Update on ciguatera research in French Polynesia

Mireille Chinain[1], H. Taiana Darius[1], Clémence M. Gatti[1] and Mélanie Roué[2]

Seafood is a source of both basic nutrition and significant income for many communities in the Pacific region. Unfortunately, many cases of food poisoning occur every year after eating seafood, including fish, shellfish and bivalve molluscs. This is because the seafood involved contains toxins produced by phytoplankton, which are then bio-accumulated in marine food webs. The rise in the number of cases of food poisoning and their spread to previously unaffected areas of the world, clearly indicate that seafood safety is a growing public health concern and economic challenge, not only regionally but globally as well.

Of the six major poisoning syndromes recorded in French Polynesia, ciguatera is the main, if not only, cause of seafood poisoning [1]. It is usually caused by eating edible reef fish that has been naturally contaminated by ciguatoxins (CTXs). Ciguatera is highly dynamic and can spread endemically or sporadically in outbreaks. CTXs are produced by the unicellular microalga *Gambierdiscus*, which proliferates episodically in highly degraded coral ecosystems (Figure 1).

causes like dynamiting, landfill and coral aggregate quarrying, are factors that should be considered likely to lead to ciguatera outbreaks. Because CTXs are very stable, they stay active even after fish is frozen, cooked, salted or smoked. In all, some 400 lagoon species are thought to be potential poison vectors. In a ciguatera-affected area, however, not all species are necessarily toxic for humans, and the same is true for even very closely related species. Also, only some fish of a particular species may prove to be toxic and, those that do vary from one island to another, making risk management in the most ciguatera-prone lagoons more difficult.
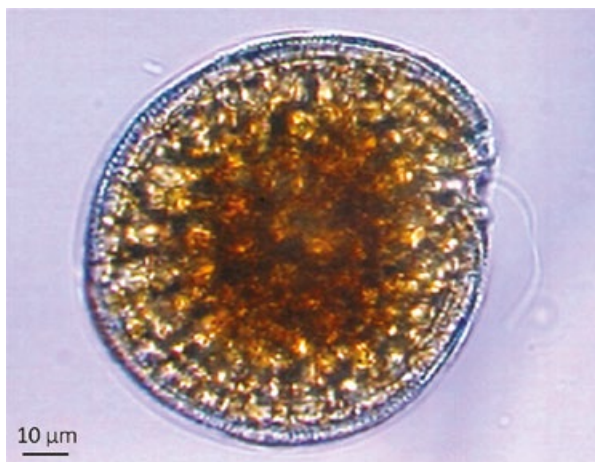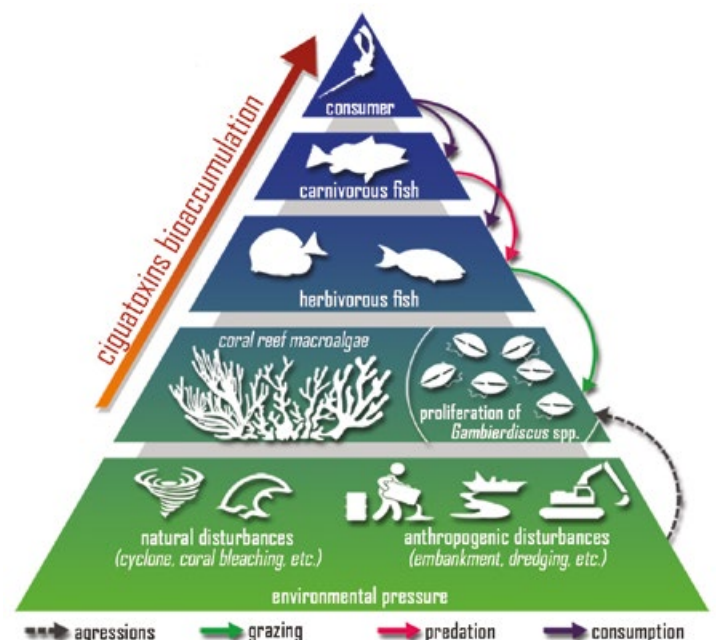

Figure 1. *Gambierdiscus* spp., the ciguatera-causing dinoflagellate, seen through an optical microscope. © ILM

Intense *Gambierdiscus* colonisation in reef ecosystems is what triggers reef-food-chain contamination. The toxins produced by the microalgae gradually accumulate in herbivorous fish as they graze on micro-algal turfs covering dead coral. The toxins then accumulate in carnivorous fish that prey on the toxic herbivorous fish. As the toxins accumulate along the food chain, they eventually reach consumers at the pyramid's summit (Figure 2). Thereby, natural disturbances in coral ecosystems such as cyclones, tsunamis, coral bleaching and *Acanthaster planci* infestation, as well as man-made

Figure 2. Diagram showing how ciguatera toxins travel up through the food pyramid. © ILM

[1] Laboratory of Toxic Microalgae, Louis Malardé Institute, UMR 241-EIO, BP 30 98713 Papeete, Tahiti, French Polynesia
[2] IRD (French Research Institute for Development), UMR 241-EIO, BP 529, 98713 Papeete, Tahiti, French Polynesia
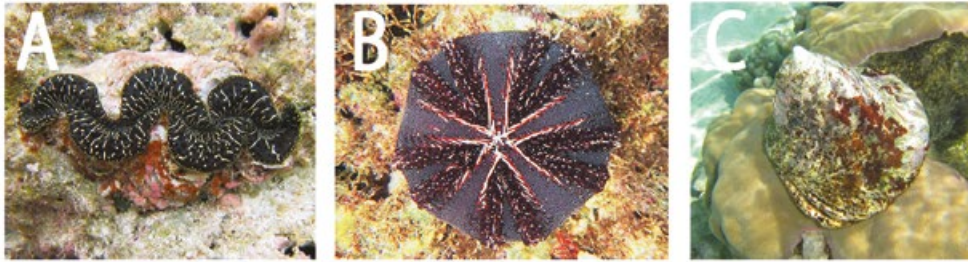
Figure 3. Examples of marine invertebrates that cause atypical ciguatera food poisoning in French Polynesia: A) giant clam or *pahua* (*Tridacna maxima*); B) sea urchin or *hava'e* (*Tripneustes gratilla*); C) trochus (*Tectus niloticus*). © ILM

While lagoon fish were long thought to be the only ciguatera vectors, recent research demonstrates that some marine invertebrates such as giant clams (*Tridacna maxima*), sea urchins (*Tripneustes gratilla*) and gastropods (*Tectus niloticus*) (Figure 3) can also contribute to atypical and sometimes more severe forms of ciguatera, also known as ciguatera shellfish poisoning. These forms have so far been reported in French Polynesia, New Caledonia, Vanuatu and the Cook Islands [2, 3].

Essentially, the seafood-related toxic hazard in French Polynesia is now a persistent public health issue with concrete social and economic fallout. Two of the main hurdles standing in the way of sustainable marine resource use in Pacific Island countries and territories (PICTs) are: (i) no internationally-approved reference detection test; and (ii) the limited availability of pure ciguatoxins required for the calibration of current detection tests, which is a definite obstacle to implementing large-scale monitoring programmes (cf. section on 'molecular detection of *Gambierdiscus*').

Early ciguatera research in the Pacific by pioneering American, Japanese and French Polynesian teams started in the early 1960s. In French Polynesia, it all began with an outbreak of 33 severe poisoning cases after eating giant clams on Bora Bora, Society Islands, between April and July 1964 and resulted in three deaths. The local authorities commissioned a consultancy to the island by two American experts, Profs Banner and Helfrich, from the University of Hawaii. It was not until 1976, however, when Prof. T Yasumoto and Dr R Bagnis conducted research in the Gambier Islands during an unprecedented toxicity outbreak, that the agent causing ciguatera, i.e. *Gambierdiscus* microalga, was at last formally identified [4]. That historic discovery would pave the way for several decades of research in French Polynesia, the only Pacific Island country that currently has a permanent ciguatera research unit, i.e. the Toxic Microalgae Laboratory (LMT) based within the Louis Malardé Institute (ILM) in Tahiti. Since 2012, the LMT has been conducting research in close partnership with the French Institute for Development Research (IRD) in French Polynesia, as part of the ESSENTIA[3] Pacific Island Ecosystem joint research unit (UMR 241-EIO).

The strategy adopted by French Polynesia in ciguatera control is an integrated approach that tackles the issue from various angles, namely epidemiology, the environment, biology, toxicology and medicine (Figure 4). On the sidelines of the research *per se*, the LMT also carries out community education, and awareness work and training for development or skill transfer purposes as part of technical co-operation with countries in the Asia-Pacific region.
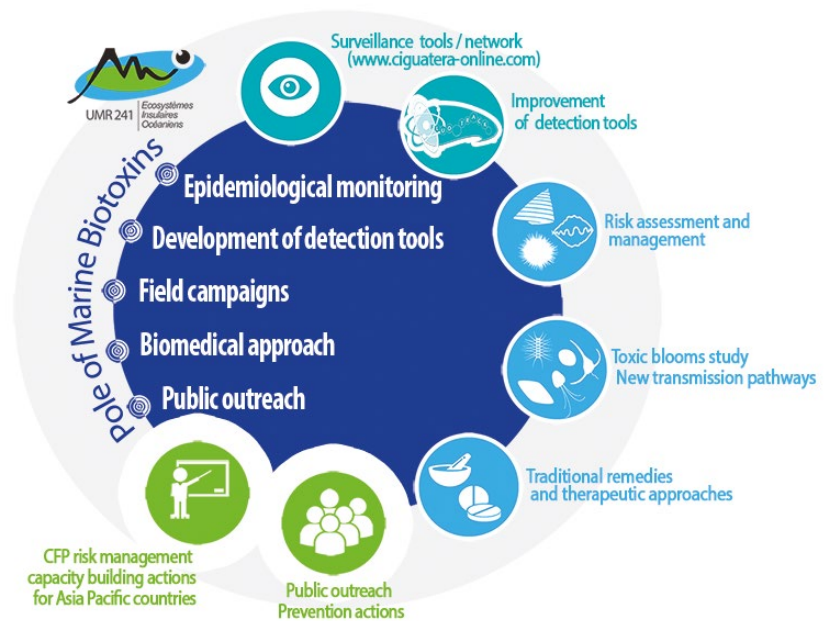

Figure 4. Integrated approach used in French Polynesia for ciguatera research.

1. Epidemiological surveillance of marine biotoxin poisoning cases

French Polynesia is one of the few Pacific countries to have a country-wide ciguatera epidemiological surveillance programme. It is implemented in collaboration with the public health staff of all 61 healthcare facilities located throughout the country, including outlying hospitals, clinics, medical centres and dispensaries, and aims at narrowing down the aetiology of the various forms of marine biotoxin poisoning and monitoring the yearly incidence both on each island and country-wide [5]. Under the programme, a standard form is completed by the relevant facility's public health staff for each reported patient. Information is gathered on age, gender, island of residence, symptoms, number of previous ciguatera poisonings and details of the seafood eaten, e.g. whether it was fish or not, the species, part eaten and fishing area. Case reporting by practitioners is, however, optional. Since 2007, all notification forms have been filed centrally at ILM, which issues a yearly summary report. The general trend observed in French Polynesia as a whole since 2007 points towards a stable annual incidence rate (IR), although rates can differ considerably from one island to another, ranging from 2 to 1,500 cases per 10,000 inhabitants, depending on the island or island group. These figures are, however, heavily distorted by a high under-reporting rate and could quite possibly be at least doubled, as in more than half the reported cases patients stated they had shared the toxic food with others at table who had also gone on to develop symptoms, but only one form had been completed [5] (Figure 5). For this reason, major efforts are being made to broaden the current reporting programme's reach, mainly by building a dedicated ciguatera website that went on line in late 2014 (www.ciguatera.pf; www.ciguatera-online.com). In addition to opening up the notification programme to private practitioners and the general public, the site also provides web users with access to participatory and dynamic, real-time mapping of toxic-hazard areas and the marine species involved in any poisoning cases. Extending the website to the Asia-Pacific region is currently being explored with two international agencies,

i.e. the International Atomic Energy Agency (IAEA) and the UNESCO Intergovernmental Oceanographic Commission (IOC), with additional funding from the French Pacific Fund (CiguaWatch project).

As a result, the surveillance programme identified both the scarce areas that are still ciguatera-free and, in contrast, a number of ciguatera hotspots [5, 6] that are ideal for research or where ecotoxicology investigations combined with preventive work could be carried out. A distance gradient has generally been observed in the IRs with the island groups furthest from Tahiti showing the highest IRs, due mainly to dietary differences observed between island groups. Also, based on the significant number of people who reported poisoning after eating only fish heads and/or viscera, it would appear vital to maintain or even reinforce the public health message that strongly warns against eating such fish parts, which are known to store more toxins than other parts do [5].

The surveillance also highlighted the fact that new forms of poisoning similar to ciguatera were emerging or re-emerging after popular marine invertebrates in French Polynesia, particularly giant clams, had been eaten [2], with the latest being a collective food-borne disease incident involving nine tourists who had eaten gastropod molluscs (*Tectus niloticus* or trochus) in 2014 on Nuku-Hiva in the Marquesas Islands [7]. These atypical poisoning forms, referred to by the generic term 'ciguatera shellfish poisoning' or CSP, were researched in depth under the ARISTOCYA programme (2009-2012) funded by the French National Research Agency (ANR). This investigation showed that such poisoning, which had been reported elsewhere in the Pacific, e.g. Lifou, New Caledonia, Vanuatu and Cook Islands, was probably caused by a proliferation of marine cyanobacteria in the Oscillatoriales family (*Oscillatoria*, *Hydrocoleum*, *Trichodesmium),* which are able to produce several toxin families that would also require surveillance [8, 9, 10].

More recently, research has shown that giant clams (*Tridacna maxima*) are also capable of metabolising *Gambierdiscus*
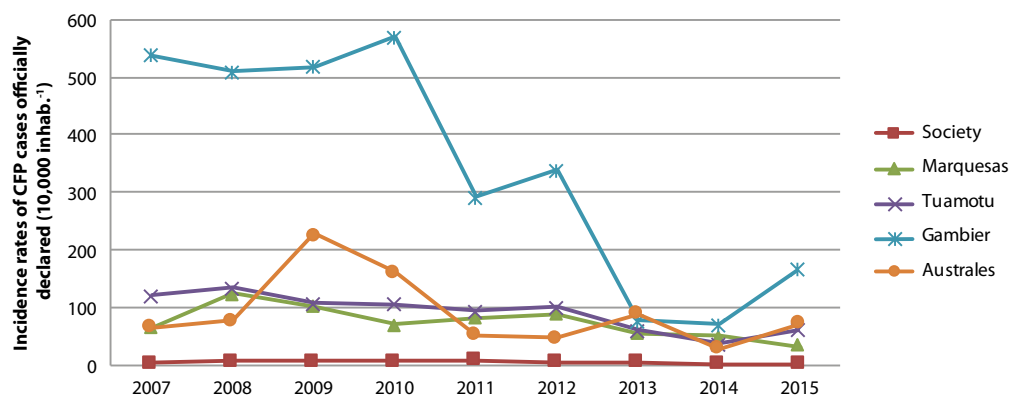

Figure 5. Incidence rate of reported ciguatera cases in French Polynesia's five archipelagos from 2007 to 2015 (www.ciguatera-online.com).

toxins in their tissues and organs after being exposed *ex situ* to highly-toxic cultures of this microalga [11]. Experiments to identify CTX depuration pathways and kinetics in this locally-popular bivalve are on-going.

2. Detection methods and technology watch

At the moment, health-hazard surveillance in terms of phycotoxins in French Polynesian waters and marine products focuses exclusively on *Gambierdiscus* and ciguatoxins. Aside from this now efficient surveillance process, there is also the issue of the possible health impact of other microalgal species that have already been reported in our waters and are behind emerging events in other parts of the world. There is considerable potential for new, emerging health hazards related to the toxicity of certain algae, as shown by recently-identified palytoxin-producing *Ostreopsis* strains on Rapa Island in the Austral Islands or the unprecedented report of the dinoflagellate *Azadinium* sp. on Nuku-Hiva in the Marquesas in 2015 [12], some species of which produce azaspiracids: cyclic imines that cause diarrheic food-poisoning in coastal Europe. As a result, the laboratory's strategy for developing *ad hoc* analytical methods is firmly based on an approach that combines surveillance (using tests that are able to detect substances that have so far not been included in the current monitoring system, or only inadequately) and a 'technology watch', i.e. constantly improving current tools. In order to meet this dual objective, several innovative microalgae and/or phycotoxin detection methods have been introduced into the current surveillance framework.

Passive monitoring devices (window-screens and SPATT filters)

Window-screens (WS) are artificial substrates for assessing microalgal species abundance in the marine phytobenthos. [13]. They are rectangular, artificial substrates made up of fibreglass screen-pieces submerged in the natural environment for short periods of less than 24 hours (Figure 6). This novel technique has a major advantage over standard natural substrate-based methods, which involve sampling the macrophytic algae that are benthic microalgae's natural substrate, because WS samples contain less debris and contaminating micro-organisms and can thus be directly tested using molecular biology techniques (e.g. qPCR, cf. section entitled 'Molecular detection of *Gambierdiscus*') and so, provide valuable information on the structure and genetic diversity of benthic communities closely associated with ciguatera-producing biotopes. By using this technique, it was shown, for example, that up to six *Gambierdiscus* species could co-exist on a single site on Mangareva Island, a historical ciguatera hotspot in the Gambier group. The artificial substrate technique also lends itself very well to monitoring other dinoflagellates often associated with *Gambierdiscus* in ciguatera-generating biotopes, including *Ostreopsis*, *Prorocentrum*, *Amphidinium* and *Coolia* [14, 15].
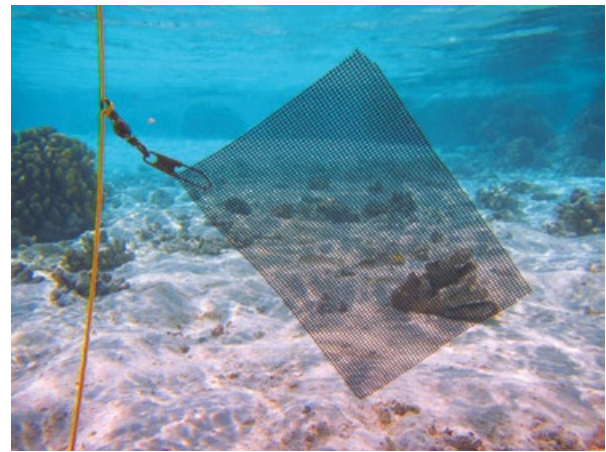

Figure 6. In situ view of window-screen artificial substrates for monitoring *Gambierdiscus* populations. © ILM

SPATT (solid-phase adsorption toxin tracking) filters are tools for concentrating toxins and consist of a resin formed by microbeads that can trap a broad range of lipophilic toxins produced and spread through the water during algal blooms [16]. When combined with high-resolution testing techniques, such as liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS), the method can prove to be an excellent toxic-bloom early-warning system. The usefulness of such cheap, easily-designed systems, which are also well-suited to French Polynesia's widely scattered islands, is currently being assessed as part of collection campaigns in several at-risk lagoons in French Polynesia (Figure 7).

Figure 7. Deploying toxin-concentration devices (SPATT filters) in the wild. © ILM

Preliminary studies show that SPATT filters are useful in the time-integrated sampling of a large array of toxins including CTXs, maitotoxin, okadaic acid and azaspiracids that already inhabit our waters [17, 18].

Molecular detection of the ciguatera-causing Gambierdiscus *microalga*

Monitoring *Gambierdiscus* populations on specific fishing grounds is a key aspect of ciguatera assessment and management campaigns. The genus displays a remarkable morphological and genetic diversity with no fewer than 13 currently-known distinct species and three related globular species (*Fukuyoa* spp.), each of which is widely-distributed geographically and has a different toxicity level [19, 20, 21]. Differences in toxicity can also be observed between the strains of the same species [22]. Such genetic diversity and, more importantly, varying and unpredictable toxin production in dinoflagellates mean that *Gambierdiscus* blooms can prove dangerous at any given time and must be viewed as suspect. Our ability to detect and quantify the different species in natural microalga populations will have profound implications for the ciguatera-risk surveillance and early-warning system's performance and reliability. Following collaboration with the Centre for Coastal Fisheries and Habitat Research (NOAA, North Carolina) team, qPCR tests targeting specific Caribbean and French Polynesian *Gambierdiscus* species are now available [23]. This technology is a major step forward in hazard management, as it allows for prior monitoring of *Gambierdiscus* blooms in both qualitative and quantitative terms before significant amounts of CTXs accumulate in the lagoon food web. It also paves the way for cross-regional research into the microalga's bio-geography in the hope of better understanding the variations observed in ciguatera outbreak severity between the regions of the world.

By systematically carrying out toxin screening on the 100 *Gambierdiscus* strains in ILM's algal collection (Figure 8), several 'super-productive' ciguatoxic strains have been identified and are prime material for several innovative research areas:

(i) mass production and purification of algal CTXs, which have enabled us to acquire a unique bank of standards. Having the pure toxins required as standards for detecting CTXs is a major development asset for the laboratory against a backdrop of globalised ciguatera outbreaks and the heightened demand for standards of CTXs from laboratories seeking to acquire *ad hoc* testing capacity;

(ii) experiments to explain and mimic algal CTX biotransformation pathways *in vitro* and *in silico* towards the more oxidised (and more toxic) metabolic forms found most often in higher trophic levels;

(iii) experimental contamination of popular local fish species through gavage so as to more clearly understand CTX toxin kinetics and the metabolic processes that govern CTX transfer to and bio-accumulation in marine food webs. Early results suggest that algal CTX retention in fish tissue is closely tied to CTX chemical composition (e.g. polarity and lipophilic nature) [24]. This approach, if used on several representative fish species for different trophic levels such as herbivorous and carnivorous, will explain why some fish families such as surgeon fish, giant grouper and bluefin trevally are more of a poisoning hazard than others.

Figure 8. Maintaining the algal collection containing approximately 100 *Gambierdiscus* strains at the Louis Malardé Institute Toxic Microalgae Laboratory. © ILM

Marine biotoxin detection tests

A succession of CTX-detection methods have been explored at ILM. Historically, the mouse bioassay was the earliest method used at the laboratory and it led to progress in toxin research spanning several decades. It was based on observing symptom severity and nature and - standardised (age, sex and weight) animal survival rates and used to assess a sample's overall toxicity, but its main drawback was its limited sensitivity. It was finally discarded in 2008, due to difficulties in implementing it and increasingly stringent legislation on live-animal experiments. Other, more precise methods were subsequently explored based on physical, chemical, pharmacological and immunological processes, though with varying degrees of success [25].

The approach currently favoured in the laboratory to provide the most reliable possible testing services to consumers and commercial fisheries is to use a combination of two functional tests, namely a neuroblastoma cell-based assay (CBA-N2a) and a radioactive receptor binding assay (rRBA) that have roughly the same advantages in that specificity and sensitivity are high with a detection limit ranging from 10^{-10} to 10^{-12} M based on the FDA-recommended safety threshold; applicability to a wide range of sometimes complex biological matrices (including algal or cyanobacterial cell extracts, fish or giant clam flesh and blood); and a high sample processing capacity, as testing can easily be automated. CBA-N2a is additionally a good alternative to the mouse bioassay for assessing a samples' overall toxicity and is remarkably flexible in detecting a wide range of toxins (e.g. ciguatoxins, palytoxin, maitotoxins, brevetoxins and saxitoxins), and so is perfectly suited to the monitoring requirement referred to in the introduction to this chapter. That is why the test is currently being used routinely for fishing-ground monitoring and lagoon seafood safety checks in French Polynesia [6], with rRBA only being used for confirming specific instances of CTXs in suspect matrices. That test requires using a radioactive marker, is difficult to operate and strictly regulated, making it very costly and financially unviable. As part of the laboratory's technology watch, collaboration has begun with the University of North Carolina at Wilmington (UNCW) to migrate rRBA towards a high-throughput format using a fluorescent marker or FRBA [26]. The clear advantages of FRBA (easy deployment, shorter testing time and nearly 25 % cost reduction per test) should contribute to making the test more readily accessible across the Pacific, which would be a major step forward for Pacific communities in managing this global hazard.

3. Ciguatera risk management and prevention in French Polynesian lagoons

In remote island groups, where lagoon seafood is a basic staple, people who have had severe seafood poisoning sometimes need to limit their consumption of fish for several months, making them more dependent on consistently more expensive and generally less nourishing imported food for their protein intake. In the long run, the situation can lead to a forced dietary transition with its array of so-called 'lifestyle diseases' [27] signalling that the ciguatera hazard also needs to be approached from a sociological and anthropological angle and not just through public health. As such, any operations promoting lagoon fisheries not only have a positive impact on the relevant communities' living standards, but can also help improve their income by developing small-scale export industries.

Several field campaigns to help communities effectively manage the toxic hazard have been conducted under our research programmes [6, 28]. They have mainly involved mapping ciguatera risk in the affected lagoons based on ciguatera-causing phytoplankton species distribution and abundance and toxic fish prevalence. Such campaigns also provide an opportunity to hold information, communication and awareness sessions for public health staff, communities and schools (Figure 9). Overall, such sessions have had a clearly positive impact on community lifestyles, as borne out by the significant fall in the annual IRs over the ensuing years [5, 6].

Figure 9. Awareness training for A) communities; and B) public schools. © ILM

These large-scale campaigns were also an opportunity to gradually compile a unique biobank containing more than 2000 fish samples taken from 84 representative species from 10 French Polynesian islands and whose toxicity has been fully described. The database is currently being analysed to attempt to create a predictive model for French Polynesian lagoon fish toxicity based, for instance, on the size of the specimen tested. Results show that there is no significant relationship between fish size and toxicity [29], belying the popular belief that the largest specimens are also the most dangerous. This raises the question of just how effective current local-community practices are, as they tend to require eating only small fish to lessen the risk of poisoning [30]. Another study into links between toxicity and fish age and/or growth-rate estimated by otolithometry has just been completed. The study results are still being analysed, but the research will eventually lead to the first-ever growth-curve models for several South Pacific species including parrotfish, grouper and unicorn fish.

Finally, these campaigns were also an opportunity to examine certain widespread traditional ciguatera-control practices in French Polynesia such as various traditional tests to detect fish that are unfit for human consumption [30]. If communities in isolated or remote archipelagos can use validated homemade tests that are cheaper and can be carried out on the spot, they would be definite everyday assets to ciguatera hazard management. Avoidance strategies developed by local communities rely on a whole host of methods that vary from one island or archipelago to another and range from live animal testing on cats, dogs, ants and flies to using coins, through to detailed examinations of certain characteristics of dead fish several hours after they are caught. The literature offers fairly little information, however, on whether all or part of such methods have been scientifically validated, so we have attempted to assess how reliable two of them were, i.e. the *rigor mortis* and bleeding tests, by comparing the diagnoses of local fishers for approximately 100 fish to laboratory toxicology data (Figure 10). The most accurate test (bleeding) scored a little short of 70 % predictability. It is, however, likely that when the test is combined with the local communities' in-depth knowledge of species and areas to avoid, it significantly reduces their poisoning risk [30].

4. Medical approach

Research on chronic forms

Ciguatera is characterised by a complex set of symptoms, such as digestive, neurological, cardiovascular and respiratory complaints that vary in severity and are often complicated by the onset of chronic neurological disorders in 20% of cases and the patent lack of antidotes [22]. In practice, 175 different symptoms have been recorded in the disease's acute and chronic phases [31]. During the chronic phase, after an initial occurrence of poisoning residual hypersensitivity triggered by eating even non-toxic seafood and its by-products, animal protein such as pork or chicken, vegetable proteins like soya or lentils, alcohol, coffee or peanuts can revive neuro-digestive attacks with or without general signs [32]. While the acute forms of ciguatera are now well-documented, the exact cause of this unusual disease's chronic residual and/or sporadic manifestations still remain unexplained. In order to estimate ciguatera prevalence and better describe the chronic symptoms in a hospital population, a study has recently been launched in conjunction with the French Polynesia general hospital (CHPF) to accurately describe those symptoms and explain the biological mechanisms behind them [33]. Ultimately, it is hoped that solutions, such as special diets, will be recommended to provide relief to patients.

Biological sample bank and biomedical research

Although ciguatera has been studied for five decades now, biomedical research resulting in better care for patients has been scarce, if not incidental. Biomedical studies are still seen as the poor cousin of ciguatera research, due mainly to the short supply of human biological samples from ciguatera patients. Because ILM is closely involved in surveillance networks, it has ready access to patients in addition to a team of doctors, pharmacists and pathologists and a pathology laboratory capable of taking samples. So the LMT is working on setting up an unprecedented human biological sample collection, which will pave the way for developing and promoting biomedical ciguatera research both locally

Figure 10. Traditional toxic-fish screening tests used by local fishers: A) rigor mortis test (limp fish are considered toxic); and B) bleeding test (a fish showing signs of heavy bleeding is considered toxic). © ILM

and internationally. Some of the research avenues currently being explored are the identification of immunogenetic factors predisposing certain people to severe forms of ciguatera and chronic side-effects, improving the description of the physiopathological mechanisms behind the chronic/severe forms which could lead to suitable treatment options and the development of diagnostic tools.

Assessing the effectiveness of traditional remedies for ciguatera

Allopathic medicine has as yet failed to develop a truly effective and specific treatment for ciguatera and is based mainly on a symptom-based palliative approach to seafood poisoning. Many South Pacific communities, however, use traditional remedies as a matter of course, particularly on remote islands and atolls where no healthcare services are available. Ethnobotanical research by IRD has produced an inventory of nearly 100 plants used in traditional medicine for ciguatera treatment or prevention [34]. Brews, teas or extracts are prepared from roots, leaves, bark and fruit, whether pure or mixed in varying proportions and dosages based on household recipes handed down through the generations. Further research narrowed the work down to a single plant, *Heliotropium foertherianum* (velvetleaf soldierbush or octopus bush) (Figure 11), and identified its main active ingredient, rosmarinic acid, isolated from the plant's leaves [35]. As a result, a patent was registered in 2010 relating to the use of rosmarinic acid and its related derivatives in treating ciguatera. The next step was to examine the potential for industrially marketing the complete remedy based on an *H. foertherianum* concentrate. As the results confirm that the remedy has neuroprotective properties against CTX toxic activity, the prospect of treating ciguatera appears promising. The treatment now requires confirmation and development through clinical trials [36, 37].

5. Regional co-operation on marine biotoxin research

ILM and IRD both wish to help broaden national and regional co-operation on marine biotoxin research, particularly regarding ciguatera, based on two considerations, namely (i) the extremely high ciguatera prevalence in the Pacific region [38]; and (ii) repeated requests from many PICTs for scientific and technical support from the region's leading ciguatera research centres in the form of capacity building training, advice and expert opinions, etc. The advantages of increased regional co-operation around marine biotoxins are major. In addition to setting up joint, harmonised ciguatera management at a regional level, such a network will pave the way for launching cross-disciplinary projects that would be in a position to receive considerable funding for issues that the region's countries and territories view as priorities. We have contributed towards this goal by participating in two community and
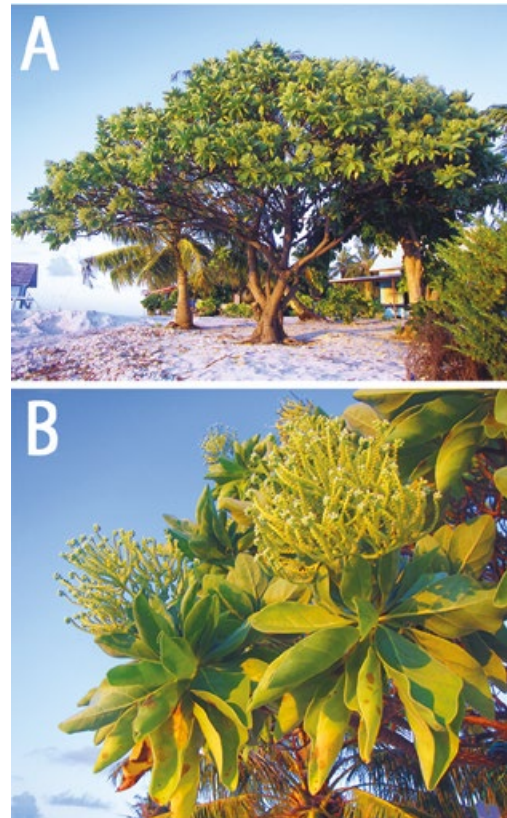

Figure 11. Velvetleaf soldierbush/octopus bush *tahinu* (*Heliotropium foertherianum* Diane & Hilger), a ubiquitous plant in coral atoll landscapes in the Tuamotu Group;
A) some specimens can grow very tall; and
B) detail of *H. foertherianum* flowers. © ILM

international initiatives for promoting pooled research efforts at the Pacific level:

1. Pace-Net+, which aims at stimulating dialogue between Europe and the Pacific in science, technology and innovation in areas relating to major societal challenges such as health and food security (http://plus.pacenet. eu/events/pacenetplus-noumea-2014). In July 2016, a workshop attended by the representatives of seven PICTs (Fiji, Cook Islands, Marshall Islands, New Caledonia, French Polynesia, Tonga and Wallis & Futuna) was held in Noumea with a view to improving ciguatoxin risk surveillance and management, in particular by setting up a common database.

2. the IAEA RAS 7/026 programme, one of whose specific objectives is to build ciguatera surveillance capacities in the Asia-Pacific region. A regional ciguatera workshop held on Tahiti in March 2015 trained 17 participants in the various standard techniques for monitoring ciguatera (field-sampling methods, identifying the main species under the optical microscope, culturing, chemical extraction and toxicology tests).

The drastic fluctuations observed in the world's island eco-systems as a result of climate change and Pacific communities' heavy dependence on fishery resources for subsistence purposes make it urgent that ciguatera research and relevant scientific resource effort pooling be accelerated. This is the only way to increase control over the health hazards related to marine resource-use by those communities so as to achieve sustainable, quality food production.

Acknowledgments

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