Fisheries Newsletter

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In the Pacific Islands region, domestic tuna fleets targeting albacore are in trouble and many boats are at anchor because of low catches and lack of profitability (see PITIA's article on p. 29). In 2012, scientific studies, based on data collected through 2010, showed that South Pacific albacore stocks were healthy and the level of fishing sustainable. But, as Graham Pilling explains in his article on page 9, there was one more essential component in the conclusions of this assessment: "despite the health of the albacore population, any increase in catches (even within sustainable levels) is predicted to have a significant impact on the catch rates in the longline fishery." Despite the warning, more boats have been allowed to enter the fishery and albacore catches have increased by more than 30% between the periods 2001–2008 and 2009–2012. Consequently, many domestic fleets, which are not heavily subsidised, are now in trouble. An obvious remark can be drawn from this situation: without proper management, healthy stocks don't necessarily mean healthy fisheries.

As shown in several articles in this issue, scientists keep exploring many corners of the tuna world: they read in their entrails (p. 5), they use forensics to unlock their mysteries (p. 7), they tag them by the hundreds of thousands (p. 11) and they study the possible impacts of the predicted increased ocean acidification levels on their population (p. 43). The better a resource is known, the better it can be managed. But it will only be well managed if the will to do so is genuine.

Aymeric Desurmont
Fisheries Information Specialist (aymericd@spc.int)

Atauro fishers, in Timor-Leste, start their relationship with the sea at a very young age (image: Michel Blanc).

Secretariat of the Pacific Community

Prepared by the Information Section, Division of Fisheries, Aquaculture and Marine Ecosystems

Is aquaponics viable in the Pacific Islands?

Fish and vegetable production by aquaponics is grabbing more attention these days among SPC member countries and territories in the Pacific Islands. Because there is not yet much of a track record of experience with aquaponics under our own local conditions, it can be difficult for people not familiar with the subject to separate fact from fad and make sound decisions about it. SPC convened a meeting of experts and representatives of interested Pacific Island countries and territories in October 2013 that aimed to collate experiences to date and find out whether aquaponics can indeed move from a nice idea to an actual industry in the insular Pacific.

But first, what is aquaponics? Here's the short answer: it's a polyculture system in which three groups of organisms — fish, vegetables and nitrifying bacteria — are grown in water that is re-circulated in an enclosed tank system (see Fig. 1). Fish excrete nitrogenous waste (mainly as ammonia), but plants need nitrogenous compounds (mainly nitrate) as their fertiliser. Nitrifying bacteria provide the link between fish and plants, by converting ammonia from the fish into nitrate for the plants. This makes aquaponics a pro-biotic system where "friendly" bacteria are encouraged.

This sounds deceptively simple and appealing. So much so, that aquaponics is creating a lot of interest in the Pacific, particularly in places where traditional soil-based agriculture or fish farming is difficult. Imagine the advantages for many Pacific Island locations of a soil-less agriculture system that is unaffected by sea-level rise, drought, and salty or sandy soil conditions; conserves fresh water and nutrients by recirculating them; and grows crops intensively in a small land area.

Balanced against these advantages, however, is the sizeable cost for the materials to build an aquaponics system, followed by an ongoing need for reliable electricity and fish food to operate it. The system needs daily checks and adjustments to keep everything running well and to rapidly fix any breakdowns.

Because of the increasing interest but lack of information about Pacific Island aquaponics, SPC's Aquaculture Section in 2013 convened a regional Aquaponics Expert Consultation in Cook Islands to gather information to answer several questions: Can aquaponic food production systems be viable in a Pacific Islands context? What should be the best form or size of such systems, in order to be successful? What gaps in knowledge need to be filled to take aquaponics to the next level?

Hosted by the aquaponics public–private partnership of Te Raurau o Te Kaingavai and Ministry of Marine Resources at Titikaveka on Rarotonga, the meeting first focused upon purely commercial approaches to aquaponics. We heard from economist John Hambrey, engaged by the New Zealand Ministry of Foreign Affairs and Trade to review the current status of the global aquaponics industry, that large industrial-scale aquaponics ventures are not very common. Those that do exist (there are three in Hawaii) were founded not purely to make money, but rather to make "sustainable food". They succeed as businesses only by clever niche marketing that allows them to sell the products at a high price. Their founders chose aquaponics not because it is the most cost-effective production method, but because it conforms to their personal philosophy about how food ought to be grown in the future. A major consideration here is the pesticide- and chemical-free nature of aquaponics food products. Aquaponicists simply cannot treat plant pests with anything toxic, because to do so would harm the fish and the nitrifying bacteria.

In addition to selling vegetables and fish, many of the bigger ventures depend heavily upon income from selling start-up equipment and offering training to those getting started in aquaponics. However, there are lately signs of a backlash by customers against aquaponics experts whose main business is selling aquaponics gadgets — it is not easy to be commercially successful by purchasing any of the expensive off-the-shelf systems. In fact, it is difficult to think of any equipment for a backyard aquaponics system that cannot be purchased locally from a regular hardware store or scavenged.

Investment in large-scale commercial aquaponics needs to be weighed against hydroponics, which is the obvious alternative soil-less agriculture system. Hydroponics produces only plants (a monoculture), so it does not have the complication and added risks of a polyculture system with fish, bacteria, biofilters, and so on. A decade or so ago, hydroponics was risky and speculative. But now it is a mature and well understood technology that works quite well, daily tasks are largely automated, and it is big business.

To the committed aquaponicist however, hydroponics is "antibiotic", while aquaponics is pro-biotic. Hydroponicists usually use pesticides to control bugs, and supply plant nutrients as industrial chemical mixes. At regular intervals, all water must be dumped from the hydroponic system so that everything can be carefully sterilised with antiseptic before the system is re-filled. Aquaponicists also claim that the quality and taste of their vegetables is superior to those grown by hydroponics, and the shelf life is longer.

But aquaponics needs more time, more skills and dedication, and more frequent management interventions, to maintain the balance of culture conditions. The interdependency of fish, plants and bacteria greatly limits options for pest and disease management. Aquaponics systems are more complicated and require more investment, and operational costs are high (mainly for energy and labour). Aquaponics has a lot more variables than hydroponics, and therefore has more risks.

This type of hard-headed economic analysis is not deterring people from engaging in aquaponics, however. It appears that the increasing amount of interest in aquaponics is not being driven purely by money. Just as for hydroponics, clearly aquaponics is an industry whose time will come. But right now, finding the rationale for aquaponics requires considering other factors.

What is the relevance of aquaponics to the Pacific? There was much discussion about this among the meeting participants. Before getting started in aquaponics, you have to know WHY you are doing it. Only then can you decide what to do, and whether it is worth it. This is very much a personal decision. Whether or not aquaponics is the best method to meet your objective will vary from place to place.

In some Pacific locations, we don't have water or soil. If you live in a "desert" environment, like on an atoll, aquaponics is an easier way of growing plants than trying to make compost and build up soil in sandy or salty conditions. Where all else fails, there is a place for aquaponics. You can even grow plants in outer space by aquaponics.

The notion of "food miles", or considering the distance that your food has traveled when shopping, is becoming increasingly relevant. Already the Pacific has chefs who prefer to buy local rather than from the continental Pacific rim, and who don't mind paying extra for a smaller carbon footprint plus added freshness. This is niche marketing that commands a high price. A premium for locally-grown produce is a competitive advantage that Pacific aquaponics should pursue.

But remember, the key to such marketing is this: Don't start with aquaponics. Start with the market. Then ask yourself — does the local market make aquaponics

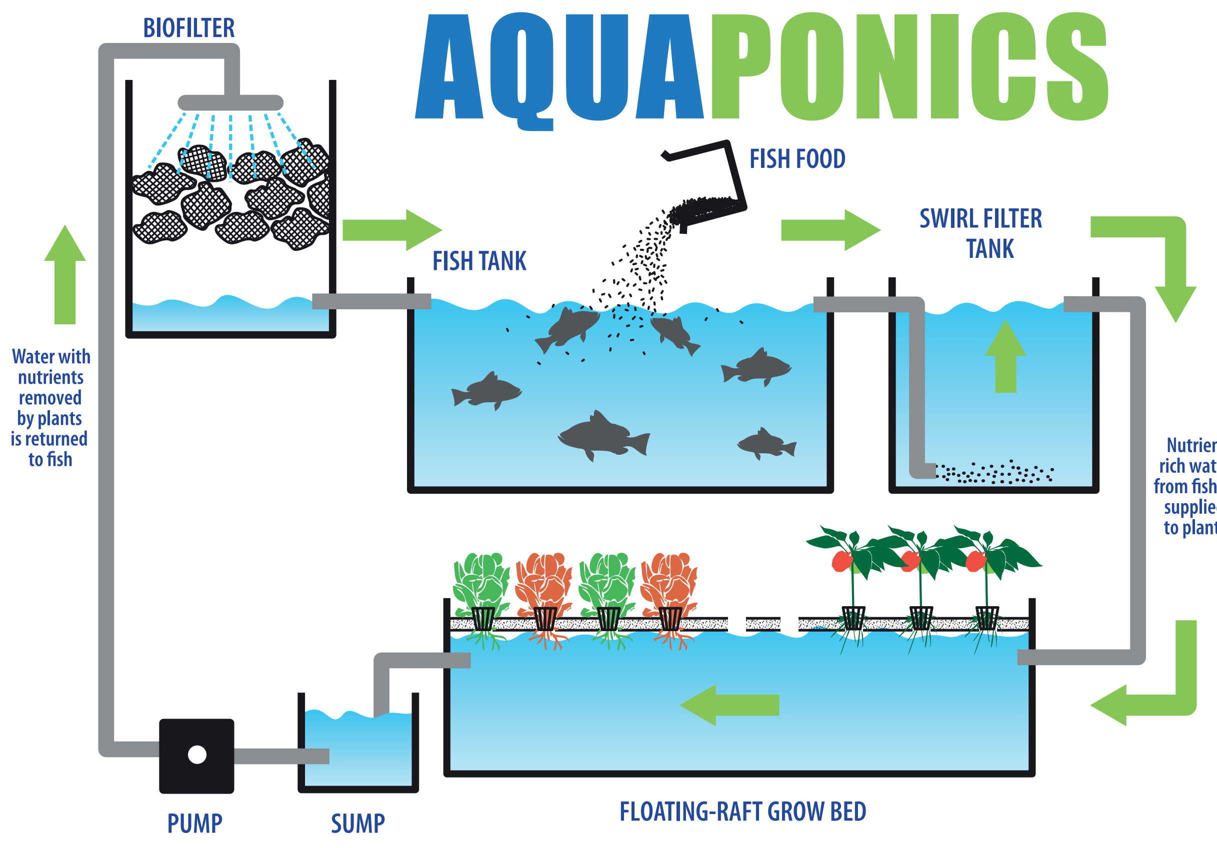


Figure 1. Schematic diagram of a typical aquaponics system

attractive? Do your sums *before* you head off to the hardware store!

While food miles and the lack of water and soil are both valid commercial drivers for Pacific aquaponics, by themselves they do not explain the fact that most aquaponics systems are small-scale systems in urban areas. Such aquaponics farms, run by backyard urban farmers, cannot hope to compete on price with industrialised organic agriculture, yet they are being established. Why?

The answer is that "backyard" is not the same as "commercial". There are other reasons to be an urban farmer aside from making a profit. Aquaponics can be fun and satisfying. The goal can be saving money (rather than earning money) and better health. Larry and Patty Yonashiro shared with the meeting their post-retirement experiences of becoming backyard urban farmers growing pak choi in a very sandy and infertile part of Molokai, Hawaii. They feel that this is the way good food ought to be produced. They are determined to demonstrate the economic, social and nutritional benefits of "growing local" through urban networks of backyard farmers, each specialising in particular crops and trading amongst themselves.

Then there are non-monetary benefits, such as food-safety, which extend beyond money to networking, community empowerment, and revival of past traditions. Recent Hawaiian experiences in places like Waimanalo were shared by Leina'ala Bright, whose approach to aquaponics is from a standpoint of maintaining community links and preserving traditional knowledge about Hawaiian medicinal plants. The benefits of backyard aquaponics to the 50+ participating households in Waimanalo are more than just nutritional. There are community, spiritual and wellness benefits. Backyard aquaponics is an absorbing pastime with tangible social benefits. It increases social ties and restores self-esteem — vital factors that lead away from the path to crime and drugs in urban settings. These findings tie in with the documented experiences of urban agriculture and community garden projects in places like New York City, where participation has been linked to a lessening of aggressive and anti-social behavior.

Schools are finding that an aquaponics system is a wonderful hands-on learning tool. It is a self-contained microcosm to demonstrate the water and nutrient cycling principles of natural ecosystems, in addition to fish husbandry and plant cropping. Learning institutions in Hawaii, American Samoa, French Polynesia and Fiji have already established demonstration aquaponics systems for educational purposes.

Leina'ala Bright's own specialisation is growing traditional medicinal plants, such as *ko'oko'olau* (*Bidens pilosa*) for treatment of diabetes, through aquaponics. She has demonstrated increased effectiveness of some medicines when produced by aquaponics. Her advice is to not worry about aquaponics being a business. Just do it! Small-scale aquaponics can be very rewarding, and the benefits cannot all be measured in terms of money.

There is no universal answer to the question "Is aquaponics worth doing?" First decide what your objective is. Then, and only then, consider aquaponics, simply as one of a range of options that might help you reach that objective. It will never be a magical solution to all problems of food security in the Pacific. But aquaponics seems sure to have an increasingly important role.

For more information:

Tim Pickering
Inland Aquaculture Specialist, SPC
timp@spc.int

Figure 2.
Participants at the aquaponics meeting at Te Raurau o Te Kaingavai are guided by Brad Fox (third from right) and Leina'ala Bright (fourth from right) of University of Hawaii in the construction of a "barrel-ponics" system. This type of aquaponic system is not even "backyard" scale, it is "backdoor" scale!

Oracles read climate impact in tuna entrails

Experts from the four corners of the globe gathered in Adelaide, Australia, from 14 to 18 October 2013 to assess the climate's impact on the ocean ecosystem. They had the hard task of predicting the future in animal entrails. Although very fashionable in ancient Rome, such predictions were quite unreliable when all was said and done. Our experts were true scientists, though, and were armed with new statistical tools developed to improve analyses and predictions based on the stomach contents of tuna and other large pelagic fish, such as swordfish and mahi mahi.

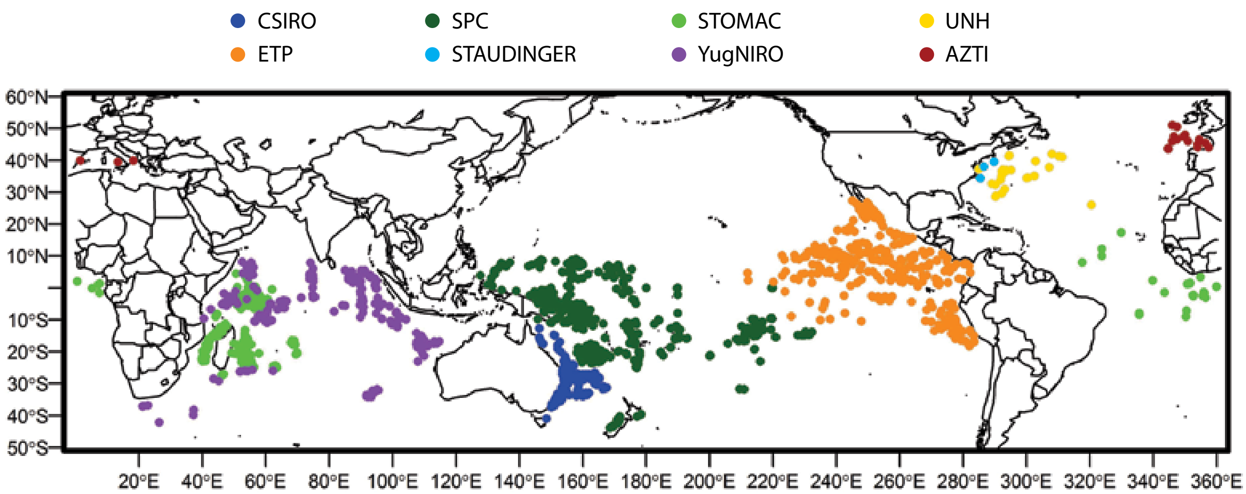
So what is the point of examining tuna stomach contents?

Tuna are what is known as generalist feeders. In other words, they eat whatever comes their way, making them excellent sentries of the marine environment in the open ocean.

The vast ocean expanse is difficult to explore; considerable amounts of staff, time, ships and money would be required to do so. But tuna roam the oceans tirelessly, eating whatever they find and so sample the small fry, crustaceans and squid for us. Fishers catch the tuna and all the teams of scientists need do is take the stomachs and see what is in them. It is no easy job, but it is a way of observing scarcely explored parts of the ocean.

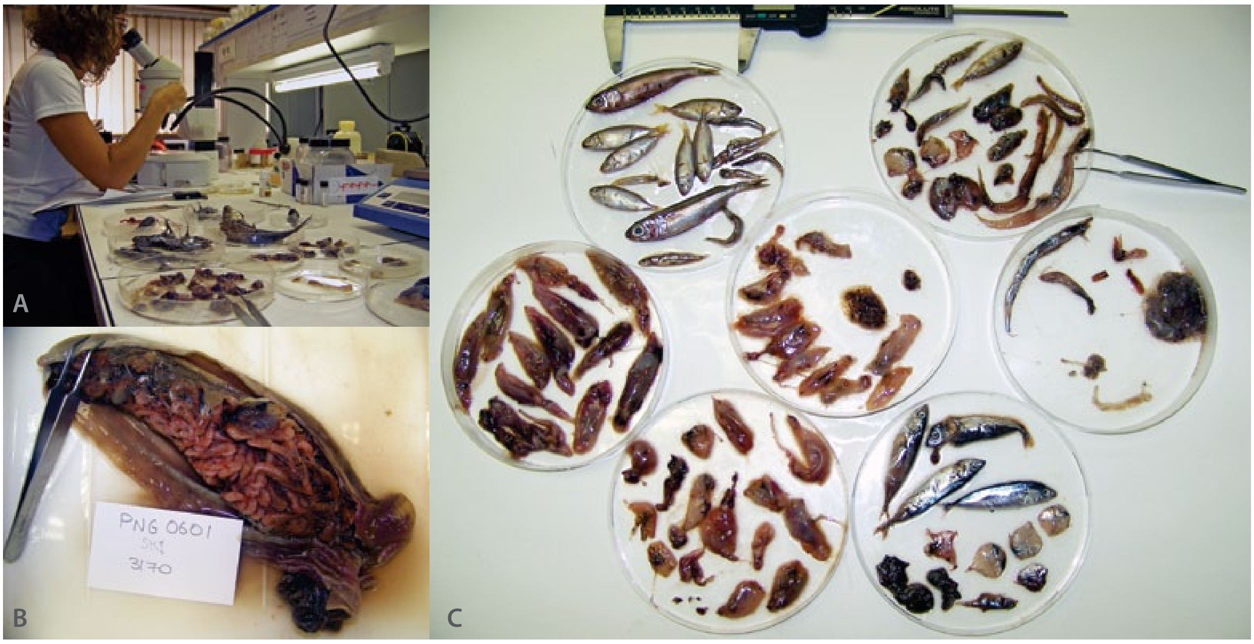
By examining the stomach contents of fish that live in different oceans and climates, we are better able to understand the impact the environment has on tuna and their prey. Very valuable information is collected on the effects that climate change has, not just on tuna, but on the whole ocean food network, which is still quite unknown even though the entire tuna industry depends on it.

It is a gargantuan task that cannot be accomplished by a single individual. So through the combined efforts of eight research organisations around the world, details about the stomach contents of nearly 22,000 fish have been pooled into a single database, paving the way for a whole host of studies. SPC is the largest contributor to the global database, with more than 7800 stomachs examined by our laboratory technicians. We would like to take this opportunity to acknowledge the tuna



Distribution of samples by Project

CSIRO:	*Commonwealth Scientific and Industrial Research Organisation, Australia*
SPC:	*Secretariat of the Pacific Community, New Caledonia*
STOMAC:	*IRD database, Institut de Recherche pour le Développement (Development Research Institute), France*
UNH:	*University of New Hampshire, USA*
ETP:	*IATTC database, Inter-American Tropical Tuna Commission, USA*
STAUDINGER:	*University of Massachusetts, Amherst, USA*
YugNIRO:	*Southern Scientific Research Institute of Marine Fisheries and Oceanography, Ukraine*
AZTI-Tecnalia:	*Centro tecnológico especializado en investigación marina y alimentaria, Spain*



A: *Sorting and examining the prey found in a tuna stomach (image: SPC).*

B: *Opened stomach of a skipjack collected in Papua New Guinea showing the predator has been feeding on small shrimps (image: Caroline Sanchez, SPC).*

C: *Mix of small partially digested squids and fish found in a tuna stomach (image: Caroline Sanchez, SPC).*

fisheries observers from all the countries in the region who collected such samples.

Pooling the data is a major achievement in itself, because such a level of cooperation covering the globe's three great oceans — the Atlantic, Indian and, largest of all, the Pacific — is very uncommon. The sample distribution map speaks for itself and clearly shows the scope of the work.

The other achievement of the expert meeting was the product of years of hard work, particularly by Commonwealth Scientific and Industrial Research Organisation (CSIRO) Adelaide statistician Petra Kuhnert from Australia and Inter-American Tropical Tuna Commission (IATTC) La Jolla fisheries biologist Leanne Duffy from the US who, together with the other experts attending, developed and tested a statistical tool that was particularly appropriate for this extraordinary database. It was a regression-tree classification method for multivariate data such as those on stomach content. The measure was not new, but what was original about the new approach was that it provided predictions about diet and uncertainty calculations. Developed in R, the new package is simply called Diet and will soon be freely available to and usable by all to analyse stomach content data and other data sets in the same, multivariate data format.

During the week of discussions in Adelaide, some interesting initial results were revealed. For example, a very clear pattern had emerged showing that albacore tuna juveniles prefer rich areas like the Bay of Biscay in Europe or New Zealand where they feed on one or two main prey, such as krill, that are plentiful in colder waters. Adults, on the other hand, were shown to hunt in warmer but poorer tropical waters, where they have to greatly vary their diet by eating smaller amounts of many different prey types. Bigeye tuna that live in deeper tropical waters appeared less affected by such climate differences than fish living closer to the surface. Climate change could, therefore, have very different effects depending on the tuna species considered, as the impact on their environment and the prey they feed on would be different.

Tuna stomachs still have a lot to teach us about tuna and their environment, and the marvellous data set plus the newly available statistical tools promise to reveal many more secrets yet.

For more information:

Valérie Allain
Fisheries Scientist, SPC
valeriea@spc.int

Conservation forensics help unlock tuna mysteries

Tunas are highly mobile fish that often undertake long-range movements to track food and to reproduce at distant spawning grounds. Information on these movements underpins the effective management of commercially important tuna stocks. In the case of South Pacific albacore (*Thunnus alalunga*), longstanding questions remain regarding the number and location of spawning areas, the degree of connectivity among larval sources, the migration routes of juveniles and adults and the biophysical factors influencing these processes.

To answer some of these questions, we applied a conservation forensics approach to examine the otoliths (ear bones) from albacore (Fig. 1). We collected otoliths from albacore captured across the South Pacific Ocean, in French Polynesia, New Caledonia and New Zealand. We then used a high-precision laser to measure the amount of trace elements (i.e. those elements that are present in very low concentrations such as strontium, barium and magnesium) in each otolith. By measuring the concentration of different trace elements at the edge of the otolith, which contains material deposited in the last few weeks before capture, we were able to obtain a clear chemical "signature" that was unique to each of the three locations (Fig. 2).

We then measured the concentration of trace elements in the core of each otolith, which contains material deposited in the first few weeks of life. We found that the trace elements from otolith cores sampled from New Caledonia and New Zealand were quite similar, suggesting that albacore from these locations may have originated from the same location. However, trace elements in otolith cores from French Polynesia were distinctly different from the others, suggesting that albacore from French Polynesia originate from a different location. These results provide important preliminary insights into connections between larval sources and adult populations of South Pacific albacore, and suggest that further application of conservation forensics to albacore will refine our knowledge of movement patterns and population structure for this species. The full results of this study have recently been published in *Fisheries Research*.[1]

In addition, expanding the use of conservation forensics to other tuna species will broaden our understanding of movement patterns of tuna in general, without the need for tagging fish. Extensive tagging of yellowfin, bigeye and skipjack tuna at tropical latitudes has generated a wealth of information about tuna movement patterns. However, difficulty with tagging programmes for these species at subtropical and temperate latitudes has limited our knowledge of the broader movement patterns of these species throughout their range. Applying a conservation forensic approach to the otoliths of all commercial tuna species provides the opportunity

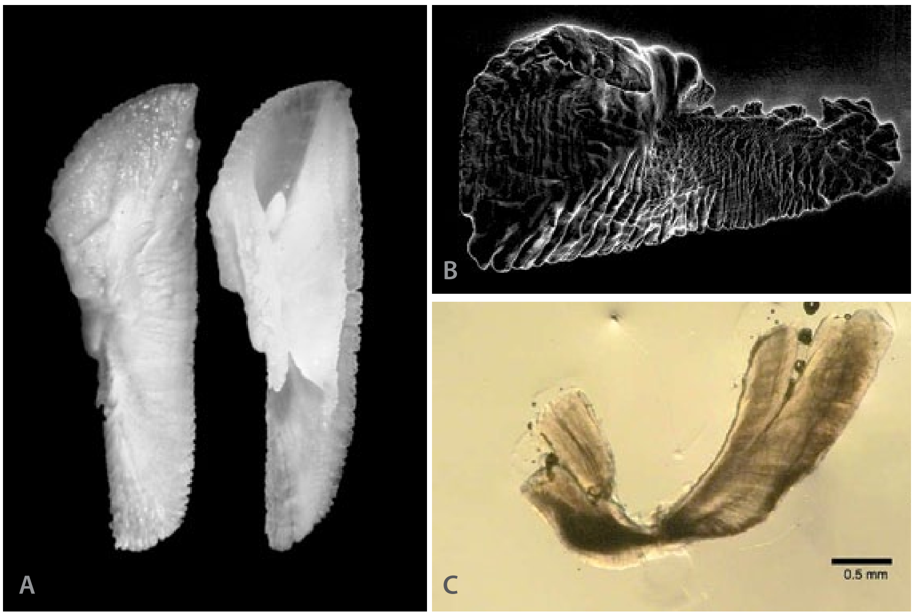


Figure 1. Whole (A and B) and transverse sectioned (C) otoliths from a South Pacific albacore.

[1] Macdonald et al. 2013. Fisheries Research 148:56–63 [http://dx.doi.org/10.1016/j.fishres.2013.08.004].

to attain a stock-wide picture of tuna movement across the Pacific Ocean. Since 2012 the Western and Central Pacific Fisheries Commission has been implementing a programme to collect biological samples from bigeye, yellowfin, skipjack and albacore tuna throughout the western and central Pacific Ocean. The samples include fish hard parts and the number of samples collected is now approaching a sufficient quantity to start a rigorous assessment of the benefits of trace element markers and other stable isotopes (e.g. oxygen and carbon) for deciphering tuna movements in the Pacific Ocean.

For more information:

Dr Simon Nicol
Principal Fisheries Scientist, SPC
simonn@spc.int

Jed Macdonald
PhD student, University of Iceland
jed@marice.is

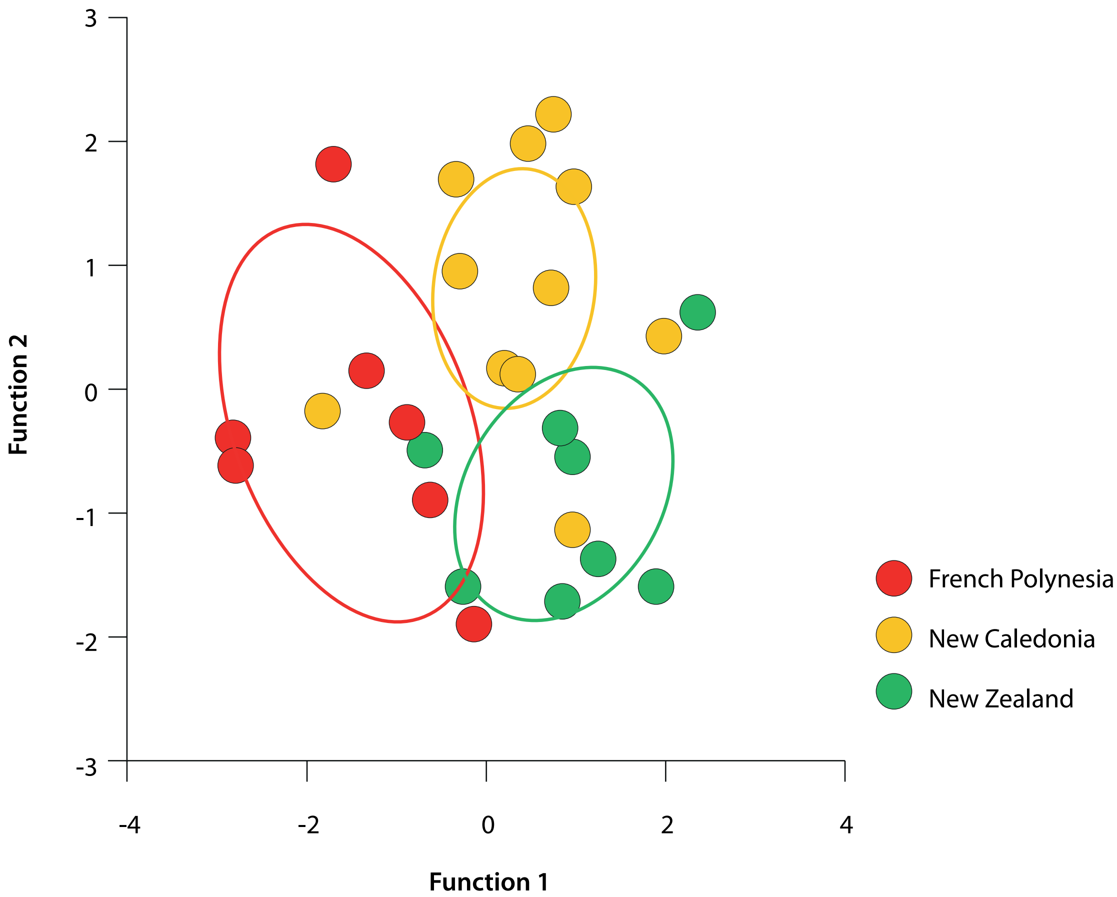


Figure 2. Discriminant function plots showing variation in trace element chemistry measured at the otolith edge among the three capture locations. Ellipses represent 95% CIs around the centroid for each location, and data points reflect the relative position of individual fish in two-dimensional space. Analyses are based on natural log transformed data.

A scientific perspective on current challenges for PICT domestic tuna longline fleets that are dependent on South Pacific albacore

Tuna longliners at anchor in Suva harbour, Fiji (image: Johann Bell).

In recent years domestic fishing fleets targeting primarily albacore in Pacific Island countries and territories (PICTs) have reported difficulties in maintaining profitability. In fact, as noted in a Pacific Islands Tuna Industry Association (PITIA) press release,[1] in the last few months many vessels based in Fiji have stopped fishing altogether and are tied up at wharves. The PITIA release notes that despite their experiences on the water, scientific stock assessments "continue to produce relatively healthy results".

The purpose of this article is to summarise some of the recent scientific analyses of south Pacific albacore. It won't discuss issues such as the prices of fish or fuel, or the mobility of fleets (which enhances or constrains their ability to follow or find fish); clearly these issues would be expected to play a large role in the profitability of individual fleets.

The key sources of scientific information are the stock assessments for South Pacific albacore. These analyses combine fishery data on catch, effort, sizes of fish, and their biology (e.g. growth and maturity) to estimate the number of albacore in the water, how this has changed through time, and what number might be caught sustainably. The last assessment for South Pacific albacore was in 2012 and used data through 2010.

There were three key findings from that assessment: (1) the estimated amount of albacore was considered large enough to keep the population healthy (more on why this conclusion was reached later); (2) the level of fishing was considered to be "sustainable" and could actually be increased while maintaining a healthy fish population; and (3) despite the health of the albacore population, any increase in catches (even within sustainable levels) was predicted to have a significant impact on the catch rates in the longline fishery.

The assessment's conclusion regarding the health of the albacore population is an interesting one and requires some background information. The most common fishing approach for catching South Pacific albacore is through longlining. This involves laying kilometres of fishing line with baited hooks into the water (Fig. 1). This fishing method tends to catch larger and hence older tuna; indeed, these fish tend to be old and large enough to have had a chance to reproduce and hence

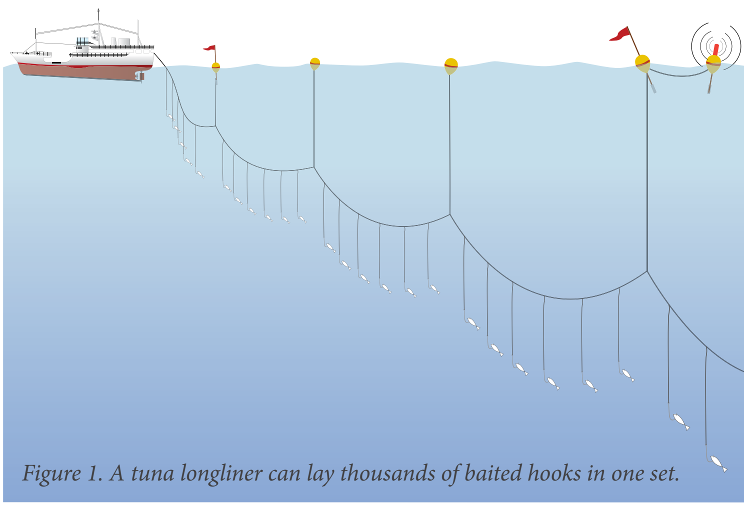


Figure 1. A tuna longliner can lay thousands of baited hooks in one set.

[1] See article on p. 29 of this issue of SPC *Fisheries Newsletter.*

sustain the albacore population, before they are caught (Fig. 2). It is actually quite rare to find a fishery that waits until after fish have had a chance to reach reproductive age before starting to catch them!

While the pattern of fishing is good for the albacore population, it has consequences for the longline fishery exploiting it, and forms the basis of the third finding from the assessment. As longliners target the largest fish, those vessels are reliant on a relatively small part of the population, and the number of large-sized albacore decreases rapidly as fishing effort and catches increase. As a result, vessels are chasing fewer fish and for each day fishing and burning fuel, they achieve lower catches (i.e. lower catch rates in terms of catch per day) and hence lower income. Again, while this is happening there are large numbers of albacore maturing and spawning — essentially untouched by fishing.

It is telling that since its first meeting in 2005, the Western and Central Pacific Fisheries Commission's Scientific Committee has warned the commission members that any increase in South Pacific albacore catches would have significant negative impacts on domestic longline fleets, but nevertheless since 2008 there have been large increases in catches (Fig. 3). For example the annual catch in 2009–2012 was 32% higher than that in 2001–2008, and this is associated with a large influx of new vessels and fishing effort.

It will not be until the next stock assessment, which is scheduled for 2015, that we will be able to re-evaluate the biological health of the South Pacific albacore stock, but it is clear that the predictions of decreased catch rates have unfortunately occurred. Bioeconomic modeling — which expands on biological stock assessments to include considerations of the costs of fishing and the price of fish — is beginning to build a picture of the economic health of the fishery that is far less rosy than the biological one.

For more information:

Graham Pilling
Fisheries Scientist (FFA Support), SPC
grahamp@spc.int

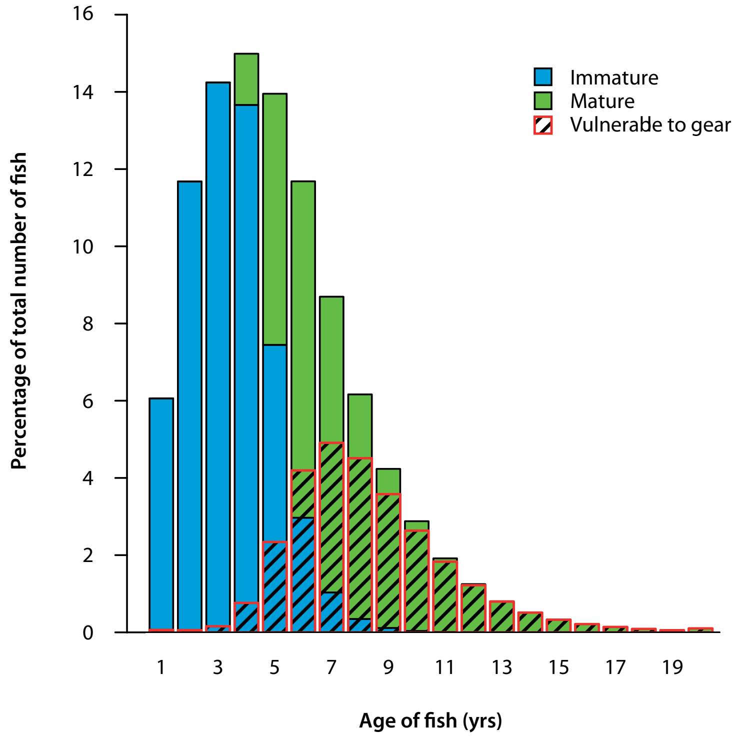


Figure 2. Percentage of the albacore tuna population vulnerable to longline gear by age, compared to the percentage of immature and mature fish.

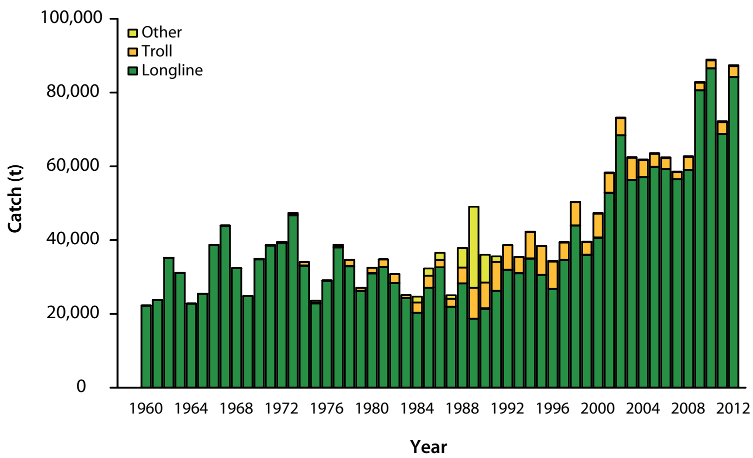


Figure 3. Albacore tuna catches in the western and central Pacific region since 1960.

100,000 tuna tagged by one individual – A world record

The tuna tagging experiments conducted by SPC's Oceanic Fisheries Programme (OFP) are acknowledged to be among the most comprehensive in the world and have recently achieved yet another milestone.

After four decades of involvement in Pacific Island tuna fisheries, Dr Antony Lewis recently achieved the mark of 100,000 tuna tagged by an individual, which is a world record unlikely ever to be surpassed. The milestone was achieved during a recent tagging cruise in Papua New Guinea (PNG) waters operating under the Pacific Tuna Tagging Project (PTTP) in collaboration with the PNG National Fisheries Authority. Dr Lewis started tagging tuna in the early 1970s, but it was during SPC's Skipjack Survey and Assessment Programme (SSAP) of the late 1970s that the numbers of tagged tuna started to accumulate. In the late 1980s and early 1990s, as head of OFP, Dr Lewis was responsible for the Regional Tuna Tagging Project, and he was recruited as technical advisor for the more recent PTTP, which started in 2006.

Tuna are highly migratory fish, which makes it very difficult to assess and monitor the health of their stocks. Approximately 60% of global tuna are caught in the Western and Central Pacific Ocean, and most of this catch comes from the waters of SPC member countries and territories. Tagging experiments are considered to be the only reliable means of obtaining some of the key information (such as movement and growth) required to conduct tuna stock assessments. SPC has been conducting large-scale tagging experiments for nearly four decades throughout the Pacific Islands.

Dr Antony Lewis

For more information:

Bruno Leroy
Fisheries Scientist, SPC
brunol@spc.int

With a deft hand, Dr Lewis quickly releases a small yellowfin tuna that he has just tagged.

New species of deepwater snapper identified from shape of ear bones

***The ruby snapper has been a prize catch for deepwater snapper fishers throughout the Pacific for many decades. But recently, we discovered that there are actually two species of ruby snapper: the ruby snapper (*Etelis carbunculus*), and the pygmy ruby snapper (*Etelis marshi*). The Ecosystem Monitoring Section of SPC's Oceanic Fisheries Programme has been working with scientists from the Western Australia Fisheries Department to develop a reliable technique to distinguish between the two species, based on the shape of their otoliths (ear bones). The results from this research have been published online in the latest issue of* Fisheries Research.[1]**

Variation in the maximum size of ruby snapper in different parts of the Pacific provided a clue that there may in fact be more than one species. So we collected fin clips from a large number of ruby snapper throughout the Pacific region for genetic analysis. Geneticists from the University of Hawaii conducted the analyses, which confirmed the presence of two distinct species.

The distribution of the two species in the Pacific is similar, but it appears that only the pygmy ruby snapper is found in Hawaii, as there have been no confirmed reports of ruby snapper. In many other parts of the Pacific, both species can be caught at the same location. Therefore, it is important for fishers to distinguish between the two species in their catch.

The pygmy ruby snapper was not identified previously because its appearance is nearly identical to the ruby snapper. So the question is, how do we distinguish between the two species without using expensive genetic analyses?

We know that the two species can sometimes be distinguished based on their size. For example, ruby snapper can reach at least 120 cm and 25 kg, whereas the largest pygmy ruby snapper is 62 cm and less than 5 kg. So we can be reasonably confident that fish larger than 70 cm are ruby snapper. But this does not help us to distinguish between species when the fish are smaller.

Preliminary research suggests that the two species can also be distinguished based on two external features: (a) ruby snapper have a black margin on the upper lobe of the caudal fin, which is absent in pygmy ruby snapper, and (b) pygmy ruby snapper have a much sharper spine on the operculum than ruby snapper (see Fig. 1).[1]

Figure 1. The ruby snapper (top) shows a black marking on the top of the caudal fin (a), which is absent in the pygmy ruby snapper (bottom); the pygmy ruby snapper has a much sharper spine on the operculum (b) than the ruby snapper.

[1] http://www.sciencedirect.com/science/article/pii/S0165783613002385

[2] See related article in issue #138 of *SPC Fisheries Newsletter* : [http://www.spc.int/DigitalLibrary/Doc/FAME/InfoBull/FishNews/138/FishNews138_04_Williams.pdf]

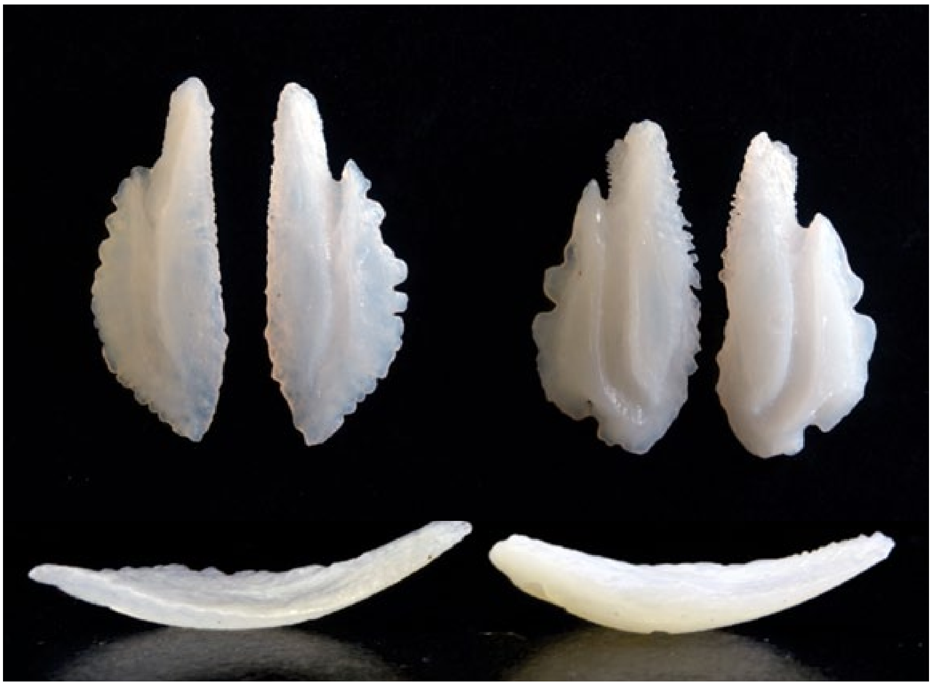


Figure 2. Top and side views of the earbones of a ruby snapper, Etelis carbunculus *(left) and a pygmy ruby snapper,* E. marshi *(right) (images: Mélanie Bunel, © SPC).*

However, both of these features can be subjective, and cannot be used if the tail and operculum spine have been damaged, which may happen during capture, transhipment or freezing. Clearly, there is a need for a more objective method to distinguish between the two species.

We examined the otoliths from ruby and pygmy ruby snapper to see if there were any consistent features that were characteristic of each species. We examined the shape and measured the length, width, thickness and weight of otoliths from both species. We found that otoliths from pygmy ruby snapper were significantly wider, thicker and heavier at a given fish length than otoliths from ruby snapper. We demonstrated that these measurements could be used in combination to predict the species identity with 100% certainty when the species was unknown.

This finding provides a reliable method for identifying ruby and pygmy ruby snapper through the collection of otoliths when it is not possible to distinguish these two important deepwater snapper species by external features.

For more information:

Ashley Williams
Deepwater Snapper Scientist, SPC
ashleyw@spc.int

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Standardising sea cucumber resource assessments in the Pacific Islands

Many Pacific Island countries and territories (PICTs) face challenges in assessing and managing their sea cucumber fisheries and have requested that SPC provide resource assessment training, advice on management measures and harvest strategies, and assistance with formulation of national fishery management plans and associated regulatory measures. Limitations in existing measures to effectively control sea cucumber fisheries are at the root of the challenge faced by many Pacific Island sea cucumber fisheries managers. They may also find it hard to decide on appropriate measures because information is not available or inadequate to understand the resource. This, however, has begun to change with improved information collection by countries and use of this information to develop advice on ways forward.

Assessment surveys and reporting

Training assistance offered to PICTs in the last three years has begun to bear fruit. Ten PICTs (Cook Islands, Federated States of Micronesia [Pohnpei], Fiji, Marshall Islands, Palau, Samoa, Solomon Islands, Tokelau, Tonga and Vanuatu) have adopted and used the improved invertebrate resource assessment protocols proposed by SPC to improve resource information gathering and use. Combining the use of transect surveys in shallow waters (0–3 m) (Fig. 1a) and manta tow surveys over shallow lagoons (2-10 m) (Fig. 1b) is proving to be an effective way of assessing invertebrate resources. The simplicity and cost effectiveness of these methods make them a better option for resource-limited fisheries agencies as well as non-governmental organisation (NGO) partners in the Pacific Islands. Details of the sampling methodologies are provided in an invertebrate manual that will be soon published by SPC (SPC in press).

Bringing officers to Noumea for further training has been helpful in allowing trainees to focus on their reports during their two or three weeks at SPC. So far more than 20 fisheries officers and two officers from NGO partners have benefitted from attachment training and a further 88 people have been trained

A

B

Figure 1. A: Reef transect surveys and B: manta tow surveys. (Illustrations by Youngmi Choi, pictures by Kalo Pakoa.)

in-country. In Noumea, trainees learn to use the reef fisheries integrated database (RFID) to process their data and extract summaries required for reporting and preparing advisory sheets. The database has been provided to fisheries departments and is being used to process new survey information. Through these attachments, trainees were able to understand species diversity, densities and population structure in an area and determine how healthy their resources are based on the existing reference densities for healthy abundances (SPC in press) and regional mean sizes of species (Purcell et al. 2008). Where available, catch and export information is cross-examined with resource information to better visualise resources' behaviour to fishing pressure or management interventions.

While stock estimates are the ultimate aim of these assessments, it is more meaningful to provide this information for a healthy stock (high species abundance and high proportion of mature fishable stocks). The final results of the assessments and recommended management measures are presented in national sea cucumber reports. The first five of these reports — for Cook Islands, Fiji, Samoa, Tokelau and Tonga — have been completed. These reports can be downloaded from the SPC website (http://www.spc.int/fame/en/projects/scicofish/activities/202-the-status-of-sea-cucumber-resources-in-cook-islands-fiji-and-samoa). The report for Vanuatu will be posted to the same website soon, and reports for Solomon Islands, Palau and Pohnpei are expected to be released during the second quarter of 2014.

The use of the improved sea cucumber resource survey protocols has increased. Between August 2010 and December 2013, new surveys were completed in 10 PICTs covering 42 islands, 63 sites (Table 1) and over 1,727 sample stations. The majority of these surveys (76%) were conducted by the countries themselves with their own funding sources. SPC provided coordination for in-country assessment surveys and provided funding for surveys, which were conducted as part of the in-country field training. A summary of assessments undertaken and state of management actions is provided in Table 1.

Future outlook

The progress in monitoring of sea cucumbers in the Pacific Islands was recognised at the 8th Heads of Fisheries Meeting held in Noumea in 2013. The Heads of Fisheries of the PICTs called for the continuation of SPC assistance to countries with emphasis on promoting the use of the standard assessment methodologies to collect appropriate data and development of species density reference points for management use. While several invertebrate in-water sampling protocols are available, PICTs have not had the opportunity to work together and benefit from each other's experiences and lessons learned. This would allow member PICTs to improve their in-house capacities in effective resource assessment and build on the progress made to accumulate resource information over the last decade.

The participation of partners in Fiji (Wildlife Conservation Society, University of the South Pacific and Partners in Community Development Fiji), Solomon Islands (The Nature Conservancy), Pohnpei State in FSM (Pohnpei Conservation Society) and Palau (Palau Coral Reef Centre) opened an initiative for closer cooperation between governments, NGOs and SPC in effective monitoring of reef resources.

Decision-makers in the Pacific have begun to understand sea cucumber fisheries and the importance of sea cucumber as a valuable commodity for community livelihoods. Several PICTs are now taking steps to put in place measures for sustainable fishing and protection of resources from collapse. But this is only the beginning; most PICTs have yet to fully translate existing information into

Figure 2.
Palau trainees on attachment in Noumea.

Table 1. Summary of sea cucumber (SC) assessments undertaken and management advice delivered.

Country	Sites assessed	Reports and advice	Management action
Cook Islands	Aitutaki, Palmerston, Rarotonga, Mangaia	Preliminary results presented to the Ministry of Marine Resources (MMR); Preliminary report provided, national SC report completed (Raumea et al. 2013)	Commercial fishing remains closed as MMR puts in place new regulations to control harvesting activities and management arrangements
Fiji	Kubulau, Bua, Naweni, Wailevu, Dakuibeqa, Muani, Ravitaki, Batiki, Oneata, Yako, plus 10 sites in Lau Province	Results presented to Permanent Secretary, Ministry of Fisheries 2012; Advisory report delivered to Director, Fiji Fisheries Dept. – Jan. 2013; Lau Province SC resource report (Jupiter et al. 2013) National SC Report (Pakoa, Saladrau et al. 2013)	Cabinet to decide the future of underwater breathing apparatus in the fishery; draft SC fishery management plan provided to Fiji Fisheries Dept for consultations
FSM	Pohnpei proper, Pingelap atoll, previous surveys at Yap proper	Preliminary results presented to stakeholders in 2013; final SC report (in press); Previous surveys at Yap proper (Tardy and Pakoa 2009)	Fishery remains closed in Pohnpei; further assessments at Pingelap Atoll and further training needed
Marshall Islands	Majuro Atoll East and West (Laura)	Advice provided in 2011	Fishery management plan finalised and new sea cucumber regulation finalised
Palau	Ngarchelong State, Ngatpang State, Ngardmau State, Peleliu State	Preliminary results presented to stakeholders, advisory report delivered to Bureau of Marine Resources (BMR); Final report to be completed in the 2nd quarter of 2014	Fishery remains closed; draft management plan delivered to BMR for in-country consultation
Samoa	Vaisala, Salelavalu, Faala, Manono, Aleipata, Faleula, Falealili	Preliminary report delivered to Samoa Fisheries Division in 2012; National SC report (Sapatu and Pakoa 2013)	Considerations are being made on protecting resources for food security
Solomon Islands	7 provinces covered with 2 sites each; 1 province (Malaita) with 1 site. Marau, West Guadalcanal, Sandfly, Russell Is., Central Malaita, Taro, Tapazaka, Kia, Tatamba, Star Harbour, Ugi, Reef Island, Santa Cruz, Rarumana, Chupikopi	Results and advice delivered to Ministry of Fisheries and Marine Resources 2012; National SC report (Pakoa et al. in prep).	Fishing pressure a challenge for effective control of the ban; 4 months open season in 2013; fishery currently closed. Draft SC fishery management plan provided to MFMR; in-country consultations underway
Tokelau	Nukunonu, Atafu, Fakaofo	Preliminary advice delivered to Tokelau Fisheries, SC report completed (Pasilio et al. 2013)	Fishing remains closed in Nukunonu; fishing at Atafu and Fakaofo to be considered when there is an interest
Tonga	Vava'u group, Tongatapu	Preliminary results and advice delivered in 2011; Tonga SC national report (Pakoa, Ngaluafe et al. 2013)	Advice presented to cabinet, Quota reduced by half (from 200 t to 100 t) for 2011; fishery closed in 2012 pending further assessments
Vanuatu	Maskelyne Islands, Paunangisu	Preliminary advice delivered in 2012; national SC report (Pakoa et al. in prep).	Extension of the 5-year ban in Dec 2012; the ban was repealed in Sept 2013 and replaced with a new harvest regulation, no fishing as yet

management actions. SPC will continue to support PICTs in these areas in 2014 and beyond. Countries and partners who would like to use these assessment protocols and be part of the regional effort are welcome to contact the Coastal Fisheries Science and Management Section for more information or visit the SPC website to view the published reports. This effort is supported under the EU-funded SciCOFish project.

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For more information:

Kalo Pakoa
Fisheries Scientist (Invertebrates), SPC
KaloP@spc.int

Community-based ecosystem approach to fisheries management (CEAFM) and climate change adaptation in the state of Yap, FSM

Community consultations in Yap State.

Current status of marine resources in Federated States of Micronesia (FSM)

In FSM, recent surveys have indicated that catches of fish and shellfish have been declining in lagoons and inshore reefs. The main reasons for this decline are:

- overexploitation due to increasing population;
- use of overly-efficient and sometimes destructive fishing gear and practices;
- other land-based activities, such as near-shore infrastructure development, affecting marine habitats; and
- impacts of climate change, which are expected to add to the already existing local threats to mangroves, coral reefs, sea grasses, and inter-tidal flats, resulting in declines in the quality and area of all habitats.

Projections show progressive decline in productivity of all components of coastal fisheries. To address this problem, national and state governments, municipalities, and island communities implemented a CEAFM programme with technical assistance from the Secretariat of the Pacific Community (SPC) and in partnership with non-governmental organisations.

The CEAFM programme represents a combination of three different perspectives:

- fisheries management;
- ecosystem management; and
- community-based management.

Therefore CEAFM embraces the management of fisheries, within an ecosystem context, by local communities supported by governments and other partners

SPC/GIZ CCCPIR's support

Since mid-2012, the regional SPC/GIZ[1] programme Coping with Climate Change in the Pacific Island Region (CCCPIR) has been supporting CEAFM with the aim of improving community awareness on climate change impacts and assisting communities in maximising opportunities to adapt to social, economic and environmental effects of climate change. This will strengthen the capacity of local communities to respond to climate change impacts through the application of integrated coastal resource management, conservation and adaptation. Thus, the resilience of marine ecosystems will be improved, as well as the livelihoods of people depending on them.

[1] *GIZ is a federally owned enterprise that supports the German government in the field of international development cooperation. For more than 30 years, GIZ has been cooperating with Pacific Island partners in strengthening the capacity of people and institutions to improve the lives of communities for this generation and generations to come. GIZ is an implementing agency providing support through technical cooperation to balance economic, social and ecological interests through multi-stakeholder dialogue, participation and collaboration*

Under the supervision of the FSM national government, the State of Yap was chosen to begin the project. Three communities in the state were selected as pilot sites: Riken/Wanyan, West Fanif, and Rumung Island.

Activities

1. Coastal fisheries resources management

Community consultations were undertaken and community fisheries management plans were developed. Management activities included:

- Strengthening of marine protected areas;
- Control of destructive fishing gear and practices;
- Control of land-based activities that impact the marine environment;
- Rehabilitation of critical habitats;
- Strengthening of community enforcement and monitoring;
- Identifying and developing alternative livelihoods (deployment of fish aggregating devices [FADs] and post-harvest activities) with the aim of diverting fishing pressure from coastal fisheries to offshore areas and facilitating climate change adaptation; and
- Strengthening of community leadership and governance.

2. Alternative livelihoods and adaptation

Fish aggregating devices (FADs)

FADs improve access for coastal subsistence and artisanal fisheries to skipjack, yellowfin tuna and other pelagic fish as coral reef production declines because of climate change. FADs can be used for management purposes as they alleviate fishing pressure on inshore areas by facilitating access to offshore fisheries. They also provide alternative livelihoods for local communities. Activities included:

- community training on FAD construction, management, deployment and maintenance;
- ongoing data collection and monitoring activities to evaluate social and economic benefits of FADs;
- community training on FAD fishing gear and technology; and
- stockpiling materials for repair, maintenance and new deployments.

Training on FAD's rigging, construction, maintenance and deployment for Yap communities.

3. Capacity building

Capacity building is being undertaken through training attachments for state counterparts at SPC headquarters on resource management planning processes and monitoring.

Next steps for CEAFM and climate change adaptation programme

- State-wide awareness campaigns/climate change open day.
- Official launch by national and state government, partners and communities.
- Capacity building for FSM national researchers to conduct resource monitoring and scientific observations in all states.
- Exploration of post-harvest and preservation options for value adding and to extend shelf life of catches.
- Vulnerability and adaptation assessments for selected communities.

For more information:

Fenno Brunken
Climate Change Adviser, GIZ
fenno.brunken@giz.de

Etuati Ropeti
Coastal Fisheries Management Officer, SPC
etuatir@spc.int

SPC and Fiji Fisheries organise practical training on microalgae production for mariculture species

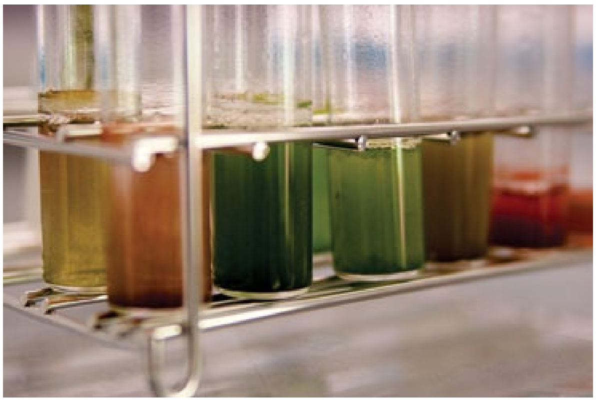
Microalgae are microscopic plants inhabiting the world's oceans and other aquatic environments. They are the world's fastest-growing plants: they can double their biomass daily, providing essential nutrition for aquatic animals, including omega-3 oils and other lipids, proteins and carbohydrates. Most marine hatcheries grow a variety of microalgae species that serve different needs throughout the production cycle.

Microalgae culture is the most expensive and technically challenging aspect of all hatchery operations. It is estimated that the cost of producing microalgae feed ranges from USD 100 to USD 400 per dry kilogram of microalgae.

The microalgae training workshop was conducted 26–29 November 2013 at the Galoa Fisheries Station in Fiji. As part of the training, practical sessions were held regarding species selection, stock maintenance, culture strategies, culture media preparation, hygiene protocols and feeding regimes. A total of 14 Fisheries Officers from different Stations in Fiji (e.g. Savusavu, Lami, Kadavu, etc.) participated in the practical seminar.

Regarding Fiji-specific needs for aquaculture feeds, efficient microalgae production is required as it is a key component of the larval diet of shrimps, of which there are currently two species being produced in Fiji, *Penaeus monodon* and *P. vannamei*. Microalgae are also crucial for the Fiji sandfish (*Holothuria scabra*) breeding programme, which was started in 2013 at the Galoa Station, with the aim of producing sandfish juveniles for reef restocking.

Ruth Garcia Gomez (centre), Shalendra Singh (right) and some of the 14 Fiji Fisheries Officers who participated in the seminar (image: SPC).



A sample of microalgae diversity (image: © Microphyt).

At the end of the training, Shalendra Signh, current manager of the aquaculture programme at the Fiji Fisheries Department, declared, "Overall the training proved to be very useful as we will soon embark on a crucial year, 2014, with a lot of activities planned for our shrimp and sandfish hatcheries in which microalgae will be playing an important part. We also hope that, in the future, similar trainings will be offered to our staff, both locally and overseas, to further build their capacity."

For more information:

Shalendra Singh
Aquaculture Programme manager, Fiji Fisheries
gonegalili@yahoo.com

Anand Prasad
Galoa Hatchery Manager, Fiji Fisheries
prasadanand09@yahoo.com

Ruth Garcia Gomez
Aquaculture Officer (Mariculture), SPC
ruthgg@spc.int

Kiribati participates in international animal disease reporting system

In the midst of climate change and disaster risk preparedness planning, raising awareness on terrestrial and aquatic animal disease reporting has become an important need for Kiribati. This was highlighted during a five-day workshop attended by government officials from Kiribati's Ministry of Environment, Lands and Agriculture and its Ministry of Fisheries and Marine Resource Development.

The training, held in South Tarawa from 23 to 27 September 2013, was also attended by fish farmers and exporters of live aquatic organisms. Kiribati is one of the largest exporters of marine ornamentals among SPC member countries and territories, and this sector could be jeopardised by the current limited knowledge regarding the health status of aquatic animals.

Kiribati is not a member of the World Animal Health Organisation (OIE), but it is a member of the Secretariat of the Pacific Community (SPC). SPC has a memorandum of understanding (MOU) with OIE that establishes guidelines and obligations governing data and information sharing between OIE and SPC. Data shared with OIE are in turn fed into the World Animal Health Information System (WAHIS), an online disease reporting system. The MOU highlights SPC's role in encouraging and facilitating the process to enable its members to regularly provide information and updates on terrestrial and aquatic animal disease status via WAHIS. SPC has also established an agreement with the European Union (EU) enabling non-OIE members to export marine ornamentals to EU, provided they regularly update their aquatic animal disease status on WAHIS.

Temwanoku Ioakim, Livestock Officer and OIE WAHIS focal point in the Ministry for Environment, Lands and Agriculture, said, "Kiribati is free from all the major exotic disease of livestock. There is no clinical evidence to suggest that any of the diseases listed in the OIE manual are present in the country."

As part of the five-day training, Ruth Garcia Gomez (SPC Aquaculture Officer – Mariculture) and Anju Mangal (SPC Information and Knowledge Management Officer, Land Resources Division) provided an overview of WAHIS from a regional perspective and discussed the relevance of animal disease reporting through the system.

WAHIS is an early warning system for informing the international community, by means of "alert messages" and basic health status information, of relevant epidemiological events that occur in OIE member countries. It is also a monitoring system for following up OIE listed diseases (presence or absence) over time. Ministry focal points were trained to provide accurate information for disease notification, including epidemiological notification, aquatic and terrestrial information.

Taere Ratieta (Fisheries Officer) and Tooreka Teemari (Livestock Officer) learning about the WAHIS software (image: Ruth Garcia Gomez).

The official OIE focal points went through a training exercise on submitting immediate notification of the occurrence of a disease outbreak. In the event of an important epidemiological outbreak affecting terrestrial or aquatic animals, and as part of a disaster risk preparedness plan, OIE delegates and focal points must immediately inform OIE by sending notifications through WAHIS.

As part of the training, the focal points submitted their official six-monthly reports and annual reports for 2012 and 2013.

For more information:

Ruth Garcia Gomez
Aquaculture Officer (Mariculture), SPC
ruthgg@spc.int

Anju Mangal
Information and Knowledge Management Officer, LRD, SPC
anjum@spc.int

Spearfishing best practices training in Timor-Leste

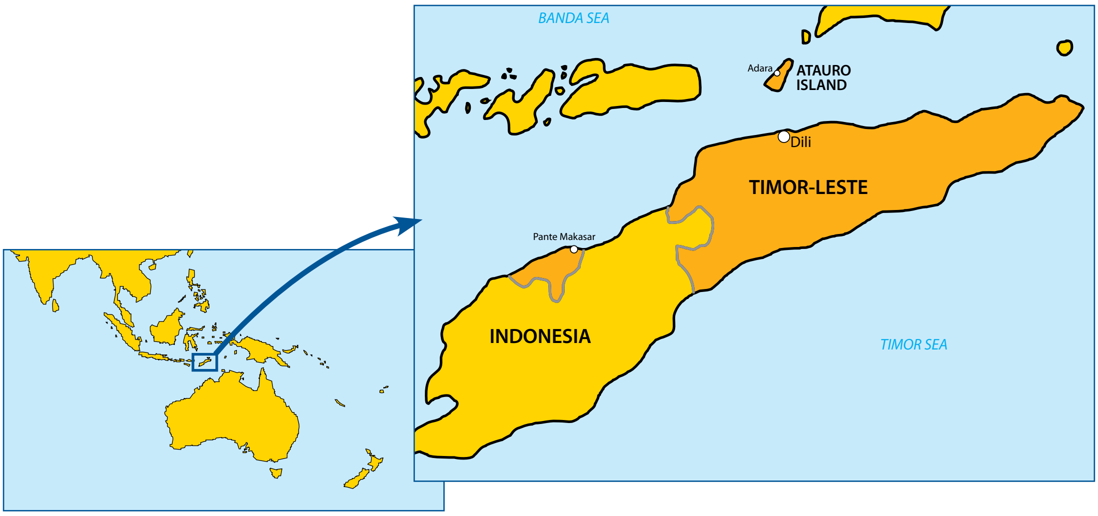
Adara women ready to test "modern gear" (image: Michel Blanc)

Although not yet officially a member of SPC, Timor-Leste, one of the world's newest countries, is receiving increasing technical assistance from the Secretariat of the Pacific Community's FAME Division. Following the attendance of that country's fisheries officials at Heads of Fisheries meetings and a couple of scoping visits by FAME staff, both the Oceanic Fisheries Programme and the Coastal Fisheries Programme have started to include Timor-Leste in their annual work programmes.

Imagine unwrapping a Christmas present as a kid and finding just the toy you've been dreaming about for months, or an Australian bloke being handed a "sweating" cold beer after a day of trekking in the Great Victoria Desert… well, this is exactly how I felt when Mike Batty, former Director of FAME, came to see me after returning from Timor-Leste and asked if we could deliver some training to spearfishers on Autauro Island in Timor-Leste! After over 20 years of dealing with all sorts of fisheries training projects for SPC members — and many hundreds of hours free-diving and spearfishing as a hobby — I would have never thought a request for such training would come my way, but it did!

Atauro Island, home of about 8,000 people, is a very special place. It lies 40 kilometres north of Dili, the capital of Timor-Leste, and, unlike the mainland, has a rich fishing tradition. Its inhabitants are in many ways similar to people in SPC member countries and territories in that fishing — netting and spearfishing are the predominant methods — and eating fish are very much part of their daily lives. On the other hand, fishing on the mainland is rare; one of the reasons is the abundance of crocodiles — absent in Atauro, which make seafood gleaning and canoe fishing very hazardous occupations. A recent study by the Food and Agriculture Organization of the United Nations (FAO) concluded that in Timor-Leste more than half the accidents at sea are crocodile attacks!

The downside for Atauro of such reliance on fish and fishing is that coastal fish stocks are declining due to the recent introduction of nylon gillnets and the impact of increasing fishing effort on the island's



Timor-Leste, with the Atauro Island, north of the capital Dili.

limited intertidal flats and reef areas. In addition, nearly all Atauro men, and even women in the famous village of Adara, spearfish, including at night. Their gear is rudimentary (home-made spear guns and goggles — no fins) and they fish in shallow waters, but they shoot with an impressive accuracy at basically anything that moves underwater. Damsels, small surgeons, butterflies and squirrelfish are the main species caught. Sadly, large parrotfish and groupers have long disappeared from shallow reef areas.

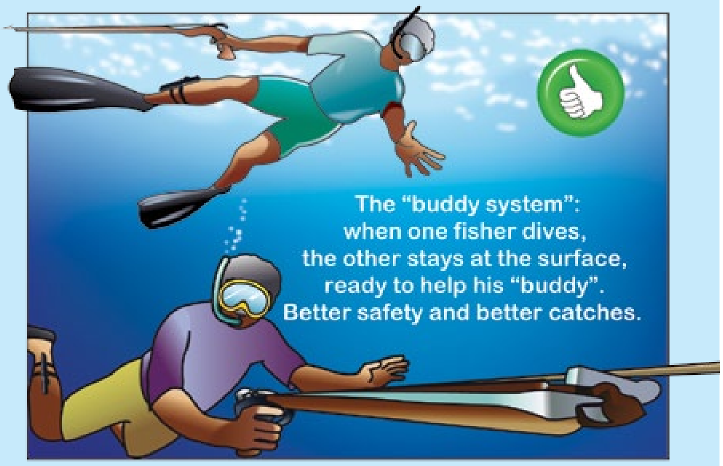
Raising awareness on best practices for spearfishing with advice on ways to conserve coastal fish resources was therefore a major objective of the SPC training. Safety in spearfishing was the other focus as, despite the shallowness of diving, several accidents have been reported, including blackouts and deaths from drowning. Ear problems, including deafness, are common as, surprisingly, the local people do not equalise when diving. In some villages, there is a widespread belief that "blood in the ear" means you have reached a milestone and "after healing you will dive deeper". Using pictures of the inner ear and some rudimentary tools, I explained the cause of ear pains when diving and how an eardrum can be torn. Importantly, the equalisation technique was explained and trainees could put this technique into practice as part of the workshop.

While advice was given on ways to minimise the negative impacts of spearfishing — e.g. by avoiding fishing at night with underwater torches or through the introduction of reserves where fish could grow and breed peacefully — it was suggested that local fishers could, provided they do it safely, target the bigger fish that live in the slightly deeper waters (5 to 15 meters) by applying the equalisation technique and using fins and

Young spearfishers with their catch (image: Michel Blanc).

The buddy system

Spearfishing is a dangerous activity and every year hundreds of spearfishers die while practicing their hobby or occupation. A typical spearfishing accident involves a blackout while the fisher is ascending towards the surface, most often near the surface (this accident is often called the "seven-meter blackout"). The blackout is a brain reflex caused by a lack of oxygen in the body; the brain virtually shuts down to save the little oxygen left at the end of a long dive. As a result of a blackout, the unconscious fisher lies horizontally at the surface, head facing down, without breathing. After a short time (less than a minute), another reflex makes the fisher take a deep breath. If the fisher was fishing alone, he/she will swallow water and drown. Blackouts can happen to even the most experienced and physically fit divers!



The most important safety rule is to always practice spearfishing using the buddy system, which is to fish with a friend. When one fisher dives, the other stays on the surface watching until he/she pops up to the surface and has taken a few breaths, showing no sign of tiredness or blackout. The buddy can then dive under the supervision of the first fisher, who uses that time to recover from his/her dive and get ready for the next one. This technique ensures the safety of both fishers and it is also very efficient, as two spearfishers who are used to fishing together will catch more fish than the two fishing separately — because they feel safe, they are more relaxed underwater and this improves their performance. Also when an injured fish gets off the spear to escape or hide in a rock, the buddy on the surface is able to dive quickly armed with a speargun, improving the chance of catching the fish.

If a blackout occurs, the buddy can apply the first aid that will save his/her friend — that is to grab the unconscious fisher as quickly as possible, holding his/her head outside the water, remove the mask and blow air sharply through the nostrils; this should make the unconscious fisher wake up immediately, and will save his/her life!

A code of conduct for responsible spearfishing has been developed by SPC. The two cards, one on safety, the other on best management practices can be downloaded from the SPC website:

1. http://www.spc.int/DigitalLibrary/Doc/FAME/Brochures/Anon_12_SpearfishingGuidelines_01.pdf
2. http://www.spc.int/DigitalLibrary/Doc/FAME/Brochures/Anon_12_SpearfishingGuidelines_02.pdf

a buddy system. Although imported fins are not yet present on Atauro, a small number of shops sell them in Dili, we purchased a few pairs on our way to Atauro for demonstration purposes at the workshops.

In all, we visited 10 coastal villages in September and at each of them conducted a one-day workshop combining theory and practice. A total of 244 people were trained, 20% of whom were women. Consultant Enrique Alonso, Atauro's first university graduate Mario Gomes and local fisheries officer Elias helped me with training delivery, with Mario and Elias running the last few workshops on their own. As part of the training, we distributed SPC spearfishing cards and a small boat safety checklist that had been translate into the local language, Tetum. In Adara, a "zero-dollar" shallow-water inshore FAD was constructed and deployed in an effort to shift fishing efforts from local reefs to small pelagic fish species (scads and fusilier), which are abundant in Atauro.

Readers wanting to learn more about traditional spearfishing in Atauro may find on YouTube a video describing the life of Adara's women spearfishers.[1] The video was produced as part of SPC's EU-funded SciCoFish project.

For more information:

Michel Blanc
Nearshore Fisheries Development Adviser, SPC
michelbl@spc.int

[1] http://www.youtube.com/watch?v=VErmbIAXF7E&feature=youtu.be

Kiribati: towards major development in small-scale tuna fisheries?

Kiribati is one of the Pacific's most disadvantaged countries in terms of poverty, available resources and climate change impact. Fishing, particularly for tuna, is the main development opportunity for the country, which has a population of 100,000 and one of the largest exclusive economic zones (EEZ) in the region, spanning 3.4 million km².

In Kiribati's remoter islands, fishing is practised for subsistence and, on the main atoll of Tarawa, small-scale fisheries provide food security and a livelihood for a large part of the population. Tarawa's small-scale fishers mainly target skipjack, which the men catch by trolling from small four- to six-metre vessels while the women sell the catch along the atoll's main road. The tuna-rich waters of Kiribati's EEZ attract foreign fishing fleets that purchase licences for catching tuna, mostly using purse seiners and longliners. Fishing licence fees are the government's main source of revenue, accounting for 60% of its income.

In October 2012, a vertically integrated company handling catch, processing and exports set up a processing plant built to European standards in Betio, West Tarawa for a cost of USD 9 million (Fig. 1). This company, Kiribati Fish Limited (KFL), is a partnership between the Kiribati Government, Fiji's Golden Ocean and Shanghai Deep Sea Fisheries, a large Chinese fishing company. KFL owns four tuna longliners and exports its products to the United States, Australia, Asia and soon to Europe. It currently employs about 100 local workers, mainly women, at its Betio plant and a dozen fishers on its vessels. Its processing potential is 15 tonnes a day, but it currently exports less than 5. If it achieved its potential output, it could create 100 more jobs on land, and catching the extra 10 tonnes of tuna a day would involve 300 to 500 local fishers, who could sell directly to KFL.

Mindful of the major social and economic role played by KFL in Kiribati and the opportunities it offers for developing and improving small-scale fishers' livelihoods, SPC, backed by international donors including the New Zealand Aid Programme, has committed to actively work with the Kiribati fisheries sector as a whole, i.e. the Fisheries Department, the private sector and community fishers, to make the most of this unique development opportunity.

With New Zealand assistance, 10 fish aggregating devices (FADs) were purchased in late 2013 and will be moored in the waters around Tarawa Atoll in February 2014. In 2012, SPC also assisted the Kiribati Fisheries Training Centre implement a sea safety and fishing course geared towards the needs of small-scale fishers. In November 2013, five training workshops were held on good hygiene practices and onboard handling of sashimi-quality tuna, with 88 fishers trained.

Figure 1. Preparing sashimi blocks for Japan. KFL currently employs a hundred people, mainly women, at its processing plant (image Michel Blanc).

Figure 2. (A) A five-metre vessel used for skipjack trolling off Tarawa and (B) one of KFL's four tuna longliners (images: Michel Blanc).

A new longliner prototype adapted to the needs of Kiribati fishers?

The main obstacle to involving local fishers in KFL's operations is that their vessels are unsuited to fishing around FADs, as they are too small for two- or three-day campaigns and refrigerating large catches (Fig. 2A). The fishers require larger vessels at affordable prices, unlike the modern tuna longliners used, for example, by KFL (Fig. 2B). As the economic situation is promising with the possibility that New Zealand guarantees loans taken out by local fishers at the Tarawa ANZ bank, a prototype vessel urgently needs to be tested to assess whether it is economically viable before encouraging Tarawa fishermen to purchase it.

Despite this obstacle, KFL is likely to operate in Kiribati for some time to come and provides a unique opportunity for the Kiribati small-scale fisheries sector. SPC is mindful of this and intends to provide considerable assistance to the sector in 2014 in close collaboration with KFL and the Kiribati Fisheries Department. Technical assistance and training (in setting up and launching FADs and fishing around FADs) will be provided to follow on from the training already provided in 2013, which included the hygiene and onboard tuna handling workshops in November and practical training for two Kiribati Fisheries Training Centre (KFTC) instructors in Vanuatu. In addition to such assistance, which is already covered by the Fisheries Development Section's work programme, SPC is actively seeking extra funding, which, once it has been identified, will help fund a new fishing vessel prototype developed by KiriCraft Central Pacific (KCP) that will be suited to both sashimi-grade tuna fishing and local fishers' limited budgets. The KIR-25 is an 11-metre longliner costing around USD 54,000 (excluding the engine and fishing gear). The vessel plans[1] are currently being finalised by Oyvind Guldbrandsen, a naval architect well known in the Pacific, and KCP, a shipyard that is managed by the equally renowned Mike Savins and has been operating in Kiribati for 20 years, proof that it is very well versed in the local social and economic context and issues. KFL has also committed to financially support the project by providing the vessels' engines, fishing gear and safety equipment.

SPC will coordinate the project and provide technical assistance for the initial fishing operations and for training the first local crew. The vessel will then be handed over to KFL, which will operate it under an agreement with SPC on the understanding that the boat's objective will be to train local crews to operate it for the purposes of commercial fishing around FADs. The crews will receive the profits from fish sales to KFL, but will have to cover day-to-day vessel operating costs such as ice, bait and fuel. Data on catches and the vessel's accounts will be managed by KFL, who will forward the information on to SPC. After the vessel has been operating for a year, SPC will assess the data collected by KFL and publish its findings on the KIR-25 prototype's economic performance.

SPC will then disseminate the information to Kiribati and other countries in the region, as KIR-25 has a number of features which, in theory, make it a highly suitable vessel for the needs of fishermen in many other Pacific Islands.

For more information:

Michel Blanc
Nearshore Fisheries Development Adviser, SPC
michelbl@spc.int

[1] See article by Mike Savins on page 27 of this issue of SPC *Fisheries Newsletter*.

A small-scale tuna longliner for Kiribati

Mike Savins

Managing Director, Kiricraft Central Pacific (michaelsavins@hotmail.com)

For Pacific Islanders to engage in commercial tuna longline ventures, affordability of an appropriate vessel is of paramount importance. Producing a vessel allowing short offshore trips at a reasonable cost could mean economic security for an island family or community. The appropriate vessel must provide a safe fishing platform capable of extended fishing and have sufficient capacity to hold high-value tuna in a superior condition.

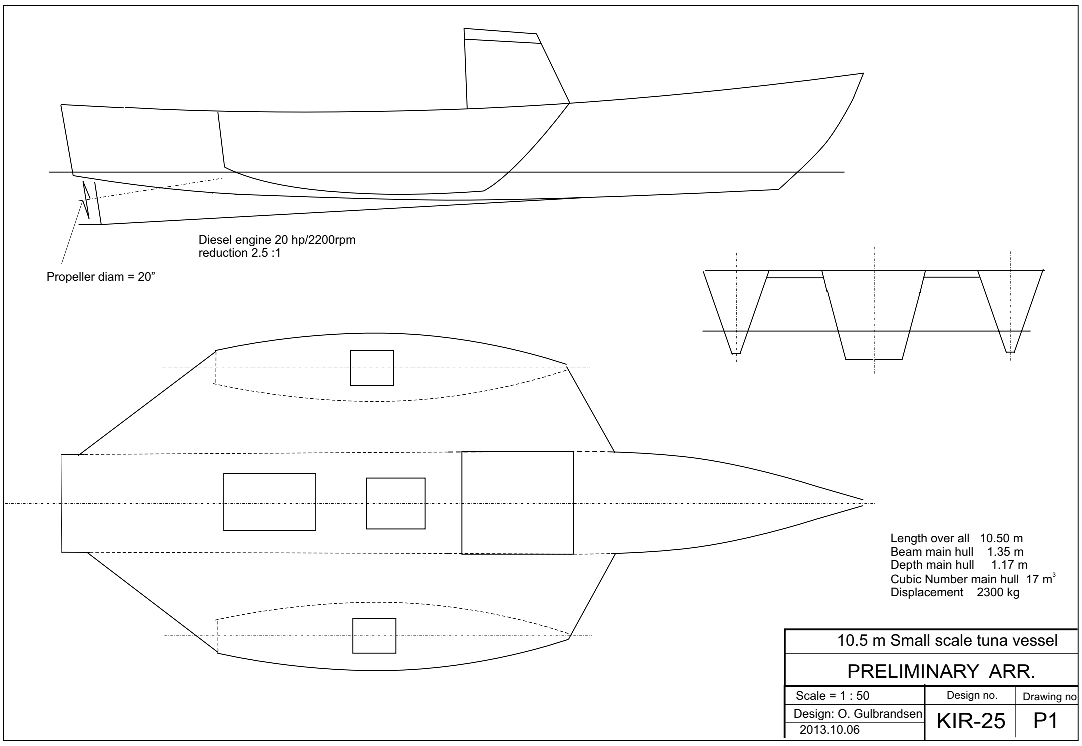
Oyvind Gulbrandsen, a reputable naval architect, shares a vision of developing appropriate designs to fill the gap between the large vessels of industrialised international fishing fleets and the very small boats used by small-scale fishers in most islands. In Kiribati, as in most other Pacific Islands, the high value tuna resource is accessible to local fishers, provided they are equipped with the right fishing tools, including boats of a suitable size.

Two prototype small-scale multihull tuna longline vessels were designed by Oyvind Gulbransden and tested in Kiribati from 1998 to 2005. Both of these designs were trialled with the assistance of master fishermen from the Secretariat of the Pacific Community (SPC): William Sokimi tested the first design and Steve Beverly tested the second design, which employed new concepts based on the experience gained with the first. In both trials the designs were proven suitable for tuna longlining and economical in operation. The trials also allowed identification of areas in which some improvements could be made, such as the ice hold capacity, which should be increased, or the mechanical fit out, which should be reorganised. However, the major constraint related to the logistics of operating in Kiribati at that time.

A project to produce two new small-scale domestic tuna longliners, using new designs benefiting from the experience of the first two boats built, was initiated in 2013 by the management team of the recently-established joint venture Kiribati Fish Ltd.[1] The first boat, the KIR-24, is an 11.9 m catamaran. It is fitted with two 24 hp inboard marine diesel engines, two inboard ice holds of 2.5 tonnes (t) capacity — one in each hull — and one 1.5-t icebox on deck. The catamaran is also fitted with a Lingred-Pitman 28 x 36 inch longline drum, with a capacity of 32 km of 3 mm monofilament mainline, which has its own hydraulic pack powered by a 10 hp diesel motor.


The KIR-24 on launching day with final fit out underway (image: Mike Savins).

[1] See the article by Michel Blanc on page 25 of this issue of SPC *Fisheries Newsletter*.



The KIR-25, designed by Oyvind Gulbrandsen.

For longline fishing, the large deck space on a catamaran gives it an advantage compared with a monohull of the same length. The hull of the KIR-24 is basically shaped like a canoe hull below the waterline, with a flat aft bottom to prevent the stern from being sucked down under power. This shape gives a good speed with little power.

The choice of engine and engine power is of crucial importance for economical operation, more so than the choice of material for the hull. With the present high fuel costs it is very important to avoid overpowering, which was common in earlier days with low fuel cost. The twin 24 hp engines are economical when operated at 70% of maximum power and have the added safety advantage that if one engine fails, the boat can still be operated and brought back to safe waters using the second engine.

Building the KIR-25's central hull (image: Mike Savins).

The prototypes have been constructed of Fiji Marine plywood on a dakua timber (Fijian kauri) frame, epoxy glued with silicon bronze fastenings. The outside is sheathed with Dynel and epoxy to reduce maintenance costs. For one-off designs, plywood construction is a practical and low cost solution. Once the KIR-24 concept is proven, making a mould to build in fibreglass will be considered.

The final cost of the 11.9 m catamaran KIR-24, made of plywood and fully equipped for fishing, is around USD 160,000.

A second design of smaller size, the KIR 25, is currently being built. It is a 10.5 m trimaran, which will be fitted with a 20 hp inboard marine diesel engine and equipped with a hydraulic-powered rope hauler to fish with 15 km of 4 mm Kuralon mainline. The mainline will be stored in holds made in the two outriggers. Fully equipped for fishing, it is expected that the boat will cost around USD 67,000.

Longlining for South Pacific albacore: The ship has sailed and the domestic industry is left to sink

Source: Press release from the Pacific Islands Tuna Industry Association (PITIA), 29/01/2014.

The ability of the domestic industry to compete in the southern longline albacore fishery has hit the point of no return. Tying-up vessels and sending employees home is now the reality that is faced by the Pacific Islands Tuna Industry Association members that have an interest in this fishery.

Scientists have warned for years that increased catches will come at the expense of economic viability.[1] The domestic industry has called for stronger management to mitigate the impact of the influx of subsidised vessels. The political force that subjects our Pacific Islands governments to other considerations have prevailed and the economic downfall of an industry of some 30 years is the result.

Stock assessments continue to produce relatively healthy results; however, actual experience at sea tells otherwise. Recent trends have shown not just decrease in catch per unit effort (CPUE) but fish size. Practice shows that there has been fast local depletion regardless of the perceived overall state of the stock.

Do we only step up to manage when overfishing is already occurring?

American Samoa with the support of the richer more powerful United States has recently put its fleet on the market. More than 50% of the Fijian fleet has been tied up. Tonga has one domestic vessel left — down from a high of 26. Similar stories come from Samoa and the once vibrant PNG domestic longline fishery is history long since gone.

The delegate from China announced at the Western and Central Pacific Fisheries Commission (WCPFC) 10, in December 2013, their intention to cap its fleet in the region at 400 vessels. That is an estimate of 150 more highly efficient and heavily subsidised vessels in a fishery where those of domestic flags are tied up and crew is sent home to seek alternative income earnings. Even those subsidised vessels join the growing fleet of tied up vessels, which dominate the scene in Suva harbour today.

Yet Pacific Island countries will consider issuing further licenses? Something is fundamentally wrong with that scenario.

As Dr Aqorau, of the Parties to the Nauru Agreement (PNA), told ABC in a recent interview, "the albacore crisis is in the hands of the Southern states". PITIA has many times in the past urged relevant governments to take control of the fishery. Ultimate control does lie with the Pacific Islands countries given that some 70% of the albacore catch is taken within their exclusive economic zones (EEZ).

So presumably, the income from licenses will compensate for a domestic industry that has collapsed? Has this theory been properly appraised? Or is this the short-term gain outweighing long-term rational and sustainable development?

A couple of governments have now stepped up to react. Whilst this is a step forward, we believe "the ship has sailed". With the correct approach, government support could possibly result in protecting future investment but current stakeholders would not be so fortunate.

PITIA has always advocated managing the fishery. The reality is that the subsidised Chinese vessel is the only party operating at maximum economic yield (MEY) in this fishery, not the licensing authority and definitely not the unsubsidised domestic vessel, nor the fisherman that is now seeking employment.

It is paradoxical that a once profitable economic domestic fishery existed before the establishment of the WCPFC. Despite two conservation and management measures (in 2003 and 2005), designed to curtail increased fishing capacity, the heavily subsidised fleet has grown exponentially.

It is a sad indictment of "fisheries management" if ever there was one.

[1] See also article on page 9 of this issue of SPC *Fisheries Newsletter*.

Unlocking the secrets of South Pacific tropical freshwater eels

Tim Pickering

Inland Aquaculture Specialist, Secretariat of the Pacific Community (timp@spc.int)

Research to uncover the remaining big secrets of freshwater eels in the tropical Pacific was the topic of a week-long workshop held in Moorea, French Polynesia, in December 2013. Convened by fish parasitologist Pierre Sasal and hosted by the CNRS-CRIOBE (Centre de Recherches Insulaires et Observatoire de l'Environnement) research centre located at the head of Baie d'Opunohu, the meeting brought prominent international eel scientists from France, Japan, and New Zealand together with local and regional experts, and representatives of French Polynesian civil society. Attendance of invited participants at the meeting was supported by the Fonds Pacifique (French Pacific Fund) and by the IRCP (Institut des Récifs Coralliens du Pacifique).

The meeting's programme of speakers addressed both natural-science and cultural heritage aspects of freshwater eels, which served to emphasise just how iconic a fish the eel is to Pacific peoples. For example, in French Polynesia the eel is so intimately linked to humans in mythology and folklore that it is not treated as a resource for consumption, but as a cultural treasure.

In contrast to the unfolding discoveries over the last decade about migration and deep-sea spawning among North Pacific eels, the life cycles of the three main South Pacific tropical eels — *Anguilla marmorata*, *A. obscura* and *A. megastoma* — are still very much shrouded in mystery. Information fundamental to the conservation and management of any fishery, such as knowledge of where and when the fish spawn, how many discrete breeding stocks exist, how long they live before the onset of sexual maturity, and the ability of new recruits to replenish exploited or threatened populations, is very scarce for the South Pacific tropical eels.

Progress in North Pacific eel research

Exhaustive oceanographic research in recent years by experts like Prof. Katsumi Tsukamoto, Dr Jun Aoyama and Dr Shun Watanabe (among others) have resulted in discovery of the spawning grounds of the Japanese eel, on a seamount at the southern end of the West Marianas Ridge. The location is a critical one for the spawning eels. Ocean-current modeling shows that if the parents were to spawn too far north, south, east, or west of this location, then the hatching leptocephalus larvae would not be able to pick up the Kurushio Current for their 300-day trek back to Japan and would be swept away to oblivion.

The meeting heard from Prof. Tsukamoto that the successful spawning and rearing of the Japanese eel in captivity has been achieved. Since the initial breeding success in large, specially-designed eel brood stock conditioning tanks, those first offspring have themselves been reared to breeding size and have spawned again, and so on, such that there are now three generations of eels that have been entirely reared in captivity. The aquaculture process is able to produce glass eels[1] (a commodity desperately sought by eel farmers everywhere) at a cost per eel of JPY 10,000 (USD 100). If the breeding and rearing process can be fine-tuned to the stage where each glass eel costs only JPY 100 (USD 1.00) then it will be very worthwhile to pursue. Until then, the world's capture-based eel aquaculture farmers will continue to compete with each other and pay exorbitant prices for dwindling glass-eel capture-fishery catches from wild resources which are threatened, not just by overfishing, but also by habitat degradation, pollution, and barriers to migration in river catchments.

Big knowledge gaps for South Pacific eels

South Pacific eel research differs from North Pacific eel research in that it has several dozen fewer scientists and several million dollars less in research budgets. Don Jellyman of New Zealand (now retired, and also present at the meeting) has done his best over many years to answer similar research questions for the temperate eels of New Zealand and Australia, *A. australis*, *A. dieffenbachii*, and *A. reinhardtii*. Through limited (by budget) use of pop-up tags on some migrating silver eels leaving New Zealand rivers, and modeling of ocean currents based on estimated age of recruiting glass eels, his best guess is that New Zealand's eels most probably head towards a spawning ground in the South Fiji Basin, between Fiji and Vanuatu.

But for the three tropical South Pacific eels *A. marmorata*, *A. obscura* and *A. megastoma* there has been

[1] A glass eel is an eel in its transparent, postlarval stage.

scarcely any ongoing and systematic research at all, apart from three years of daily glass eel sampling by Pierre Sasal at the mouth of the Opunohu river in Moorea, and three months of data from a similar but uncompleted glass eel study at Navua in Fiji by University of the South Pacific MSc candidate Chintaka Hewavitrarane in 2006. It is hypothesised, but not yet known for certain, that the tropical eels may also spawn in the South Fiji basin. They may have more than one spawning ground.

High status, but facing threats

The anguillid eels have high status in the SPC countries and territories, where they are either revered in mythology or are highly prized as delicacies in inland areas where there has always been a shortage of fresh fish.

In addition there are increasing number of enquiries from Asian businesses who want to capture and export glass eels to stock farms in China or Korea, or send juveniles alive by air freight to market. At a local level, catchment developments like deforestation, pollution, and construction of dams and weirs are already making an impact.

Yet for many Pacific peoples the situation is serious if rivers no longer have eels in them. This is summed up by a saying in Tahitian that "A river without eels is a dead river".

Timiri Hopu'u of the French Polynesian Service for Culture and Heritage handles a live Anguilla marmorata specimen, caught by electro-fishing in a demonstration of eel population research methods for Pacific Island streams. (image: Tim Pickering).

The workshop on tropical eels in Moorea was refreshing for its unusual learning approach whereby it was the instructor Pierre Sasal of CRIOBE (on the left) who got wet, while all the trainees in glass eel net deployment (on the right) were able to remain dry (image: Tim Pickering).

Taking all this into account, the timeliness of new efforts to gain biological knowledge fundamental to Pacific eel conservation and management becomes easily apparent.

Research goals for the new Eel Network for the South Pacific

The meeting participants resolved to prioritise and coordinate South Pacific eel research in a way that addresses regional needs and can also benefit from the well-supported eel research initiatives in other places. This can begin with pure science research on eels, but also should incorporate research on the economic and applied aspects (such as eel fisheries and aquaculture) and the cultural aspects. Traditional knowledge and culture surrounding eels is important to study for its own sake, and can reveal insights about eel biology.

Fundamental to conservation and management of South Pacific eels is information about:

- spawning in the oceans and recruitment of glass eels back to the adult populations on land; and
- escapement of mature (silver) eels from land to the spawning grounds in the oceans for breeding.

Knowledge of spawning grounds is needed to conserve and protect them, to monitor them, to know the conditions there, and to use this knowledge to predict future recruitment. Knowledge of recruitment underpins both fisheries management, and climate change adaptation. For example, we need to know the vulnerability of local fisheries to interruptions in recruitment, especially if it is discovered that they are a long way from the spawning grounds.

Knowledge of fish age and the conditions for silver eel escapement is vital to avoid possible extinction of eels, but many questions remain about how best to ensure that escapement is possible. Many Pacific Islanders assume that eels breed in the same places they live and feed. There is very low awareness that eels undertake long migrations out to sea for spawning, and that big eels need to be able to escape. In contrast, a strategy now being adopted to avoid extinction of the Japanese eel is to set up sanctuaries where there is no fishing at all for eels. In New Zealand, harvest of eels larger than 4 kg is now banned.

There will be an opportunity in 2015 to replicate the type of research that led to the discovery of the Japanese eel's spawning grounds. The University of Tokyo research vessel Hakuho-Maru plans to make a cruise to the South Pacific. It has the capability to deploy fine-mesh mid-water trawl nets to sample for newly-hatched eel leptocephalus larvae, or even to find unhatched eel eggs in the plankton.

But first, it is necessary to narrow down the possible ocean area where South Pacific eel spawning takes place. This can be achieved during 2014 if there is coordinated sampling of glass eels using nets in river mouths in at least four countries or territories. This coordinated sampling would involve different teams of researchers catching glass eels in all four places at the same time. Using otolith analysis to find out the age of the glass eels, and genetic tools to estimate the probability that they came from the same or different spawning aggregations, it may be possible to back-track using ocean current data to find out the most likely general location where the collected eels were spawned and hatched.

Based on present knowledge, the best places to carry out this glass eel sampling are in rivers of Fiji, Vanuatu, New Caledonia, and French Polynesia. The newly formed Eel Network for the South Pacific intends to make links with regional fisheries departments and universities to carry out this sampling in a coordinated way during 2014. This will be a first step toward solving one of the long-standing big riddles of natural science in the Pacific — "Where do eels spawn?"

Pierre Sasal and Tahitian PhD candidate Herehia Helme demonstrate tag and release methods for eel population study using electro-fishing gear to stun the fish before capture (image: Tim Pickering).

International workshop on "Different survey methods for coral reef fish, including methods based on underwater video"

Honiara Campus, University of the South Pacific, Solomon Islands (10 to 13 September 2013)

Responsible: David Lecchini

Institute for Pacific Coral Reefs, CRIOBE, Moorea, French Polynesia

In September 2013, staff from the University of the South Pacific (USP) Honiara campus, the Secretariat of the Pacific Community (SPC) and IFREMER in New Caledonia, and the French Institute for Pacific Coral Reefs (IRCP) in Moorea, French Polynesia, co-facilitated a workshop entitled "Different survey methods of coral reef fish, including the methods based on underwater video". The workshop was funded by the French Embassy (Pacific Fund), and had two key objectives: to allow the eight USP students involved to learn the different techniques of fish monitoring; and to increase capacity at the level of USP, government and NGO staff (20 persons) already involved in fish monitoring, particularly with regard to recent underwater video techniques and data analysis tools. To achieve these objectives, the workshop was split into two parts.

1. Seminars

Seminars were held at USP campus on day one. These seminars provided participants with background information on coral reef fish ecology and some of the various in-water methods currently used to survey fish populations in the Pacific region. Each of the different monitoring networks in the Pacific — IRCP, IFREMER, IUCN, SPC and WorldFish — was explained to the participants.

2. Field-training programme

A field-training programme was run at Naro village during days 2 and 3, and the data collected in the field was analysed on day 4 at USP campus. The objective of the two field trip days was to allow survey participants to try four different survey methods for surveying coral reef fish.

The first method was based on the technique implemented by the Global Coral Reef Monitoring Network (GCRMN), which is currently used by local participants in Solomon Islands. In this method, certain species of ecological and economic importance are counted along a single pass of a 25 m long x 5 m wide fixed belt transect. The second method consisted of a variation of the "traditional" GCRMN method that used the same fixed width belt transect size, but where surveys were based on three passes along the transect. This method is largely used by IRCP, and its goal is to simplify the process by counting only specific groups along each pass. For the Naro trip, surveyors counted mobile fish (e.g. snappers, parrotfish) on the first pass, more "resident" species (including groupers, damselfish and surgeonfish) on the second pass, and cryptic species (e.g. soldierfish, scorpionfish, hawkfish, gobies and blennies) on the third pass. The third method was distance-sampling underwater visual census (D-UVC), the method currently used by SPC. In this method, surveyors count individuals of the species of interest along a transect line, and estimate their length and perpendicular distance from the transect line, with no set limit to the distance at which fish are recorded. The fourth method examined was based on the use of videography, using a fixed position rotating system developed by IFREMER. This system consists of two waterproof housings related by an axis. The lower housing contains an electric engine powered by 2.4V rechargeable batteries, which sets in motion the axis related to the upper housing enclosing a high definition (HD) camera. The camera was a Sony HDR-SR11 with an integrated 30 Gigabyte hard drive enabling the recording of up to 4 hours of HD video. The system was set on the sea floor at Naro reef (at three sites) and rotated at predefined time intervals from a fixed angle (60° at each rotation and every 30 seconds).

David Lecchini (IRC–CRIOBE, Moorea), Robson Lasimae and Lawrence (USP students) in front of Naro village.

Table 1. Comparison of the value of different qualitative criteria across the four monitoring methods.

Evaluation criteria	GCRMN method	IRCP method	SPC method	Video method (IFREMER)
Taxonomic level fish are identified to	+	++	++	++
Level of skill and training required	+	++	++	+
Time in the field	+	++	++	–
Time in laboratory	–	–	–	++
Staff required	2 divers	2 divers	2 divers	1 fish expert + 1 technician to check the equipment*
Costs	–	–	–	++

– : Low; + : Moderate; ++ : High
* 2 divers are needed for the equipment installation under water.

On the fourth day of the workshop, the data collected in the field at Naro were analysed at the USP campus in Honiara by all participants, who compared the difference in indications of fish abundance generated by the four techniques (GCRMN, IFREMER, SPC and IRCP methods). Each participant was given the opportunity to express an opinion about the advantages and disadvantages of each technique (Table 1).


The underwater video system developed by IFREMER.

For more information:

David Lecchini
IRCP–CRIOBE (website: www.ircp.pf)
lecchini@univ-perp.fr


Smiling participants during the two field days at Naro village.

Juvenile reef fish can survive without mangroves on Mayotte

Rakamaly Madi Moussa[a] and René Galzin[b]

[a] USR 3278 CNRS-EPHE, CRIOBE & CBETM, Perpignan, Corail Labex (high-profile laboratory) (rakamalymadimoussa@gmail.com);
[b] USR 3278 CNRS-EPHE, Moorea, French Polynesia, Corail Labex (high-profile laboratory) (galzin@univ-perp.fr)

Image: Rakamaly Madi Moussa

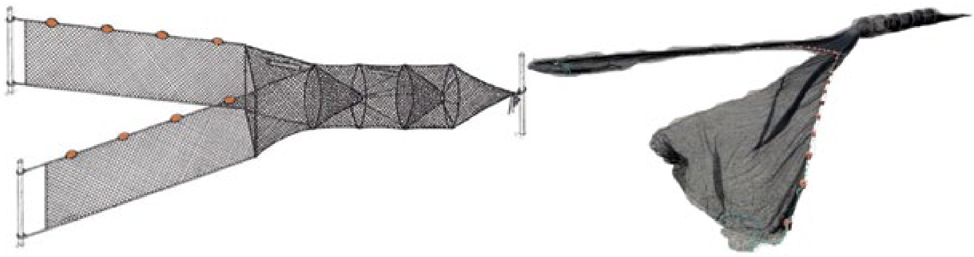
Although studies in the Caribbean indicate that mangroves play a major role as nurseries for juvenile coral reef fish, most research in the Indo-Pacific show the opposite. The juveniles of only a few species in the Carangidae, Sphyraenidae, Mullidae and Lutjanidae families swim in mangrove swamps on Mayotte. If mangroves disappear, however, coastal erosion will increase, lagoon water will grow murky and neighbouring coral reefs will disappear.

In the Caribbean, mangrove swamps contain high densities of several coral reef fish species that migrate to the reef once they reach the sub-adult stage. Such areas are considered important nursery habitats for juvenile fish. Several hypotheses have been advanced to explain the abundance of juveniles in mangroves, including that juveniles are attracted by the swamps' varied structure, low predation risk or higher food availability, etc.

On Mayotte Island, mangroves account for 29% of the coastline and extend across 740 ha, mainly in bay heads. The biotope has unfortunately been damaged by human activity such as bush clearance, grazing, landfill and other coastal development. It is, therefore, essential to understand the role played by mangroves for reef fish on the island today so as to assess the dangers if their habitat is lost due to man-made disturbances or climate events.

Sampling was carried out during the wet season in February and March 2013 in four areas on the mangrove front, including two in a river estuary. A fyke net was used as fishing gear, as it is passive and highly effective in lagoon environments. When visibility was adequate, a visual count near the net was combined with sampling. The net was cast and hauled as the tide ebbed or flowed, i.e. four times per area. The island had a broad tidal range of four metres with the fishing area lying completely exposed at low tide.

The fishing gear performed satisfactorily with more than 4129 specimens sampled along the mangrove front for a biomass of 41,460 g representing 43 species and 28 families. Species richness varied from one area to another, although the difference was not significant. Distance from the coral reef had little effect on species richness



Fishing gear (fyke net) used for sampling on the mangrove front.

variations, although a river appeared to affect the number of species seen ($r^2 = 0.92$). Generally speaking, the coastal *Atherinomorus lacunosus* species dominated the fish population at 74% of total numbers, followed by the Leiognathidae (*Leiognathus dussumieri* 4.3%, *Leiognathus equulus* 4.1%), Apogonidae (*Apogon amboinensis* 3.6%), Carangidae (*Caranx heberi* 2.7%) and Sillaginidae (*Sillago sihama* 2.6%) families. Biomass varied according to tide, with the rising tide containing more. The broad tidal range in the mangroves, along with fairly deep water at high tide, increased carnivore predation on smaller fish. Species such as *Lethrinus harak*, *Sphyraena barracuda*, *Lutjanus monostigma*, *Platax orbicularis* and *Lutjanus argentimaculatus* moved trophically as the tide rose. They could be considered ubiquitous, as they swam in both mangroves and coral reefs. However, the mangrove's importance to Mayotte's reef fish is limited, and its role as a nursery for juveniles was not borne out by this study.

As there is no major interaction, the loss of this habitat would most probably have no direct effect on the coral reef's fish population. However, on Mayotte, losing the mangrove could conceivably result in serious coastal erosion, and increases to water turbidity, earth deposits in the lagoon and, in the long run, changes to the coral reef population. Because of this, and as the mangrove is at risk, preserving the habitat could usefully be incorporated into coastal management programmes.

Examples of the various species caught on Mayotte's mangrove fronts (images: Rakamaly Madi Moussa).

Building better pearl aquaculture businesses in Fiji

Dr Damian Hine[a] and Bill Johnston[b]

[a] Associate Professor Innovation and Commercialisation, UQ Business School, University of Queensland
[b] Principal Agricultural Economist, Department of Agriculture, Fisheries and Forestry Queensland

Two workshops were conducted in Fiji recently to improve the business planning skills of local pearl farmers. The workshops, which took place in November, are built around a whole farm economic model, which creates industry-wide information aimed at the future development and viability of the pearl industry in Fiji.

The first workshop was held at Rakiraki and targeted the small-scale pearl farmers in Fiji who are looking to expand beyond a predominantly Fiji market driven business model to accessing more lucrative international markets. The second workshop was undertaken in Savusavu and was focused on a group of more established farms loosely known as the Northern Alliance. The second workshop aimed to take a broader view of industry issues and opportunities and develop strategies to address them. The workshop presenters were part of a joint venture of the University of Queensland and the Queensland Department of Agriculture, Fisheries and Forestry, with the project funded cooperatively by SPC's EU-funded Increasing Agricultural Commodity Trade (IACT) project and the Australian Centre for International Agricultural Research (ACIAR) and James Cook University (JCU).

The overall goal of the project is to utilise the whole farm economic models of Fijian pearl farms as a basis for sustainable growth of the industry through a range of instruments including:

- an improved decision-making framework;
- price and production risk analysis including risk mitigation strategies;
- establishing a minimum "viable" pearl farm size;
- improving access to capital and financial support;
- collection of benchmark data for ongoing reviews of industry health;
- revealing industry impediments and opportunities; and
- improving local extension and support services through "train the trainer" events.

The project will help local pearl farmers understand their businesses better, make more informed decisions and be equipped to develop their farms in a more sustainable fashion with greater awareness of actual production and financial positions. The whole farm modelling process lends credibility to the industry in their dealing with financial institutions as it gives farmers the ability to forecast and predict future profits and potential risks. The information generated by the pearl farm economic model can be presented to local banks as part of a broader business plan, developed with the skills learnt in the workshops, to secure much needed access to finance. Indeed, the issue of *access to finance* is one of the key problems stifling the development of the Fijian pearl industry today. This discussion was enhanced by having a WestPac Pacific Bank representative present at the Rakiraki workshop.

Pearl grafter at work in Fiji.

The workshops revealed other key impediments facing the industry in the current environment. These include:

- lack of industry standards in assessment of quality and associated pricing;
- high input costs;
- property rights — licensing and security of tenure; and
- lack of shell availability.

The lack of industry standards in grading of pearls and pricing was identified as a particular problem when trying to develop an export industry. To strengthen the Fijian pearl industry in the international arena there needs to be an agreed industry standard around grading backed up by the training of local farmers and jewellers.

As for the issue of tenure and licensing, the Fijian Government is on the cusp of introducing an Aquaculture Decree, which will provide powers to create a licensing system and a framework providing a mechanism for creating value in oceanic sites. The workshop participants did stress the need for greater participation by industry in the process and the need to participate in the dialogue between the government and aquaculture industry stakeholders in order to better protect pearl farmer interests and welfare.

Another problem facing the industry is the high input costs — particularly the cost of hiring international seeding technicians — which impede further development and greater output and profit. As a result of the lack of skilled technicians locally, farmers have to acquire the services of technicians predominantly from Japan. In addition, the quality of the nuclei used to seed the oysters is determined by the technicians and is beyond the control of the small-scale farmers.

In the process of delivering the workshops an industry survey was undertaken to ascertain the key issues of the industry. One recurring theme in responses was that the continued expansion of the industry was significantly restricted by the availability of spat. There is capacity to seed many more juvenile shells than are actually available. One positive from this is that Fijian communities have a great opportunity, with the support of the project partners and the Ministry of Fisheries and Forestry, to develop village-based spat collection entities and diversify local livelihoods. The establishment of a community-based spat collection industry would not only support the existing pearl industry to further develop, but could provide a pathway for new entrants.

Many of the issues discussed at the workshops are a function of scale. There is a wide range of significant costs for Fijian pearl farmers that can be better absorbed as farms increase in scale and industry power.

One of the other pillars of the project is the collection of benchmark data. As the project continues, the project partners believe the story revealed by the data will provide greater insights to the farmers and lead to a greater understanding of the industry by those with an interest in seeing a successful, growing industry. From this new platform, everyone involved in the industry, and the researchers who presented the workshop, will be better equipped to undertake further industry development work towards addressing the issues and capturing the opportunities of the Fijian pearl farming industry.

Roadmap for inshore fisheries management and sustainable development 2014–2023

Melanesian Spearhead Group Secretariat
Secretariat of the Pacific Community

Melanesia: Our home, our fish, our wealth and our future

Background

At their March 2012 summit, the leaders of the Melanesian Spearhead Group (MSG) of countries (Fiji, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu) agreed to develop a roadmap for the protection of inshore fisheries. This document presents that management framework and subregional roadmap for sustainable inshore fisheries, developed by the MSG Secretariat in cooperation with representatives of the fisheries departments of the MSG countries and with the technical assistance of the Secretariat of the Pacific Community (SPC).

This roadmap was initially developed by the Inshore Fisheries Working Group (IFWG) in Port Vila in October 2013. The process was facilitated by SPC and informed by a comprehensive Strategic Review of Inshore Fisheries Policies and Strategies in Melanesia, commissioned and managed by SPC. This strategy enhances the inshore fisheries management elements of the Memorandum of Understanding on Technical Cooperation in Inshore Fishery and Aquaculture Development, developed by MSG members in 2012.

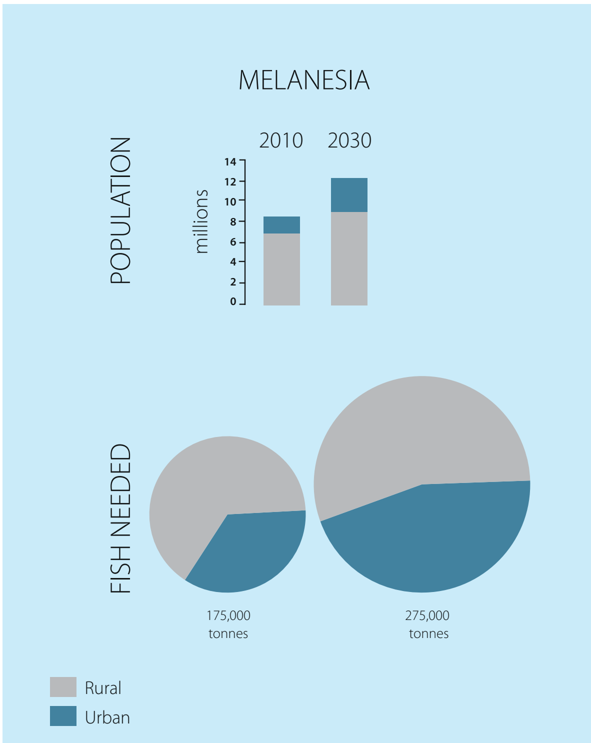
The regional roadmap provides overarching guidance for MSG members and enumerates the actions they have agreed to take to address the management of inshore fisheries in Melanesia.

Context

A looming crisis: Inshore fisheries, upon which the majority of coastal populations depend, are generally fully exploited, or in some cases, overexploited. Increases in population and demand will drive many of them to collapse unless ways can be found to manage them sustainably.

Millions of people at risk: The majority of the population of Melanesia is dependent on inshore fisheries for subsistence and local economic needs. The risk resulting from this high reliance on inshore fisheries is exacerbated by the limited alternative opportunities and increasing external pressures which have already driven the most valuable fisheries such as beche de mer (BDM) into a spiral decline of boom and bust. Climate change will increase vulnerability and management strategies are urgently needed to increase resilience and adaptive capacity.

Potentially large economic benefits: While management efforts and political attention have traditionally been monopolised by the high-value tuna fisheries, in fact the largely subsistence inshore fisheries



Projected population growth in rural and urban areas of Melanesia to 2030, and the fish needed for future food security (Bell 2009).

contribute 30%–95% of the overall value of all fisheries to the national GDP of Melanesian countries. In addition, it is estimated that sustainable management of the BDM fishery could make it possible to double the value of production to over USD 35 million each and every year; most of this would be returned as valuable cash income to coastal communities. The costs of improved inshore fisheries management in general would be offset by benefits to the national economies.

The need for a strategic approach to securing fisheries and livelihoods: Considerable efforts have been made by fisheries departments to sustain or increase seafood production, including the use of aquaculture, fish aggregating devices (FADs) and a variety of other interventions. Despite these efforts there remains considerable concern about the health of inshore fisheries. Community-based resource management (CBRM) is widely agreed to be a fundamental approach, although its implementation and support still require refining if it is to be fully effective. However, the experiences, both positive and negative, provide the basis for a strategic selection of approaches that should lay the basis for successfully co-managed inshore fisheries. This should be built on a strong partnership between coastal communities and the various levels of government. Importantly, while alternative livelihoods will be useful in creating opportunities; pursuit of these should not detract from the real and immediate benefits that can arise from improved management.

Political will and leadership will continue to be required: The initiative and support demonstrated by leaders in requesting the development of the roadmap will need to be sustained to ensure its implementation and even increased if inshore fisheries are to realise their full potential in contributing to sustainable development and the livelihoods of the people of Melanesia.

Managing communities rather than fish: An understanding of communities and their social and economic circumstances is key to effective community-based management. If individuals in communities are not engaged, or are not supportive of inshore management initiatives, it is highly unlikely they will be effective. Communities are, understandably, more interested in development opportunities; the challenge will be balance development with effective management, the latter tending to be seen as telling fishers "what they cannot do". In reality, effective management allows fishers to continue to harvest benefits from their marine resources for the long term.

The size of the challenge: MSG members have extensive coastlines and widespread, isolated communities and islands. Inshore management approaches have not always reflected this reality, instead focusing efforts on small areas, using intensive approaches that are neither sustainable nor easily adapted to achieving national coverage.

Many users of the marine environment: Fishing is only one use of the marine environment. It may be seen as a dumping ground for pollutants, either directly or through run-off from rivers. Coastal development for tourism may devastate valuable mangroves and destructive fishing methods can have adverse impact on stocks. Without a healthy sustaining marine ecosystem and a balanced use of the marine environment, inshore fisheries cannot exist.

Guiding principles

The following principles will guide the overall implementation of the roadmap:

- It is important to achieve sustainability of resources to provide long-term economic, social, ecological and food security benefits.
- Coastal communities should be empowered with appropriate support from national and local

Aquaculture and FADs can be used to sustain or increase seafood production (images: Antoine Teitelbaum and William Sokimi).

government as well as regional agencies and other non-government stakeholders, to implement CBRM for the benefit of our nations.

- A bottom-up approach, requiring government support to communities, should be provided at or as close as possible to community level, using provincial/local government and other mechanisms and collaborations.
- Approaches should be realistic, achievable, step-wise and measurable, and should focus initially on the better use of existing human and financial resources for long-term food security and sustainable livelihoods for coastal communities.
- Development pressures should not distract from the pursuit of the real and immediate benefits that will arise from improved management to secure the long terms sustainability of resources.
- The approach should be based on a Melanesian partnership that builds on and shares the diversity of experiences while recognising the differences between MSG members, species and stock status.
- Climate change will adversely impact inshore fisheries and their supporting ecosystems; therefore, investing in improving management systems, especially with an emphasis on ecosystem approaches to fisheries management, will increase resilience and adaptation ability complementary to the MSG Leaders' Declaration on Environment and Climate Change.
- The roadmap should be an instrument that facilitates delivery of existing national inshore fisheries objectives, with minimal additional administrative burden.

Vision

Sustainable inshore fisheries, well managed using community-based approaches that provide long-term economic, social, ecological and food security benefits to our communities.

Objectives

1. Development of an effective policy, legislation and management framework for the management of inshore resources, in accordance with other relevant international agreements, to empower coastal communities to manage their marine resources.
2. Education, awareness raising and the provision of information on the importance and management of inshore fisheries.
3. Capacity building to sustainably develop and manage inshore resources with particular reference to experiences in the MSG members.
4. Adequate resources to support inshore fisheries management and best available science and research.
5. Secure long-term economic and social benefits to coastal communities from the sustainable use of inshore resources.
6. Establishment of effective collaboration with stakeholders and partners.
7. Restoration and maintenance of BDM stocks to maximise long-term economic value to coastal communities.

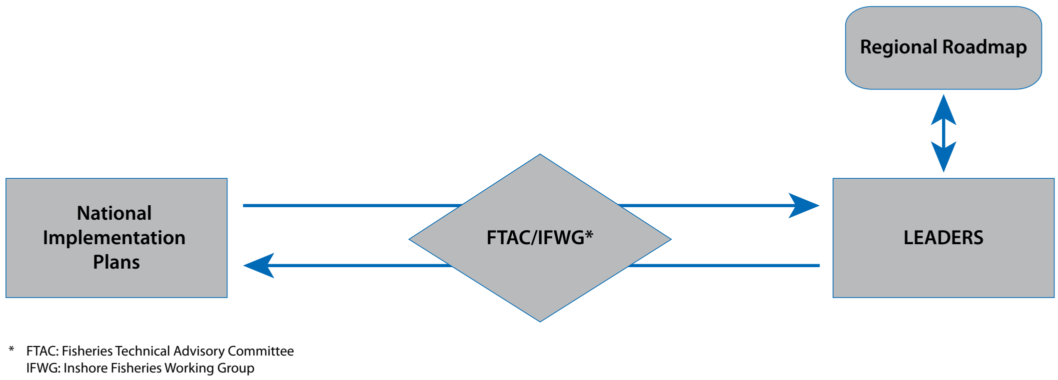
Timeline and priority actions

The roadmap is to be implemented over a 10-year period, from 2014 to 2023. The timelines in the roadmap provide a general indication of goals and milestones to be met; however, it is noted that a few priority and relatively easily actionable objectives can be achieved in the short term to:

- make best use of existing human and financial resources;
- build the profile of and promote "success stories" in inshore fisheries management; and
- attract additional support from donors and government for longer-term, more resource-intensive activities.

Implementation at the national level

The sub-roadmap provides overarching guidance for MSG members and enumerates the actions they have agreed to take to address the management of inshore fisheries in Melanesia. Individual members have committed to national implementation plans, which will give effect to the regional roadmap at the national level, noting that a number of the regional actions are underway or are planned under existing national arrangements.



Monitoring and evaluation process.

Considerable progress was made with national implementation plans by the members during the October 2013 workshop.

Monitoring and evaluation

If this plan is to be effective it is vital to monitor progress and identify and address emerging shortfalls in a timely manner. The process described above seeks to clearly assign roles and define the process for achieving this.

Role of MSG Secretariat

The MSG Secretariat will support members in meeting reporting requirements, with the information to be provided to the MSG Fisheries Technical Advisory Committee (FTAC) annual meetings and to help ensure leaders are updated at the biennial leaders meetings. The Secretariat will also coordinate and harmonise approaches for regional agencies and development partners regarding assistance to members for implementation of the roadmap at the national level, as agreed by members from time to time.

Role of national administrations

The draft sub-regional roadmap is complemented by national implementation plans developed by MSG members. Each member will:

- Self-assess progress.
- Provide reports through national fisheries departments, including for activities carried out by partners or other ministries.
- Endeavour to obtain independent assessment through an existing or specifically formed national committee or network which includes civil society and community participation.
- Address shortfalls in performance.

Frequency and format of reporting and review

- Reporting by national fisheries departments will be annual.
- Reports will be provided to leaders at their meeting every two years (via FTAC).
- The roadmap will be reviewed every three years.

Performance measurement

- Specific performance indicators will be incorporated as appropriate in national implementation plans and reported by national fisheries departments in their annual reports.

The endorsement process

- The draft roadmap was presented and endorsed by IFWG at its meeting on 2–8 October 2013. This will be presented to the FTAC at its meeting in April 2014 before final endorsement by the MSG leaders through the Trade and Economic Officials Meeting, Senior Officials Meeting and Foreign Ministers Meeting.

Reference

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For more information:

Laisiana Tugaga
Economic Affairs Officer, MSG Secretariat
l.tugaga@msg.int

Ian Bertram
Coastal Fisheries Science and Management Adviser, SPC
ianb@spc.int

Assessing the impacts of ocean acidification upon tropical tuna

*Don Bromhead, Vernon Scholey, Daniel Margulies, Simon Nicol, John Wexler, Maria Santiago, Simon Hoyle, Cleridy Lennert-Cody, John Havenhand, Jane E. Williamson, Tatiana Ilyina and Patrick Lehodey**

Introduction

Increasing concentrations of CO_2 in the Earth's atmosphere (IPCC 2007) are causing a gradual warming and acidification of the Earth's oceans (e.g. Barnett et al. 2005; Caldeira and Wickett 2003; Feely et al. 2004). Both warming and acidification have the potential to affect the distribution and population dynamics of many marine organisms (IPCC 2007; Raven et al. 2005; Fabry et al. 2008). Significant advances in knowledge have been made over the last decade that have advanced understanding of how increasing ocean acidity will impact nearshore and coral reef ecosystems (Fabry et al. 2008). Our understanding about the effects of acidification on pelagic ecosystems, however, remains rudimentary. In the Pacific Ocean, improving our knowledge on the possible impacts on the pelagic environment is important, as the Pacific's tuna populations are of one of the largest and most valuable fisheries in the world (Williams and Terawasi 2009). The income derived from tuna fisheries provides a significant contribution to the economies of many Pacific Island countries and territories (Gillett 2009). To ensure such economic benefits are maintained through the sustainable management of this fishery requires an understanding of not only fishery impacts, but impacts of other factors upon population biomass and structure over time. While fishery scientists are now attempting to predict how ocean warming will affect Pacific tuna populations (Lehodey et al. 2010, 2013), no one has previously investigated how ocean acidification (OA) may affect these species and associated fisheries.

To advance our knowledge of the impacts of OA upon tuna populations and fisheries, a pilot study was undertaken at the Inter-American Tropical Tuna Commission (IATTC) Achotines Laboratory in Panama. The objectives of the pilot study were to develop and test experimental protocols to examine the potential effects of OA on yellowfin tuna (*Thunnus albacares*) egg fertilisation, egg and larval development, growth, and survival, and on the rapid selection of resistant genotypes. The following article provides an overview of the project, including a description of the trials conducted and a summary of the results. A full description of the study and the results has been submitted to *Deep Sea Research Part II* for publication.

* Author affiliations are given at the end of the article.

Projected changes in ocean acidity

Concentrations of CO_2 in the ocean (pCO2) tend towards equilibrium with the CO_2 in the atmosphere. Since the start of the industrial revolution, the world's oceans are estimated to have absorbed about 30%–50% of global man-made CO_2 emissions, which has lowered the average sea-surface pH by 0.1 units (i.e. making the ocean more acidic and less alkaline) (Feely et al. 2004; Sabine et al. 2004; Orr et al. 2005). It is estimated that uptake of atmospheric CO_2 by global oceans will further reduce sea-surface pH by 0.3–0.4 units by 2100 and up to 0.7 units by the year 2300 (Caldeira and Wicket 2003, 2005).

Concentrations of pH show spatial heterogeneity both between oceanic regions (surface waters) and throughout the water column. Currently, surface layer pH values are lowest in higher latitudes and areas where upwellings may bring subsurface waters with lower pH to the surface. Although the mean seawater pH is expected to decrease globally, the rate of this change is predicted to be greater in high latitudes, and lower in tropical and subtropical waters (Ilyina et al. 2013; Bopp et al. 2013). The degree of change is also dependent on future anthropogenic CO_2 emissions and whether these are higher or lower than "business as normal" IPCC projections, and may be impacted by other predicted consequences of climate change, such as changed ocean circulation patterns (IPCC 2011).

In the Pacific Ocean there is considerable seasonal and vertical/horizontal spatial variation in pH and pCO2. In the eastern tropical Pacific Ocean, surface water pH is on average lower than in the western tropical Pacific, and the pH at 50 m depth (in the eastern Pacific) is on average 0.54 pH units less than at the surface. Across the region of tuna spawning habitat, mean surface water pH is predicted to decrease between 0.26 and 0.49 pH units by 2100 (under the high atmospheric CO_2 scenario of IPCC) (Ilyina et al. 2013). In the eastern Pacific Ocean the pH of surface waters is predicted to decrease from 8.05 to about 7.73 while in the western Pacific Ocean, the mean decline in pH is projected to be 0.40 pH units (with a maximum predicted decline of 0.46) (Ilyina et al. 2013).

Impacts on fish

Our synopsis of the available literature suggests that the early life stages of fish may be more vulnerable to direct OA impacts than adult fish, due to different modes of respiration and ion exchange (Jonz and Nurse 2006; Pelster 2008). Adult fish generally show a stronger capacity to compensate for prolonged exposure to elevated pCO2 due to their ability to control acid base balance by bicarbonate buffering across the gills and to a more limited degree, via the kidneys (Brauner and Baker 2009; Esbaugh et al. 2012). Conversely, exposure to elevated pCO2 has been found to adversely affect embryonic development (Tseng et al. 2013), larval and juvenile growth (Baumann et al. 2011), tissue/organ health (Frommel et al. 2011), and survival (Baumann et al. 2011). Such effects however appear to be species specific, with numerous studies failing to detect direct relationships between "near future" levels of elevated pCO2 and embryogenesis (Franke and Clemmesen 2011), hatching (Frommel et al. 2012), growth and development (Bignami et al. 2013a; Hurst et al. 2012, 2013; Munday et al. 2011a; Frommell et al. 2011, 2012), swimming ability (Bignami et al. 2013a; Munday et al. 2009a) or survival (Frommell et al. 2012; Munday et al. 2011a). Similar results are reported for the growth of otoliths, with increased size and/or density observed in some species (Checkley et al. 2009; Munday et al. 2011b; Hurst et al. 2012; Bignami et al. 2013a, 2013b) but not in others (Frommell et al. 2012; Franke and Clemmesen 2011; Munday et al. 2011a).

The sub-lethal effects of OA may present the largest risk to individuals and populations for many species (Briffa et al. 2012). Somatic impacts such as reduced growth and size at age have been linked to increased mortality in natural fish populations due to increased risks of predation and reduced ability to find food (e.g. Houde 1989; Leggett and Deblois 1994). Otoliths play an important role in detecting sound, acceleration and body position in fish (Bignami et al. 2013b) and altered otolith formation may change predator avoidance and foraging efficiencies of individuals. Neurological and behavioral effects associated with elevated CO_2 levels have also been observed in coral reef fish (Briffa et al. 2012). These include disruption to mating propensity (Sundin et al. 2013), impaired ability to make settlement choices (Munday et al. 2009b), altered timing of settlement (Devine et al. 2012), impaired response to predator and prey olfactory cues (Allen et al. 2013; Cripps et al. 2011; Dixson et al. 2010; Nilsson et al. 2012), reduced escape distances (Allen et al. 2013), altered responses to visual threats (Ferrari et al. 2012a) and auditory signals (Simpson et al. 2011), behavioral lateralisation (Domenici et al. 2012; Nilsson et al. 2012) and a reduced capacity to learn (Ferrari et al. 2012b). Such behavioral changes were recently linked in reef species to the impact of elevated pCO2 upon key brain neurotransmitter GABA-A (Nilsson et al. 2012), with potential implications for other species given the highly conserved nature of GABA-A across species.

Potential vulnerability of tunas

While many of the original studies in this area focused on reef species, recent studies have expanded to include non-reef species (e.g. Bignami et al. 2013a, 2013b; Frommel et al. 2010, 2011, 2012; Sundin et al. 2013; Tseng et al. 2013), but these have not included tuna species. The only experiment known to have tested impacts upon a tuna species (eastern little tuna) tested pCO2 levels that far exceeded those predicted using IPCC scenarios (Kikkawa et al. 2003). Pelagic fish species are considered in general to have evolved in a relatively more stable pH environment than coastal and reef species, and this, in addition to low blood pCO2 levels that can be expected to result from their high rates of gas exchange, may make them more vulnerable to changes in ocean pCO2 and pH (e.g. Nilsson et al. 2012).

Tropical tunas range and spawn in equatorial and subtropical waters from the far western Pacific Ocean to the far eastern Pacific Ocean, and in both near coastal waters and oceanic waters (Schaefer 2001). It is unknown whether the historical level of OA variability across the tropical Pacific has been sufficient to have conferred some evolved resilience in tropical tunas to predicted future levels of OA.

Although the likely effects of OA on tuna populations have not been investigated, such research is clearly a high priority. Decision-makers need timely and appropriate scientific advice for current and future tuna fisheries management and worldwide adaptation planning. In October 2010 the Pelagic Fisheries Research Program (PFRP) recognised this need and funded a collaborative study of the impact of OA on the early developmental stages of Pacific yellowfin tuna. The study, led by the Secretariat of the Pacific Community and IATTC, is investigating the effect of OA upon embryonic development, hatching rates, condition, development, and growth and survival in pre- and post-feeding yellowfin larvae. The collaboration includes scientists from the Max Planck Institute of Meteorology (Germany), Collecte Localisation Satellites (France), the University of Gothenburg (Sweden), and Macquarie University (Australia). As tolerance to OA has been found to be variable on an individual level in other species, the project has included a component to look at whether genotypes (the genetic makeup) of individual yellowfin larvae vary in their responses to different CO_2 levels. This last component is a first step towards determining if OA causes genetic selection of resistant genotypes in this species. Analyses to estimate the effects of OA on life stage development and rates of deformity, otolith formation and genetics are ongoing and not presented.

Achotines facility

Experimental trials were conducted at IATTC's Achotines Laboratory, Panama, in October and November 2011. The facility was inaugurated in 1985 and is one of only a few in the world with the location, equipment, and expertise to conduct investigations of this type. Achotines Bay is located on a section of coastline (Fig. 1) where the continental shelf drops rapidly and deep oceanic waters are close to shore, allowing researchers to easily access local tuna populations for either field studies of early development or to obtain yellowfin tuna as captive broodstock. At the lab an in-ground concrete tank holds a broodstock population of yellowfin tuna that have spawned on a near-daily basis since October of 1996, providing a reliable source of eggs and larvae for early developmental studies.

Experimental trials

Experimental trials were grouped into three categories: sperm and fertilisation trials, egg and larval trials, and genetics analyses. The egg and larval trials were replicated, with the initial trials in October and the replications in November.

Tank set up and pH control

The experimental setup for the fertilised egg and larval trials consisted of 15 experimental tanks. Each 840-liter (l) capacity tank was nested inside of an 1100-l tank filled with seawater that acted as a buffer/insulator to stabilise the water temperature in the smaller tank during the trials. Water flow, lighting, aeration, and turbulence levels were adjusted to set these parameters as uniformly as possible across all tanks.

Four pH treatment levels (6.9, 7.3, 7.7 and 8.1) were targeted in each trial with three replicate tanks per treatment level (Fig. 2). These levels were chosen based on results from the ocean-carbon-cycle models using the IPCC IS92a Scenario (e.g. the Hamburg Ocean Carbon Cycle model) (Ilyina et al. 2009) and reference to published studies on predicted pH levels (Ilyina et al. 2013; Caldeira and Wickett 2003) and take into account spatial variation in predicted declines, not just the global average predicted declines. Target pH levels 6.9 to 8.1 encompass potential mean ocean pH levels estimated for the current oceans and predicted for near future oceans (to 2300). A fifth treatment with a pH of 6.5 was also included. This treatment was applied as a range test to ascertain that extreme values of pH would result in mortality. This value is well below the lowest predicted pH for the time period to 2300.

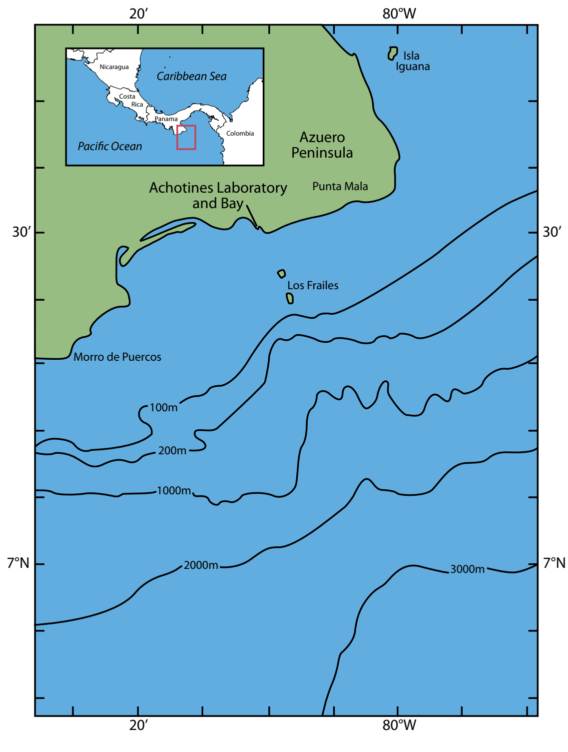

Figure 1. The location of the Achotines Laboratory. The bay in the centre of the photo is Achotines Bay.

Figure 2. The multiple experimental tanks with nested egg incubators used in experiment 1 and experiment 2 of the pilot study.

The local coastal waters that supply the Achotines Laboratory seawater system were very close to pH 8.2 during the trial period and therefore ambient seawater was used for the high pH level. The four lower treatment levels of seawater pH were maintained by regulation of mixtures of compressed air and CO_2 bubbled through air diffusers in each tank. The use of CO_2 was critical to modifying water chemistry (i.e. increasing carbonic acid, increasing H+, lowering pH) in a manner consistent with CO_2-induced ocean acidification.

In all trials, water-quality parameters (pH, temperature, salinity, dissolved oxygen, CO_2, alkalinity) were measured at frequent intervals in each tank. Controlling pH in ocean-acidification experimental systems is a difficult task (Riebesell et al. 2010). For these experiments, sophisticated electronic gas-flow controllers were used to precisely control the mix of air and CO_2 supplied to the tanks in each module. The average pH attained in each module (treatment level) for the first experiment was within 0.15 units of the target pH (and generally much closer). In the second experiment average pH levels in each module varied, at times, by several units from the target pH.

Fertilised egg and larval trials

The effects of OA upon mortality, growth, and development of eggs and larvae of yellowfin tuna were tested by rearing larvae from egg stage to first-feeding stage in 15 tanks comprising the five treatment (pH) levels. Trials were continuous but effectively comprised three phases: egg phase, yolk-sac larval phase, and first-feeding larval phase, with sampling regimes differing in each phase.

To start the experiment, fertilised eggs were collected from a daily spawn in the broodstock tank of the Achotines Laboratory and randomly stocked in each of 15 cylindrical egg-incubation nets nested one per experimental tank (Fig. 3). Eggs were stocked in each egg-incubation net at a density of 177 eggs L^{-1}, and eggs were immediately sampled fresh for weights and measurements. Additional samples of eggs were taken during the incubation period and fixed for subsequent histological examination of tissue and organ development.

Yolk-sac larvae were then dispersed from the egg-incubation nets into their respective experimental tanks 1 hour (h) after hatching. The yolk-sac phase in yellowfin tuna larvae continues until approximately 50–70 h after hatching depending on water temperature. Yolk-sac-stage and feeding larvae were maintained in the same experimental tanks until early on the seventh day of feeding (approximately 8.5 days post-hatching; 9.38 days total from egg transfer), when the experiments were terminated.

Larvae were fed cultured *Brachionus plicatilis* (rotifers) at densities of 3–5 mL^{-1}. Dense blooms of unicellular algae (500,000–750,000 cells mL^{-1}) were maintained in each tank to facilitate rearing (Margulies et al. 2007).

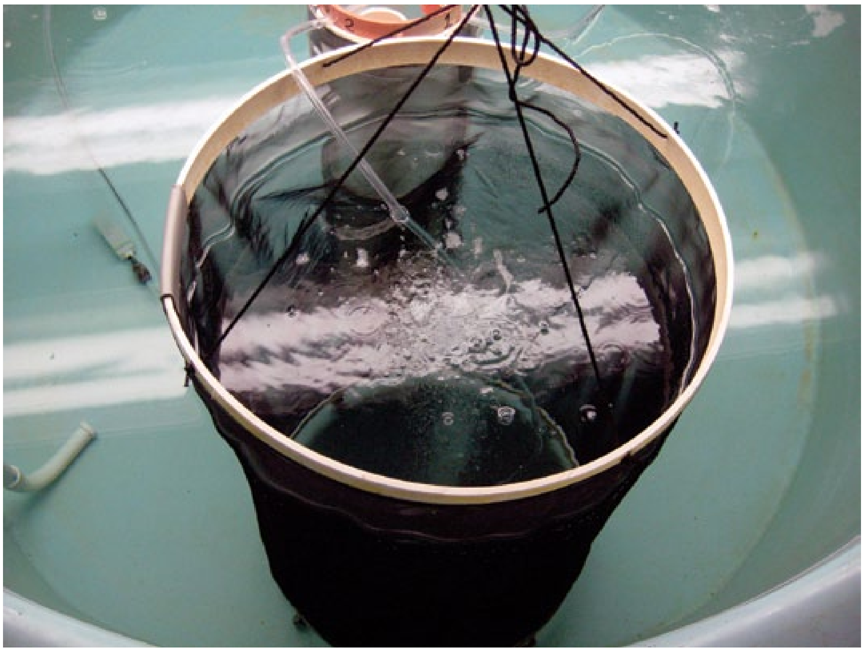

Figure 3. The cylindrical egg-incubation nets used in the pilot study. One net was nested in each experimental tank.

During each phase (egg, yolk-sac, and first-feeding), 15–17 fresh samples were taken at various intervals from each tank to be measured (total length, notochord length, body depth at pectoral, body depth at vent) and processed for dry-weight determination. Samples collected during each developmental phase were also fixed and stored for later analyses of tissue histology and organ development, feeding success, genetic variability and otolith development.

At the termination of the experiment each tank was slowly drained of water and all surviving larvae were removed by beaker and counted. The percentage of expected survival (adjusted for sample removals) was estimated for each tank.

Results and discussion

Our study tested the effect of a range of pH (~6.9–8.2) and pCO2 (330–10,467 microatmospheres [uatm]) conditions upon yellowfin tuna eggs and larvae. This range is broad enough to take into account current and future (to the year 2300) spatial variability in water chemistry across the yellowfin tuna spawning habitat range in the Pacific. Experimental tanks with mean pCO2 of less than 2500 uatm provided conditions that are relevant to the assessment of "near future" (i.e. year 2100) impacts on yellowfin tuna. Over longer time frames (e.g. to 2300) or with further increases in CO_2 emissions, pCO2 may increase further and pH decrease further (e.g. by 0.7 pH units according to Caldeira and Wickett [2003]), in which case our experimental tanks with mean pCO2 between 2500 and 5000 uatm are relevant.

The most consistent impacts across larval yellowfin early life history processes occurred at the highest pCO2 levels tested (>8500 uatm; Table 1). These levels are outside those predicted to occur in the next 300 years. However, there was evidence of significantly reduced survival at mean pCO2 levels of ≥ 4700 uatm (experiment 1) and significantly reduced larval size (experiment 1) and extended egg hatch time (experiment 2) at mean pCO2 levels ≥ 2200 uatm, that are relevant to near future predicted levels (Table 1). Significant effects at near future pCO2 levels were not, however, consistently predicted in both trials.

We observed reduced survival of yellowfin larvae after 7 days of feeding in the first trial with increasing mean pCO2. The mean survival at the control level (pH = 8.23, pCO2 = 368) was not significantly different to survival at pH 7.56 (pCO2 ~2108) but was significantly greater than survival at pH 7.35 (pCO2 ~4732) and pH 6.90 (pCO2 ~8847). The relationship between survival and mean pCO2 in the second trial was neither clear nor statistically significant, due in large part to the high level of intra-treatment variability in survival. There was a sudden mortality event (crash) in tank 15 (pH 8.1) on the last night of trial 2, associated with a very high density of larvae throughout the trial in the same tank. Such events are uncommon but have been observed previously in

Table 1. Experimental results for the pilot study on how ocean acidification may impact yellowfin tuna. Statistically significant differences between control (current day pCO2 levels) and treatment levels are presented as red squares. The green squares represent where statistically significant effects were not detected in experiments 1 and 2. The mean pH and pCO2 for the control tanks for experiments 1 and 2 were 8.2/368 and 8.1/464 respectively.

	Experiment 1			Experiment 2		
	pH range pCO2 range			pH range pCO2 range		
	7.6 2108	7.4 3820	6.9 9824	7.6 1719	7.2 4733	7.0 8847
Egg stage duration	[green]	[green]	[red]	[red]	[red]	[red]
Survival	[green]	[red]	[red]	[green]	[green]	[green]
Growth dry weight	[green]	[green]	[red]	[green]	[green]	[red]
Growth standard length	[red]	[red]	[red]	[green]	[green]	[red]

high larval density tanks at Achotines after 4–5 days of feeding. High survival in that tank, if it had been included in the analysis, would have provided a declining survival trend with increasing pCO2 in trial 2.

The egg stage and growth results were more consistent between the two trials. Pair-wise comparisons for both experiments indicated a significant difference in dry weights between larvae reared in the control treatment (mean pCO2 ~368 in trial 1 and ~464 in trial 2) and the highest pCO2 treatments (mean pCO2 ~9824 in trial 1 and ~8847 in trial 2) but not between larvae reared at the control and intermediate pCO2 levels. Effects at intermediate pCO2 levels were detected for standard length. Pair-wise comparisons for experiment 1 indicated that larvae reared in the treatment tanks with mean pCO2 ~2108 and mean pCO2 ~4732 were significantly smaller than those reared in the control treatment (pCO2 ~368). Slower larval growth during the first week of feeding may subsequently impact survival by affecting foraging success and by prolonging stage durations, increasing larval size-dependent susceptibility to predation (review in Leggett and Deblois 1994).

A significant positive relationship between mean pCO2 and hours until complete hatching was detected in both experiments. The hatch times at mean pCO2 values less than ~2200 were very similar in experiment 1, and the significant increasing trend in hatch time for this experiment represents an increase in mean hatch time at mean pCO2 > ~8800 (target pH 6.9) as compared to the mean hatch times at the lower pCO2 levels. In experiment 2 the mean hatch time at pH 8.1 was significantly less than that at each of pH 7.3, 7.7. and 6.9. The mean hatch time at pH 7.3 was also significantly less than that at pH 6.9 in this experiment. The difference in hatch time between the current conditions and mean pCO2 > ~8800 was one hour. Similar delays in hatching have also been observed during adverse physical conditions of very low dissolved oxygen levels and extremely high water temperatures (Wexler et al. 2011).

The purpose of the pilot study was to trial techniques to help design more intensive experimental trials. Power analyses of variability in survival responses within and between tanks/treatments indicated that more replicate tanks per treatment are needed to increase the statistical power and sensitivity of the experiments, so that the functional form of survival relationships can be identified and described. This was less of an issue for the growth analyses for which sample numbers were an order of magnitude higher. An additional design consideration for future experiments is the application of elevated pCO2 conditions to the parental stock. Recent research has demonstrated that exposure of broodstock to elevated pCO2 prior to spawning may reduce or remove negative impacts of elevated pCO2 upon behavior of larvae derived from subsequent spawnings (Miller et al. 2012).

Future experimental trials should include a lower pCO2 treatment (~1000 uatm) to test yellowfin larval responses to lower "near future" pCO2 levels. Including the interactive effects of temperature and oxygen, which will also vary under future climate change (Gruber 2011) would also be beneficial. OA and other parameters such as temperature have already been shown to interact for some species (Nowicki et al. 2012; Munday et al. 2009a; Enzor et al. 2013). Hypoxic zones in the ocean may increase in the future as a result of climate driven changes in temperatures and deep ocean mixing (Hofman and Schellhuber 2009). Survival during the onset of feeding in yellowfin tuna larvae is greatly affected by short-term oxygen deficits at water temperatures ≥26 °C (Wexler et al. 2011). Larval sensitivity to dO2 might increase under elevated pCO2 conditions, and this needs to be tested in future experiments.

The very high fecundity and relatively short generation time of yellowfin tuna may permit them to adapt more rapidly than less fecund, longer-lived species. It will be important to determine the extent to which inter-individual variation mediates different selection responses (Schlegel et al. 2012). Genetic analyses of samples taken from the current trials are in progress to assess whether some genotypes are more robust to changes in pCO2, and these results should provide insights on the designs needed to assess this important question. Results of our supplemental sampling on the feeding patterns, otolith morphology and histological condition of internal tissues of larvae will also permit us to further investigate how acidification affects early life stages. Analyses of samples taken from yolk-sac and early feeding larvae will allow us to assess at what point in development any effects on growth first became apparent.

The ultimate goal of this research is to provide information that will allow models such as the Spatial Ecosystem and Population Dynamics Model (SEAPODYM) to be parameterised to include acidification effects and subsequently enable scientists and tuna fishery managers to better understand how these changes in ocean chemistry will alter the distribution and abundance of yellowfin tuna. Environmental data are used in SEAPODYM to functionally characterise the habitat of the population depending on its thermal, biogeochemical, and forage preferences (Lehodey et al. 2008, 2010). To this end, it will be critical that that further empirical trials are conducted to more clearly identify the functional form of the relationship between pH (or pCO2) and larval survival, and in particular, identify any interactions between pH (or pCO2) and other key physical oceanographic factors such as temperature and oxygen, so as to provide relevant information for appropriately altering the spawning-habitat index in SEAPODYM. Subsequent population level predictions of ocean acidification impacts will enhance the capacity of regional fisheries management organisations to make better-informed decisions regarding the management of the highly valuable tropical tuna resources, particularly with regard to attaining key sustainability-related objectives (Bell et al. 2013).

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Author affiliations

1. Vernon Scholey is the Director of Achotines Laboratory (Inter-American Tropical Tuna Commission), Las Tablas, Los Santos, Panama.
2. Don Bromhead, Simon Hoyle and Simon Nicol are Fisheries Scientists with the Oceanic Fisheries Programme, Secretariat of the Pacific Community, BP D5, 98848 Noumea CEDEX, New Caledonia.
3. Daniel Margulies, Jeanne Wexler, Maria Santiago and Cleridy Lennert-Cody are Fisheries Scientists with the Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, California, 92037, USA.
4. Jane E. Williamson is a Senior Lecturer within Biological Sciences and runs the Marine Ecology Group at Macquarie University, NSW, 2109, Australia.
5. Jon Havenhand is a larval ecologist working on ocean acidification in the Tjärnö Marine Biological Laboratory, University of Gothenburg, 45296 Strömstad, Sweden.
6. Tatiana Ilyina leads the Ocean Biogeochemistry Group at the Max Planck Institute for Meteorology, Bundesstrasse 53, 20146 Hamburg, Germany.
7. Patrick Lehodey is head of the Marine Ecosystem Department of the Space Oceanography Division of CLS, France, 8-10 rue Hermes, 31520, Ramonville St Agne, France.

Original text: English

Secretariat of the Pacific Community, Fisheries Information Section, BP D5, 98848 Noumea Cedex, New Caledonia

Telephone: +687 262000; Fax: +687 263818; cfpinfo@spc.int; http://www.spc.int/fame