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Australian Government
Department of Education, Employment and Workplace Relations

HATCHERY PRODUCTION OF YELLOWFIN TUNA

Dr Gavin Partridge
International ISS Institute/DEEWR Trades Fellowship

Fellowship supported by the Department of Education, Employment and Workplace Relations, Australian Government

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Executive Summary

Tuna are amongst the fastest growing and most valuable fish in the ocean. Their high regard with consumers has lead to their over exploitation and stocks of the most sought after species are now in serious danger of collapse. This over exploitation has been exacerbated by the practice of 'tuna ranching' whereby juvenile or sub-adult tuna are caught for fattening. Closing the life cycle of tuna in captivity and developing commercial-scale hatchery rearing techniques is therefore essential to satisfy the growing demand for tuna and to alleviate the subsequent fishing pressure on wild stocks.

The culture of tuna in captivity is a relatively new science, with few facilities and experts engaged in this endeavour throughout the world. This Fellowship, sponsored by the Australian Government's Department of Education, Employment and Workplace Relations (DEEWR), aimed to obtain the skills required to develop a hatchery capability for yellowfin tuna in Australia and to identify the current bottlenecks to commercial-scale production of the juveniles of this species. Key objectives were to:

- Seek the skills required to capture and transport yellowfin tuna over long distances and time frames while minimising stress and maintaining optimum health.
- Obtain the skills required to produce commercial quantities of larval tuna to the pre-metamorphic stage.
- Learn the techniques required to successfully wean these pre-metamorphic larval tuna onto an artificial diet.

In order to achieve these objectives, the Fellow travelled to Central and North America, where he learnt from international experts in the field of tuna propagation.

Appropriate fishing and fish handling techniques were identified to minimize stress and physical damage, and designs and advice for the most appropriate vessels to transport these fish over long distances were obtained. Being such large, fast-swimming fish, broodstock tuna have different housing requirements to most marine fish to ensure they remain sufficiently comfortable to allow natural spawning to occur. During his time at the Inter American Tropical Tuna Commission (IATTC) in Panama, the Fellow studied the design criteria for such tanks and the appropriate cues required to encourage spawning.

The Fellow reviewed and documented the current practices used to rear tuna larvae and also contributed to the design and implementation of a study aimed at overcoming the high rates of mortality typical of early stage larvae. A recently hypothesized factor for this mortality is that the larvae's body density is greater than water and when they stop swimming at night they subsequently sink to the bottom of the tank and die. An experiment was therefore conducted in which the growth and survival of pre-flexion tuna larvae were compared under a standard photoperiod of 12 hours of light and 12 hours of darkness, against a continuous photoperiod. The results of this experiment were highly significant. Those larvae reared under continuous light for nine days experienced a highly significant, nine-fold improvement in survival and a 22 per cent improvement in growth.

The Fellow was able to observe weaning-aged juveniles and test their response to various artificial diets. Although these advanced larvae clearly preferred the newly hatched tuna larvae, to which they had been accustomed, it was very encouraging to witness at least some interest and ingestion of the various artificial diets.

Executive Summary

The findings of this Fellowship are to be disseminated through a number of channels. The Fellow has been invited as a speaker at a number of seminars and conferences including The 2009 Second Global Centre of Excellence Symposium of Kinki University on 'Sustainable Aquaculture of the Bluefin and Yellowfin Tuna – Closing the Life Cycle for Commercial Production' hosted at the South Australian Research and Development Institute in Adelaide.[1] The symposium will be attended by Australian tuna researchers, industry representatives and other international experts. The findings will also be shared through invited presentations in the tuna propagation session of the World Aquaculture Society conference in San Diego in March 2010[2] and the Australasian Aquaculture Conference to be held in Hobart in May 2010.[3]

The Fellow has also been invited to participate as a co-investigator on a yellowfin tuna aquaculture project funded by the Australian Centre for International Agricultural Research. Based at the Gondol Research Institute for Mariculture in Indonesia, this project has been endorsed by Australian industry and will provide the Fellow the opportunity to implement the skills and findings of the Fellowship for the benefit of Australian industry.

It is the recommendation of this report that the Australian government continues to support all existing tuna projects it currently has an interest in and to seek other opportunities to increase Australian understanding of tuna propagation and farming. This approach will enable the Australian industry to keep abreast of the latest developments and techniques in tuna propagation and enable them to make an informed decision as to if or when commercially viable hatchery propagation of yellowfin tuna is going to become a reality. The Fellow also recommends that the current Australian bluefin tuna aquaculture industry investigate the potential of using the techniques described in this report for improving survival and growth of tuna larvae.

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1 www.misa.net.au/__data/assets/pdf_file/0013/120910/Kinki_University_Tuna_Symposium_Flyer_2009.pdf

2 www.was.org/WasMeetings/meetings/Default.aspx?code=AQ2010

3 http://www.australian-aquacultureportal.com/austaqua/sponsors.html

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Abbreviations and Acronyms

ACIAR	Australian Centre for International Agricultural Research
ACWA	Aquaculture Council of Western Australia
ADC	Aquaculture Development Council
ADU	Aquaculture Development Unit
DEEWR	Department of Education, Employment and Workplace Relations
DPH	Days Post Hatch
EPA	Environmental Protection Agency
FRDC	Australian Government's Fisheries Research and Development Corporation
GRIM	Gondol Research Institute for Mariculture
IATTC	Inter-American Tropical Tuna Commission
ISS Institute	International Specialised Skills Institute
lx	The lux (symbol: lx) is the SI unit of illuminance and luminous emittance
MPA	Marine Produce Australia
NAC	National Aquaculture Council
NOAA	National Oceanic and Atmospheric Administration
R&D	Research and Development
SARDI	South Australian Research and Development Institute
SI	International System of Units
TAFE	Technical and Further Education
UMEH	The University of Miami Experimental Marine Hatchery
WA	Western Australia

Definitions

Design	Design is problem setting and problem solving. Design is a fundamental economic and business tool. It is embedded in every aspect of commerce and industry and adds high value to any service or product - in business, government, education and training and the community in general. *Reference: 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.*
Purse seine	A fishing seine net that is drawn into the shape of a bag to enclose the catch.
Rotifers	Very small invertebrates that are generally used as a food source for first feeding larvae
Skills deficiency	A skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas. There may be individuals or individual firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the IP to themselves; and over time they retire and pass away. Firms likewise come and go. *Reference: 'Directory of Opportunities. Specialised Courses with Italy. Part 1: Veneto Region', ISS Institute, 1991.*
Sustainability	The ISS Institute follows the United Nations NGO on Sustainability, *"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* *Reference: http://www.unngosustainability.org/CSD_Definitions%20SD.*htm

Acknowledgments

Gavin Partridge would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide him throughout the Fellowship program.

Awarding Body - International Specialised Skills Institute (ISS Institute)

We know that Australia's economic future is reliant upon high level skills and knowledge, underpinned by design and innovation.

The International Specialised Skills Institute Inc (ISS Institute) is an independent, national organisation, which has a record of nearly twenty years of working with Australian industry and commerce to gain best-in-the-world skills and experience in traditional and leading-edge technology, design, innovation and management. The Institute has worked extensively with Government and non-Government organisations, firms, industry bodies, professional associations and education and training institutions.

The Patron in Chief is Sir James Gobbo AC, CVO. The ISS Institute Board of Management is Chaired by Noel Waite AO. The Board comprises Franco Fiorentini, John Iacovangelo, Lady Primrose Potter AC and David Wittner.

Through its CEO, Carolynne Bourne AM, the ISS Institute identifies and researches skill deficiencies and then meets the deficiency needs through its *Overseas Skill Acquisition Plan (Fellowship Program),* its education and training activities, professional development events and consultancy services.

Under the Overseas Skill Acquisition Plan (Fellowship Program) Australians travel overseas or international experts travel to Australia. Participants then pass on what they have learnt through reports, education and training activities such as workshops, conferences, lectures, forums, seminars and events, therein ensuring that for each Fellowship undertaken many benefit.

As an outcome of its work, ISS Institute has gained a deep understanding of the nature and scope of a number of issues. Four clearly defined economic forces have emerged out of our nearly twenty years of research. The drivers have arisen out of research that has been induced rather than deduced and innovative, practical solutions created - it is about thinking and working differently.

A Global Perspective. 'Skills Deficiencies' + 'Skills Shortages'

Skill deficiencies address future needs. Skill shortages replicate the past and are focused on immediate needs.

Skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas. This is the focus of the work of ISS Institute.

There may be individuals or firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the IP to themselves; and over time they retire and pass away. Firms likewise come and go. If Australia is to create, build and sustain Industries, knowledge/skills/understandings must be accessible trans-generationally through nationally accredited courses and not be reliant on individuals.

Our international competitors have these capabilities as well as the education and training infrastructure to underpin them.

Addressing skill shortages, however, is merely delivering more of what we already know and can do to meet current market demands. Australia needs to address the ***dual*** challenge – skill deficiencies and skill shortages.

Acknowledgments

Identifying and closing skills deficiencies is vital to long-term economic prospects in order to sustain sectors that are at risk of disappearing, not being developed or leaving our shores to be taken up by our competitors. The only prudent option is to achieve a high skill, high value-added economy in order to build a significant future in the local and international marketplace.

The Trades

The ISS Institute views the trades as the backbone of our economy. Yet, they are often unseen and, in the main, have no direct voice as to issues which are in their domain of expertise. The trades are equal, but different to professions.

The ISS Institute has the way forward through its ‘Master Artisan Framework for Excellence. A New Model for Skilling the Trades’, December 2004. The Federal Government, DEEWR commissioned ISS Institute to write an Australian Master Artisan School, Feasibility Plan.

In 2006, the ISS Institute established an advisory body, the **Trades Advisory Council.** The members are Ivan Deveson AO; Martin Ferguson AM, MP, Federal Labor Member for Batman; Geoff Masters, CEO, Australian Council of Educational Research; Simon McKeon, Executive Chairman, Macquarie Bank, Melbourne Office, and Julius Roe, National President Australian Manufacturing Workers’ Union. ISS Institute also puts on record its gratitude to the former Chairman of Visy Industries, the late Richard Pratt, for his contribution as a member of the Trades Advisory Council.

Think and Work in an Holistic Approach along the Supply Chain - Collaboration and Communication

Our experience has shown that most perceive that lack of skills is the principal factor related to quality and productivity. We believe that attitudes are often the constraint to turning ideas into product and a successful business; the ability to think laterally, to work and communicate across disciplines and industry sectors, to be able to take risks and think outside the familiar, to share – to turn competitors into partners.

Australia needs to change to thinking and working holistically along the entire Supply Chain; to collaborate and communicate across industries and occupations - designers with master artisans, trades men and women, Government agencies, manufacturers, engineers, farmers, retailers, suppliers to name a few in the Chain.

‘Design’ has to be seen as more than ‘Art’ discipline – it is a fundamental economic and business tool for the 21st Century

Design is crucial to the economic future of our nation. Australia needs to understand and learn the value of design, the benefits of good design and for it to become part of everyday language, decision making and choice.

Design is as important to the child exploring the possibilities of the world, as it is to the architect developing new concepts, and as it is to the electrician placing power points or the furniture designer working with a cabinet-maker and manufacturer. As such, design is vested in every member of our community and touches every aspect of our lives.

Our holistic approach takes us to working across occupations and industry sectors and building bridges along the way. The result has been highly effective in the creation of new business, the development of existing business and the return of lost skills and knowledge to our workforce, thus creating jobs - whereby individuals gain; industry and business gain; the Australian community gains economically, educationally and culturally.

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Acknowledgments

Fellowship Supporter

This Fellowship has been supported by the Department of Education, Employment and Workplace Relations (DEEWR), Australian Government.

The Australian Government's Department of Education, Employment and Workplace Relations (DEEWR) implements Government policies and programs to provide education and training opportunities for all Australians, to increase employment participation and to ensure fair and productive workplaces. Education, training and workforce participation are central to our goal of building a productive and socially inclusive nation, one which values diversity and provides opportunities for all Australians to build rewarding social and economic lives.

Partridge would like to thank DEEWR for providing funding support for this Fellowship.

Supporters

- In addition to the funding provided by DEEWR, additional sponsorship was supplied by The Aquaculture Development Council of Western Australia and The University of Miami's Rosenthal School of Marine and Atmospheric Science.
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- University of Miami
  Professor Daniel Benetti, Program Chair
  John Stieglitz, Tuna Program Manager
- Inter-American Tropical Tuna Commission
  Vernon Scholey, Laboratory Manager.

About the Fellow

Name: Gavin Partridge

Qualifications

- Bachelor of Science – Zoology and Aquatic Chemistry, University of Western Australia, 1994
- Honours (Class 1) Aquaculture , James Cook University of North Queensland, 1996
- PhD in Veterinary and Biomedical Sciences, Murdoch University, 2008

Memberships

- Marine Fishfarmer's Association (Western Australia)
- The Aquaculture Council of Western Australia
- The World Aquaculture Society
- Australian Society for Fish Biology
- Western Australian Fish Foundation

The Fellow is the Senior Research Scientist at Challenger Institute of Technology's Aquaculture Development Unit and an Adjunct Associate Professor at Murdoch University's Centre for Fish and Fisheries Research.

As a senior research scientist, the Fellow undertakes relevant research to assist Western Australia's developing aquaculture industry. He has a broad range of marine aquaculture experience and has published on a wide range of topics. He has experience in the hatchery production of a number of marine fish species, has worked extensively towards developing an aquaculture industry based on inland salinised water and is experienced in the grow-out of marine fish in both re-circulating aquaculture systems and sea cages.

The Fellow's vision for the future of aquaculture in Australia is to have a large-scale, environmentally sustainable industry that employs cutting edge technology to ensure it remains globally competitive.

Aims of the Fellowship Program

The overall aim of this Fellowship was to learn the skills required to develop a yellowfin tuna hatchery capability in Australia. The specific aims were to:

- Learn how to capture and transport tuna over long distances and time frames whilst minimising stress and maintaining optimum health.
- Determine if it is possible to hormonally induce mature broodstock at sea.
- Obtain the skills required to produce commercial quantities of larval tuna to the pre-metamorphic stage.
- Learn the skills required to successfully wean these pre-metamorphic larval tuna onto an artificial diet.

The Australian Context

Aquaculture is the only industry capable of meeting the ever-widening gap between seafood supply and demand, both in Australia and internationally.

The most recent production figures for the Australian aquaculture industry show that approximately 36,000 tonnes of finfish were produced in 2005–2006, with a value of $AUD451 million[4]. Given Australia's shortage of freshwater resources, it is not surprising that marine fish made up 86 per cent of this production. For the same reason, it is this sector that has the greatest potential for expansion and the Australian Government's Fisheries Research and Development Corporation (FRDC) have set a goal to increase production of marine fish to 100,000 tonnes by 2015.[5]

Three species contribute over 92 per cent of the production of marine fish in Australia. The Atlantic salmon industry is the largest (18,336 tonnes in 2005–06, worth $220 million), followed by southern bluefin tuna (8,800 tonnes, worth $156 million) then yellowtail kingfish (1,200 tonnes, worth $9.8 million)[1]. Production of tuna differs from the other two species in that these fish are not produced in a hatchery but are 'ranched'. That is, sub-adult fish are caught from the wild, transferred to cages and fattened for market.

Although tuna are the most valuable of the species currently cultured, expanding production beyond the current 9,000 tonnes per annum is not possible, due to the constraints placed on the number of wild fish that can be caught for fattening. In fact the Commission for the Conservation of Southern Bluefin Tuna has recently (October 2009) announced a worldwide cut in quota by 20% for this species and a cut to Australia's quota of 23%. Further growth of the salmon industry is likely to be constrained by the availability of sites in this climatic zone; however, expansion of yellowtail kingfish production should continue.

Production of these three species currently occurs in only two Australian states: Tasmania and South Australia. Although Western Australia has the longest coastline of any state in Australia, with climatic zones ranging from cool-temperate to tropical; production of marine fish in this state is very low. Although one farm in the far north of the state is currently producing approximately 650 tonnes of barramundi per year, there is no large-scale production of cool-temperate or temperate fish. A number of factors contribute to this situation including very onerous government licensing and site permit processes that can be a discouragement to investors.

Furthermore, while the zone between Perth and Geraldton is climatically ideal for the production of temperate species and has access to the necessary population and critical infrastructure, sheltered locations suitable for near-shore cages are uncommon along this coast. Where such sites do exist, they generally have high conservation and/or social-use value. Two attempts within the last decade to establish a near-shore seacage industry for the ranching of southern bluefin tuna in Western Australia have failed due to opposition on environmental grounds from local residents.

Nevertheless, interest and activity in marine fish aquaculture has been rekindled in recent years by both government and industry. Industry has been investing in pilot-scale production of mulloway and yellowtail kingfish and government is addressing obstacles within the regulatory processes.

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4 O'Sullivan, D., Savage, J., Fay, A., 2008. Status of Australian Aquaculutre in 2005/2006. Austasia Aquaculture Trade Directory, 4–22.

5 http://www.frdc.com.au/documentlibrary/FISH%2016-2.pdf

The Australian Context

The Aquaculture Development Council (ADC)—a ministerial advisory body—has also been encouraging the development of aquaculture by seeking from the Government of Western Australia the introduction and passage through Parliament of a separate aquaculture bill that would streamline the licensing and permitting processes and enable the identification and gazetting of suitable sites for marine fish aquaculture.

The lack of suitable near-shore sites is also being addressed by the ADC, which has been actively investigating offshore aquaculture technologies. Offshore aquaculture has many benefits compared with traditional, near-shore cage farming. These cages are located in deep water, with strong consistent currents and, as such, their environmental impact is negligible (and in most cases undetectable). The offshore location of these cages also means they create no visual pollution and they do not usually have special ecological significance or competing interests. On the downside, however, offshore farming systems are more expensive to build and operate compared with near-shore farms.

The ADC recently commissioned a study in which the potential economic benefits of an offshore aquaculture industry in temperate Western Australia were examined.[6] This report showed that a large-scale farm producing 2,000 tonnes of yellowtail kingfish would be profitable. Based on this outcome, the ADC plans to build a demonstration farm to showcase this offshore technology to industry participants and investors and test the biological and technical assumptions made in the study.

Although the ADC study showed that such a farm would be profitable growing yellowtail kingfish, it is clear that growing a higher value species would further offset the high capital and operating costs associated with such farms and make them more profitable. Tuna are among the fastest growing and highest value fish in the ocean. While mulloway and yellowtail kingfish can grow to between one and three kilograms respectively in one year, yellowfin tuna can obtain in excess of ten kilograms. Unlike southern bluefin, yellowfin tuna are not currently ranched in Australia.

The very long distances between where the fish aggregate and the licensed grow-out sites makes it high-risk, particularly as the aggregation season corresponds with cyclone season. Yellowfin tuna are, however, the most popular tuna with consumers in the USA and are ranched successfully in Mexico. Other sites are under development in both Costa Rica and Panama. This fact, combined with the opinion of several international tuna experts that yellowfin tuna should be easier to culture in a hatchery (compared to southern bluefin), has led both industry and government in Western Australia to target yellowfin as the tuna species of choice for further development.

Producing yellowfin tuna in a hatchery will enable the Australian industry to immediately utilise those grow-out sites that are already licensed for yellowfin tuna. The capacity to grow yellowfin tuna in offshore sites will also increase the profitability of this industry and facilitate expansion of marine fish aquaculture in Western Australia. With the worldwide popularity of tuna increasing at a rapid rate, current farming practices of ‘tuna ranching’ are placing a significant strain on wild tuna stocks. Many wild fisheries are presently under threat of collapse. Closing the life cycle of tuna will also bring the benefit of reducing pressure on wild stocks.

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[6] Partridge, G.J., Michael, R.J., Jenkins, G.I., Crawte, D., 2008. An Opportunity Study of an Open Ocean Aquaculture Project in Western Australia. Aquaculture Development Council of Western Australia, Perth, WA, pp. 73.

SWOT Analysis for Yellowfin Tuna Culture in Australia

Strengths

- Australia's clean/green image
- Climatic conditions suitable for optimum fish growth
- Close proximity to Asian markets
- Recent government investment in Open Ocean Aquaculture species and sites (Western Australia)
- Locally available broodstock and fishers experienced in their capture
- Experienced government marine fish culture units
- Industry interest in culturing the species

Weaknesses

- High labour costs
- Current government framework for licencing of sites
- Shortage of inshore grow-out sites
- Remoteness of suitable grow-out sites
- No current ability for yellowfin tuna hatchery production

Opportunities

- Declining wild caught fisheries
- Increasing population and demand for fish
- Increasing awareness of the health benefits of eating fish
- Improving technology for offshore grow-out
- Increasing government interest in yellowfin tuna culture
- Commonwealth and State grants available

Threats

- Not being able to develop hatchery protocols
- Increasing importation and consumer acceptance of cheap fish
- Disease
- Government divestment of aquaculture support facilities
- Economic downturn making it more difficult to raise funds

Identifying the Skill Deficiencies

The Australian aquaculture industry currently lacks the skills and knowledge required to propagate yellowfin tuna. In order to build an industry around this highly valuable marine fish, the following must be addressed:

- Acquire the skills necessary to collect wild yellowfin tuna for broodstock.
- Learn the skills required to spawn yellowfin tuna in captivity.
- Obtain the skills required to produce commercial quantities of larval yellowfin tuna to the pre-metamorphic stage.
- Learn the skills required to successfully wean these pre-metamorphic larvae onto an artificial diet.

The Fellow identified the following specific tasks to be undertaken during his overseas study program:

1. Identify effective methods of transporting live adult tuna.

Learn from those skilled in transporting live tuna. Inspect their transportation infrastructure and record the vital parameters that must be maintained and learn of any precautionary steps that must be taken in order to ensure that the fish arrive alive and in optimum health.

ACTION: *Learn how to transport adult tuna over long distances.*

2. Identify the factors likely to be limiting survival of yellowfin tuna larvae.

Observe the set of physical and chemical parameters currently used for rearing yellowfin tuna. In particular the size, shape and colour of the larval rearing tanks; the rates of air and water flow and the subsequent hydrodynamic patterns within the tanks; light intensity, photoperiod and spectral distribution; larval stocking densities, feeding strategies, microalgal cell density, bacterial fauna and basic water quality parameters including water temperature, pH and dissolved oxygen.

ACTION: *Become familiar with the current rearing strategies being used to rear yellowfin tuna larvae.*

3. Determine if yellowfin tuna can be weaned onto conventional aquaculture weaning diets.

The current practice of feeding tuna larvae to older tuna larvae is not viable for a commercial aquaculture hatchery. It is also the Fellow's experience that once larval marine fish begin feeding on larvae of their own species (or other species) that subsequent weaning onto an artificial diet becomes more difficult. Weaning onto artificial diets is a crucial stage in the process of producing commercial quantities of juvenile tuna for grow-out.

ACTION: *Develop an effective weaning strategy to encourage juvenile yellowfin tuna to accept artificial diets.*

Why it Needs to be Addressed

With declining catches of seafood in Australia, aquaculture is the only industry capable of meeting the ever-widening gap between seafood supply and demand. Aquaculture of temperate marine fish in Australia currently consists of only two species: mulloway and yellowtail kingfish. Combined production of these species is approximately 1,750 tonnes, worth approximately $15 million.[7]

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[7] O'Sullivan, D., Savage, J., Fay, A., 2008. Status of Australian Aquaculture in 2005/2006. Austasia Aquaculture Trade Directory, 4–22.

Identifying the Skill Deficiencies

Not only are tuna very fast growing, they are also more valuable than the other temperate species currently cultured in Australia. Farm gate prices of the former species are approximately $10 per kilogram, whereas tuna are typically over $30 per kilogram. Currently, tuna farming in Australia is limited to ‘ranching’ where wild fish are caught, transferred into pens and fattened. Strict quotas exist for the capture of all wild tuna, and the entire quota is used for ranching.

The value of tuna ranching is therefore constrained by these quotas but is currently worth approximately $150 million[4]. Being able to culture tuna larvae in a controlled hatchery environment will allow the tuna aquaculture industry to expand rapidly, beyond the constraints currently imposed through the quota system. Learning the skills necessary to rear tuna larvae in captivity will enable the Australian aquaculture industry to increase their profitability by producing these fast growing and high-value species.

The International Experience

The Fellow visited Panama and the United States of America. The tuna aquaculture sessions at the World Aquaculture Society Conference in Vera Cruz, Mexico were also on the Fellow's itinerary. Regrettably, however, the conference was cancelled due to the swine flu pandemic.

The Inter-American Tropical Tuna Commission (IATTC)

Contact: Vernon Scholey, Laboratory Manager

The Inter-American Tropical Tuna Commision's (IATTC) tuna facility is located in Los Santos, Panama. The IATTC is the most experienced and successful yellowfin tuna laboratory in the world and has been spawning yellowfin tuna successfully since 1996. This facility represents the best opportunity for learning successful techniques for spawning tuna. Its research focus is to understand the ecology and life history of tuna in the wild so that wild fisheries can be better managed. Because their focus is not on commercial hatchery production, efforts have not been made to improve survival to commercially acceptable levels. However, with the only year-round adult spawning population of tuna in the world, this facility provides an excellent opportunity to learn advanced techniques for successful larval rearing.

During his visit to the IATTC facility the Fellow focused on three aspects of tuna propagation and rearing:

- broodstock capture, transport and prophylaxis
- broodstock system design and management
- egg incubation and larval rearing.

Broodstock Capture, Transport and Prophylaxis

In order for Australian industry to develop a hatchery-based yellowfin tuna aquaculture capability, it must first develop the capability to capture and successfully transport broodstock tuna back to the hatchery. Over the past 20 years IATTC has refined their broodstock capture and handling techniques.

The facility in Panama was purpose built on the Azeuro Peninsula to take advantage of the plentiful supply of yellowfin tuna in the surrounding waters. IATTC staff fish from small fibreglass boats, equipped with a 400 litre fibreglass 'live-well'.

Figure 1: Image of a live-well

The International Experience

The well is lined with soft blue foam, which prevents injury to the fish if they rub against the walls. Local tuna stocks are pre-adults, ranging in size between two and eight kilograms. They are caught on heavy fishing line by trolling lures 50 to 100 metres behind the boat at a speed of four to six knots. Prior to use, the barb on the hook is ground down, to ensure fish are removed easily without damage. Once a fish strikes the lure, they are retrieved as quickly as possible to ensure they are not exhausted during a lengthy fight. Care is taken to avoid rubbing the fishing line across the eye of the tuna, as this causes permanent damage. IATTC staff pointed out that, as the tuna's epidermis is only one cell thick, the skin is susceptible to damage.

Hooked tuna are therefore lifted, either with a plastic sling or directly into the well. From there the hook is removed carefully and the fish released into the well. If the hook has punctured the roof of the mouth and has entered the eye, the fish are discarded. Experience has shown these fish will not survive. Fresh seawater is constantly pumped through the live well to maintain water quality. Typically, no more than two fish are stocked into the well at once. If more are stocked the fish become visibly stressed, even if the water quality is good. Tuna are very sensitive to changes in light and therefore the well is not covered. Taking the live-well cover on and off results in stressful changes in light intensity that can cause the tuna to collide with the tank walls.

Figure 2: Showing how a plastic sling is used

Figure 3: Live fish transfer

The quarantine facility for newly caught broodstock is located within a few hundred metres of the boat dock. Staff radio ahead to notify land-based staff that fish are on board and to prepare for their arrival. Land-based staff meet the boat and transfer the fish in plastic bags to a bin of water on the back of a utility vehicle.

The fish are transported to the facility where they are weighed, measured and administered with an injection of the antibiotic, oxytetracline at the dosage of 50 milligrams per kilogram weight. This antibiotic is primarily used to stain the fish's otolith (ear bone), allowing it to be accurately aged when it dies. Oxytetracline also provides an added benefit of reducing bacterial infections. The fish is then released into a large floating 'bottomless bag' within a 20 cubic metre tank (4.6m Ø x 1.2m deep). The bag prevents the newly caught fish from striking the walls of the outer tank as it acclimates to captive conditions.

The smaller tank gives IATTC staff the opportunity to closely observe the fish so as to ensure they are not developing infections or problems associated with line damage. Using these capture and handling techniques, survival rates of approximately 50 per cent are expected. This includes fish that are immediately discarded at sea due to line or eye damage. Smaller fish survive the capture and transfer process better than larger fish. The small size of the fish and the close proximity to the fishing grounds is a major factor contributing to the high survival rate.

After a few days the fish are transferred to the smaller of the two broodstock tanks. To transfer the fish, the tank water level is lowered, the fish corralled using a plastic barrier net and they are then transferred into a water-filled sling. A concentrated antibacterial solution of nitrofurosan is added to the sling at twenty times the recommended dose. The fish are kept in the bath for three minutes while being transferred to the new tank. This high nitrofurosan dose is administered because of the brief bathing time. In the new tank, fish are offered feed for the first time. With a 'mentoring' fish present in the tank, new fish will usually feed within one to two days. If there are no other fish in the tank, feeding may take up to two weeks to commence.

Figure 4: Bottomless bag in observation tank

Figure 5: Fish transfer using a water-filled plastic sling

No anaesthetics or chemicals are used to calm the fish or adjust its blood parameters during any part of the capture and handling process. IATTC staff advised that, compared with other species such as skipjack tuna and wahoo, yellowfin tuna are very calm and easy to handle.

Broodstock System Design and Management

The main tuna broodstock facility at the IATTC comprises two concrete tanks housed under a roofed shed with open walls. A skylight in the tin roof directly above each tuna tank provides some sunlight. This is considered to be important for tuna as they have a pineal gland on top of their head.

The largest tuna broodstock tank is 17 metres in diameter, six metres deep and holds 1360 cubic metres of water.

The International Experience

Figure 6: Main broodstock tank

The tank is built partially into the ground in order to insulate it from noise and vibration. It houses the main tuna spawning population. During the Fellow's visit to the facility, the tank held nine fish ranging in size from 30 to 70 kilograms. Successful spawning has occurred in this tank with fish numbering between five and 55. Despite such a wide range in fish numbers, an overall stocking density is always maintained at no more than 0.75 kilograms per cubic metre. Wall strikes are more prevalent above this density.

The second tuna broodstock tank is considerably smaller, measuring 8.5 metres in diameter, three metres deep with a volume of 170 cubic metres. This tank holds the newly caught sub-adult fish. Fish from the smaller tank are used to replenish the main broodstock population as mortalities occur. The average survival time in captivity is two years and most deaths are the result of wall strikes. Wall strikes usually occur in the dark and in the early morning hours. Wall strikes are believed to be the result of the fish being startled. Wall strikes are also more common in larger fish and when the stocking density is greater than 0.75 kilograms per cubic metre. It is believed that larger fish are more prone, as they are less able to make the rapid and sharp turn required to avoid the collision.

In an effort to minimise wall strikes, the walls of all tuna tanks have been painted with black stripes, to improve contrast and help the tuna see the wall. Each stripe is one inch wide and 25 inches apart. The spacing is based on the angles of retina; the theory being that the fish can always see at least one stripe. Research at the Gondol Research Institute for Mariculture (which is an identical facility to that in Panama) has shown that such stripes reduce the incidence of wall strikes.

The International Experience

Although wall strikes still cause the loss of approximately 30 per cent of the broodstock per year, the success of the Panamanian system has been partially attributed to the very dark nights in Panama and minimum stray light.

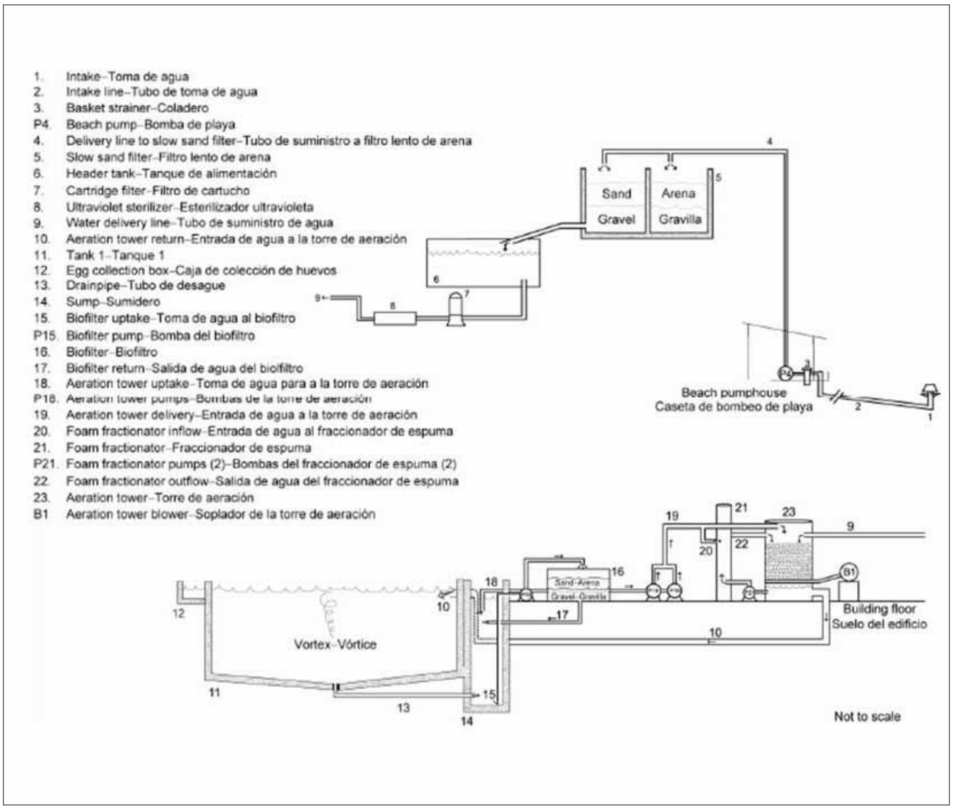

Figure 7: Schematic diagram of broodstock system. Seawater delivery and filtration systems (upper diagram) and broodstock tank (11) systems (lower diagram) at the Achotines Laboratory. (diagram taken from Margulies, et al., 2007)

Each tuna broodstock tank has its own independent re-circulating system, which comprises three separate loops (see 'broodstock schematic diagram' image).

The filtration system ensures that optimal water quality is maintained at all times. Dissolved oxygen concentration is always greater than 70 percent saturation with pH between 7.6 and 8.3. Concentrations of ammonia, nitrite and nitrate are always below the detectable limits. Interestingly, carbon dioxide has apparently been measured as high as 50 milligrams per litre without any adverse affect. Such a concentration would be lethal to most pelagic fish.

In the main tank, the water is turned over seven to eight times each day. Pumping water into the tank in a clockwise direction takes advantage of the Coriolis effect; creating a 0.5 to one knot current at the edge of tank and a large vortex in the centre, which the tuna are regularly seen 'playing' in. The fish can swim within one centimetre of the tank wall, perhaps sensing the laminar flow created by the very high flow rates.

The low pressure and high volume pumps used to create the high turnover rate are very energy efficient and are made of fibreglass to ensure no metal parts come in contact with seawater. Care is taken to ensure they are installed in such a manner to minimise vibration within the tank. The volume of new water flowing through the system varies from 1 to 5 per cent per day. All new water is filtered to 20 microns (1 micron = 1 millionth of a metre) using a paper filter cartridge. Parasites have never been an issue with tuna broodstock in this system and this may be partially attributable to the very high flow rates. The smaller back-up broodstock tank has a lower water turnover rate of two to three times per day, but a similar rate of new water.

Feeding

Broodstock fish are fed daily on a fixed ration based on their weight and water temperature. Daily ration ranges from approximately 5 per cent for the smaller fish in warm water, to 1 per cent for the larger fish in cooler water. All broodstock are fed on equal ratios of squid and sardines. While the fish prefer the sardines, squid contribute essential nutrients for ensuring optimum egg quality. A vitamin and mineral premix is also added to the food at 0.5–1.5 per cent of the food weight. During feeding the food is thrown from several places around the tank to prevent collisions between the actively feeding fish.

Spawning

Yellowfin tuna mature at two years of age and at a size of approximately 15 kilograms, respectively. For two to six kilogram sub-adult fish caught, it usually takes a further six to eight months in captivity for them to reach maturity. Depending on water temperature, once mature, spawning occurs naturally (ie without hormone induction) on an almost daily basis. Spawning occurs whenever the temperature is above 24°C which, for the IATTC facility, is approximately nine months of the year. The broodstock are very sensitive to rapid changes in temperature. If the average daily temperature drops by just 0.5°C over a one week period spawning will cease, even if the temperature is within the optimum range of 24 to 28°C.

The time of spawning has also been found to be temperature dependant, with the broodstock spawning at a time that will result in the eggs hatching at around sunset the following day. When the temperature is greater than 25°C, broodstock will spawn in the evening, between 6pm and 10pm. When the temperature is less than 25°C, spawning occurs in the afternoon or early evening, between 2pm and 6pm. At temperatures below 25°C, eggs hatch after 28 hours, whereas at 29°C, incubation lasts only 18 hours. The positively buoyant eggs are collected from the tank shortly after spawning by hanging a large plankton net tangential to the tank wall and facing the current. Fertilised eggs measure 950 to 1000 microns in diameter with a 220 micron oil globule.

Eggs are counted and their viability assessed by float separation before transferring them to an egg incubation tank. Incubation tanks of 250 litres in volume and with a steep conical base are housed inside an egg incubating room with artificial lighting. Up to 80,000 eggs are stocked into each tank and they are provided with gentle aeration and a flow of clean seawater. Just prior to hatching the eggs become negatively buoyant and at this stage the aeration rate is turned up to prevent the eggs from sinking. Hatch rates are usually in excess of 90 per cent, but can be as low as 50 per cent, particularly if young fish are contributing to the spawn. At hatch the larvae measure 2.5 millimetres in length and like all marine fish larvae are poorly developed.

The International Experience

Figure 8: Eggs are collected using a large plankton net placed tangential to the tank wall

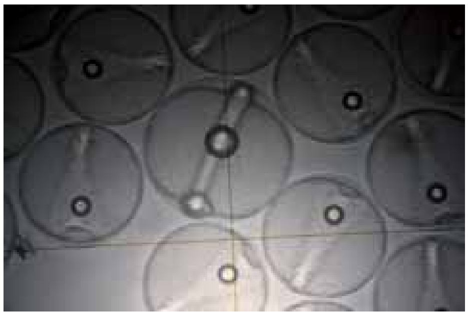

Figure 9: Fertilised eggs

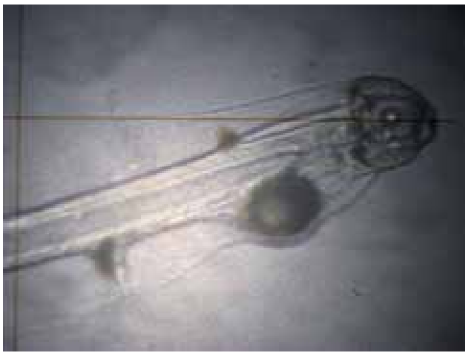

Figure 10: Newly hatched larvae

Figure 11: Larval tanks

The majority of larval rearing studies at the IATTC are conducted in twelve relatively small, light blue fibreglass tanks, of either 700 or 1000 litres in volume. These sized tanks are used to enable replicated research to be undertaken. They have also reared larvae in larger tanks (up to 20,000 litres), but experienced similar rates of survival in both tank sizes. All larval rearing tanks are housed under a metal roof with open walls providing indirect light to the tanks. There are no skylights in the roof as there are over the tuna broodstock tanks. Each larval rearing tank is illuminated with 4 x 40 watt daylight fluorescent tubes, which are turned on and off at dawn and dusk, respectively, providing approximately 12 hours of light per day.

Each light is covered with two layers of shade cloth, which are removed one at a time after the lights are turned on to provide a gradual increase in light intensity, rather than a sudden burst of light which has been shown to stress the larvae. The lights provide a surface light intensity of approximately 30 micromoles per metre squared per second (the standard international unit of photosynthetically active radiation).

The larvae are stocked into the tanks the day after hatching, one Day Post-Hatch (DPH), at a density of 15 larvae per litre. This is lower than most cultured marine fish larvae. Research at the IATTC has demonstrated that rearing larvae at higher densities results in significantly slower growth. Feeding commences at 2.5 DPH. The first feed of rotifers is the same as used in most marine fish hatcheries around the world. Prior to feeding, rotifers are enriched on a combination of the commercially available enrichment diet Algamac 3050 (Aquafauna, Biofauna Inc.) and preserved microalgae paste (*Nannochloropsis,* Reed Mariculture). Rotifers are maintained in the larval rearing tank at the fairly low density of 4–5 animals per millilitre.

The density is checked three times per day and adjusted back to this target density as required. It has been found that higher rotifer densities are not required as the larvae are very efficient predators. Throughout the day, live microalgae (a 60:40 blend of *Nannochloropsis granulata* and *Thalassiosira weissflogii*) are added to the larval rearing tank to achieve a cell density of approximately $2x10^6$ algal cells per millilitre. This is a relatively high density compared to that used in the culture of other marine fish larvae. This density is used to improve the visual contrast of the prey, and also to minimise cannibalism by the larvae as they develop. During the rotifer-feeding phase, tank flow through is set at one to 1.5 litres per minute and the water exits the tank through a central standpipe screened with 200-micron mesh. Prior to use, water is filtered to 20 microns via bag filtration, and is sterilised with ultraviolet light. Four air-stones provide gentle aeration. The rate of aeration is set to achieve a surface current of approximately 5–7 centimetres per second, which is measured using a surface drogue[8]. With these air stones, dissolved oxygen concentrations are maintained at greater than five milligrams per litre (80 per cent saturation). No pure oxygen is used.

When the larvae reach 4.5 mm in length (typically nine to 11 DPH), they are transitioned from rotifers to enriched Artemia nauplii over a two-day period. Artemia are also enriched with Algamac 3050. At this stage the 200 micron screen on the central standpipe is replaced with a 500-micron screen to ensure any uneaten Artemia are flushed from the tank.

When the larvae reach six millimetres in length (approximately 14 DPH), newly hatched tuna larvae are also introduced to the larval rearing tanks as a food source for the more advanced larvae. It is believed that this is the stage at which they become piscivorous (ie fish-eating) in the wild and, hence, this is why newly hatched larvae are introduced at this time. Feeding of enriched Artemia is continued until 24 DPH. This practice of feeding early larvae to more advanced larvae is atypical of other cultured marine fish larvae, which are weaned directly from Artemia onto artificial diets. The inability to wean tuna larvae onto an artificial diet is one of the constraints to the development of commercial-scale hatchery production. Due to their aggressive behaviour towards each other, the addition of microalgae to the water is continued into this feeding stage in order to reduce encounters between larvae. IATTC staff advised that they have tried on numerous occasions to wean larvae onto artificial diets, but without success. At approximately 60 days, newly hatched larvae are slowly withdrawn, and replaced with finely chopped fish. Mortalities of these juveniles continue at this stage and the longest that IATTC staff have kept the juveniles alive has been approximately 100 days.

The Fellow was also able to observe a tank of tuna larvae at 23 days of age. Approximately 100 of these fish remained in a tank of approximately eight cubic metres in volume (see ‘weaning tank and metamorphosed fish’ photo).

Although these fish had already commenced feeding on live tuna larvae, the Fellow was given the opportunity to attempt to wean these fish onto an artificial diet. At sunrise each day time was spent observing the larvae and offering them various types of weaning diet. This time of the day was chosen as it was before the addition of any newly hatched larvae and therefore when the larvae were most hungry and most likely to accept the diet. Despite this, some newly hatched larvae left over from the previous days feeding were usually still present in the tank. It was observed that the larvae were very inquisitive and aggressive feeders, not only to the newly hatched larvae that were added to the water, but also to other larvae from their own cohort.

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[8] The drogue used is a round polystyrene disk, 38mm in diameter and weighing 9 grams.

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Figure 12: Weaning tank and metamorphosed fish

They also reacted to and investigated anything else that landed on the water surface, such as mosquitos. The Fellow tried several commercially available weaning diets including Otohime, Gemma Micro and Proton. Like all items that landed on the surface, the larvae reacted to the addition of the various artificial diets by swimming up to them. On several occasions larvae were observed ingesting the diets, which was very encouraging. On the majority of occasions, however, they did not and no obvious preference for a particular diet was observed.

During the Fellow's visit, a private aquaculture company was in the process setting up a small facility on the IATTC premises to test if it could produce sufficient quantities of juvenile tuna to stock into seacages. The Fellow has maintained contact with this group and since returning to Australia has learnt they have had success weaning juvenile tuna onto an artificial diet.

While at IATTC, the Fellow contributed to the design and implementation of an experiment devised to improve the survival of yellowfin tuna larvae during their first nine days of life. Like all tuna species, this early stage represents a period of major mortality. Recent data from Japan suggests that tuna larvae may sink at night; which causes them to die[9]. In order to test this hypothesis and prevent night-time sinking, a trial was conducted in which the survival of larvae exposed to 24 hours of light per day was compared against those reared under a control photoperiod of 12 hours light and 12 hours of darkness. The results of this trial were highly significant. A nine-fold increase in survival and a 22 per cent increase in growth in those larvae reared under a 24-hour photoperiod was obtained. The Fellow has prepared a manuscript on this trial for submission to the international journal 'Aquaculture' and has also been invited to present the results at a number of upcoming aquaculture conferences. An abstract of one of these presentations is provided in Attachment 1.

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[9] Takashi, T., Hirotoshi Kohno, Wataru Sakamoto, Shigeru Miyashita, Osamu Murata, Yoshifumi Sawada, 2006. Diel and ontogenetic body density change in Pacific bluefin tuna, *Thunnus orientalis* (Temminck and Schlegel), larvae. Aquac. Res. 37, 1172-1179

The University of Miami Experimental Marine Hatchery

Contact: Professor Daniel Benetti, Director John Stieglitz, Tuna Project Manager

The University of Miami operates the Experimental Marine Hatchery (UMEH) at its Rosential School of Marine and Atmospheric Science on Virginia Key, Miami. This hatchery has an international reputation for developing commercial-scale hatchery techniques for difficult marine species, including pelagic fish. For example, after developing and refining hatchery protocols for cobia, this facility is now the largest hatchery in all of the Americas for this species, providing juveniles to all grow-out operations in the region.

Unlike the laboratory at IATTC, UMEH is dedicated to the commercial production of marine fish. UMEH has recently received a grant from the National Oceanic and Atmospheric Administration (NOAA) to develop a tuna propagation program. John Stieglitz is managing the tuna project under the direction of Professor Daniel Benetti. Atlantic blackfin tuna (*Thunnus atlanticus*) have been selected for the program. This is the smallest of all 'true' tuna (ie members of the *Thunnus* genus), growing to a maximum size of 20 kilograms and maturing at 2–4 kilograms. The species is endemic to the Western Atlantic and is found seasonally off the coast of Miami. Its small size and local availability make it an appropriate species for UMEH, as they are a small facility without access to the very large broodstock tanks required to keep species such as yellowfin or bluefin. Nevertheless this smaller but closely related species has very similar early life history characteristics to yellowfin tuna and therefore makes an excellent surrogate for learning appropriate rearing techniques for the larger and more valuable species.

The time of the Fellow's visit coincided with the natural spawning season of blackfin tuna off the coast of Miami. It was planned to capture mature broodstock and test whether or not the administration of reproductive hormones immediately upon capture could prevent the oocyte atresia (ie breakdown of mature eggs within the ovary prior to ovulation) that commonly occurs in mature fish when they are caught. This technique has been used successfully on other species of marine fish and enables fertilised eggs to be obtained from newly-caught mature fish. If successful with tuna, this approach would provide immediate access to fertilised eggs and larvae without the need for a lengthy acclimation period to the captive environment before natural spawning takes place.

Broodstock System Design

The UMEH has two 80 cubic metre broodstock tanks that have been used historically for cobia broodstock. With the NOAA tuna grant, one has been converted to a tuna broodstock tank (see 'UMEH broodstock system' photo). Although the tank is only 6 per cent of the volume of the main broodstock tank in Panama, the small size of mature blackfin tuna means that up to 15 mature fish of four kilograms can be held while maintaining the density at 0.75 kilograms per cubic metre; the maximum figure recommended by IATTC staff for yellowfin tuna.

Like the IATTC broodstock system, the UMEH broodstock tank operates as a re-circulating system, with the same set of components such as mechanical and biological filtration, ultraviolet sterilisation, degassing and oxygenation systems. The system has a similar percentage of new water added per day (5–10 per cent). The current internal water turnover rate is the same as it was for cobia (ie three to four exchanges per day) but if necessary, can be increased to the same level as used in Panama.

The International Experience

Figure 13: UMEH broodstock system

Figure 14: Tuna tubes constructed by UMEH

Broodstock Capture

With a strong recreational fishing presence in Miami, sports fishing boats are common and UMEH utilises one of these for broodstock fishing. Although a similar size to the fishing boats used in Panama, the boats in Miami do not have in-built live wells and have limited deck space for an on-deck live well. As such, staff at UMEH have been utilising smaller, space saving 'tuna tubes' (see 'tuna tubes constructed by UMEH' photo) for broodstock transfer. These devices are designed for holding tuna as live bait for marlin fishing and are able to keep tuna alive for many hours. Having the tuna fit snugly into the tube ensures that more water is pushed through the tuna's mouth and subsequently over its gills than around its body. The tight fit also limits movement and subsequent damage to the body. UMEH has therefore manufactured its own set of tuna tubes with varying diameters to accommodate different sized fish. The outer blue bin is filled with seawater, which is pumped through the bottom of the required tube and then overflows from the top of the tube.

Mature blackfin are found off the Miami coast in the spring and early summer. Several broodstock-fishing trips occurred during the Fellow's visit. Similar to the techniques employed in Panama, UMEH use either trolling lures or live bait to fish. On capture, tuna are placed head-first into the tubes and a bilge pump delivers high volumes of well oxygenated water over the tuna's gills. During the Fellow's visit, two successful fishing trips resulted in the capture of two mature fish weighing between seven and eight kilograms. Using the tuna tubes, these fish were successfully transported back to the hatchery, a distance of approximately ten nautical miles and taking approximately one hour. Although it had been intended to attempt to induce maturation of the fish at sea through the use of exogenous hormones, it was decided not to attempt this on these first fish; but rather see how well they acclimated to captivity with the minimum amount of handling and interference.

Based on the practices used in Panama, the two fish were transferred from the tuna tubes into a small tank (15 cubic metres volume, 80 centimetres deep) to enable close observation prior to stocking into the larger broodstock tank. In this tank the newly caught broodstock were offered various live and dead feeds to encourage them to commence feeding. Despite looking healthy and swimming well, the fish did not commence feeding and after 13 days and 21 days respectively, the two fish were transferred to the larger tank where it was considered they would be less stressed and therefore more likely to feed. After one week in the large tank, feeding still had not commenced and, based on the successful use of 'mentoring fish' used in Panama to promote feeding, a similar sized cobia was added to the tank.

Although the cobia fed very well and the tuna showed some interest in the live feeder fish added to the tank, they never commenced feeding and both fish died after being in captivity for approximately six weeks. The dead fish had what appeared to be large growths over their faces (see 'puffy snout syndrome' photo). Given that the tuna tubes are primarily used for keeping tuna alive to use as bait (and not for long durations), it was hypothesised that perhaps this damage was the result of the tuna 'standing on their heads' in the tuna tubes, thereby putting lethal pressure on the head.

Despite this loss, valuable lessons were learnt by the Fellow and UMEH staff. The other fishing attempts that occurred during the Fellow's visit were unsuccessful and it was therefore not possible to refine the capture and handling techniques or test the use of 'at-sea' hormone administration during his visit. The Fellow's subsequent visit to the Monterey Bay Aquarium shed some light on why these fish did not acclimate to captivity.

Figure 15: Puffy snout syndrome

The Monterey Bay Aquarium

Contact: John O'Sullivan, Head of Collections

The Monterey Bay Aquarium is one of the most renowned public aquariums in the world and they display both large yellowfin and pacific bluefin tuna. Although not an aquaculture facility, staff at the aquarium have the demonstrated skills required to effectively transport large tuna over long distances.

The Fellow met with John O'Sullivan, head of collections. O'Sullivan gave a detailed tour of the aquarium's holding and quarantine facilities. The transport vessels were inspected and O'Sullivan explained in detail their collection protocols. Their tuna capture and handling techniques are very different to those used in Panama and more relevant to Western Australia. Twice a year the aquarium charters a large fishing vessel for an 11-day collection trip. The boat sails from San Diego (approximately 600 kilometres south of the aquarium in Monterey Bay) to the Baja Peninsula in Mexico.

The boat has three below-deck live wells, each approximately ten cubic metres in volume. As previously described, tuna are very sensitive to rapid changes in light and as such, light is provided to the captured fish in the wells 24 hours a day. Aquarium staff temporarily modify the live wells with a tower that ensures water does not slosh heavily in rough seas and damage the fish, but can remain open to provide light to the fish.

Figure 16a: Tower for live well

Figure 16b: Lights over the tank

The fishing grounds on the Baja Peninsula are the same as those used by Mexican tuna ranchers to purse seine large schools of yellowfin tuna for fattening in cages. The boats work together and use spotter planes to locate the schools of tuna. Several days can pass before any tuna are located but once a school is found, it can take as little as seven minutes to catch the required 40 to 45 fish for transport back to the aquarium.

Unlike Panama, tuna are caught by 'poling', whereby tuna are chummed into a feeding frenzy at the surface next to the boat using bait fish. During this frenzy the fish bite at anything and are captured with an unbaited, barbless hook on a short length of heavy line attached to a long pole. Not only does this technique have the advantage of being able to catch many fish in a short time, it also eliminates the lengthy fight that can occur during retrieval with a conventional fishing rod. This method also reduces the chance of line abrasion and subsequent damage to the fish. Fifteen fish are placed into each of the three live wells of the boat. Here they are inspected. Any fish with line damage are removed and replaced. Due to the long transport distance back to Monterey, fish are offered food immediately after capture, which they usually start taking within one to two days. This feeding technique has been found to be more successful than waiting until the fish are back at the aquarium. Delaying feeding for too long can result in the fish not feeding at all and consequently starving.

Once the required numbers of fish are on board, the boat steams back to San Diego. The trip takes approximately two days. Water is pumped continuously through the wells to provide oxygen and flush metabolites from the water. On return to San Diego, the fish are transferred to a purpose-built, live transport tank and towed by truck to Monterey Bay.

The inside of the transport truck has similar stripes to those used in the Panamanian tuna broodstock tank to prevent wall strikes. The volume of the transport tank is very similar to the live wells on the boat. As stocking density in the transport tank is maintained below ten kilograms per cubic metre, three trips are required from San Diego to Monterey to transport all 45 fish. Given that, each road trip takes approximately ten hours (one way), fish transferred in the last trip have had to remain on the boat for an additional 40 hours.

Figure 17: Transport truck

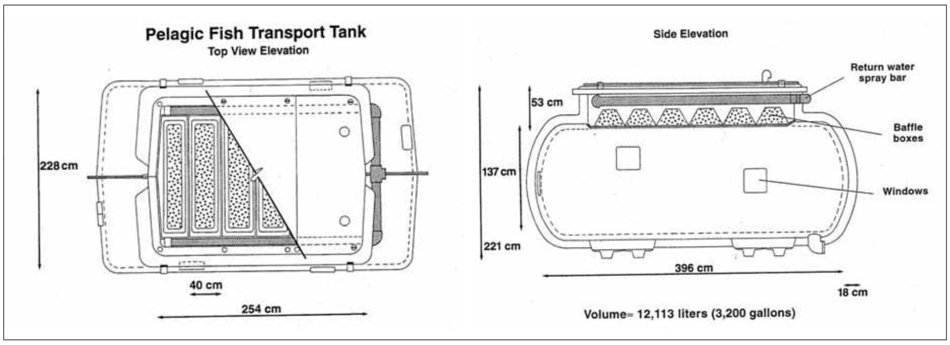

Figure 18: Schematic drawing of transport truck

During the ten-hour drive from San Diego to Monterey Bay water is not replaced. To maintain water quality it is circulated through a basic filtration system. Although tuna are fed on the boat, they are not fed in the transport tank, as this would adversely affect water quality. Water is drawn from the transport tank and pumped through paper cartridge filters (to remove particulate wastes) and is then returned to the tank via baskets of degassing media held within the lid of the tank (see 'degassing media in lid' photo). This method of water return oxygenates the water and removes carbon dioxide. Water quality probes within the transport tank send data back to the cab of the truck, enabling aquarium staff to monitor vital water quality parameters including dissolved oxygen, pH and temperature.

Throughout the capture and transport process, no drugs, chemicals or prophylactic treatments are given to the fish. Nor are any buffers or additives added to the transport water. Due to the stress-free poling technique and timely removal of suspect fish, survival rate from the trip to the aquarium is in excess of 90 per cent.

Monterey Bay Aquarium has greater success in terms of survival and adaptation when smaller yellowfin tuna (between four to six kilograms) are captured. The fishing and transport methods used by the aquarium have been used successfully on fish as large as 15 kilograms; a similar size to those found off the Western Australian coast.

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Figure 19: Degassing media in lid *Figure 20: Shallow transport tanks*

Prior to the design and construction of the large fish transport tank, aquarium staff made several unsuccessful attempts to transfer fish in a small, shallow tank (see 'shallow transport tanks' photo). When placed in this tank, fish swimming speeds increased, indicating that they were stressed. These fish did not survive. Although the live transport tank on the IATTC fishing boats is very small and shallow, these fish only remain in this tank for a maximum of two hours. The difference in transport time between the IATTC and Monterey Bay Aquarium transport protocols is believed to be the difference between the successes of transport in small tanks.

On showing O'Sullivan the photos of the blackfin tuna mortalities from Miami he immediately diagnosed them as having puffy snout syndrome, which he attributed to facial line damage. O'Sullivan has seen this many times before and believes it would not have been the cause of mortality, as fish which have developed puffy snout syndrome post-capture have previously survived in the aquarium for long periods. Based on the aquarium experience of the stress caused by shallow tanks, it was O'Sullivan's opinion that stocking the blackfin tuna in the shallow holding tank at UMEH would have led to stress that prevented them feeding and consequently caused death through starvation.

Knowledge Transfer: Applying the Outcomes

The three institutions visited enabled the Fellow to meet all of the objectives of the Fellowship. The skills required to catch, transfer, maintain and spawn yellowfin tuna in captivity were acquired and the current methods used to rear these larvae documented. Methods to significantly improve the survival and growth of these larvae were identified and described.

The skills acquired through this Fellowship would ensure that any yellowfin tuna broodstock facility that is constructed in the future would be able to obtain mature fish producing sufficient eggs to stock a commercial hatchery. Due to the very large size of the broodstock tanks and array of associated equipment, the construction of such a facility would require a significant investment in excess of $1 million.

Current survival rates of yellowfin tuna larvae in the hatchery are inadequate for commercial-scale production. During this Fellowship, significant improvements in survival and growth of early staged tuna larvae were obtained. Ingestion of micro diets by juvenile tuna was also witnessed, and contact has been maintained with a private company who has recently reported successful weaning of tuna juveniles onto an artificial diet. Regardless of these excellent achievements, knowledge gaps still exist and must be overcome to facilitate sufficient production to support commercial farming.

The application of the outcomes learnt during this Fellowship would be the development of a yellowfin tuna hatchery facility in Australia. Although there is great interest in the culture of yellowfin tuna in Australia, there is still no assurance that commercial-scale production of juvenile tuna in a hatchery environment is currently achievable and as such the significant investment funds required to construct such a facility are difficult to attract.

Since being awarded the ISS Institute Fellowship, the Fellow has been invited to be a co-investigator in a yellowfin tuna aquaculture project funded by the Federal Government's Australian Centre for International Agricultural Research (ACIAR). ACIAR commissions agricultural research between Australia and developing countries for mutual benefit. This project is based at the Gondol Research Institute for Mariculture (GRIM) in Indonesia, where a very similar facility to that in Panama was constructed in 2003. Australian industry participants interested in tuna propagation fully endorse this collaboration with GRIM as it will allow them access to the data, techniques and lessons learnt by Australian and Indonesian scientists participating in this project and will allow the refinement and further development of valuable hatchery techniques without the high cost of developing a similar yellowfin tuna facility in Australia. The outcomes from this Fellowship will therefore be implemented in this collaborative project with the aim of transferring these techniques to Australian industry. Success in large-scale larval rearing at Gondol would provide a high degree of confidence that a similar yellowfin tuna facility would work in Australia.

A copy of this report will be sent to all Australian hatcheries (both government and private) and companies interested in the propagation of tuna species, as well as the National Aquaculture Council (NAC), Aquaculture Development Council (ADC) and the Aquaculture Council of Western Australia (ACWA). The knowledge has already been transferred to staff at the Aquaculture Development Unit through a series of discussions and slideshows.

Research conducted during this Fellowship on the effects of photoperiod on growth and survival of yellowfin tuna were highly significant and represent a major breakthrough towards the development of commercial juvenile production. The Fellow has subsequently been invited to present these findings at a number of upcoming events.

Knowledge Transfer: Applying the Outcomes

The Fellow is an invited speaker at the Second Global Centre of Excellence Symposium of Kinki University on 'Sustainable Aquaculture of the Bluefin and Yellowfin Tuna – Closing the Life Cycle for Commercial Production', being hosted by the South Australian Research and Development Institute in Adelaide in December 2009 and attended by tuna researchers worldwide. At this symposium Dr Partridge presented these research findings as well as an overview of the potential for yellowfin tuna culture in Western Australia. The extended extract relating to this presentation (and which refers to this Fellowship report) is given in Attachment 2.

Dr Partridge has also been invited to present the findings of this Fellowship at the World Aquaculture Conference in San Diego in March 2010. The latter meeting has a dedicated tuna aquaculture session and will be attended by both industry and academia from around the world. In addition, the bi-annual Australasian Aquaculture Conference is to be held in Hobart, Tasmania in May 2010, giving Dr Partridge the opportunity to present this important data to Australian industry and scientists.

Recommendations

Government

The Australian Government has a demonstrated interest in tuna propagation and culture, as evidenced through investments by the Fisheries Research and Development Corporation and the Australian Centre of International Agricultural Research. This Fellowship will help to underpin this investment by adding the necessary skills to further advance Australian understanding of tuna propagation and culture. Government at all levels must take every opportunity to assist industry to keep abreast of the latest developments and techniques in tuna propagation so that informed decisions can be made regarding the establishment of commercially viable hatcheries.

Recommendation: That the Australian Government maintains its support and investment in the ACIAR yellowfin tuna project in Indonesia.

The Government of Western Australia has an interest in developing a yellowfin tuna aquaculture industry. The Aquaculture Development Council (ADC) of Western Australia is developing a strategy for an offshore aquaculture industry in this state and has conducted feasibility analyses for culturing mulloway and yellowtail kingfish in such systems. The ADC acknowledge that the culture of higher-value species in such systems would improve their profitability and have subsequently maintained a watching brief on yellowfin tuna aquaculture and have supported the Fellow in acquiring the skills required to develop this species as an aquaculture candidate in Western Australia.

Recommendation: That the ADC undertake a cost-benefit analysis of culturing yellowfin tuna in offshore aquaculture systems and compare their profitability against mulloway and kingfish. Continue to keep abreast of all developments relating to tuna aquaculture.

Industry

Clean Seas Tuna are the only industry participant in Australia growing southern bluefin tuna.

Recommendation: That Clean Seas Tuna investigate the potential of using the techniques described in this report for improving larval survival and growth of this tuna species.

Education

The skills obtained during this Fellowship are relevant to several Australian Skills Training packages.

Recommendation: That the findings detailed in this report be incorporated into the following TAFE courses and units:

Course: Certificate IV in Seafood Industry (Aquaculture) (SFI40104)
Relevant Unit: Operate Hatchery (SFIAQUA404B)

Course: Diploma of Seafood Industry (Aquaculture) (SFI50104)
Relevant Unit: Develop and implement an aquaculture breeding strategy (SFIAQUA502B)
Relevant Unit: Plan and design stock culture systems and structures (SFIAQUA508B)

Course: Graduate Diploma in Marine Hatchery Management (9642)
Relevant Unit: Undertake commercial larviculture practices for marine finfish (57344)
Relevant Unit: Manage intensive fish production (57345)
Relevant Unit: Design a marine hatchery (57346)

Recommendations

ISS Institute

Propagating tuna in an artificial environment is essential to saving wild stocks as well as being able to meet growing consumer demand for tuna. Propagating tuna is, however, a relatively new science. Work conducted to date has demonstrated the need for different skill sets in rearing tuna larvae compared to other species of cultured marine fish.

Recommendation: That the ISS Institute continues to seek international opportunities to acquire and/or develop the unique skills required for culturing tuna. Obtaining these skills in a timely manner will ensure the Australian tuna aquaculture industry will remain globally competitive.

That ISS Institute seek funding support from the Fisheries Research and Development Commission to provide further ISS Institute Fellowship opportunities that will enhance the Australian skill base in tuna propagation.

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Attachments

Attachment 1

THE EFFECT OF A 24-HOUR PHOTOPERIOD ON THE GROWTH AND SURVIVAL OF PRE-FLEXION YELLOWFIN TUNA (*Thunnus albacares*) LARVAE.

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Low survival of hatchery reared tuna larvae currently constrains the growth of tuna farming worldwide. Survival rates of <0.5 per cent to weaned juveniles are typical and high mortality during the first 10 days has been identified as one of the major limiting factors to their mass culture.

In an attempt to improve the early survival of tuna larvae, a series of three trials investigating the effects of extended photoperiods on growth and survival of pre-flexion yellowfin tuna (*Thunnus albacares*) larvae were conducted at the Inter-American Tropical Tuna Commission, Achotines Laboratory in Panama. During the first two trials, treatment tanks were illuminated with 150 lx for 12 hours followed by a 12-hour phase, during which the light intensity was reduced to 44 lx. Survival of larvae under this regime was 2–3 times higher than those in the control treatment of 12L:12D; however, the differences were not significant. There was also no significant difference in larval growth between treatments. A third trial subsequently compared the growth and survival of larvae reared under a 24-hour photoperiod with a light intensity of 150 lx maintained throughout the night, against those exposed to the control photoperiod of 12L:12D. Larvae reared under a 24-hour photoperiod achieved a nine-fold improvement in survival and were significantly larger (22 per cent) than those reared under the control lighting regime. Results suggest that the success of a continuous photoperiod is due to the extended foraging time combined with the prevention of mortality caused by night-time sinking.

Attachments

Attachment 2

YELLOWFIN TUNA (*THUNNUS ALBACARES*) AS A CANDIDATE FOR AQUACULTURE IN WESTERN AUSTRALIA.

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Introduction

The state of Western Australia (WA) is the largest in Australia, with over 12,000 km of coastline and a climate ranging from cool temperate to tropical. Despite such a long coastline, appropriate sites for marine fish culture (both land-based and near-shore) are limited due to a range of factors including isolation or competing interests, large pumping heads and exposed coastlines. For these and other reasons, including government licensing and site permitting processes, marine finfish aquaculture in this state has been slow to develop.

In recent years, the WA Government has been taking steps to provide more certainty in the approvals processes involved in establishing aquaculture ventures, and pioneering industry groups have succeeded in identifying suitable sites and commenced production of marine finfish. Two industry groups have demonstrated an interest in the culture of yellowfin tuna, due to its very rapid growth rate and it being highly regarded as a sashimi fish. This interest is shared and supported by the WA Government, which has invested in acquiring the knowledge required for developing off-shore cage culture and hatchery-based technology for this species.

Industry

Latitude Fisheries

Latitude Fisheries is a Geraldton based family fishing company that has been fishing for rock lobster, prawns, demersal fish, tuna and swordfish for the past 30 years. In recent years Latitude Fisheries has expanded into pearl oyster and finfish aquaculture. In 2004, in partnership with a second local fishing company, WT Newbold, it secured an 800 ha marine finfish site in the Zeewijk Channel of the Abrolhos Islands, an established base for the rock lobster fishery 70 km off the coast of Geraldton. This site was originally issued with an aquaculture licence for yellowfin tuna.

After an extensive environmental impact assessment, the proponent was granted a one-year trial licence from the Environmental Protection Authority (EPA). During this period, 200 tonnes of yellowfin tuna were to be ranched using a similar model to that used in Port Lincoln (South Australia) for Southern bluefin tuna. Up to 200 tonnes of fish were to be purse seined at the fishing grounds off Exmouth and towed approximately 750 km to the site before being transferred to sea pens where they would be conditioned for up to seven months. During this trial, environmental impacts were to be carefully monitored and used as the basis for assessing future commercial expansion.

Attachments

Permitted aquaculture lease area in the Abrolhos Islands.

Despite EPA approval, the trial did not proceed due to various economic factors, which made the cost and risks of purse seining the initial biomass too high. The site licence has since been modified to include southern bluefin tuna and other marine finfish that can be produced in the hatchery, including mulloway and yellowtail kingfish. Mulloway are currently being used as test candidates for both assessing the environmental impact and investigating the logistics of operating a marine fish farm at the Abrolhos Islands.

Marine Produce Australia

Marine Produce Australia (MPA) has been producing saltwater barramundi at its 699 ha site in Cone Bay off the northwest coast of Australia since 2005. Production in 2010 and 2011 is set for 1000 tonnes and 1800 tonnes, respectively. The company is applying for a further 300 ha of lease area within two other nearby bays and considering expanding into an open ocean site west of Broome. Given the suitably warm water temperatures in this region, MPA is very interested in pursuing yellowfin tuna aquaculture and has also supported the WA Government's initiatives to acquire the necessary skills to enable commercial-hatchery production of juvenile yellowfin tuna.

Both companies believe that, for a sustainable tuna aquaculture industry to develop, knowledge must be acquired to enable juveniles to be produced from a hatchery. Consequently, they support WA Government initiatives being undertaken to obtain this knowledge.

State and Federal Governments

Aquaculture Development Council

The Aquaculture Development Council (ADC) is an advisory body to the Western Australian Minister for Fisheries. It has been instrumental in improving the licensing and permitting processes for finfish aquaculture and taken several other initiatives to encourage the development of marine finfish aquaculture industry in the State. For example, due to the aforementioned shortage of suitable near-shore sites, the ADC has actively investigated the economic feasibility for development of an offshore aquaculture industry. Economic modelling has suggested that such an industry would be profitable based on those species for which hatchery-produced juveniles are available, but the ADC also acknowledges the culture of faster growing and more valuable species, such as yellowfin tuna, would further increase the profitability of such an industry. As such the ADC, along with the Department of Education, Employment and Workplace Relations (DEEWR) and the Aquaculture Development Unit (ADU), have invested in obtaining the skills required to achieve the goal of hatchery production.

Aquaculture Development Unit, Challenger Institute of Technology

The Aquaculture Development Unit (ADU) is a Government training and R&D facility. The ADU has a large marine finfish hatchery and undertakes research and development projects for WA industry and the state. Currently operating as the WA hatchery for mulloway, yellowtail kingfish, snapper and emerging species for restocking, it has infrastructure and personnel capabilities for the future culture of yellowfin tuna.

International Specialised Skills Institute (ISSI)

In 2008, Dr Partridge was awarded a Fellowship from the ISSI, sponsored by the Department of Education, Employment and Workplace Relations (DEEWR). The aims of this Fellowship were to acquire the skills necessary to develop a hatchery capability for yellowfin tuna in Australia and identify the current bottlenecks to commercial-scale production of the juveniles of the species. To achieve this goal an international tour was undertaken to Panama and the United States of America. A detailed report on the findings of this Fellowship can be obtained from Dr Partridge.

Australian Centre for International Agricultural Research

In collaboration with the South Australian Research and Development Institute (SARDI), the Aquaculture Development Unit and Western Australian industry participants are involved with the yellowfin tuna propagation project at the Gondol Research Institute for Mariculture (GRIM) in Indonesia, funded by the Australian Centre for International Agricultural Research (ACIAR). ACIAR commissions agricultural research between Australia and developing countries for mutual benefit. Australian industry participants interested in tuna propagation fully endorse this collaboration with GRIM as it provides them access to the data, techniques and lessons learnt by Australian and Indonesian scientists participating in this project and will allow the refinement and further development of valuable hatchery techniques without the high cost of developing a similar yellowfin tuna hatchery in Australia. The outcomes from the Fellowship will be implemented in this collaborative project with the aim of transferring the techniques to the Australian industry. Success in large-scale larval rearing at GRIM would provide a high degree of confidence that a similar yellowfin tuna facility would work in Australia.