that this species has a wider geographical distribution than has been previously published.

The absence of mortality in the present study agrees with the data obtained by several authors in relation to other species of snapper (Rios Filho 2001, Botero and Ospina 2003), showing the rusticity and adaptability of the species for mariculture.

The use of bycatch fish for feeding led to good growth results for the cubera snapper, which reached an average weight gain of 107.4 grams in just 30 days (Table 1), supporting the assertion of González-Sansón and Aguilar Betancourt (1986), that fish are the main food source of *L. cyanopterus*.

The feasibility of using bycatch fish for feeding marine fish culture in Brazil has already been demonstrated by Sanches *et al.* (2007) with real-grouper *Epinephelus marginatus* (Lowe 1834), that study highlighting the low cost of this diet in relation to other commercial operations.

The results relating to final weight, daily weight gain and survival rate of *L. cyanopterus* were higher than those obtained for mutton snapper *Lutjanus analis* (Cuvier 1828) by Watanabe (2001) and Benetti *et al.* (2002). Watanabe (2001) obtained 140.8 g of fish in 168 days, with weight gain of 0.78 g day^{-1} and a survival rate of 97.8 percent when fed with a 50 percent crude protein diet, and this low weight gain was justified by the author as a result of low temperatures (from 18 to 25° C).

Benetti *et al.* (2002), studying the performance of mutton snapper *L. analis* in cages, showed that the fish grew from 16.5 g to 330.7 g in 246 days using a commercial diet with 50-53 percent crude protein and 13-14 percent crude fat. The daily weight gain was 1.28 g day^{-1}, and the survival rate of 70 percent. The results presented here are also more impressive than those reported by Botero and Ospina (2003), who evaluated a culture of *L. analis* that was fed with a 45 percent crude protein diet and that obtained a weight gain of 372.9 g in 118 days (average daily gain of 3.16 g) with a survival of 97.6 percent.

In comparison with the growth of other snapper species fed with alternative food sources, the productive performance of *L. cyanopterus* showed superior results, demonstrating its suitability for intensive culture.

Cabrera *et al.* (1997), using bycatch as a food source for gray snapper *Lutjanus griseus* (Linnaeus, 1758), achieved a daily weight gain of 1.63 grams, with the fish reaching 425.0 g in 8 months and having a survival rate of 88 percent. In other research, Castillo-Vargasmachuca *et al.* (2007) studied the performance of spotted rose snapper *Lutjanus guttatus* (Steindachner 1869) in net cages fed diets containing 35 percent crude protein and 7 percent crude fat; the fish grew from 110.2 g to 366.1 g in 153 days, with a weight gain of 1.82 g day^{-1} and survival rate of 71.5 percent.

Table 1. Means and standard deviations of the productive performance of cubera snapper *L. cyanopterus* kept in net cages during the experimental period of 30 days.

Variable	Results
Initial length (cm)	32.6 ± 5.8
Initial weight (g)	456.3 ± 289.1
Initial biomass (g)	3194
Survival (%)	100
Final length (cm)	32.9 ± 5.7
Final weight (g)	563.7 ± 332.1
Final biomass (g)	3946
Weight gain	107.4 ± 36.8
DWG (g day^{-1})*	3.8 ± 0.6
SGR (%LW day^{-1})**	1.5 ± 0.3
FCR***	2.8 ± 0.5

**DWG = daily weight gain; **SGR = specific growth rate; ***FCR = food conversion rate*

To date, there are no studies on the growth of *L. cyanopterus* under culture conditions. Cervigón (1993) reported that this species had a fast growth rate, based on specimens kept in public aquariums. This study provides pioneer research data on the species.

The specific growth rate (SGR) of *L. cyanopterus* in this study, is similar to those obtained by Watanabe (2001), also 1.5, but higher than those obtained by Benetti *et al.* (2002) and Botero and Ospina (2003), who reported rates of 1.0 and 1.1, respectively.

Feed conversion rates (FCR), were better than those obtained by Rios Filho (2001) in a culture of *L. analis* using different types of food (FCR from 5.09 to 26.9), but similar to those obtained by Sanches *et al.* (2007), who suggested that FCR between 3 and 5.1 could be expected when using bycatch in marine fish farms.

Grilled cubera snapper: A typical meal at Florianópolis, Brazil.

Conclusions

The cubera snapper, *L. cyanopterus*, can adapt well to culture, confirming their potential for marine fish farming.

Notes

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Aquaculture status and potential in the northeastern region of India

Debtanu Barman*[1], Sagar C. Mandal[2] and Vikash Kumar[3]

Aquaculture is developing quickly in most of northeastern India because of high demand for fish in the region. However, this growth is not uniform because of the different food consumption habits of the people, though all states in the region have excellent potential for aquaculture. Among these, Assam, Manipur and Tripura have most of the population and a tradition of consuming fish. The literacy rate in most of the northeastern states is high as compared to the rest of the country and in particular those states where fish is not a commonly consumed item. With increasing evidence demonstrating the health benefits of eating fish and the ill effects of eating red meat, it is likely that the literate people in other parts of northeastern India will also gradually increase intake of fish. Hence, it is important that policymakers recognize the future demand for fish and make appropriate plans to meet the expected demand.

Northeastern states also have enormous water resources that are appropriate for aquaculture. High rainfall in the region provides an additional opportunity to develop mechanisms to collect water during the rainy season and store it for use in aquaculture throughout the year. Data available on the various types of aquatic resources in the region is presented in Table 1. All states in the region have good riverine resources and vast areas of paddy fields, yet to be utilized intensively for aquaculture purposes. Among the types of resources that have been used so far for aquaculture are ponds and mini barrages. Even these have not been harnessed to optimum potential to obtain the maximum yield. In Table 2, a summary of total fish production that has been obtained from capture fisheries and aquaculture for the five year period from 1999-2000 to 2003-2004 is presented based on

Fig. 1. Wood ash can be used as a liming material to increase pH.

Table 1. Fishery resources of Northeast India (values in parentheses indicate area yet to be developed)

States	River (km)	Reservoirs (ha)	Beel, Lake & Swamps (ha)	Ponds/Mini barrages (ha)	Paddy fields* (ha)	Forest fisheries
Arunachal Pradesh	2,000	(160) NA	2,500	250 (1,250)	12000	--
Assam	5,050	10,730	100,000	22,500	248980	5017
Manipur	2,000	100 (40,000)	40150	5,000 (4,500)	15790	--
Meghalaya	5,600	8,430	375	500 (1,900)	15790	--
Mizoram	1,700	32	NA	1,795	6810	--
Nagaland	1,600	(27,100)	215	500 (1,500)	14500	--
Sikkim	900	1,20,000		--	450	--
Tripura	1,200	4,500 (1500)	3,000	10,264 (3,136)	25780	--
Northeast	20,050	1,43,792 (68,760)	500	40,809 (12,286)	340100	NA

**10% of the total paddy cultivation area is taken as low lying potential for paddy cum fish culture*

Table 2. Contribution of capture fisheries and aquaculture to total fish production during the past five years (1999-2000 to 2003-04)

States	Capture fisheries in MT	Capture fisheries % of Total	Aquaculture in T	Aquaculture % of Total	Production (in T) Total	Production (in T) Annual Average
Assam	452120	54.62	375140	45.35	827260	165452
Arunachal Pradesh	3325	26.08	9422	73.92	12747	2549.40
Nagaland	-	-	26760	100.00	26760	5352
Mizoram	1800	10.67	15070	89.33	16870	3374
Tripura	3434.45	4.45	73765.05	95.55	77199	15439.80
Meghalaya	16165.47	61.36	10177.92	38.64	26343.38	5268.68
Sikkim	425	76.58	130	23.42	555	111
Manipur	49350	60.00	32900	40.00	82250	16450
Northeast (Total)	526619.92	49.22	543364.97	50.78	1069984.38	213996.88

the information provided by various state fisheries departments of the region. More than 50% of production came from aquaculture alone. Interestingly in some of the states, almost all the production was reported to be coming only from aquaculture as in the state of Nagaland. In Mizoram, nearly 89% of production came from aquaculture with an annual total production averaging about 3374 t. In Tripura, more than 95% of production came from aquaculture. This reflects not only the growing importance of aquaculture, but also the great urgency and need to focus on aquaculture to meet the growing demand for fish.

Fig. 2. Stocking of stunted seed. Note large head relative to body size.

Human Health Benefits

Fish is considered a healthy food for all people. Fish protein is known to be well digested by children as well as elderly people. Fish has the most essential amino acids required for human nutrition. In addition, the fat of fish is considered to be healthy because of its rich resources of omega-3 fatty acids. Consumption of fish with high fat content has many positive health benefits, particularly in preventing the heart disease. Most importantly, consumption of fish by pregnant women enhances the intelligence of the growing baby in the womb. Further, eating fish on a regular basis from early childhood contributes to the development of various organs, including the brain. The positive effects of eating fish contribute to increased demand and an urgency to increase production.

The overall average fish-eating population for the region is 88% (Table 3). However, states such as Mizoram and Sikkim report only 10% of the population as regular fish eating people. Based on the human population size and the total fish production reported, per capita fish consumption is 4.1 kg/year in Mizoram, with a regional average of 6.0 kg/year (Table 4).

Fig. 3. Providing vegetation for fish food.

This shows that a large amount of fish is imported from other parts of the country and even from neighboring countries through border trade. The data gathered on the amount of fish imported to various northeastern states is presented in Table 5. More than 38,000 t of fish is imported to the

Table 3. Fish consumption pattern in Northeastern States

States	Regular fish eating population (%)	Occasional fish consumers (%)	Non fish eating population (%)	Total population
Assam	90	0	10	26638407
Arunachal Pradesh	97	2	1	1097968
Nagaland	99	0.50	0.50	1988636
Mizoram	10	90	0	891058
Tripura	95	0	5	3291000
Meghalaya	90	0	10	2306069
Sikkim	10	70	20	525000
Manipur	80	10	10	2334000
Northeast (average)	87.58	3.67	8.75	39072138

Table 4. Per capita availability of fish in Northeastern states

States	Per capita availability of fish (kg/year) As Reported	As Calculated[1]
Assam	7.30	6.79
Arunachal Pradesh	2.40	2.42
Nagaland	3.55	2.80
Mizoram	3.22	4.13
Tripura	5.50	5.46
Meghalaya	5.00	2.23
Sikkim	1.06	0.27
Manipur	8.40	7.54
Northeast (average)	6.58	5.98

[1]*Per capita availability of fish was calculated by dividing the total production of 2003-04 by the total population as per Census 2001. In case of Tripura, production is reported to have increased and hence per capita availability*

Table 5. Amount of fish imported to Northeastern States

States	Amount (t/annum)	Percentage of Northeast total	Value of fish/ year @ US$ 1.10 /kg
Assam	12720	33.18	63.60
Arunachal Pradesh	4500	11.74	22.50
Nagaland	3600	9.39	18.00
Mizoram	720	1.88	3.60
Tripura	3000	7.82	15.00
Meghalaya	6000	15.65	30.00
Sikkim	2400	6.26	12.00
Manipur	5400	14.08	27.00
Northeast (Total)	38340	100	191.70

region, though Mizoram imports only 720 t. Total fish production of the region is 233,709 t with a deficiency of 196,163 t (Table 6). Fish production is greatest in Assam (180,950 t) and least in Sikkim (140 t).

Increasing Aquaculture Production

Fish produced in the local area fetch almost 50-100% higher price as compared to fish imported from places such as Andhra Pradesh because of the quality difference. Transport of fish from Andhra Pradesh to various parts of northeastern India requires almost seven days. Changes in biochemical composition of fish preserved in ice contribute to quality decline and, thereby, greater demand for local fish. Further, resources available in the region are not fully exploited for aquaculture and, in areas where water resources are used for aquaculture, productivity is far below potential. Data related to area availability and utility for aquaculture is presented in Table 7.

The productivity level obtained by farmers in the region as a whole is far less than the national average of 2400 kg/ha per year. Most farmers in Tripura state stock fish at a very high density, apply manure and chemical fertilizers at a very low rate, and feed fish irregularly. As a result, the average productivity of the farmers is only 1400 kg/ha per year. Though some states have reported the presence of integrated farming systems with better productivity, there are very few good examples of such practices. Rice-fish culture has enormous potential in the region, but is restricted to a few areas.

Poor farmers are also confronted with many challenges, though they understand the potential of aquaculture. Among these challenges are social issues, such as poaching and poisoning, which are considered to be the biggest problems encountered by the majority of farmers. Hence, there is a need to provide technical support to farmers to increase aquaculture productivity, but also develop mechanisms to reduce the risk of crop loss to farmers, such as constructing fences.

Table 6. Fish supply and requirements in Northeastern States

States	Total population	Nutritional requirement (T)@ 11 kg per capita	Production (T)	Deficiency (T)
Arunachal Pradesh	1097968	12077.65	2652	9425.65
Assam	26655528	293210.81	180950	112260.80
Manipur	2388634	26274.97	17600	8674.97
Meghalaya	2318822	25507.04	5147	20360.04
Mizoram	888573	9774.30	3680	6094.30
Nagaland	1990036	21890.40	5560	16330.40
Tripura	3199493	35191.23	17980	17211.23
Sikkim	540493	5945.42	140	5805.42
Northeast	39079257	429871.83	233709	196162.83

Table 7. Area utilized for aquaculture and potential area suitable for aquaculture

State	Area under aquaculture (ha)	Area available for aquaculture (ha)
Assam	60000	31232
Arunachal Pradesh	2270	6500
Nagaland	3000	30000
Mizoram	2600	24000
Tripura	21169.24	2000
Meghalaya	2500	6.03
Sikkim	38	38
Manipur	17000	26986
Northeast (Total)	108577.24	120762.03

Potential Steps to Increase Fish Production

Improve pH of fish ponds

The northeastern region has more acidic soils than other regions of India. Water pH is an important criterion to produce an adequate amount of natural food in the water through effective release of nutrients. Application of lime is essential to rectify pH of water. In rural areas, the availability of lime may be a constraint. In place of lime, ash produced at home from cooking fires or from various other sources can also be used (Figure 1). Ash produced from banana has a very good impact in improving pH of water. As a general rule, three kg of ash has the same effect as one kg of lime. Ash is also a good fertilizer and, hence, farmers are advised to apply all available ash to fish ponds.

Stock stunted seed of higher weight

Indian major carps, particularly rohu and mrigal, grow rapidly in the second year of life. Farmers in Andhra Pradesh stock stunted fish that are 6-8 months old and allow them to grow in the second year to their full potential (Figure 2). The average weight of rohu stocked in Andhra Pradesh is about 100 g. Such fish will grow to about 1 kg in about one year. Adoption of such a strategy would be very useful to increase fish yield from ponds. Some farmers in eastern India adopt a strategy of stocking large numbers of seed, harvesting larger fish, and leaving smaller fish to grow to their potential in the following season. As a general rule, stocking seed of over 50 g of any species at 5000-10,000/ha will result in the best potential yields.

Keep water green

Green water is essential to increase growth of fish based on natural food produced in the pond (Figure 3). Most carps depend on natural food produced in the pond and this is eaten by fish through filtration or grazing. The Northeast region has abundant vegetation that can be composted in pond corners by creating bamboo fences and dumping the vegetation in such enclosures. Adding manure to a vegetation pit stimulates composting in the aquatic environment and increases primary productivity. Silver carp and tilapia grow rapidly when such an environment is created. Repeated applications are far more efficient than all at once.

Apply manure and fertilizers

In addition to vegetation, it is useful to add various types of manures (Figures 4 and 5). Farmers generally have cattle and cattle manure is popularly used in fish culture, though its efficacy is far lower as compared to pig or poultry waste and the amount of manure applied could be as much as 30 t/ha per year. The amount required to keep the water green depends on the soil and water quality. In addition to organic manures, chemical fertilizers, such as nitrogen and phosphorous fertilizers, need to be applied. Application of up to 200 kg each of nitrogenous and phosphorous fertilizers would be useful, though farmers now use increased levels in Andhra Pradesh and Punjab to get higher levels of fish productivity. Apply the manure and inorganic fertilizers to keep the water green and prevent over application by carefully monitoring water quality and fish movement.

Provide adequate supplementary feed

When fish are stocked at higher density, it is essential that they are provided with proper amount of supplementary feed. Farmers use mustard seed oil cake and rice bran to

Fig. 4. Pig manure can increase pond productivity.

Fig. 5. The access to fish ponds by ducks is restricted to one area.

Fig. 6. Providing bagged feed to increase fish productivity.

feed fish. For good growth, a 1:1 ratio of oil cake to rice bran is used. However, cost is the key factor in feeding fish and farmers have to regulate the level of oil cake in such a way that best results are obtained without wastage. In winter, the feed conversion efficiency is low and farmers in Andhra Pradesh avoid using oil cakes in this season. As a general rule, with a good amount of natural food, the farmer provides 1.5-2.0 kg of rice bran and oil cake mixture as a supplementary feed.

Feeding strategy

Feed the fish daily and ensure that feed is given either in tray or in feed bags that can be made with fertilizers bags (Figures 6 and 7). The bag feeding method developed by farmers in Andhra Pradesh prevents the wastage of feed to a great degree and well-trained fish generally exhaust feed within one to two hours from the time of feeding. Even feed given in small quantity should be provided daily. Adding up to 1% salt in the feed can improve fish growth and reduce stress.

Use bamboo as substrate

When placed in water, bamboo provides good surface area for the growth of periphytic food organisms and these are actively grazed by rohu, common carp, tilapia, gonius (*Labeo gonius*), and small cyprinids (Figure 8). Evolved by fishers, this is an age-old technique to aggregate fish by dumping tree branches in rivers and lakes, and capturing them. This traditional technique, which has been investigated scientifically, is an effective approach to increase the growth of fish and crustaceans, such as freshwater prawns. In species such as rohu that have special fringed lips, the growth increment was up to 60% greater than fish in ponds without substrate. As little as a 20-30% increase in growth would bring a substantial amount of revenue. Hence, it is recommended that farmers use tree branches or bamboo as substrate in the pond (Figure 9). Ponds are installed with an equivalent of 50% of the pond surface area with bamboo substrate, about 4-5 pieces per m^2, depending on bamboo diameter. In addition to promoting growth, bamboos will prevent poaching of fish from the pond because poachers cannot operate nets easily without removing bamboo.

Choose the right species for culture

Effectiveness of the practices described above depends on the species cultured. Chinese carps, including common carp, grass carp, and silver carp have not been used by Andhra Pradesh farmers for various reasons. They culture mostly rohu (almost 90% of fish stocked), with the remainder being catla only or catla mixed with mrigal. Farmers of Andhra Pradesh target the eastern India market where demand for rohu is high. This species also grows well in high temperature locations with a large water surface area. In contrast to Andhra Pradesh, Chinese carps are best suited in northeastern India because of temperature. Chinese carps grow well as long as feed is made available, irrespective of pond size. If fed well, grass carp can help several other species to grow. Silver carp is best suited to harvest the plankton and demonstrates good growth. Further, minor /medium carps, such as

Fig. 7. A row of feed bags installed in a pond.

Fig. 8. Bamboo installed as substrate for periphyton growth.

Fig. 9. Palm leaves used as substrate for periphyton growth.

bata, gonius, and reba, are now proving to be successful species in small water bodies. Small-bodied species like *Amblyopharyngodon mola*, which was once viewed as a weed fish, is now recognized as a fish with very high levels of Vitamin A as well as rich in minerals. This species is now used popularly for making pickled fish. Farmers can select the species depending on local market demand. Culture techniques are available for each of the species combinations and they can be adapted to suit local conditions.

Conclusion

The average per capita fish consumption recommended for a healthy body and mind is 100 g/day (36.5 kg/year). The average per capita fish consumption globally is only 16.3 kg/year, while in India it about 9.0 kg/year, and in the northeastern region it is about 6.0 kg/year. These differences in fish consumption support the need for increased fish production in the region and the country as a whole. Farmers in Andhra Pradesh now produce an average of 8000 kg/ha per year, while in Punjab, average productivity level has increased to 6000 kg/ha per year. In various parts of the country, farmers with even modest efforts are able to obtain a productivity level of 4000 kg/ha per year. The northeastern region of India has substantial resources, not yet tapped. In addition, some of the rice growing areas appear well suited for fish culture. The information presented in this paper indicates the resources available for fish farming and the potential technical strategies that can be implemented to benefit poor farmers.

Notes

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Impacts of the Deepwater Horizon oil spill on the Auburn University Shellfish Laboratory aquaculture program

Scott Rikard[1] and William C. Walton

The explosion of the Deepwater Horizon oil rig on April 20, 2010 and the subsequent oil spill (DHOS) presented immense challenges for residents and businesses along the Gulf of Mexico coast. The Auburn University Shellfish Laboratory (AUSL) located on Dauphin Island, Alabama was no exception (Fig. 1). AUSL has faced its share of challenges in the past, especially in the form of hurricanes. But unlike hurricanes where the damage is immediately apparent and recovery begins quickly, the DHOS was a disaster moving in slow motion with potential impacts that may not be known for years. Questions of when would oil impact the Alabama coast, what would be the effects on water quality and when would the spill be stopped, presented difficult decisions about running the production and research operations of AUSL.

Fig. 1. The Auburn University Shellfish Laboratory located on the Gulf of Mexico coast on Dauphin Island, Alabama.

The Auburn University Shellfish Laboratory

The AUSL was established in 2003 with local oyster industry input to conduct practical research in the tradition of the Land Grant University to foster production of high-quality shellfish products by improving technology for shellfish culture and developing techniques for enhancing or restoring natural production. To meet the AUSL mission, research is conducted on shellfish aquaculture, ecology, restoration, disease, and human pathogens associated with shellfish.

A portion of the AUSL facility is dedicated to hatchery production of shellfish, primarily the Eastern oyster *Crassostrea virginica*. These oysters are used for AUSL research, research at other institutions, and support of commercial interests. Typically broodstock oysters are spawned at the AUSL hatchery from late April through early September and the resulting larvae are reared in static tank systems. Larvae reared to the setting stage are set on a variety of cultch materials. Larvae for restoration or fisheries enhancement projects typically are allowed to set on whole oyster shell packaged in large mesh bags, resulting in production of oyster clumps that will be eventually planted on water bottoms. Larvae destined for aquaculture or experimental purposes are set on finely ground oyster shell, a technique that produces single oysters. Larvae attached to cultch are maintained in flow-though seawater systems in the AUSL hatchery for a variable duration.

Oil Spill Effects on Hatchery and Field Operations

The DHOS coincided with the start of the 2010 AUSL hatchery production season. Immediately there was concern that oil from the DHOS could contaminate the seawater supply to the hatchery because the seawater supply pipeline extends 300 m from Dauphin Island into the Gulf of Mexico. Potential impacts of the oil spill on AUSL hatchery operations included immediate water quality effects detrimental to oyster larvae and post-set juveniles and long-term contamination of hatchery water delivery and rearing systems. It was clear that the oil spill would severely impact and possibly delay hatchery production and implementation of the AUSL research program.

Another potential area of impact from the DHOS was AUSL's field operations. Broodstock oysters are maintained on the north side of Dauphin Island, where oysters are held in cages suspended above bottom on an adjustable long-line system under a boat dock in a protected inlet of Mobile Bay. Additionally, AUSL established and helps maintain a demonstration oyster farm in Sandy Bay, Alabama, as part of a research program assessing the potential for developing an off-bottom oyster aquaculture industry in Alabama (Fig. 2). At the farm site, AUSL researchers are testing various types of oyster grow-out gear and developing best management practices for off-bottom oyster culture in Alabama. At the demonstration farm, AUSL maintains stocks of juvenile and adult oysters for supporting research and commercial interests. During the DHOS, AUSL was concerned with direct oiling of oysters in the broodstock holding area and at the demonstration farm that could potentially cause mortality, impact fecundity of broodstock oysters, or contaminate oysters and gear at the demonstration farm.

Despite uncertainty about the nature and timing of potential impacts from the DHOS, AUSL decided to press forward with hatchery production of oysters and the AUSL research agenda. Hatchery operations at AUSL proceeded with alteration of the normal seawater pumping and use protocol. With guidance provided by NOAA oil spill trajectory maps, the AUSL hatchery modified water pumping operations and managed to continue hatchery activities through May and early June to meet obligations for oyster spawning, larval rearing and setting for juvenile oyster production. Initially water was pumped continuously as normal until oil reached near-shore waters in late May 2010. Then, water pumping was suspended at the end of each work day and re-assessed each morning before start up using NOAA oil trajectory forecast maps and a visual and olfactory inspection of nearshore waters. It was anticipated that complete suspension of water pumping would be required at some point in time. For that reason, AUSL maintained 45,425 L of reserve seawater in large reservoir tanks on-site normally used to settle water for larval rearing. Another 45,425 L of water was stored in the hatchery's discharge sump at the end of each day until pumping operations began the next day. For approximately 20 days in late June and early July, AUSL did not operate pumps because oil was present in local waters (Fig. 3). The hatchery discharge sump and pumping systems were modified to recirculate water through the hatchery during this time. It was possible to maintain post-set oysters in this recirculation system but growth was slowed considerably after naturally occurring phytoplankton was depleted. To maintain post-set oysters, the hatchery incurred unplanned costs for the provision of supplemental algal feed[2]. Capping of the Macondo oil well in mid-July and favorable wind conditions allowed water pumping to resume during work days with a reassessment of conditions each morning until the first week of August when continuous pumping operations were resumed. Despite the challenges of the DHOS, the AUSL hatchery was able to meet all obligations for oyster larvae and post-set juvenile to support AUSL research and the needs of other institutions and commercial interests.

The ability to continue operations allowed AUSL to assist long-time cooperator Dr. John Supan from LSU and the Louisiana Sea Grant program. Hatchery operations at the Louisiana Sea Grant Program's Grand Isle Bivalve Hatchery were suspended indefinitely when oil impacted nearshore waters. The AUSL was able to conduct cooperative hatchery operations to provide assistance to meet production needs of the Grand Isle Bivalve Hatchery during the DHOS. Oyster larvae produced for Dr. Supan's research were set and resulting post-set juveniles were returned to non-impacted, protected waters in Louisiana in July 2010.

Fig. 2. Demonstration oyster farm in Sandy Bay, Alabama.

The adjustable long-line system used to hold shellfish broodstock at AUSL proved to be beneficial in preparation for potential oil impacts. In this system, baskets of oysters are suspended from a large monofilament cable stretched between a series of pilings under a boat dock and the line can be adjusted to different water depths. When the threat of oil to the broodstock area was imminent, the long-line system was adjusted to the lowest possible setting near bottom and below the lowest tide level. This kept oysters submerged and away from oil floating on the surface. In addition, broodstock oysters were protected from surface oil impacts by placement of oil booms across the inlet entrance. There were no visible oil impacts on this area and EPA water sampling nearby indicated no water contamination of concern. Once the threat of oil in the area subsided in early August 2010, the long-line system was readjusted to the normal mid-water position. Effects of the oil spill on fecundity of broodstock oysters have not yet been determined.

At the Sandy Bay demonstration farm site, AUSL was conducting research trials on four types of oyster aquaculture gear during the time-frame of the DHOS. The gear under investigation was an adjustable long-line[3], a floating pontoon cage[4], a floating bag[5], and a bottom cage[6] (Fig. 2). When oil trajectory maps indicated a threat to the area, the long-line system was adjusted to the lowest possible setting near bottom and below the lowest tide level, keeping the oysters below any surface oil. Similarly, pontoons on the floating cage were flooded to sink the cage to the bay bottom, away from any surface oil. The bottom cage system required no modification because it was positioned directly on the bay bottom. There was not a good option for the floating bag system other than removing floats to allow the bag to sink to the bay bottom. This option was rejected because of concern that oysters in bags would suffocate in the bottom mud and also be susceptible to predation by oyster drills, a snail known for their voracious appetite for oysters. Floating bags were maintained on the surface, knowing that oysters might be directly impacted by floating oil. In the event of oiling, these oysters would provide a comparison of impacts to oysters that were held submerged.

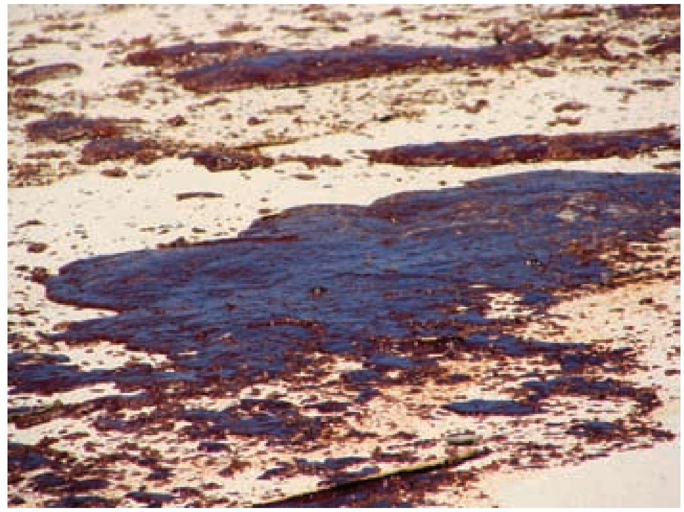

Fig. 3. Weathered oil from the Deepwater Horizon oil spill washed ashore on Dauphin Island, Alabama in June 2010.

Oil Spill Aftermath: Meeting the Challenge

Obvious impacts to the demonstration oyster farm site appeared to be minimal. Only small patches of light oil sheen were seen in this area on two separate occasions. When oyster drill predation was apparent on oysters cultured in gear placed near the bottom and presence of oil in the area appeared to be minimal, oyster gear was returned to normal operating positions. No attempts were made to relocate oysters to other areas because of the high cost associated with relocating an entire farm site. The major cost associated with the oil spill at the farm site was the increase of labor involved in managing gear. Waters in the area of the demonstration farm were reopened to harvest and testing has not indicated the presence of polycyclic aromatic hydrocarbons or oil dispersant in oyster tissues. Subsequent testing by an independent laboratory indicated that concentrations of contaminants were near or below levels of detection and hundreds of times below established levels of concern.

Major impacts of the spill for the AUSL program were associated with increased time required for personnel to manage water supply for the hatchery and manage gear for the broodstock system at the hatchery and the demonstration oyster farm site, and the added feeding cost in the hatchery for post-set juvenile oysters. A less obvious but important effect was the stress on personnel of not knowing when the DHOS would end and how severely the programmatic impacts would be. With constant monitoring of the oil spill, innovative solutions to oil-related problems, and many extra hours invested by personnel, AUSL was able to persevere and meet its obligations to research and production needs for the AUSL program as well as the needs of other institutions. Despite the challenges of the DHOS, great leaps forward were made in developing and supporting an aquaculture industry for oysters in Alabama.

Notes

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[3]Adjustable Long Line System, BST Oyster Supply, Cowell, South Australia

[4]OysterGro ™, Bouctouche Bay Industries Ltd., Bouctouche, New Brunswick, Canada

[5]Floating Bag, supplied by Chesapeake Bay Oyster Company, Wake, Virginia, USA

[6]LowPro cage, Chesapeake Bay Oyster Company, Wake, Virginia, USA

Drought in Urmia Lake, the largest natural habitat of brine shrimp *Artemia*

ALIREZA ASEM[1,2] AND FEREIDUN MOHEBBI[3], REZA AHMADI[3]

Urmia Lake is an oligotrophic and extremely hypersaline lake that is the largest natural habitat of brine shrimp *Artemia* (Ahmadi 2005, Eimanifar and Mohebbi 2007). It has a surface area between 4000 and 6000 km^2 and a maximum depth of 16 m, located in northwestern Iran at an elevation of 1274 m. Salinity of lake water ranges between 120 and 280 g/L. Urmia Lake is the saltiest lake on earth with an active food web. It is a UNESCO biosphere reserve and a Ramsar wetland (Asem *et al*. 2010).

Urmia Lake has been experiencing a serious ecological crisis over the past decade. Lake water is saturated with salts to the point where salt crystals form on the lake surface year round. The salinity of Urmia Lake has increased from 169 g/L in 1995 to more than 300 g/L in 2003-2004 (Fig. 1) (Sorgeloos 1997, Ahmadi 2005, 2007). Many hectares of surrounding land have been converted to salt marshes and, in the southern and southeastern areas, the coastline has retreated several kilometers (Fig. 2). The salt-saturated water of the lake has disrupted the development of waterbirds (Fig. 3).

In 1995, *Artemia urmiana* cyst production (dry weight) in the surface half-meter of Urmia Lake was calculated by integration and summation to range from 4243 to 4536 t/yr. The lake area was estimated to be 5500 km^2 that year.

The concentration of cysts can be estimated as follows:

1) lake area in 1995: 5500 km^2 = 5,500,000,000 m^2
2) volume in 0.5 m of lake surface = 5,500,000,000 × 0.5 = 275 × 10^7 m^3 = 275 × 10^{10} L
3) 1 g of cysts = 250,000 cysts (Sorgeloos 2007) mean biomass of dry cysts in 0.5 m of lake surface (t) = (a_i + a_s)/2 = (4243 + 4536)/2 = 4389 t/yr = 438,914 × 10^4 g/yr, where
   a_i = amount of dry cysts calculated by integration
   a_s = amount of dry cysts calculated by summation
5) number of cysts in 0.5 m of lake surface = (438,914 × 10^4) × 250,000 = 10,972,925 × 10^8 cysts
6) concentration of cysts = (10,972,925 × 10^8) / 275 × 10^{10} = 399 cysts/L

Since 2000, with the drought in Urmia Lake, the harvest of *Artemia* cysts has collapsed (Ahmadi 2005). A resource assessment of *A. urmiana* measured cyst concentrations in the surface 20 cm of 27 cysts/L (2003) and 25 cysts/L (2004) (Ahmadi 2005). Cyst concentrations declined further to 11 (2005), 8 (2006), and 3 (2007) cysts/L (Ahmadi

Fig. 1. Clear evidence of the retreating coastline of Urmia Lake.

Fig.2. The difficult and disrupted life of waterbirds.

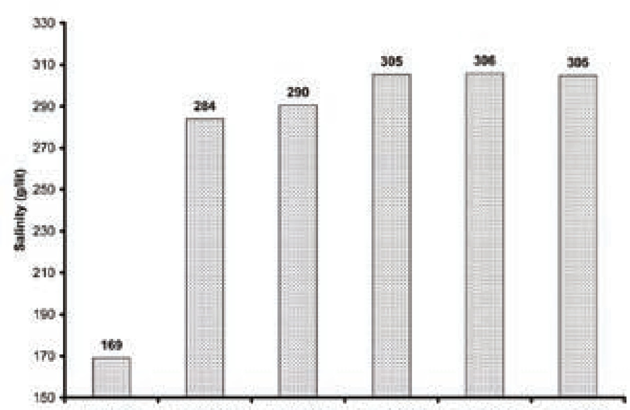

Fig 3. Annual salinity of Urmia Lake in different years

2007). Although there was no resource assessment of *A. urmiana* after 2007, unofficial reports indicate that there is less than1cyst/L of *Artemia urmiana* in Urmia Lake.

According to an evaluation in West Azerbaijan Province in 2002 (Mohebbi 2002), the establishment of a 100-ha *Artemia* farm, construction of an *Artemia* cyst processing facility with 210 tons capacity, and the establishment of a facility for *Artemia* culture in tanks with a 9000-m^3 capacity, may create 76, 21, and 82 jobs, respectively. With regard to recent drought years and the environmental crisis in Urmia Lake, employment opportunities arising from the harvest, production, and processing of *Artemia* have been lost.

Experts believe the current situation of Urmia Lake is a result of global climate change, dam projects in the watershed, and the development of non-mechanized farming in the lake basin. However, historical documents indicate that Urmia Lake experienced a severe drought more than 200 years ago. In 1800, the maximum depth was only 75 cm. The lake was so shallow that an east-west road was created through the lake bed and oral histories from elders confirm the presence of this road (Tamaddon 1971). This history indicates that Urmia Lake has undergone more extreme droughts than present but the lake subsequently recovered.

Figure 4 shows the water level fluctuations of Urmia Lake from 1965 to 2009 (Ahadnejad Reveshty and Maruyama 2010, Asem *et al.* 2010). Figure 4 indicates that Urmia Lake experienced a drought from 1965 to 1968. The water level in that period matches that of 2003-2004 and the average salinity at that time was conceivably greater than 280 g/L (Asem *et al.* 2010).

Although drought in Urmia Lake has been described as a crisis, this lake ecosystem has also experienced rising water and landward shifts of the shoreline. In 1993-1998, the lake reached its highest historical level (Fig. 4). During that period, hypersaline lake water and the advancing shoreline affected farms and coastal buildings, causing large financial losses. In those years, the average salinity was 180 g/L (Asem *et al.* 2010). Figure 5 shows Osman Yumrugu, the smallest island of Urmia Lake in two different ecological conditions, illustrating the wide range in historical lake elevation. This variability is also indicated in Figure 6, which displays the shoreline of Urmia Lake from 1976 to 2009 (Ahadnejad Reveshty and Maruyama 2010).

Urmia Lake is one of the principle global ecosystems for *Artemia* production. The current drought has negatively affected *Artemia* production and consequently threatens the biodiversity of Urmia Lake National Park.

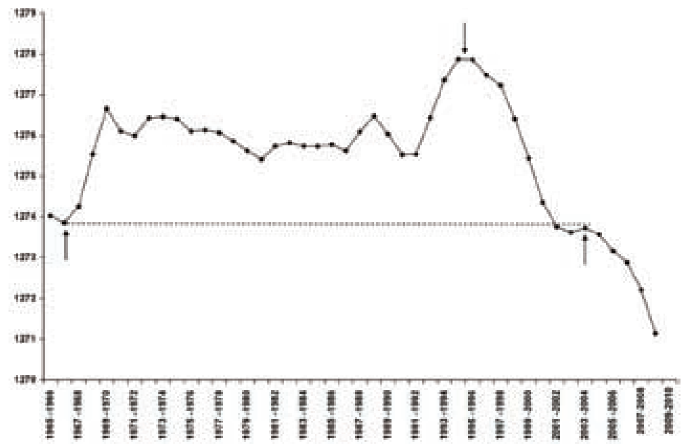

Fig 4. Water level fluctuation of Urmia Lake (1965-2007)

Fig. 5. Osman Yumrugu, the smallest island of Urmia Lake in two different ecological conditions.

Notes

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Fig. 6. Changes in extent of Lake Urmia from 1976-2009 (Ahadnejad Reveshty and Maruyama 2010). Note decline in lake area during the last decade.

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Developments in selective breeding for resistance to *Aeromonas hydrophila* in fish

S. Das[1] and P.K. Sahoo[1]

Aeromonas hydrophila is a gram-negative, facultatively anaerobic, oxidase-positive bacterium causing a wide range of acute, chronic and covert infections in fish, such as dermal ulceration, fin rot and tail rot, ocular ulcerations, erythrodermatitis, hemorrhagic septicaemia (Fig. 1), red-sore disease, red-rot disease, and scale-protrusion disease. Many freshwater fishes (including Nile tilapia, channel catfish, rainbow trout, catla, rohu, mrigal, catfish, eel, goldfish, *Puntius* sp., Asian catfish, gizzard shad), a few brackish water species, and some marine fishes are affected. Although *A. hydrophila* is part of the normal intestinal flora of fish, it can cause severe disease under stress. The disease caused by this bacterium is considered a principal microbial disease called Motile Aeromonad Septicaemia (MAS). Once a disease outbreak occurs, the spread of this type of septicaemia is rapid and can cause high mortality in cultured fishes. Aeromoniasis has also been reported in outbreak forms in intensive carp farms (Mohanty *et al.* 2008).

Emphasis has been placed on prevention of this disease. Different types of vaccines have been tried to prevent *A. hydrophila* infection in fish, including whole cells (WC), outer membrane protein (OMP), extracellular products (ECPs) such as extracellular proteases, lipopolysaccharide (LPS) preparations, and biofilms. Recently a recombinant S-layer protein vaccine of *A. hydrophila* has been shown to render protection to common carp *Cyprinus carpio* against six virulent isolates (Poobalane *et al.* 2010). However, the bacterium is so heterogeneous that available vaccines are not effective against all strains.

In addition to vaccines, some polyherbal immunomodulatory formulations enhance growth, survival, and disease resistance against *A. hydrophila* (Kumari *et al.* 2007). A large number of immunomodulatory substances have been screened and some are partially effective in rendering protection to aeromoniasis and raising the vaccine titer in fish (Sahoo 2007, Sahoo and Sakai 2010). Disease prevention with antibiotics and chemotherapeutic agents cannot bring a permanent cure and there will always be a risk of accumulation of these substances in the fish body and the environment, with the threat of developing antibiotic-resistant bacterial strains (Sahoo and Mukherjee 1999). The possibility of large-scale mortality in young hatchling stages, when vaccination cannot be considered, is of great concern. Thus, one of the few major alternatives remaining is the development of aeromoniasis-resistant fish through selection, bringing long-term protection against the disease.

Fig. 1. Rohu showing distended haemorrhagic ventral surface after experimental infection with Aeromonas hydrophila.

Selective Breeding

There are two basic types of selection: 1) mass selection for a single trait and 2) family or combined selection for multiple traits such as growth, disease resistance, meat quality, feed conversion efficiency, salinity and low-temperature tolerance, and reduced fat content. Selective breeding for disease resistance can result in improved lines for aquaculture, reduced use of antibiotics and drugs, and ultimately reduced fish losses to disease. Selective breeding programs have been reported for different economically important fishes for resistance against different diseases, including common carp against dropsy (Kirpichnikov *et al.* 1993); rainbow trout against enteric red mouth disease, rainbow trout fry syndrome, and viral haemorrhagic septicaemia (Henryon *et al.* 2002, 2005); Atlantic salmon against furunculosis, bacterial kidney disease, cold water vibriosis, and infectious salmon anaemia (Standal and Gjerde 1987, Gjedrem and Gjoen 1995, Odegard *et al.* 2007); Atlantic cod against vibriosis (Kettunen and Fjalestad 2006); rohu against aeromoniasis (Mahapatra *et al.* 2008); and Pacific white shrimp against white spot syndrome virus (Fjalestad *et al.* 1997, Argue *et al.* 2002, Gitterle *et al.* 2005).

Here we highlight the achievements made with respect to ongoing selection programs to prevent aeromoniasis in fish and the constraints and future of these programs.

Ongoing Selection Programs

There are three major culture species for which selection programs for *A. hydrophila* resistance have been reported.

Common Carp

The Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) at Szarvas, Hungary, is a unique live gene bank of common carp *Cyprinus carpio* comprising of 17 foreign and 20 Hungarian strains (Bakos and Gorda 2001). Initially Jeney *et al.* (2009) studied the stress response in two genetically distinct carp strains (wild Duna, D and inbred Szarvas, 22) by measuring cortisol level. Males of high (H) and low (L) stress response from both lines were crossed with inbred Szarvas 22 females, producing four lines of fishes (22 × 22 H, 22 × 22 L, 22 × D H, 22 × D L). These four lines, along with the initial D and 22 strains, were vaccinated and immune responses were studied in vaccinated and control groups by measuring plasma antibody titer. The wild carp D and crossbred 22 × D with high and low stress responses were most sensitive to the challenge test, with 80 percent mortality in response to *A. hydrophila* infection. The inbred line 22 and the crossbred 22 × 22 L were more resistant, with 50 percent mortality rate and higher antibody titer against *A. hydrophila*.

Later the group performed a diallele cross using four genetically distinct common carp strains (inbred minor line Szarvas, 15; scaly noble carp Tata, T; Hungarian wild carp Duna, D; and an East Asian wild carp Amur, A) differing in their origin and breeding history, and produced 96 families. The challenge test with *A. hydrophila* showed no significant correlation of pond survival with resistance, and heritability was also low (Odegard *et al.* 2010). The wild strains (Duna and Amur) indicated better heterosis for pond survival and growth rate compared to the two farmed strains (Tata and Szarvas 15). Survival in ponds of Szarvas 15 was even lower than that of previous generations from greater inbreeding. The heritability estimate for growth with pond survival was also high, indicating a successful selective breeding for growth in common carp (Nielsen *et al.* 2010). The challenge test to *A. hydrophila* indicated that families belonging to the domesticated strains Tata and Szarvas 15 were more resistant, while the wild Duna and Amur strains were most susceptible (Jeney *et al.* 2011). From the challenge results ten most-resistant and ten most-sensitive families were selected and immune responses were studied from challenged and their respective control groups separately (Ardo *et al.* 2010). Results indicated some correlations in phagocytic, lysozyme activities, and level of specific antibody titer between resistant and sensitive families, but no relation between the two could be established in non-infected or control groups. The selection program continues.

Rohu

A selective breeding program on rohu *Labeo rohita*, the major contributor to freshwater aquaculture production in India, was carried out through Indo-Norwegian collaboration. Initially the goal of the selection program was increased growth (Reddy e*t al.* 2002). Later, genetic variation was studied for different immunological parameters and their association with survival against aeromoniasis in 13 full-sib families (Sahoo *et al.* 2004). The specific immune response (such as haemagglutination titer) and nonspecific immunity levels (such as lysozyme activity and natural haemolysin titer) were not significantly different between resistant and susceptible groups. However, aeromoniasis resistance was positively correlated with bactericidal activity of serum. *A. hydrophila* challenge of these 13 full-sib families resulted in mortalities ranging from 0 to 100 percent. These preliminary findings open up the scope for selection against aeromoniasis based on wide differences in survival among full-sib families.

Furthermore, genetic variation studied by taking different full-sib families of two year classes (2003 and 2004) after *A. hydrophila* challenge indicated that mean body weight of 2003 year-class fish that survived the challenge test was less than those that died during the test. However, contradictory results were found for 2004 year-class fish due to inconsistent challenge survival results in duplicate tanks (Mahapatra *et al.* 2008). In another study, seven immune system parameters were investigated in 64 full-sib families of the 2003 and 2004 year classes and correlations with the challenge survival data were obtained. The data indicated absence of correlation of survival to aeromoniasis with serum myeloperoxidase, superoxide and lysozyme activities, negative correlations with bacterial agglutination titer, haemolysin titer and haemagglutination titer, and a significant positive correlation with ceruloplasmin level among families (Sahoo *et al.* 2008). In first-generation lines generated from 15 higher-ranked (resistant) and ten lower-ranked (susceptible) full-sib families, challenge testing resulted in differences in immunological response and differential expression of a few immune-related genes, in addition to a very high selection response (i.e., 58 percent greater survival in challenge test in the resistant line over the susceptible line) (Sahoo *et al.* In press). Few immune parameters measured showed significantly greater response in the resistant line compared to the susceptible line, such as respiratory burst activity of blood phagocytes, serum myeloperoxidase activity and ceruloplasmin level. However, the reverse was the case in the level of blood glucose and serum natural haemolysin titer. Whereas no significant difference was reported in total serum protein concentration, antiprotease activity and bacterial agglutinin level between the two lines. Expression of few immune genes (viz. transferrin, complement factor C3 and TLR 22-like transcripts) were significantly greater in liver samples of the susceptible line, while no such difference was found in β_2 microglobulin and lysozyme gene expression between the two lines. Research on molecular markers, like SNPs and microsatellites associated with aerononiasis-resistance, is also being conducted by the group in collaboration with Nofima, Norway.

Clarias catfish

Aquaculture plays a special role in the economy of Thailand. Among cultured species (including tilapias, *Puntius*, and *Pangasius*), two of the catfishes *Clarias macrocephalus* and *C. batrachus* are the most popular. Hybrids such as "Big-Oui" (a hybrid of broadhead catfish *Clarias macrocephalus* and African sharptooth catfish *Clarias gariepinus*) can reach market size faster than either parental species. However, reported disease outbreaks also increased in conjunction with increased use of hybrid catfish (Areechon 1992).

The resistance and immunological response to *A. hydrophila* infection by hybrids was compared with that of the parent species (Areechon and Karoon 1995). The researchers conducted challenge studies with these three types of fishes (both vaccinated and control groups) and studied the immune response with an antibody titer of the vaccinated group. Hybrids had greater resistance than broadhead catfish but African catfish were the most resistant among the three. There was an active immune response and less mortality in vaccinated groups, signifying that more research on vaccines is needed. Unfortunately, no further work has been reported from the group.

Developments in Selection Procedures

Previously it was believed that selection could be performed on two bases: directly by challenge survival results and indirectly by immunological markers. With the advancement of molecular techniques, molecular markers are now used in Marker Assisted Selection (MAS) programs.

Direct Challenge Test

The challenge test is the traditional method for selection with some limitations. Injection with a LD50 dose of bacteria intramuscularly (Lio-Po *et al.* 1996) or intraperitoneally (Angka 1990, Sahoo and Sahoo 1997) and calculation of survival 48 hours after infection was most practicable. However, this approach bypasses the natural defense barriers of skin and mucous membranes, the two most important barriers against bacterial entry. Challenging experimental fish with cohabitants of bacteria-injected fishes of the same size is also not possible for aeromoniasis because there is complete mortality of cohabitants within 48 hours, while no or low mortality occurs in control groups, making it difficult to develop a proper cohabitation challenge model (Mahapatra *et al.* 2008, Jeney *et al.* 2011). For selection of breeders, fish that survive after challenge can be more efficiently utilized. However, with the hypothesis that these fish could serve as carriers of pathogens to the next generation, selection of fish from the same family remains preferable. Based on the challenge test, two lines of fish, resistant and susceptible, can be generated through Bulk Segregant Analysis (BSA). The segregation here would be on the basis of phenotypic character (resistance or susceptibility) of the animals.

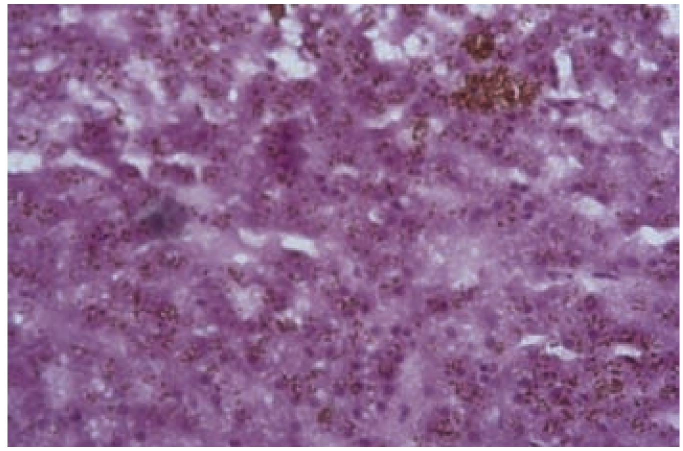

Fig. 2. Spleen sections of aeromoniasis-infected rohu showing focal necrosis and increased numbers of melanomacrophage centers (H & E × 100).

Immunological Markers

Wiegertjes *et al.* (1996) detailed a comparative approach to immunogenetic studies of disease resistance in various fish species and discussed its application to selective breeding, suggesting the immunological parameters that function as a response to selection. Immune responses to *A. hydrophila* injection were correlated with resistance. Although Sahoo *et al.* (2004) found no significant difference in specific immune response measured through haemagglutination titer against sheep red blood cells and in a few nonspecific immune responses, such as lysozyme activity and neutral heamolysin titer. Only serum bacterial activity was positively correlated with survival from exposure to aeromoniasis. In catfish, there is no correlation of antibody titer with resistance but the immune response to *A. hydrophila* infection varies among groups (Areechon and Karoon 1995). Total IgM level can be used as an indirect marker for selection in common carp against aeromoniasis (Jeney *et al.* 2009) and in Atlantic salmon against furunculosis (Lund *et al.* 1995). There are significant differences in immune response, as measured by phagocytic and lysozyme activities and specific antibody levels, between resistant and susceptible groups of common carp challenged with *A. hydrophila* (Ardo *et al.* 2010). However, there was no correlation between respective control groups. Sahoo *et al.* (2008) observed no corre-

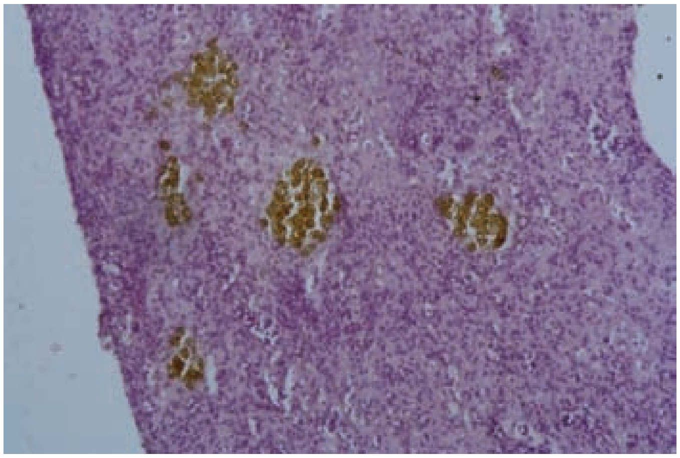

Fig. 3. Focal necrosis of liver in A. hydrophila*-infected rohu (H & E × 100).*

lation of survival to aeromoniasis with myeloperoxidase, superoxide and lysozyme activities; negative correlations with bacterial agglutination titer, haemolysin titer and haemagglutination titer; and a significant positive correlation with ceruloplasmin level among different rohu families. Because negatively correlated parameters cannot be applied as a selection criterion, only the acute-phase protein ceruloplasmin could, potentially, serve as a marker trait for resistance to aeromoniasis. The first generation resistant line of rohu showed a significantly higher level of response in the case of respiratory burst activity of blood phagocytes, serum myeloperoxidase activity and ceruloplasmin level compared to the susceptible line (Sahoo *et al.* 2011). However, the traits should be heritable to be incorporated into a selection program. Hence, in this scenario, the use of immunological markers in this selection program is of questionable value.

Molecular Techniques

Selection generally depends on genetic variation to disease resistance (Lund *et al.* 1995). Molecular markers, such as single nucleotide polymorphism (SNP) markers and microsatellites, are providing new tools for selection programs. Comparison of molecular markers identified from resistant and susceptible lines can give information about the polymorphic loci that govern resistance. Association of markers with any trait (QTL) can lead to identification of genes responsible for resistance or susceptibility. Selection based on marker data is called Marker Assisted Selection (MAS) and, if a gene is used, the process is called Gene Assisted Selection (GAS). Genotyping different families and correlation with survival will further confirm the identified polymorphic markers. Screening individuals can be achieved with a SNP chip. A SNP chip is only available for an Atlantic salmon breeding population as a potential genomic tool for selecting for resistance to amoebic gill disease (AGD) in a breeding program run by the Salmon Enterprises of Tasmania (Saltas) (Dominik *et al.* 2010). Selection of breeders can be based on the presence of individual markers or causative genes (QTL), rather than phenotypes of sibs only. Pedigree relationships could be replaced by genomic similarities estimated through information on genetic markers (Odegard *et al.* 2011). Genomic selection yields high genetic gain, accuracy of selection, and lower rates of inbreeding (Sonesson and Meuwissen 2009). Incorporation of identified QTLs in the selection program has already started in Scotland (Houston *et al.* 2008) and Norway (Moen *et al.* 2009) for the selection of Atlantic salmon against infectious pancreatic necrosis virus. Presently only one group in the Central Institute of Freshwater Aquaculture, India, in collaboration with NOFIMA, Norway is trying to identify molecular markers for disease resistance against aeromoniasis in rohu. The transcriptome sequence generated 330,327 SNPs, and indels and fixed allele differences between the resistant and susceptible line were detected. Ninety-six SNP loci contained allele frequency differences of 1.0, while 104 SNP loci contained allele frequency differences > 0.95 between the lines. MH class I antigen and galactoside-binding soluble lectin 9 gene showed fixed allele frequency differences between susceptible and resistant lines (Robinson et al., in manuscript).

Constraints and Future Directions

Initially selection was based on survival in ponds. Subsequently artificial challenge experiments in controlled and semi-controlled environments were used to select individuals or families based on resistance to a particular disease. Although few selection programs on disease resistance to various pathogens are active, each approach has drawbacks and practical difficulties. The following points of concern should be considered during an experimental challenge test, where large numbers of fish are subjected to challenge from a particular pathogen:

1. There are many strain variations within a particular bacterial pathogen such as *A. hydrophila*. Therefore, before conducting a challenge test, the isolate should be selected on the basis of thorough biochemical and molecular characterization of the pathogen. The organism should be highly virulent and have an array of toxic protein expression.
2. Inasmuch as the challenge test must be conducted over a period of years, it is essential for estimation of heritability to maintain pathogen virulence for a long period for subsequent challenge testing.
3. The appropriate route of challenge and the consistency in obtaining lethal dose are crucial.
4. A direct challenge study needs skilled manpower, a separate challenge facility, and is time consuming.
5. For a family-based selection program, it is often difficult to get similar-size fish from all families at the same time, which may influence the challenge picture.
6. Environmental factors, including temperature and climatic conditions, may influence bacterial pathogenicity.

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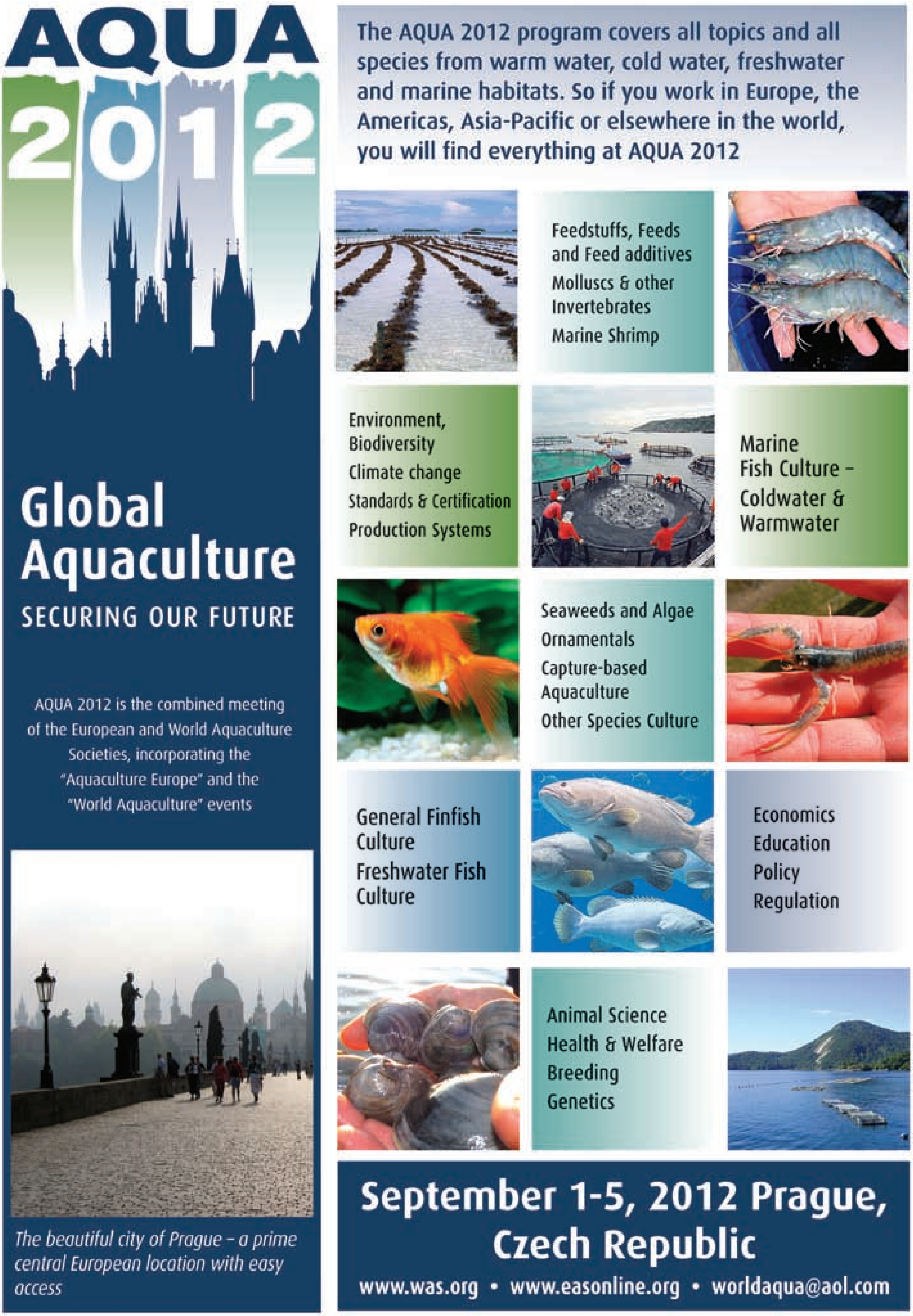

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7. Ethical issues in killing large numbers of fish, biosafety in the challenge facility, and proper disposal of dead fish and water used in the facility that can pose a threat to human health must be considered.

Infection has an effect on the immune system and there are some correlations between immunological markers and disease resistance. The major concerns that should be considered are:

1. Immunological markers should be highly heritable.
2. The marker should be easy to measure in a standard laboratory within a short time.
3. Multiple factors are responsible in a cyclic manner for rendering protection to a disease. Therefore, it is difficult to develop a single marker for one pathogen. Hence, multiple immunological markers with high heritability and correlation with resistance should be considered, while developing indirect selection based on immunological markers. Emphasis should be placed on developing simple assay systems that allow measurement of a large number of samples simultaneously.

Taking these criteria into consideration, molecular marker-based selection may be a good option for a successful selective breeding program for disease resistance. For developing the most-sensitive SNP and microsatellite marker-assisted selection program, prior knowledge of ESTs in the fish species is essential. The construction of genetic maps based on molecular marker information for a large number of loci would facilitate identification of quantitative trait loci of economic importance. Selectable molecular markers for resistance allows the maintenance of relatively few broodstock, thereby reducing time, cost and effort, and avoids sacrificing large numbers of potentially valuable fish. Molecular markers can also be used for selection in phylogenetically related species. Because molecular markers provide genetic information, heritability can be measured and associated with traits responsible for rendering disease resistance.

In an e-mail conference hosted by FAO in 2003, representatives of 26 countries discussed molecular marker-assisted selection as a potential tool for genetic improvement of crops, forest trees, livestock and fish in developing countries (Guimaraes *et al.* 2007). Marker-assisted selection is a complementary technology that can be used in conjunction with more established and conventional methods of genetic selection. Although the current impact of MAS on production of species and strains used by farmers is low, future possibilities and potential impacts are considerable. For developing countries, the main issues are the present high cost of the technology, limited infrastructure, absence of conventional selection and breeding programs, poor private sector involvement, and lack of research on species of importance. Intellectual property rights also play a vital role in the process. Therefore, collaboration between scientists in developing and developed countries, including the involvement of public-private partnerships, could pool and share resources, thereby reducing costs, and develop capacity to achieve breeding goals.

Notes

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An economic analysis of oyster aquaculture on the Patuxent River, Maryland using AQUASIM

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Problem

Historically the Chesapeake Bay has been a vital part of the regional ecosystem and resource to the human inhabitants of the region. Oysters have been the single-most valuable commodity humans have harvested from the Bay. In its heyday in the 1880s, annual catches were around 12 million bushels, with a peak of 15 million bushels, supporting a many jobs in multiple industries. In addition to providing a living for watermen catching oysters, shipbuilders, shucking houses, transportation lines, and restaurants were also needed to sell products of the bay (Locke 1993). Today the oyster industry is a faint glimmer of what it once was. The annual catch in 2006 was 154,436 bushels, supporting around 700 watermen (Maryland Department of Natural Resources 2006).

The collapse of the oyster fishery is an economic and ecological problem. Oysters are a vital part of the ecosystem of the Bay, providing habitat on their reefs for shellfish—such as crabs—and small fish that shy away from open water. They act as the Bay's filtration system; an adult oyster can filter approximately 189 L of water each day. The collapse of the oyster fishery has contributed to the overall decline in the health of the Chesapeake Bay.

Solution

In response to the current situation, the Morgan State University Estuarine Research Center (MSUERC) established a demonstration project to examine the viability of oyster aquaculture in the Patuxent River region of the Bay. If successful, aquaculture can provide an alternative livelihood for watermen on the Bay and a mechanism to enhance the oyster population. Two watermen have agreed to work on this project and their reasons for participating are easily understood. Many traditional activities of watermen, such as shaft-tonging for oysters, are now unprofitable. The decline of the oyster fishery means fewer watermen can find work, putting more pressure on other struggling fisheries in the Bay.

Study Methods

We examined the business model of oyster aquaculture as an alternative to the wild harvest fishery. We estimated costs of establishment and operation of a small-scale part-time oyster aquaculture farm. The farm must be a part-time endeavor to be acceptable to watermen. Watermen typically work in multiple fisheries, inasmuch as many of them are seasonal. Doing aquaculture part time provides watermen with a source of income from oysters and time to work in other fisheries.

The farm started with 150,000 seed oysters purchased from the Virginia Institute of Marine Sciences hatchery for $0.03 per oyster. Seed oysters were 20 mm at the time of purchase and from a disease-resistant strain. This larger seed size has a lower mortality rate but a greater cost. Because the MSUERC was supplying the oysters and had adequate funds in the project budget, the project team made the judgment that it was worth reducing the expected mortality rate given the high degree of uncertainty in the project. The estimated start-up cost for the business was $19,223. A breakdown of the cost is provided in Table 1.

For the economic analysis, we used the AQUASIM model developed by C.M. Gempesaw and colleagues to predict the project outcome. AQUASIM requires a user to enter data for operating assumptions, variable costs and prices, and other financial information. The model provides the mean, range and coefficient of variation of the cash flow, balance sheet, and other financial indicators.

Based on discussions with growers and wholesalers in the area, we selected a baseline sales price of $0.25 per oyster. The model allows the user to adjust price by $0.04 in either direction around the $0.25 average. Other key variables include survival rate, grow-out period, and labor cost. The survival rate increases over three years to an average of 82 percent. Survival rates fluctuate in model iterations, reflecting good years and bad years. The grow-out period was set to 15 months.

Annual labor cost was estimated to be $14,750. Based on observations of time cleaning and sorting cages, primarily in summer, an annual labor input of 240-250 hours is required, with an estimated labor rate of $30/hour. Labor is a cost because watermen could have done numerous other activities with that time, such as working in a different fishery. To achieve what the model defines as "economic success," profit must be greater than the start-up cost plus interest. To be worth the investment, the yield must be greater than that from another use, such as yield interest from a bank bond.

Fig. 1. The per year cashflow is shown for net income, labor cost, loan payments and profit.

Table 1. Breakdown of project costs.

Oyster seed (150,000 at 20 mm)	$4,500
Oyster cages (50)	$7,294
Rope and line	$ 489
Boat supplies	$ 462
Crane and winch	$2,498
Power washer	$1,980
Fuel, maintenance, etc. (estimate)	$2,000
Total Cost	**$19,223**

Results

After considering all variables of costs, probability and revenue, the model estimated an economic success rate of 93 percent. In the 7 percent of cases where economic success was not attained, the farm did not fail, but had not yet reached the profit threshold for economic success. After the first year, net yearly revenue averaged $17,643. Cumulatively this resulted in an average wage to the watermen of $132,000, or $66,000 per person, with $49,899 of profit, more than double the start-up cost (Fig. 1).

We conducted a sensitivity analysis by varying the three main variables in the model: grow-out period, survival rate, and sales price. The grow-out period, originally 15 months, was reduced to 12 months or increased to 18 months. When the grow-out period was 12 months the rate of economic success was 97 percent, with an average profit of $57,029. When the grow-out period was 18 months, the rate of economic success was 86 percent, with an average profit of $45,167. In all cases, the farm remained solvent.

The average survival rate, originally 82 percent, was decreased to 78 percent and increased to 86 percent. When the survival rate was 78 percent, the rate of economic success was 84 percent, with an average profit of $43,807. When the survival rate was 86 percent, the rate of economic success was 96 percent with an average profit of $55,001. In all cases, the farm remained solvent.

The final sales price, originally averaging $0.25, was decreased to $0.22 and increased to $0.28. When the sales price was $0.22, the rate of economic success was 1 percent and, in 2 percent of model iterations, the farm became insolvent. The average profit was $13,015. However, the farm typically had debt outstanding after 10 years. When the sales price was $0.28 the rate of economic success was 100 percent, with an average profit of $86,976. The economic success figure of 100 percent for the price of $0.28 is suspect because no business endeavor can have zero risk. However, it simply means that the farm will not fail to be successful because of anything programmed into the model. The model is a useful simplification of the real world and cannot fully account for all variables that affect aquaculture production.

The sensitivity analysis indicates that sales price overwhelms the importance of the duration of grow-out and survival rate. A price increase of $0.03 per oyster resulted in a profit increase of $37,077. If prices fall by $0.03 there is little chance of economic success. This suggests that additional effort in getting a better price, such as selling directly to local restaurants or farmers markets, is a very good investment.

The reduction in economic success from an increase in the duration of grow-out or a decrease in survival rate may mean the difference between acceptance or rejection of a new business model. However, these effects are much smaller than the effect of sales price. Efforts to reduce the duration of grow-out or increase survival result in progressively smaller increases in returns.

Conclusion

The current wild harvest model has clearly failed. Oyster aquaculture offers a better strategy to replenish the oyster population and provide job opportunities for watermen. Results of model simulations using AQUASIM indicated that oyster aquaculture can be done as an economically viable part-time activity to complement other traditional activities of watermen. In this way, oyster aquaculture can also help preserve the culture of the Chesapeake Bay.

Notes

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Natural spawning and larviculture of southern flounder *Paralichthys lethostigma*

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Southern flounder *Paralichthys lethostigma* is an important recreational and commercial flatfish, ranging from North Carolina in the western Atlantic Ocean south (discontinuous around the southern tip of Florida) and along southwestern Florida to south Texas in the Gulf of Mexico (Daniels 2010). It lives in a wide range of salinity from freshwater to full-strength saltwater but is most commonly regarded as an estuarine and bay species within its range. Flounder are harvested by gig and rod and reel, with most fish in Texas taken during the annual spawning run to the Gulf of Mexico from October through December. During this time, Southern flounder are concentrated in great numbers in tidal passes that connect estuaries and bays with the Gulf of Mexico, where they are much easier to catch compared to other times of the year. Larger, gravid female flounder, in particular, are targeted by fishermen and generations of anglers have enjoyed the benefits of the spawning migration.

Unfortunately the population of southern flounder along the Texas coast has decreased greatly, according to recent surveys conducted by Texas Parks and Wildlife Department (TPWD) (Riechers 2008, Froeschke *et al.* 2010). During the past decade, bag limits for flounder have been reduced and the size limit increased for commercial and recreational fisheries in Texas in an effort to reverse the downward trend. Most notable were rule changes implemented in 2009 that cut the daily bag limit in half to five fish, with only two fish in November, and prohibited harvest by gigging altogether during November for commercial and recreational anglers. The TPWD is investigating the feasibility of establishing a stock enhancement program for southern flounder if size and bag limit restrictions fail to result in recovery of fish stocks.

Scientists in North Carolina, South Carolina and Florida have been investigating spawning, optimal larval rearing conditions, and general husbandry since the mid-1990s, and have developed an extensive knowledge base about flounder aquaculture (Smith *et al*. 1999, Watanabe *et al*. 2006, Daniels *et al*. 2010). However, there are regional genetic differences between flounder from the western Gulf of Mexico and those from the eastern Gulf of Mexico-Atlantic region (Blandon *et al.* 2001). As such, optimal culture conditions for flounder from the Atlantic coast may be different for flounder from the western Gulf of Mexico.

Despite the interest in flounder culture and fairly well-established methods for producing Atlantic coast southern flounder, there has not yet been any major commercial production or large-scale stock enhancement efforts in the USA. Research on southern flounder at the Fisheries and Mariculture Laboratory (FAML) of the University of Texas Marine Science Institute is ongoing, with an emphasis on developing improved spawning and larval rearing methods for western Gulf of Mexico southern flounder. Southern flounder were first spawned at FAML in 1978 using photoperiod and water temperature manipulation (Arnold 1978). More recently, broodstock flounder have been collected at FAML annually since 2002 and maintained in recirculating tank systems to allow natural spawning and egg production. Current research focuses on weaning (Faulk and Holt 2009), sex determination and temperature (Montalvo 2011) and methods to improve the quantity and quality of eggs produced by captive broodstock.

Broodstock Collection

Typically male flounder begin offshore migration through estuarine passes along the central Texas coast during October, whereas female flounder migrate primarily during November. During late autumn, adults can be collected in large numbers at night using an airboat to access shallow water along channel edges. Water depths less than 60 cm allow personnel to easily and safely enter the channel to collect fish with a dip net. Once captured, fish are placed in a saltwater holding tank provided with diffused pure oxygen. Upon returning to FAML, flounder are dipped in freshwater for 20 minutes and injected with oxytetracycline to help prevent bacterial infections. This is an effective way to collect broodstock flounder with advanced gonadal development inasmuch as collections are made just prior to the natural spawning season.

Southern flounder males are identified by milt expression from light abdominal pressure. Females are identified by the presence of ovaries that are visible as a long bulge along the ventral side. Recently collected fish are handled carefully and as little as possible to reduce stress that might affect future spawning. When sorting or moving large numbers of fish to a broodstock tank, flounder are first anesthetized with eugenol, which makes handling them much easier for workers and less stressful for the fish. Survival rates of broodfish captured and handled with this protocol are greater than 95percent. Since 2002, southern flounder have spawned naturally every year after acclimation in broodstock tank systems.

Broodstock Husbandry

Flounder are held in raceway and round fiberglass recirculating tank systems, each equipped with a heat pump for temperature regulation, sand filter, and biological filter (Fig. 1). Tanks are covered or placed in a designated room with light control to allow photoperiod manipulation. Raceways are 15 m long, 0.75-1.2 m deep, and 2.4 m wide, with a volume of 38-45 m^3. Round tanks are 3.6 m in diameter, 1.4 m deep, with a volume of 15 m^3. With good water quality and monitoring for diseases and parasites, flounder can be maintained and spawned in these systems over several years following wild collection.

Broodfish are fed to satiation once daily with a combination of frozen shrimp and cut sardines (Fig. 2). Recently captured flounder are fed a mixture of live and frozen shrimp during the first few weeks while fish learn to accept frozen shrimp. Mixing several older flounder with recently captured fish can promote more rapid acceptance of frozen food. It is important to train flounder to accept frozen foods quickly for continued gonadal development. In general, flounder do not feed aggressively so food is carefully and slowly broadcast in the center of the tank, allowing observation of the feeding response. If fish suddenly cease feeding or are observed to increase opercular beat rate, scratch their bodies against the tank walls or bottom, or cough, preventative measures are taken to minimize the impact of potential parasitic infestation. *Amyloodinium* infestations can be particularly devastating if left untreated. Copper sulfate is administered over several days when flounder show signs of this gill and skin parasite.

Female flounder (1-2 kg) are typically larger than males (0.5 kg) and will usually consume the bulk of offered food, often biting or pushing smaller males away during feeding. As a consequence of this aggression, when flounder were held over from year to year with both sexes in the tank, many males were lost to malnutrition. This issue was resolved by separating male and female fish at the end of each spawning season and combining them approximately one month before spawning is anticipated, usually October or November. This protocol has resulted in larger, healthier males while greatly reducing mortality associated with competition for food. Male flounder typically produce small volumes of sperm, usually less than 0.5 mL, an important factor to consider for successful spawning of this species (Daniels *et al.* 2010). Separating flounder broodfish by sex has resulted in increased milt production and better overall health of males and has become an important part of broodstock management procedures at FAML in recent years.

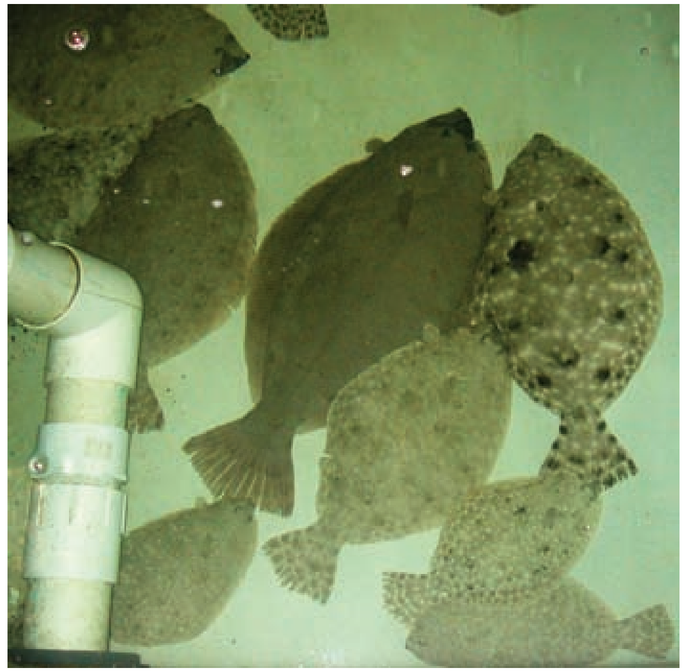

Fig. 1. Flounder broodstock in a raceway system. (Photo by Jeffery B. Kaiser).

Fig. 2. Broodstock flounder in a raceway system feeding at the surface. (Photo by Jeffery B. Kaiser).

Spawning

After broodfish are collected, producing a large number of high-quality flounder eggs over several months is the overall goal. Having a reliable source of viable eggs over an extended period has facilitated research on culture of larval and juvenile flounder. After collection from the wild, 30-40 males and 10-15 females are placed in a broodstock tank and exposed to a specific photoperiod and water temperature regime. Initially these parameters simulate ambient conditions for the central Texas coast in November, which is 11 hours of daylight and approximate-

Fig. 3. Gravid broodstock flounder showing advanced gonadal development. (Photo by Jeffery B. Kaiser).

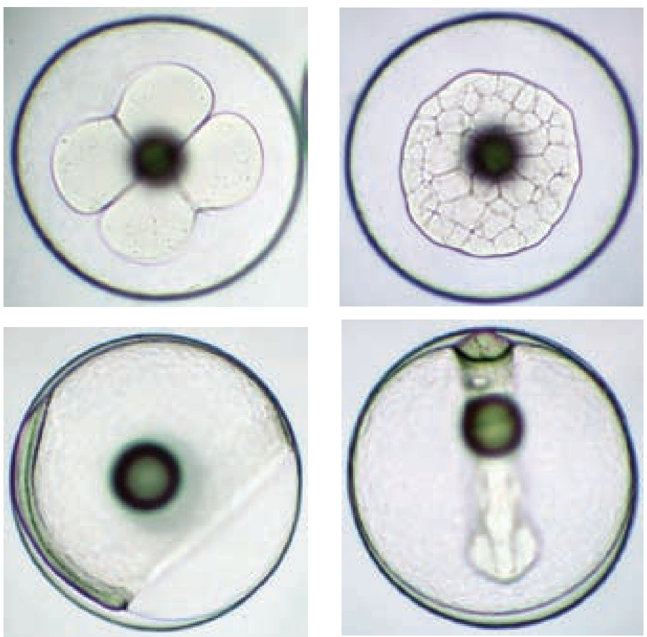

Fig. 4. Southern flounder eggs during development a) 4-cell, b) morula, c) early embryo d) tail bud. (Photos by Cynthia K. Faulk).

ly 21-22 °C. At two-week intervals, day length is gradually reduced to 10 hours of light and temperature to 19-20 °C, which are considered conditions for flounder spawning in the area. This manipulation results in continued gonadal maturation (Fig. 3) with spawning usually beginning in mid-December and continuing for approximately three months, if spawning conditions are maintained.

Flounder eggs (Fig. 4) are collected nearly every day during this period by placing a 500-µm nylon screen bag into a filter box that receives surface water from a broodstock tank. Spawns vary in terms of quantity and egg viability, ranging from a few thousand to several hundred thousand eggs, depending on the number of females that spawn on a particular day. Eggs are enumerated by measuring floating egg volume with a graduated cylinder and applying a conversion factor of 1300 eggs/mL. On a few occasions, FAML personnel have observed flounder during spawning, which typically occurs from noon until early afternoon. One female swims around the tank at or near the surface, typically with one male following her closely. Eggs are released while fish are swimming together and collected from the filter box a few hours later.

Several combinations of broodfish have been used for spawning—all new wild-caught, a mix of new and previously spawned fish, and all previously spawned fish—with variable results from year to year. The 2010-2011 season at FAML was the most productive to date as indicated by number of spawns, quantity of eggs, and egg viability. Two spawning raceways were used, one with flounder spawned during the previous year and the other with new wild-caught females and previously spawned males. More than 300 natural spawns were collected from these tanks from November 2010 to March 2011, with an average spawn size of 222,000 eggs and viability rate of 18percent (Table 1). Results were similar between the two combinations of fish in terms of quality (i.e., viability), although the system with larger, previously spawned female broodfish produced more eggs. Flounder typically spawn batches of approximately 100,000 eggs per kg of body weight (Daniels *et al*. 2010) so it is advantageous to have large females in broodstock systems to increase overall production.

After collection, viable flounder eggs were used in various studies conducted on larvae and juveniles at FAML. Excess eggs were given to the Coastal Fisheries Division of the Texas Parks and Wildlife Department to support efforts to develop a stock enhancement program for flounder, similar to their successful program for red drum. During the 2010-2011 spawning season, over three million eggs on 30 occasions were donated to the Coastal Fisheries Division, allowing their staff to gain experience with grow-out of flounder in outdoor ponds.

The Effects of Temperature on Larval Rearing

Larval rearing is often a significant bottleneck to the establishment of stock enhancement and aquaculture programs for marine fishes. For successful larviculture, a thorough knowledge of optimal rearing parameters—such as temperature, salinity, density, and feeding regimes—is necessary. As indicated previously, considerable research has been dedicated to optimizing larval rearing conditions for southern flounder inhabiting Atlantic waters. However, because of potential genetic differences among populations, current rearing practices for Atlantic flounder may be different for fish from the western Gulf of Mexico.

For larvae spawned by wild-caught fish in North Carolina and held in small, static systems, the optimal rearing temperature is 17 °C from first feeding through the onset of metamorphosis and 21 °C from the onset to the

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Table 1. Spawning parameters and egg production of southern flounder from 2009 through 2011.

Tank	Spawning period	Number of spawns	Temperature (°C)	Salinity (ppt)	Eggs/spawn (x 1,000) Mean	Range	Viability (%)
A	Dec. 2009-Mar. 2010	68	18.3 ± 0.9	30.3 ± 0.4	151	13-488	6.9
A	Nov. 2010-Mar. 2011	121	19.9 ± 0.8	33.6 ± 0.3	353	20-1,859	21.9
B	Jan.-Apr. 2010	56	18.7 ± 0.8	33.7 ± 0.2	230	7-956	12.9
B	Dec. 2010-Mar. 2011	72	19.3 ± 0.9	34.6 ± 0.6	156	20-416	31.4

Fig. 5. Southern flounder larvae a) 8 and b) 32 days after hatching (Photo by Cynthia K. Faulk).

completion of metamorphosis (van Maaren and Daniels 2001). Daniels *et al*. (2010) recommends that temperature should be maintained at 17 °C for egg incubation and hatching, but then increased by 1 °C per day to 21-22 °C for larval rearing. We examined the effects of different rearing temperatures (12-24 °C) on the growth and survival of flounder larvae spawned by adults collected from waters near Port Aransas, TX in the western Gulf of Mexico.

We initially examined the effects of temperature on larval rearing during two feeding stages: (1) from hatching through the end of the rotifer feeding period and (2) from the beginning of *Artemia* feeding through the onset of metamorphosis. The rate of growth and development in marine fish larvae is more strongly linked to a combination of temperature and age than chronological age alone. Therefore, endpoints for each stage were established by calculating degree-days (DD) as the cumulative product of mean daily temperature (°C) and age (days after hatching). For example, a 10-day old larva reared at 10 °C would accumulate 100 DD. The degree-day ranges that represent the two feeding stages were 0-414 DD for stage 1 and 414-612 DD for stage 2.

Adult flounder were collected and spawned using the temperature and photoperiod manipulation protocol described previously. For each temperature tested, larvae were reared in three replicate 150-L (18-24 °C) or 265-L (12-18 °C) recirculating tanks at a photoperiod of 10 h light and 14 h dark and mean salinity of 31.5 ± 0.5 ppt. Larvae were fed rotifers (3/mL) from 72-414 DD and *Artemia* (0.05-0.10/mL) from 414-612 DD. Prior to feeding, live prey were enriched for 12 h with a commercial product consisting of heterotrophic microalgae high in lipids, particularly those containing the fatty acid docosahexaenoic acid (DHA).

For stage 1, eggs (10/L) were placed in each tank at 18 °C. On the day after hatching, temperature in the larval rearing tanks was either held constant or gradually changed by 2 °C/day until reaching 12, 15, 21 or 24 °C. For stage 2, eggs (10/L) were placed in six replicate tanks and larvae reared at a constant temperature of 18° C. Two days prior to the start of *Artemia* feeding, larvae were counted and moved into additional rearing tanks (5/L) at 18 °C. At 414 DD, *Artemia* feeding commenced and tank temperatures were either held constant (at 18 °C) or gradually changed by 2 °C/day until reaching 12, 15, 21 or 24 °C. Separate experiments were conducted for temperatures ranging from 18-24 °C (trial 1) and 12-18 °C (trial 2).

At the end of each study, the standard length of 20 larvae from each tank was measured and all remaining fish counted to calculate survival (Fig. 5). Survival was calculated by dividing the number of larvae remaining by the number of eggs or larvae initially placed in each tank, expressed as a percentage. The effect of temperature was evaluated with a one-way ANOVA followed by a Tukey's test for multiple comparisons of means using SYSTAT 10.0 (SPSS Inc., 2000, Chicago, IL).

Larval growth and survival during the rotifer feeding period (stage 1) was greatest at 18 °C and significantly less at higher or lower temperatures (Table 2). Survival was greatly improved at all tested temperatures when larvae were first held for 414 DD at 18 °C (Table 2, stage 2) and was significantly lower only at the temperature extremes. Further, growth was depressed only at temperatures less than 18 °C. Because survival and growth improved when the temperature change was delayed until the start of *Artemia* feeding, we conducted an additional study in which larvae were reared for one week (126 DD) at 18 °C and temperature gradually increased to 21 or 24 °C as described above. Upon study termination at the end of the rotifer feeding period (414 DD), survival was significantly greater at 18 °C although there were no significant differences in larval growth (Table 3).

Cumulatively these results indicate that growth and survival of newly hatched southern flounder larvae from the western Gulf of Mexico is greatest at 18 °C and highly sensitive to relatively small changes in temperature (±2 °C), especially during the first three weeks after hatching. This temperature is less than that commonly used to

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Table 2. Standard length (mm) and survival (% from hatch) of southern flounder larvae reared in various temperatures.

Trial	Stage	Temperature (°C)	Survival (%)	Standard length (mm)
1	1	24	0.4 ± 0.4 a	4.9 ± 0.7 a
		21	3.0 ± 2.4 a	5.7 ± 0.4 ab
		18	32.3 ± 9.9 b	6.3 ± 0.1 b
2	1	18	18.2 ± 1.0 a	5.5 ± 0.1 a
		15	7.2 ± 2.2 b	4.1 ± 0.1 b
		12	No survival	--------
1	2	24	71.3 ± 9.4 a	7.1 ± 0.5
		21	83.7 ± 10.4 ab	7.2 ± 0.2
		18	87.5 ± 6.5 b	7.4 ± 0.2
2	2	18	66.7 ± 3.8 a	7.3 ± 0.3 a
		15	71.7 ± 6.3 a	7.3 ± 0.3 a
		12	46.0 ± 4.6 b	5.8 ± 0.5 b

Table 3. Standard length (mm) and survival (% from hatch) of southern flounder larvae.

Temperature (°C)	Survival (%)	Standard length (mm)
24	3.4 ± 2.2 a	5.1 ± 0.2
21	3.6 ± 3.2 a	5.3 ± 0.2
18	19.8 ± 8.7 b	5.9 ± 0.5

(Continued from page52)

rear southern flounder larvae along the Atlantic coast (21-23 °C).

Sex determination in southern flounder from both areas is sensitive to rearing temperature. Genetic males (XY) always develop into phenotypic males, but genetic females (XX) may differentiate into phenotypic males or females, depending on juvenile rearing temperatures. Recent studies suggest that there are differences in the effects of temperature on sex determination between the two populations. The water temperature that results in a 1:1 sex ratio is 23 °C in Atlantic coast fish (Luckenbach *et al*. 2009) but 18 °C in Texas fish (Montalvo 2011). Differences in the optimal rearing temperatures between Atlantic and western Gulf of Mexico fish may be a result of genetic differences between populations and/or adaptation to local environmental conditions (Luckenbach *et al*. 2009).

Outlook

Collaboration with various state hatchery facilities is ongoing, with the objective of developing large-scale southern flounder production, either for aquaculture or stock enhancement. Southern flounder research at FAML has been progressing steadily over the past several years with improvements in egg production, larval rearing, and juvenile stages. Major improvements include separation of male and female adult flounder during the offseason, growing large female broodstock in captivity, and spawning and rearing eggs and larvae at 18 °C.

Acknowledgments

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Evaluation of various hatchery-nursery procedures to maximize survival and growth of juvenile Australian redclaw crayfish (*Cherax quadricarinatus*)

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Red claw, *Cherax quadricarinatus* (von Martens 1868), is a freshwater crayfish native to northern Australia and the Southeast of Papua, New Guinea (Jones 1990, Holthuis 1986). Over the past two decades, commercial interest in the species has led to introductions into countries in Southern Asia, North and South America and Africa (Lawrence and Jones 2002). Because it is an omnivore, in tropical conditions can have multiple annual spawns (3-5 times), has a relatively rapid growth rate, tolerates a wide range of water quality parameters such as low oxygen concentrations (> 1 ppm), hardness and alkalinity (20 to 300 ppm), and pH (6.5 to 9) (Masser and Rouse 1997, Sammy 1988, Lawrence and Jones, 2002), the species is considered a very good aquaculture organism. Red claw crayfish are presently cultured semi-intensively in earthen ponds and intensively in large tanks quite successfully in both tropical and sub-tropical regions (Lawrence and Morrisy 2000, Lawrence and Jones 2002).

Over the last few decades, there has been an increasing interest in the development of hatchery and nursery protocols for intensive production of juvenile freshwater crayfish (Verhoef and Austin 1999, Manor *et al.* 2002). Various hatchery-nursery protocols were described by Jones (1995a), Masser and Rouse (1997) and Parnes and Sagi (2002) but no unified set of procedures has been tested or described. Development of hatchery techniques have been investigated for other crayfish, such as red swamp crawfish *Procambarus clarkii* in the United States (Trimble and Gaudé III 1988), the royal crayfish *Astacus astacus* in Northern Europe (Huner and Lindqvist 1987), the white-clawed crayfish *Austropotamobius pallipes* and the introduced signal crayfish *Pacifastacus leniusculus* in Spain (Celada *et al*. 1989, Perez *et al*. 1999, Gonzalez *et al.* 2008). However, as the redclaw aquaculture industry develops, demand for quality juveniles is increasing rapidly. The need for proven rearing protocols that optimize the quantity and quality of juveniles is a must if the industry wants to maintain its present rate of growth. To achieve this, understanding the biology and behavior of the species under culture conditions is imperative.

AGY Redclaw Hatchery and Farm of Megar S.A. de C.V.

Intensive redclaw production is hindered by two main factors: The benthic nature of the species and cannibalism during early juvenile stages (Jones 1995b, Parnes and Sagi 2002). Although juveniles are less benthic than adults (Jones 1995b), juvenile *C. quadricarinatus* still spend most of the time on bottom, leaving the water column virtually empty. Hatchery operators working with *Macrobrachium rosenbergii* have increased production by supplying adequate substrate and increasing the water volume while keeping the same surface area (Tidwell *et al*. 1999, D'Abramo *et al.* 2000). During early juvenile stages, redclaw crayfish are subject to cannibalism of newly molted individuals, and larger individuals on smaller individuals. The fact that juveniles molt frequently and that competition for resources leads to size hierarchy among individuals only exacerbates the situation. Consequently, precise predictions of juvenile production in hatchery-nursery systems are not possible because of poor survivals (5 to 10 percent) and size variability among congeneric juveniles (Jones 1995a). Although enough production of juveniles to support limited demand has been achieved by maintaining sexually mature redclaws in earthen ponds from which juveniles are periodically harvested, the model is land and labor intensive and is not the most efficient way to supply seed organisms in a sustainable manner. Juvenile redclaw survival of 5 to 10 percent obtained from reproduction ponds (Jones 1995a, Masser and Rouse 1997) is not space and resource efficient for producers. This problem cannot be solved by stocking younger individuals directly into grow out ponds because survival remains low and production becomes more difficult to predict.

For the redclaw industry to further develop, survival during the hatchery-nursery phase must increase dramatically, average size of juveniles at stocking should be larger and overall juvenile production should be better controlled and streamlined. In the present study, we evaluated three hatchery-nursery protocols in an attempt to better understand hatchery/nursery phase survival and growth of juvenile Australian redclaw crayfish (*Cherax quadricarinatus*). First, we investigated the effect of water volume on production of juvenile redclaws. Second, we evaluated the effect of female stocking density on juvenile growth and survival. Third, we investigated the effect of nursery period and broodstock density on juvenile survival and growth.

Study Methods

All experiments were performed at the AGY Redclaw Hatchery and Farm of Megar S.A. de C.V. in Soto La Marina, Tamaulipas, Mexico. Based on the stage of development of redclaw eggs published by Yeh and Rouse (1994) and Jones (1995a) and on practical experience at the hatchery, a stage development table specific for the region was prepared (Table 1) and used in the present study. Female broodstock redclaw used in the present work were selected from three 2,000-m^2 reproduction ponds stocked at 1.5 females/m^2 at a 1:3 male to female ratio. Ponds were pre-conditioned for redclaw by adding one terracotta block/m^2. Each terracotta block had 4 cavities, which resulted in four individual hideouts per square meter. A bundle of onion sac mesh per 4 m^2 was also provided as refuge for juveniles. Water was pumped from a local stream, replacing evaporative water losses. Females at egg stage 5 were selected and held in flow-through systems prior to initiating the experiments. Females were harvested with extreme caution to prevent egg dislodging. A random sample of thirty gravid stage-5 females had their eggs removed gently with the aid of a toothbrush and a pair of forceps and then females were individually weighed. Total eggs/female and eggs per unit weight of female were calculated. Hatching success was assumed to be 95 percent based on Yeh and Rouse (1994) and all calculations of juvenile survival were performed based on this assumption.

Water Quality

Dissolved oxygen (DO) concentration (> 5 pp) and temperature (24.9- 28.7 ºC) were measured twice daily using a YSI 55 DO meter (Yellow Spring Instrument Co., Yellow Springs OH, USA). Ammonia-N concentration was measured twice weekly using a Lamotte® Freshwater Aquaculture kit and remained within acceptable limits for indoor production of redclaw crayfish according to Masser and Rouse (1997).

Empty broodstock pond at AGY Redclaw Hatchery.

Table 1. Morphological characteristics and duration (days) of successive stages of fertilized egg and larval development of redclaw, *Cherax quadricarinatus*.

Egg stage	Morphological characteristics of egg	Approximate duration
1	Olive green to Khaki	10
2	Yellow	5
3	Orange	5
4	Red, eyes not visible	7
5	Red, eyes and pereiopods visible	7
6	Gray-released	5

Experiment 1: Effect of water volume on juvenile production

Females with stage-5 eggs were randomly taken for the experiment and individually weighed so production of juveniles/g of female could be calculated. The females were then randomly divided into six groups of 9 individuals and 3 groups of 18 individuals and each group stocked into one of nine circular tanks (1.9 m diameter) supplied with water from an outside reservoir at approximately 20 L/hr. Each tank contained plastic containers that held female redclaws and allowed juveniles to drop through after release to prevent predation. Tanks were also provided with four submerged air diffusers for aeration and water mixing. Experimental treatments were: 1) 9 females/tank and an average water depth of 10 cm (9FV1); 2) 9 females/tank and an average water depth of 20 cm (9FV2); 3) 18 females/tank and a water depth of 20 cm (18FV2). Each tank contained onion mesh bundles to provide refuge for the juveniles. The size of refuge was directly related to the volume of water to keep mesh per unit of water at a constant value. Once all females spawned and

Mrs. Lidia G. Fournue Guerrero, Mr. Nabor Medina Vasquez . and Dr. Antonio Garza de Yta (second, third and fourth from left) at the AGY Redclaw Hatchery.

Round tanks and rectangular tanks where research was performed.

juveniles detached, all females were removed from the tanks. All juveniles detached within a 96-hour period. When the last group of juveniles in a tank had detached, the tank was managed as a nursery system for 30 days. Juveniles were offered ground commercial pelleted feed (30 percent protein, 8 percent lipid) at 10 percent body weight initially and later adjusted based on observations of uneaten feed. Uneaten feed was removed once a week by siphoning the bottom of the tanks. At the end of the experiment, all juveniles were counted and weighed.

Experiment 2: Effect of female stocking density on juvenile growth and survival

The methodology used was similar to that of experiment 1 with a few exceptions. Females with similar stage eggs were randomly taken from a pond, individually weighted and stocked into one of 20, 288 L rectangular tanks (2.4 x 1.2 x 0.1 m). Five treatments with four replicate tanks per treatment were established. Treatments were 8, 12, 16, 20, or 24 female broodstock redclaw per tank, corresponding to 2.8, 4.2, 5.6, 6.9, and 8.3 females/m^2. Feeding was similar to the previous experiment and survival and growth were determined 30 days post spawning.

Experiment 3: Effect of nursery period and broodstock density on juvenile performance

Protocols used were similar to those of the previous two experiments with a few modifications. The experimental design consisted of a 3x3 factorial arrangement. Gravid females (egg stage 5) were randomly stocked into one of 36 rectangular tanks (2.4x 1.2 x 0.1 m; 2.88 m^2 bottom area) divided into nine treatments with four replicate tanks per treatment. Treatments were 8, 12, or 16 female broodstock and a 20-day, 30-day or 40-day juvenile nursery period. At the end of each priod, juveniles were counted and weighed.

Statistical Analysis

Total Juvenile Production, Juveniles/female, Juveniles/g of female, Biomass, Average weight and Survival of juveniles were calculated. Results of the first two experiments were analyzed using one-way analysis of variance (ANOVA) and considered significant at $P<0.05$. Because of the potential for differential total production of juveniles and differences in average weight among the various nursery periods in Experiment 3, data were analyzed by two-way ANOVA, using number of females and days in the nursery as factors. The data was also sorted by nursery period of juvenile production and average weight. Tukey's test was used to identify statistically significant differences among treatment means. All statistical analysis was performed using MINITAB software[6].

Results and Discussion

Average egg count per unit weight (g) of female at stage 5 was 7.8±2.15 (mean±SD). Similar results were reported by other investigators where the reported egg count ranged from 7.5-8.7 eggs/g of female (King 1993, Yeh and Rouse 1994, Jones 1995a, Austin 1998). Accordingly, expected juvenile production per gram of female using a 95 percent hatch success was 7.4 juvenile/g of female. Water volume had no effect on the production performance of a hatchery-nursery system, but surface area had an effect and is thus a better variable to use when predicting juvenile production of *Cherax quadricarinatus*. Additionally, stocking densities of 12 to 20 females/tank with a 30-day nursery period produced the greatest number of juveniles and would thus maximize Total Production without a

Table 2. Juvenile production of redclaw, *Cherax quadricarinatus,* hatched in tanks and nursed for a 30-day period.

Parameters	9FV1	9FV2	18FV2	P. Value	PSE[2]
Area (m^2)	2.84	2.84	2.84		
Depth (cm)	10	10	20		
Females	9	9	18		
Females/m^2	3.17	3.17	6.35		
Total weight of females (g)	721	591	1101		
Average weight of females (g)	80.19	65.74	61.2		
Estimated juvenile/ gram of female	7.4	7.4	7.4		
Total juveniles hatched	5340	4378	8152		
Nursery period (days)	30	30	30		
Total juvenile production	1516	1147	1225	0.528	230.709
Juveniles per female	168.48	127.48	68.07	0.082	25.518
Juveniles/g/female	2.12	1.95	1.11	0.174	0.350
Biomass (g)	322	235	235	0.218	35.596
Average weight of juveniles (g)	0.65	0.59	0.55	0.744	0.098
Survival %	29	26	15	0.174	4.731

[1]*No significant differences were found between treatments ($P>0.05$).*
[2]*Pooled standard error of treatment means ($n=3$).*

negative effect on Survival or Average weight of juvenile redclaws.

Experiment 1: Effect of water volume on juvenile production

Results of the present experiment are presented in Table 2. No significant differences among treatments were observed in total juvenile production (1147-1516), juveniles/female (68-168), juveniles/g of female (1.11-2.12), biomass (235-322g/m^2), average weight of juveniles (0.55-0.65g) or survival (15-29 percent) although the ranges of reported results were large. However, there was an apparent trend where survival decreased as stocking density increased.

D'Abramo (2000) reported that weight gain for *Macrobrachium rosenbergii* was maximized through a simultaneous increase in water volume and surface area. However, their experiment did not assess the effect of increased water volume alone. Our results suggest that increasing volume beyond a certain minimum is without effect but female stocking density has a significant effect on juvenile weight. Therefore, if the goal is to increase average individual juvenile weight, irrespective of total production, we should reduce stocking density of brood females. If number of juveniles produced is important, manipulating brood stocking density is not effective.

Experiment 2: Effect of female stocking density on juvenile growth and survival

Stocking between 12 and 20 (4.1 to 6.9/m^2) females/tank had no effect on average weight of juveniles produced, yet resulted in best Total Juvenile Production. Accordingly, if hatcheries can make more profit by selling large numbers of small juveniles than by selling smaller quantities of larger juveniles, a female broodstock density of 4 to 7/m^2 is advised.

Handling of newly hatched redclaw juveniles usually results in very poor survivals. Accordingly, a hatchery/nursery technique where a number of berried females are placed in hatchery tanks, their eggs allowed to hatch, and females removed when broods drop off seems to produce healthier and more numerous juveniles (Jones 1995a, Masser and Rouse 1997, Parnes and Sagi 2002). This hatchery-nursery protocol has been preferred by redclaw producers in Australia and Latin America. A drawback to such a system is lack of good production estimates but this can be mitigated by weighing the females and then estimating 7.8 eggs/g female and a 90 to 95 percent survival of hatchlings as suggested by Yeh and Rouse (1994) and observed in the first part of the present work. However, it is recommended that hatchery operators calculate survival specific to their operation to increase the accuracy of their estimates.

Masser and Rouse (1997) recommended that stocking density of juveniles in nursery tanks should not exceed 270 juveniles/m^2 whereas Jones (1995a) stocked juveniles at densities between 980 and 1842 /m^2. In the present work, juveniles were stocked at 1317-3461/m^2, significantly more than recommended by other workers. This increase in stocking densities might be the reason for poor survivals (14.2 to 38.1 percent) observed in Experiment 2. Survival in the treatment stocked with 24 females/tank was significantly less than survival in all other treatments (Table 3), and survivals in all treatments were inferior to survivals reported in pre-

Table 3. Juvenile production of redclaw, *Cherax quadricarinatus,* hatched in tanks from 8, 12, 16, 20 or 24 females and nursed for a 30-day period.

Parameters					
Females	8	12	16	20	24
Total weight of females (g)	512.75	686.75	940.75	1136.25	1347
Average weight of females (g)	64.09	57.23	58.80	56.81	56.13
Total juveniles hatched	3794	5082	6962	8408	9968
Biomass of females (g/m^2)	178.04	238.45	326.65	394.53	467.71
Total Juvenile Production	1445[a]	1846[a,b]	2269[b]	2596[b]	1420[a,b]
Juveniles/female	181[a]	154[a]	142[a]	130[a]	59[b]
Juveniles/g/female	2.86[a]	2.69[a]	2.41[a]	2.27[a]	1.07[b]
Biomass (g/m^2)	192.71[a]	293.40[a,b]	305.56[b]	320.75[b]	233.51[a]
Average weight of juveniles (g)	0.382[a]	0.454[a]	0.403[a]	0.381[a]	0.516[a]
Survival %	38.1[a]	36.3[a]	32.6[a]	30.9[a]	14.2[b]

[1] *Means within the same row with different superscripts are significantly different (P<0.05).*

vious studies (Jones 1995a, Masser and Rouse 1997). Furthermore, a trend suggesting a negative correlation between female number and juvenile survival was observed. In commercial operations, a decrease in survival would be acceptable only if the total production of juveniles is increased. Our results suggest that this is possible at stocking densities of 7 females/m^2.

Juveniles/female (59 to 181) and juveniles/g of female (1.07 and 2.86) in the treatment stocked with 24 females/tank were significantly less than in all other treatments. Total juvenile production in the treatment with 8 females/tank was significantly less than production in treatments stocked with 16 or 20 females/tank but similar to production in other treatments (Table 3). Total production of juveniles in Experiment 2 was 493-901 juveniles/m^2 and was superior to the total production of juveniles (135 to 202 juveniles/m^2) projected by Masser and Rouse (1997) and comparable to the total production of juveniles (80-1212 juveniles/m^2) reported by Jones (1995a). Although in Experiment 2, only the treatment stocked with 8 females/tank was different from all other treatments, a clear trend can be observed: Total juvenile production constantly increases as density of female increases from 3 females/m^2 to 7 females/m^2 and decreases at a density of 8 females/m^2. Poor survival of juvenile at broodstock densities of 8 females/m^2 could be because of the cannibalistic behavior of the juvenile redclaw. Cannibalism occurs mainly at the beginning of the nursery period when juveniles are competing for shelter areas. In the system we used, ample shelter was supplied and consequently cannibalism was not observed until juveniles reached a high density.

Juvenile biomass produced in treatments stocked with 8 females/tank and 24 females/tank were significantly less than biomass in treatments stocked with 16 and 20 females/tank. Individual weight of juveniles at harvest (0.38-0.52 g) was not significantly different among treatments. Average weight of juveniles is similar to the one obtained by Jones (1995a) who also nursed the juveniles for a 30-day period and reported an average weight of 0.4 ± 0.2 g/juvenile. Masser and Rouse (1997) projected juvenile sizes of approximately one gram but did not specify the nursery period length. Again, depending on the size required for stocking, nursery period can be lengthened or shortened, keeping in mind that it would affect survival. Hatchery managers generally tend to prefer producing large numbers at the expense of juvenile size, thus preferring short nursing periods.

Experiment 3: Effect of nursery period and broodstock density on juvenile performance.

An analysis of numbers of juveniles produced and average individual weight should be performed when deciding on the hatchery-nursery procedure to be used in commercial settings. Results of Experiment 3 suggest that a 30-day nursery period would maximize juvenile production without sacrificing average weight of individuals, and would also increase the amount of times a nursery tank could be used throughout the year, thus reducing capital costs. Appropriate nursery periods for *Cherax quadricarinatus* have not been determined and the 30-day nursery period used in Experiments 1 and 2, although arbitrary, was selected because Jones (1995a) used a 23 to 50 day period for his experiments. In the present experiment, juveniles maintained in the nursery for 30 days performed better than juveniles maintained in the nursery for 20 days or 40 days for all parameters studied except for average weight per juvenile, which was significantly less in the 20-day nursery period treatment than in the other two treatments (Table 4).

Based on two-way ANOVA analysis, both nursery period and number of stocked broodstock significantly affected production. (Table 5). Juveniles held for 30 days in the nursery resulted in better total production, survival and biomass than juveniles held for 20- and 40- day nursery periods. Biomass (98.96 and 305.56 g/m^2) in the treatment with 16 females/tank and a 30- days nursery period was significantly different from all other treatments except stocked with 12 and 16 females/tank and maintained for 40 days. Production in tanks stocked with 12 females and held for a 30-day period was significantly greater from that of tanks stocked with 8 females and nursed for a 20-day or a 40-day period, and also greater than production in tanks stocked with 12 females and nursed for 20 days (Table 5). Treatments that had 12 females and were nursed for a 40-day period differed from treatments stocked with 8 and 12 females and nursed for 20 days. Also, tanks stocked with 16 females and had a 40-day nursery period gave different results than tanks stocked with 12 females and nursed for 30-days.

Average weight of the 30- day nursery period group was superior to the 20-day period and similar to the 40-day period. Even if the results of survival had been similar to the 20-day period, the 53 percent average weight difference makes the 30-day period a better option as bigger juveniles would have a better survival rate when stocked into a growout tank or pond (Masser and Rouse 1997).

Survival ranged between 17.6 and 36.1 percent. Only juveniles in the treatment stocked with 8 females/tank and nursed for 30-days survived better than juveniles in the treatment stocked with 16 females/tank with a 40-day period nursing period. Total juvenile production in tanks stocked with 16 females with a 30-day nursery period was significantly greater than juvenile production in tanks stocked with 8 females with 20-day or 40-day nursery periods and also significantly greater than production in tanks stocked with 12 females with 20-day nursery period (Table 5). There were no significant differences among other treatments. Survival had a tendency to decrease as the number of females stocked in the tank increased whereas total juvenile production tended to increase as stocking density of females increased. These observations were consistent with results of Experiment 2 at similar female stocking densities.

Table 4. Juvenile production of redclaw, *Cherax quadricarinatus,* hatched in tanks and nursed for a 20-day, 30-day or 40-day period.

Nursery period (days)	20	30	40
Total weight of females (g)	721	713	764
Average weight of females (g)	60.21	60.04	63.28
Total juveniles hatched	5335	5279	5654
Biomass of females (g/m^2)	250.35	247.71	265.31
Total Juvenile Production	1354^a	1853^b	1362^a
Juveniles/female	119^a	159^b	119^a
Juveniles/g/female	1.99^a	2.65^b	1.93^a
Biomass (g/m^2)	121.53^a	263.89^b	203.85^a
Average weight of juveniles (g)	0.270^a	0.413^b	0.444^b
Survival %	25.4^a	35.1^b	24.1^a

[1]Means within the same row with different superscripts are significantly different (P<0.05).

Table 5. Juvenile production of redclaw, *Cherax quadricarinatus,* hatched in tanks from 8, 12 or 16 females and nursed for a 20-day, 30-day or 40-day period.

Females	Nursery period (days)	Production weight (g)	Average	Survival (%)
8	20	1180^a	0.31^{a,b,c}	30.4
12	20	1393^a	0.21^{a,b,c}	26.0
16	20	1489^{a,b}	0.29^{b,c}	19.5
8	30	1445^{a,b}	0.38^{a,b,c}	36.1
12	30	1846^{a,b}	0.45^{a,c}	34.5
16	30	2269^b	0.40^{a,b,c}	30.9
8	40	1169^a	0.45^{a,c}	29.2
12	40	1427^{a,b}	0.51^a	26.4
16	40	1492^{a,b}	0.37^{a,b,c}	17.6

[1]Means within the same column with different superscripts are significantly different (P<0.05).

A hatchery-nursery facility as the one used for the present study can produce approximately 1,400,000 juveniles/year, which stocked at 4/m^2 can fulfill the juvenile needs of approximately 35 ha of farm ponds, and represents US$140,000.00 in sales for the owner of the hatchery. The development of good hatchery protocols and the creation of new profitable hatcheries will allow the current producers to increase their grow-out area and decrease the labor associated with the reproduction-nursery phase. Moreover, utilizing all pond space for grow-out instead of partitioning some for hatchery operations would increase total farm yield by at least 15 percent. Eliminating the need for a reproduction-nursery phase would reduce the initial farm size needed for culturing redclaw profitably, previously considered 3.6 ha, and reduce the initial investment, broadening the redclaw industry to a larger spectrum of investors. Furthermore, this would allow small pond owners whose facilities were previously considered inadequate due to lack of the required pond area, to venture into redclaw aquaculture.

Notes

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Dr. I. Patrick Saoud, Mr. Nabor Medina Vasquez. and Dr. Antonio Garza de Yta next to a broodstock pond at AGY Redclaw Hatchery and Farm in Tamaulipas, Mexico.

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[6]version 15.1, MINITAB Inc., State College Pennsylvania

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Channel catfish *Ictalurus punctatus* growth in single and multiple-batch production

William A. Wurts[1]

Research at the University of Arkansas at Pine Bluff (UAPB) indicated that, as stocking density increases in single-batch channel catfish production ponds, the number of market-size fish produced in a single season declines (Southworth *et al*. 2006a, Engle 2010). The same effect was observed for advanced size stockers as well as smaller juveniles (Figs. 1 and 2). The effect was more pronounced in ponds stocked with smaller juveniles. This suggests that social dominance becomes a significant factor as stocking density increases. As size disparity grows, the effect would be amplified.

Because processors and large retail buyers demand specific fish sizes, channel catfish are harvested on the basis of size, using size-selective nets. Fish of desired size are removed, allowing undersize fish to remain and continue growing. To maintain maximum year-round production, catfish fingerlings are periodically stocked with the larger, remaining undersize catfish in multiple-batch production ("under-stocking"). This creates a mixed size-class fish population in production ponds. The combined fish population is fed to satiation with floating feeds that target larger fish. Survival of under-stocked fingerlings has been reported to be around 70 percent but is frequently less (Engle and Stone 2002, SRAC 2007). Survival ranging from 24 to 76 percent (Table 1) was observed in multiple-batch channel catfish research ponds at UAPB (Engle and Valderamma 2001, Southworth *et al*. 2006b). None of the fingerlings in the UAPB research ponds grew to market size in a single growing season. It is likely that the larger fish already present when fingerlings were stocked were more aggressive at feeding time. The dominant, more aggressive fish consumed more feed than needed, leaving insufficient feed to promote good growth and survival of under-stocked fingerlings.

Fingerling growth is exponential. They grow significantly faster and require more feed per unit of body weight than 0.4-0.6 kg catfish. Feed deprivation slows fingerling growth during this critical period of the production cycle. As a result, they do not reach market size during a single production season. Larger and near food-size catfish are stronger and more aggressive. It is unlikely that under-stocked fingerlings can compete effectively with larger fish for bigger, floating feed pellets (Tucker *et al*. 1994, Wurts 2001). If 1400-3500 kg/ha of large 0.4-0.6 kg fish are crowding out smaller fingerlings at mealtime,

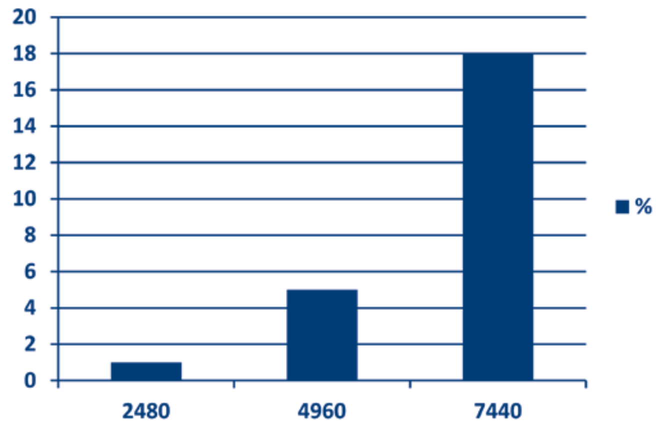

*Fig. 1. Percent under-size channel catfish harvested from single batch production ponds stocked at three densities ranging from 2480 to 7440 fish per hectare (adapted from Engle, 2010).**

** Individual fish less than 1.36 kg were considered under-size at harvest.*

** Individual fish size at stocking was 0.36 kg.*

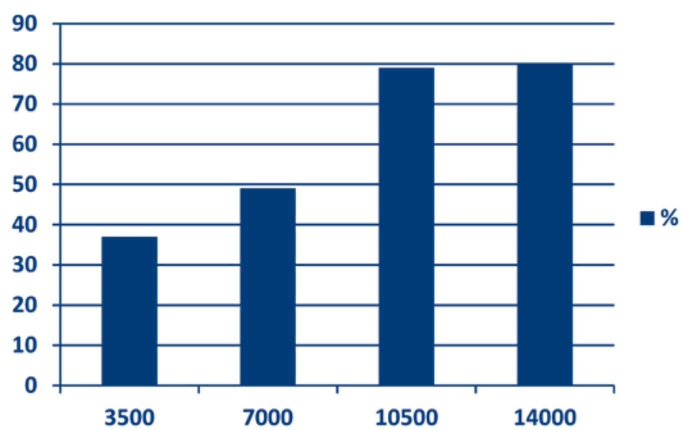

*Fig. 2. Percent under-size channel catfish harvested from single batch production ponds stocked at four densities ranging from 8600 to 34600 fish per hectare (adapted from Southworth et. al. 2006b).**

** Individual fish less than 0.57 kg at harvest were considered under-size.*

** Mean individual fingerling size at stocking was 16 g.*

** Survival ranged from 67 to 83 % with a mean of 73 percent.*

Table 1. Channel catfish fingerling survival in multiple batvh production ponds.

Study	Fingerling Size (g)	Density fiingerlings/ha	Survival (%)
Engle and Valderarma, 2001[x]	6	15,000	50
Engle and Valderarma, 2001[x]	12	15,000	76
Engle and Valderarma, 2001[x]	37	15,000	68
Southworth et al., 2006a[y]	19	8,600-34,600	24-36

[x]*1369 kg/ha carryover biomass, average initial fish weght = 0.58 kg each. Mean harvest weights for fingerlings stocked = 0.28-0.46 kg after 203 days.*

[y]*2268 kg/ha carryover biomass, average initial fish weights = 0.37-0.45 kg each. Mean harvest weights for fingerlings stocked = 0.32-0.35 kg after 196 cays.*

This sequnce of photographs (right and below) shows larger catfish, not quite harvest size, feeding aggressively. (All photos by Charles Weibel at Kentucky State University)

the fingerlings are not likely to perform well in terms of growth or survival.

As channel catfish grow, feed intake as percent of body weight (biomass) decreases. But their feed conversion ratio increases with size. The amount of feed it takes to produce a kilogram of fish increases as fish get larger. It takes 1.1 kg of feed to produce 1.0 kg of gain in 15-cm catfish, and 1.9 kg of feed for 1.0-kg of gain in 38-cm catfish (Robinson *et al*. 1998), 73 percent more feed for the same amount of growth in 38-cm catfish. Because juvenile channel catfish smaller than 200 g are growing much faster, require more feed, and convert feed to weight gain more efficiently; producers must do their best job of feeding when fish are young (Wurts 2001).

It is likely that under-stocked juvenile catfish do not compete effectively with larger fish for larger, floating feed pellets. An alternative feeding practice could improve growth, survival and health of channel catfish fingerlings in a mixed size-class population (multiple-batch production), promoting the development of a more sustainable channel catfish production system. A sinking feed with a smaller pellet size could be used to increase the availability of food for fingerlings. The amount fed would be adjusted in accordance with the rapid growth rate of fingerlings. A smaller sinking feed (Wurts 2001, Li and Robinson 2008) could be simultaneously offered to fingerlings along with the floating pellets for larger fish. Satiation feeding with floating feed would be used for larger fish.

The use of growth-adjusted feeding with sinking feed for several weeks after stocking could significantly improve health and survival of fingerlings in a mixed size-class catfish population. However, it might be simpler to routinely feed a fixed percentage of the daily allotment as sinking feed for 8-12 weeks after new fingerlings have been stocked. Higher fingerling survival rates and efficient feeding would reduce costs of production and decrease the time required to grow fingerlings to market size fish.

Notes

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larvalfishcon.org

(Continued on page 72)

Specific pathogen free shrimps: Their scope in aquaculture

Debtanu Barman[1], Vikash Kumar[2], Suvra Roy[2] and Sagar C Mandal[3*]

Shrimp farming underwent a major expansion mainly in Ecuador, the Philippines, Thailand and Indonesia during 1980's. In each country, production continued to increase in the 1990s and is now experiencing problems with many diseases. Reports are that specific pathogen-free (SPF), or IHHN virus-free *Penaeus vannamei* will be well accepted in Ecuador because SPF stocks have been demonstrated to be effective against the runt deformity syndrome. The captive maturation infrastructure required to propagate these stocks is already in place and the demonstrated efficacy will result in higher yields and higher value crops. In addition, the ability to produce a continuous, year-round supply of high quality nauplii will increase the efficiency of grow out sectors and result in lower costs and higher profit margins for shrimp farmers. Specific pathogen-free *P. monodon* have not yet been studied under production conditions in Asia. However, shrimp farmers in Southeast Asia have shown an interest in pursuing the development of an SPF *P. monodon* stock. The long-term viability and market value of SPF *P. monodon* post larvae (PL) will be determined by their performance in commercial production. Therefore, the process of identifying and isolating SPF *P. monodon* broodstock should begin as soon as possible so that their performance in commercial production systems can be evaluated.

Specific Pathogen Free (SPF) Animals

The SPF animals are special stock of animals that are kept in SPF facilities under a rigorous monitoring system. These animals are subjected to sensitive and accurate diagnostic methods. They are repeatedly bred under controlled conditions to maintain their freedom from specific pathogens and the SPF designation itself is tested on a regular basis. The SPF animals are not innately resistant to the specified pathogens or infections, although they can possibly be developed as specific pathogen resistant (SPR) species. They are not produced to provide either superior genetic stock or improved culturing attributes, such as faster growth. Specific pathogen-free shrimp are maintained in highly biosecure facilities and have been routinely checked and free of specified pathogens. There is no single internationally recognized SPF list, although it is generally agreed that SPF shrimp must be regularly tested for and be declared free from the pathogens.

Specific Pathogen Resistant (SPR) shrimp are those that are not susceptible to infection by one or several specific pathogens, and Specific Pathogen Tolerant (SPT) shrimp are those that are intentionally bred to develop tolerance to disease caused by one or several specific pathogens. There are lines of commercially available *L. vannamei* in the USA that are SPF and SPR, but only to Taura syndrome virus (TSV). These shrimp are not necessarily any more resistant to other viruses than any other shrimp.

This process has occurred for the production of domesticated lines of *L. vannamei* and *L. stylirostris* broodstock throughout the America and now moves some Asian countries like China, Thailand, Indonesia and Malaysia with *L. vannamei*. In fact, the advantages that the use of such animals offers has in the past four years, led to *L. vannamei* becoming the world's most important cultured shrimp species.

Advantages of Using Domesticated and SPF/SPR Stocks:

- Ready, year-round availability of disease-free broodstock
- Ability to be selected for desirable traits such as fast growth rate, disease resistance and, hence, high survival, good FCR and increased production and productivity
- Reduced use of chemotherapeutants
- Better adaptability of domesticated shrimp to captive environments, leading to reduced stress and better mating and reproductive success
- Increased traceability of the origin of stocks, their past performance and future potential

Status of SPF around the World

Currently, there are a number of programs aimed at producing domesticated stocks of disease-free *P. monodon* broodstock; these include projects in Hawaii, Thailand and Australia. Recent claims by the private sector are on the commercial availability of domesticated *P. monodon* in Thailand and Hawaii. Private, government and academic institutional cooperative development of SPF *P. monodon* broodstock domestication also began in Australia in 1997. Although significant success has been achieved, stocks from the program are not yet commercially available.

Status of SPF in India

The development of SPF stocks is probably a viable long-term solution for India. The marine product export development authority (MPEDA) has already begun efforts in SPF development. Two entrepreneurs have been permitted to import 500 SPF *L. vannamei*, while a proposal to import 10000 *P. monodon* broodstock has been approved by the government. A consultant for transfer of technology on SPF shrimp has been identified and he has already prepared a prefeasibility report. The site for the nuclear breeding center has also been identified on the Andaman and Nicobar Islands and hatchery facilities at the Andhra Pradesh Shrimp Seed Production and Research Centre (TASPARC) and the Orissa Shrimp Seed Production Supply and Research Centre (OSSPARC) will be testing the SPF broodstock in a commercial production environment.

Production of SPF Shrimp

Major elements of an SPF process include the capture of apparently healthy wild stock from areas of low disease prevalence followed by individual primary quarantine where the shrimp can be individually screened for specific pathogens and the contaminated individuals destroyed. The shrimp are then transferred to secondary quarantine where they are reared to broodstock size and monitored regularly. The disease-free broodstock are then transferred to the breeding center for production of multiple families from different sources. Larvae are then reared in bio secure hatcheries from the selected families. Any infected stock detected through continual monitoring are immediately discarded.

For development of SPR lines of broodstock *P. monodon*, the primary steps are similar to those for the SPF program. However, a more rigorous genetic selection program utilizing a greater number of families to select for desirable traits is required. Whichever programme is selected; the development of SPF and/or SPR lines of *P. monodon* should be regarded as a long-term investment. It requires absolute control on all aspects of culture on a continuous basis, highly trained scientific personnel, the highest standards of discipline and team work, specialized training for staff and continuous laboratory analysis.

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Advantages of SPF

Specific pathogen-free animals offer an advantage to a country introducing a species for the first time as it offers some assurance that the imported animals will not introduce the listed pathogens to native species. However, SPF stocks may harbor non-specified pathogens and this should be taken into account, inasmuch as it can pose a risk when the animals are under stress. With regard to shrimp culture, biosecurity systems are adopted to overcome a threat of disease outbreaks. The main concepts of biosecurity systems are to exclude pathogens and aid eradication if they occur. Specific pathogen-free stock is one of the major components considered in any biosecurity system, because the specific pathogen can be eliminated and contamination minimized. Specific pathogen-free animals are extremely useful for basic and applied science research, especially to immunological studies and vaccine trials, because the listed interfering pathogens can be ruled out. The SPF animals are also essential for other bioassay; for instance a study of shrimp viral diseases, where the shrimp cell line is not available, the pathogen free animals are needed for bioassay study.

Limitations of SPF Shrimp

All pathogens that pose a major threat need to be reliably diagnosed and physically excluded from the facility. However, it must be remembered that the shrimp could still be infected with a pathogen not included in the list. Offspring of SPF shrimp are not SPF unless they are produced and maintained at a biosecure SPF facility. Once they leave that facility, they can no longer be termed SPF. It should not be forgotten that domestication of *P. monodon* is far more difficult than working with *L. vannamei*. Because maturation of *P. monodon* in captivity is very difficult, a much longer holding period is required until they reach a viable size.

Risks in SPF

The major concern of SPF stock is the potential problems caused by inbreeding and genetic deterioration. This may pose problems like reduction in disease tolerance, growth and other developmental abnormalities. Inasmuch the SPF animals are cultured under hygienic condition, their acquired immunity is very low. Thus, SPF stock may not perform well under non-biosecure or outdoor open culture operations. Specific pathogen-free animals are only free from tested specific pathogens, however the unknown pathogens are usually overlooked. Mutation of specific pathogens commonly occurs, especially in viral diseases. This means that although the monitoring program is active, the pathogenic agent may be missed out. This hidden risk can, consequently, pose a threat to the health status of the animal.

Notes

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Book Review

(Continued from page 3)

and his associates have produced a large body of knowledge and experience centered on this species.

There are 26 chapters in this volume, many of which include black and white figures, illustrations, and photographs relating to relevant materials. Each page is arranged in two 2.5-inch columns of text, which I found difficult to read with ease. A number of larger chapters conclude with a useful section titled "Key Summary Points" and each chapter is organized with subheadings. Forty pages of the book are dedicated to an extensive glossary that adequately defines hundreds of relevant key terms. The references for this edition are provided at the end of the book rather than at the end of each chapter. An index allows the reader to locate quickly the topics and major species discussed throughout the book.

The book begins with a chapter that defines biotechnology and reviews the history of genetics and the inclusion of biotechnology advances with cultured fishes and shellfish. The first few chapters cover basic principles of genetics as applied to aquaculture organisms. Topics in these chapters include the role of environmental effects and the extent that phenotypic variation play in production aquaculture and related research populations. The chapter on qualitative traits and their selection provides a number of practical examples through the use of illustrations of complete/incomplete dominance, dihybrid crosses, and epistasis. Unfortunately some of these illustrations are formatted in the same narrow columns as the text, making them difficult to interpret for students new to aquaculture genetics. A four-page chapter on strain selection could have been better developed than the brief examples from tilapia, channel catfish, and common carp. The chapter on inbreeding, random genetic drift, and maintaining genetic quality covers a number of considerations on this important topic.

Chapters 6 through 11 address topics that are at the core of many of the advancements in aquaculture we see today. Specifically these chapters cover gynogenesis/androgenesis, intraspecific crossbreeding, interspecific hybridization, selection, polyploidy and xenogenesis, and sex reversal. These chapters present concepts with a comprehensive review of relevant peer-reviewed work and readers will note numerous sections that have been updated with new advances and literature citations since publication of the first edition.

The middle of the book contains discussion of most of the advanced topics in aquaculture genetics, representing application of recent molecular approaches to aquaculture. The most notable topics are addressed in chapters on biochemical/molecular markers, gene mapping, quantitative trait locus mapping, marker-assisted selection, gene expression, and gene transfer technology. The information is presented to demonstrate current uses and applications where applicable as well as an allusion to their future application in aquaculture generally. As with previous chapters, the author tends to rely on self-citation from his own experiences on a variety of topics, which greatly narrows the variety of available examples in the text. An advantage of this is the ability to demonstrate the application of these molecular techniques to a commercially important culture species, although this causes specific work to be referenced numerous times.

Towards the end of the book a brief chapter summarizes the application of topics presented in other chapters—such as selection, hybridization, and other enhancement regimes—to commercial aquaculture. There are three lengthy chapters that address a variety of aspects related to transgenic organisms in aquaculture, including environmental risks, food safety, a case study on transgenic salmon, and government regulation of transgenic organisms. These chapters are well connected with each other and represent current views and levels of knowledge on an often controversial topic. The last remaining chapters are brief and cover genetic conservation, ethics, and constraints and limitations of biotechnology in aquaculture. These final chapters address important aspects of aquaculture biotechnology, beyond regular technical topics, and can be used as the basis for potential discussion or debate in an aquaculture genetics course.

This volume would be most useful to upper-level undergraduates and graduate students in aquaculture who have had an introductory genetics course. This book can serve as a stand-alone text for an aquaculture genetics course. However, as with any book on such an expansive topic, the course could be supplemented with additional specific literature depending on the direction and depth of the course. There are sections that cover the application of biotechnology to natural fish populations; however, aquaculture is predominately featured. Fisheries students are advised to investigate the population genetics book by Hallerman (2003), which covers a number of biotechnology applications to natural populations. Researchers could also benefit from this book by the extensive literature citations used to support the written material.

The literature covered and examples presented within this volume tend to emphasize channel catfish and its hybrids, making portions of the book appear excessively weighted to this species. Overall, the topics are ordered to provide a logical presentation of topics to its audience. *Aquaculture and Fisheries Biotechnology: Genetic Approaches* can be used to demonstrate principles of genetics as currently applied to aquaculture and many advanced topics and material just beginning to be integrated and realized in research and development programs for genetic improvement of commercially important species.

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