Development of the shrimp industry in the Western Indian Ocean - a holistic approach of vertical integration, from domestication and biosecurity to product certification

MARC LE GROUMELLEC[1], VINCENT RIGOLET[1], PANCHAYUTHAPANI DURAISAMY[1], MARC VANDEPUTTE[2] and VEMULAPALLI MANAVENDRA RAO[1]

[1]*Aqualma. Immeuble S.C.I.M. 4, Rue Galliéni. BP 93. 401 Majunga. Madagascar*
[2] *IFREMER, Chemin de Maguelone, 34250 Palavas les Flots. France*

ABSTRACT

The shrimp farming industry in the western Indian Ocean started with Aqualma's project in 1989, and now several companies farm shrimp in the Mozambique Channel. Despite the remoteness of these projects and their high investment and operating costs, they compete in the global marketplace by efficiently producing high value quality products. To address sustainability and biosecurity issues, Aqualma developed domesticated specific pathogen-free (SPF) broodstock of *Penaeus monodon* from western Indian Ocean stocks, which have been its exclusive source of post-larvae since 2003. Specific molecular diagnostic tools have been developed for each endemic pathogen detected since 1996, and these are used for routine surveillance of Aqualma's shrimp stocks along with histology. Biosecurity has become a major issue due to the inherent risk associated with semi-intensive farms and development of more projects in the zone. Introduction of exotic and endemic pathogens into the farms by infected wild fauna is a real concern, and reinforced biosecurity procedures are in place to mitigate this at Aqualma. Quality management through ISO 9001 helped in achieving capacity building on biosecurity. There is also a need for a national and regional level veterinary surveillance program for shrimp diseases with support from international organizations like the Food and Agriculture Organization of the United Nations (FAO) and the World Organisation for Animal Health (OIE). In order to secure our investment and sustain the industry worldwide, we intend to participate in its safe development.

Key words: shrimp, Madagascar, domestication, biosecurity, certification

Le Groumellec, M., Rigolet, V., Duraisamy, P., Vandeputte, M. and Rao, V.M. 2011. Development of the shrimp industry in the Western Indian Ocean – a holistic approach of vertical integration, from domestication and biosecurity to product certification, pp. 291-308. *In* Bondad-Reantaso, M.G., Jones, J.B., Corsin, F. and Aoki, T. (eds.). Diseases in Asian Aquaculture VII. Fish Health Section, Asian Fisheries Society, Selangor, Malaysia. 385 pp.

Corresponding author: Marc.Le Groumellec, marc.legroumellec@unima.mg

INTRODUCTION

The Western Indian Ocean shrimp farming industry was developed according to an original strategy of rearing *P. monodon* in bigger semi-intensive ponds at an industrial scale. It started in Madagascar, and then extended to Mozambique and Tanzania. The Madagascan model of shrimp farming is based on rearing of *P. monodon* in earthen ponds of 5-10 ha with continuous water exchange. It is basically a combination of South American and Asian rearing techniques. It was originally developed by Aqualma, and has then become a model for other farms in the region. The targets are a maximum biomass of 1.8 to 2.2 tons / Ha at harvest, and bigger sizes at harvest depending on the clients' demand. Grow out ponds are usually stocked with juveniles of 1-2 g shrimp coming from nursery ponds (1 Ha). The industry is totally integrated vertically with synchronized supply chain, and the capacities at each production step are optimized. The production takes place throughout the year, which facilitates production planning.

It is aimed at a consistent final product of superior quality head-on shrimp mostly for European markets, positively differentiated by the consumer. The freshness of the head is essential for the product, requiring specific methods for harvest, transport and freezing to keep the texture of the flesh crunchy and salty. The costs of production are high, mostly because of difficult logistics (no roads, transports are only through boats and planes) and high-energy costs (no public network of electricity available on production sites). Therefore production performances have to be high and sustainable in order to stay economically viable.

The Aqualma farms located at Mahajamba and Besalampy have started producing since 1992 and 1999, respectively. Since then the productions are remarkably consistent despite adverse climatic events like cyclones and floods. The site selections for the farms were mainly done on otherwise unproductive salt flats with minimum mangrove clearing and the farm design promotes semi-intensive way of rearing in big ponds of 10 Ha in average. Regarding the water use, intake and discharge are separated, and the renewal is based on continuous water exchange. The feed management requires high quality feed, to ensure very high survival rates (over 75 % in pre-growth, and 90 % in grow-out in average), faster growth and lower food conversion ratio (FCR). In order to achieve higher performances, it has been necessary to stock domesticated SPF post-larvae, and master other critical steps like good pond preparation, optimized water filtration and continuous surveillance by in-house pathology laboratory. Due to the remoteness and absence of laboratories, competence has also been acquired on food safety analysis being run in an internal food bacteriology laboratory.

The social responsibility and community development activities have always been considered as part of the projects leading to building of hospitals, schools, electrification, and drinking water availability to ensure quality of life of the employees. Environmental responsibility is a major aspect of Madagascan shrimp industry, which has recently been acknowledged by several NGOs like WWF or third-party certifications. Activities like ecological surveillance of the bay and mangrove plantation programs are routinely undertaken on each site of production. The projects conform to the recommendations made by FAO in its international principles for responsible shrimp farming (FAO/NACA/UNEP/WB/WWF, 2006), aiming a long-term sustainable business.

As a fully vertically integrated company, Aqualma has one domestication Center, with brood stock selection and nauplii production at Moramba, industrial scale post-larval production at Nosy Be and Mifoko, shrimp grow-out ponds at Mahajamba & Besalampy and related processing plants in Besakoa & Besalampy as shown in Fig. 1. It also has a feed plant in La Reunion Island and a cooking plant in Boulogne in France.

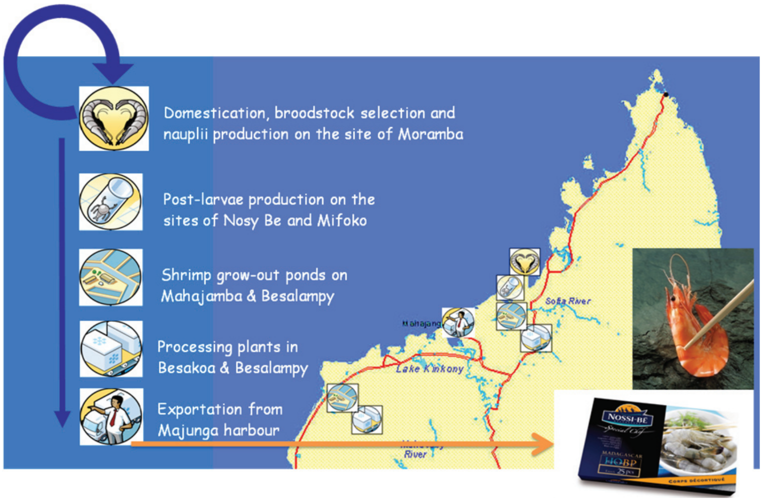


Figure 1 Location of different production sites of Aqualma in Madagascar, showing ful vertical integration

Since the species, *P. monodon*, selected for aquaculture was quite rare in Madagascan waters constituting only around 2 % of the shrimp fishery (Fig. 2), Aqualma decided to start a domestication project in order to be sustainable on a long term, though several previous attempts concluded that *P. monodon* was difficult to domesticate and produce on a commercial scale (Pullin, Williams and Preston, 1998).

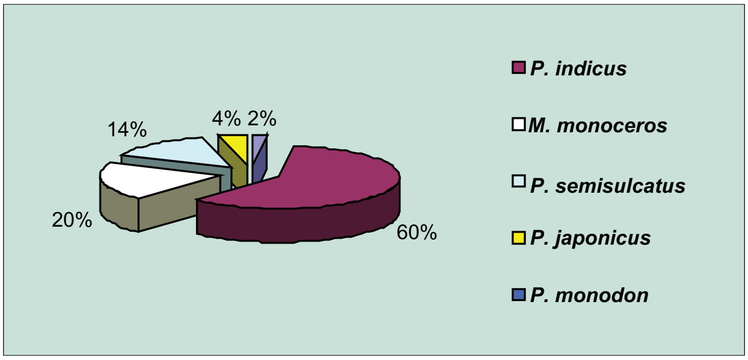


Figure 2 Species wise distribution of shrimp capture fishery in Madagascar (1999)

This paper presents a successful holistic approach in developing a sustainable shrimp farming industry involving various components. After a short description on how domestication program and wild broodstock selection was initiated, the importance of identification of endemic pathogens and development of adequate diagnostic tools for the sustainability of semi-intensive rearing method will be stressed out, leading to biosecurity management at different levels, from compartmentalization at a company level to global sanitary policy at National or even regional levels.

Other essential aspects ensuring success include optimizing rearing conditions and husbandry practices to ensure higher levels of animal welfare and adequate management of genetic resource, which will be further commented.

Finally, the achievement of complete traceability along the supply chain and product certifications to ensure maximum food safety and service to the customer will be described.

Initiation of the domestication program

The following were the objectives and expectations of the company from its domestication program:

- Independence from wild stocks and year round guaranteed supply.
- More consistent performances than wild stocks, allowing more precise projections and budget calculations. The aim was to obtain performances at least equal to wild brood stock (percentage of spawning females, eggs & nauplii per female, quality of nauplii, survival rate in larval rearing) with an expected improvement through domestication and natural selection after several generations.
- Providing a safe source of specific pathogen-free (SPF) seeds, certified free of all economically important pathogens (eventually to all viruses and intracellular bacteria, which is much easier to achieve in domesticated stocks), as it can be checked over several generations.
- Providing a base for further work on selective breeding of important traits like growth, resistance to stress or to a specific disease (Specific Pathogen Resistant).
- Providing a potential to develop more intensive, biosecure systems due to an enhanced control of disease.
- Opening an economical potential for brood stock / seed stock export business.

Maximizing the genetic diversity and better quarantine were considered as key elements in the initial stage of domestication. The founding populations of *P. monodon* were all endemic to Madagascar and collected in deep water from all the major fishing zones of the island, as presented in Fig. 3 along the western coast of Madagascar in order to start with a maximum genetic diversity. Particular attention was made to avoid those animals being captured in shallow water along the coasts to limit the risks of contamination of pathogens from other species of crustaceans. All incoming brood stocks were submitted to a primary quarantine; wherein a complete evaluation of sanitary status was performed through molecular biology and histology methods was done for all OIE listed shrimp pathogens in addition to local

Figure 3 Major fishing areas (yellow stars) of *P. monodon* on the west coast of Madagascar where the founding population for Aqualma's domestication programme were collected.

pathogens known at the time. During this pre-domestication phase, adaptation of wild animals to the culture environment and the continuous controlled reproduction are being considered as major issues (Bilio, 2007). Once they cleared quarantine, they were used for reproduction, and their offspring reared in batches. Systematic sanitary control was performed on each generation, for each batch produced, at each growing step (Fig. 4). Runts, animals with clinical signs or abnormal behavior were scrutinized, fixed and studied, and each suspicious batch was eliminated. The absence of all major endemic pathogens discovered / detected in Madagascar since 1999 until 2008 was ensured, progressively demonstrating an SPF status for this population.

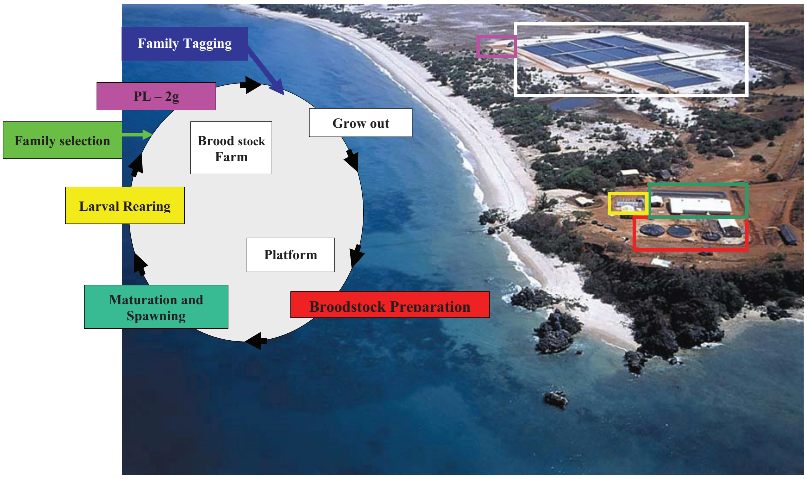
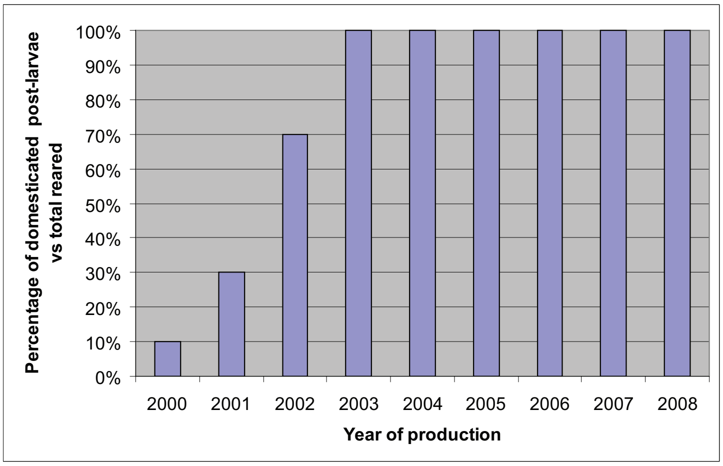


Figure 4 Facilities involved in closing the biological cycle of *Penaeus monodon* in the Domestication Centre of Aqualma, site of Moramba

The final expected product of domestication is an SPF breeder with good growth and high fecundity, genetically defined through its pedigree and physically identified through individual tagging. Based on the post-larvae requirements of the farms, simulations are made approximately 18 months before on the number of brood stocks to be produced, in order to be able to supply the required amount of post larvae on time for stocking the ponds. The performance of first generations of domesticated breeders was variable, but stabilized to satisfactory levels due to improvements in animal husbandry and selection. They exhibited subsequently good fertility and fecundity rates, producing an average of over 400,000 nauplii per spawn, similar to what can be produced from wild females of the same weight. This demonstrated that the animals adapted well to its controlled environment, and that the chosen rearing methods were adequate.

In terms of impact of domestication on shrimp production of the company, the increasing availability of this domesticated SPF population since the year 2000, provided a safe and consistent source of seeds to Aqualma, thus playing a major role in the sustainability of its results, and allowed it to pursue its development strategy. The estimated quantity produced by Aqualma with a domesticated SPF broodstock is over 30,000 tons as of January 1st, 2007, compared to 48,000 tons of total shrimp production since the beginning in 1992. The part of domesticated animals reared progressively increased from 10% to 100 % of the total post-larvae produced from the year 2000 until 2003, and has been kept 100 % since then (Fig. 5).

Figure 5 Evolution of use of domesticated post-larvae stocked in Aqualma farms from 2000 onwards



Acquiring knowledge on local pathogens

At the start of the project, there was little or no information available on the sanitary status of wild populations of shrimp and other crustaceans. Consequently the company took every effort to rapidly acquire and continuously update knowledge on endemic pathogens of crustaceans that may impact its operation through pathogen surveillance programs coordinated with the group company's fishing boats. Absence of competent local scientific institutions on this domain forced the company to work with international institutions like the Shrimp Pathology Laboratory, University of Arizona, with which we signed a yearly renewed Technical Agreement, and occasionally with several other research institutes like University of Montpellier II, University Blaise Pascal-Clermont II and others. Collaboration with these institutes resulted in in-house capacity building in terms of developing diagnostic facilities (histopathology and molecular diagnostics), training of manpower and routine counter analysis. Thanks to these collaborations and its internal team, the company was able to participate actively in new discoveries of endemic pathogens (Fig. 6) and in the development of specific diagnostic tools. As Madagascar still continues to enjoy pathogen-free status with respect to many pandemic pathogens like WSSV, YHV, TSV, Brazilian IMNV and NHP, histopathology is still being considered as a principal diagnostic tool as the majority of diseases cases reported were due to local unknown pathogens, or non OIE listed pathogens. A well-equipped molecular biology laboratory with PCR and *in situ* hybridisation capabilities together with histology laboratory form an essential component in strategies to assure bio-security to various production units. Following are the endemic pathogens that were identified during this period of time, and taken into account in the surveillance program.

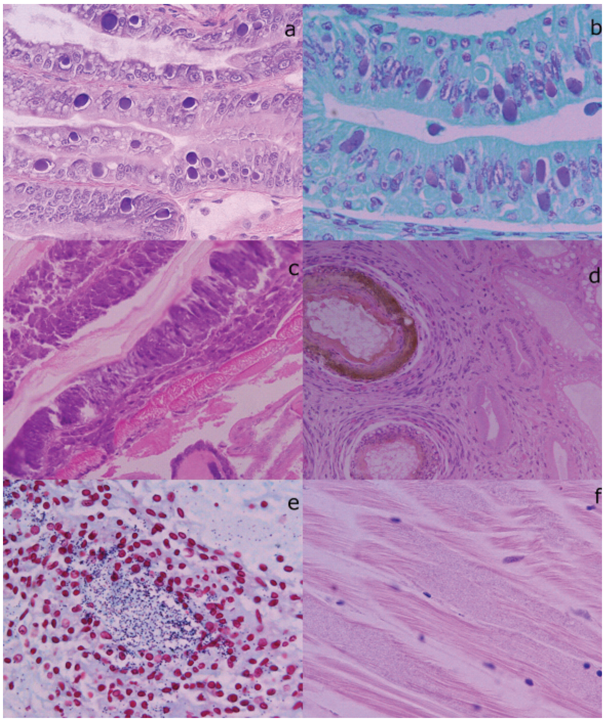


Figure 6 Some of the pathogens encountered in the wild and/or farmed populations of crustaceans in Madagascar: a) Madagascan strain of HPV in a wild P. monodon juvenile, H&E stain b) a parvovirus from wild *P. indicus*, Feulgen c) an iridovirus from *Acetes erythraeus*, H&E d) septic hepatopancreatic necrosis by an opportunistic *Vibrio sp.*, H&E e) a Gram +ve micrococcus in LO, Twort and f) a microsporidian infection in striated muscle, due to *Ameson michaelis*, H&E.

Rickettsia-like bacterium

A rickettsia-like bacterium (RLB) was reported in 1999 to be responsible for severe mortalities of farmed *P. monodon* in the southwest region of Madagascar. Specific molecular methods, PCR and *in situ* hybridization assays, were developed (Fig. 7) for these rickettsia

(Nunan *et al.*, 2003; Nunan *et al.,* 2003). So far, it has been considered to be transmitted horizontally through wild crustacean vectors like crabs, and vertical transmission has never been observed (Le Groumellec, M. and Duraisamy P., pers. comm.).

Iridovirus
An iridovirus (tentatively named SIV, sergestid iridovirus) was reported to cause high mortality in a sergestid shrimp, *Acetes erythraeus* in 2004. However there was no mortality observed in *P. monodon* population. A PCR method and *in situ* hybridization assays were developed anyway, thus allowing monitoring the evolution of this pathogen in case it becomes a threat in the future (Tang *et al*., 2007).

IHHNV
As for as IHHNV is concerned, neither symptoms nor lesions were observed in the massive monitoring programme spanning over 10 years. The published information (Tang *et al.,* 2003; Krabsetsve, Cullen and Owens, 2004) purportedly involving IHHNV strain from Madagascar might have been due to the false positive PCR reaction obtained with *P. monodon* from the region that are known to have an IHHNV related sequence with a high degree of similarity inserted in their genome. Development of a discriminating PCR assay is now available to distinguish real IHHNV from virus-related sequences in the genome of *P monodon* (Tang, Navarro and Lightner, 2007).

Hepatopancreatic Parvovirus
A strain of HPV is reported with high prevalence (Tang, Pantoja and Lightner, 2008) in the wild shrimps and found to be different from HPV isolates from Tanzania, Korea, Australia and Thailand based on nucleotide sequence analysis. However, this strain of HPV seems to never have been reported to cause mortality or have any negative impact in the farms that continue to depend on brood stock from the wild under the rearing condition adopted by Madagascar farmers (Le Groumellec, M. and Duraisamy P., pers. comm.).

Microsporidians
Presence of at least two species of microsporidians was reported in the wild population of penaied shrimp, *Fenneropenaeus indicus*, *P. monodon* and *Penaeus semisulcatus*, in the west coast of Madagascar (Toubiana *et al.,* 2004). Strain specific molecular diagnostic tools (PCR primers and *in situ* hybridisation probes) were developed to monitor potential carriers like several types of wild crustaceans.

Monodon Slow Growth Syndrome, local form (MSGS)
Detection of a previously undescribed virus in the lymphoid organ and gills of growth retarded population of *P. monodon* from a commercial shrimp farm has been reported in the zone, suggesting resemblance with monodon slow growth syndrome (MSGS) that has been problematic with *P. monodon* in Thailand since 2001 (Anantasomboon *et al*., 2006). Efforts are being made to understand more about the condition and to develop a diagnostic

tool, as this syndrome could be of major concern for the industry if its presence in the zone is confirmed. Meanwhile histology diagnostic remains adequate to demonstrate the absence of such a syndrome in our domesticated stocks or farms.

Others pathogens

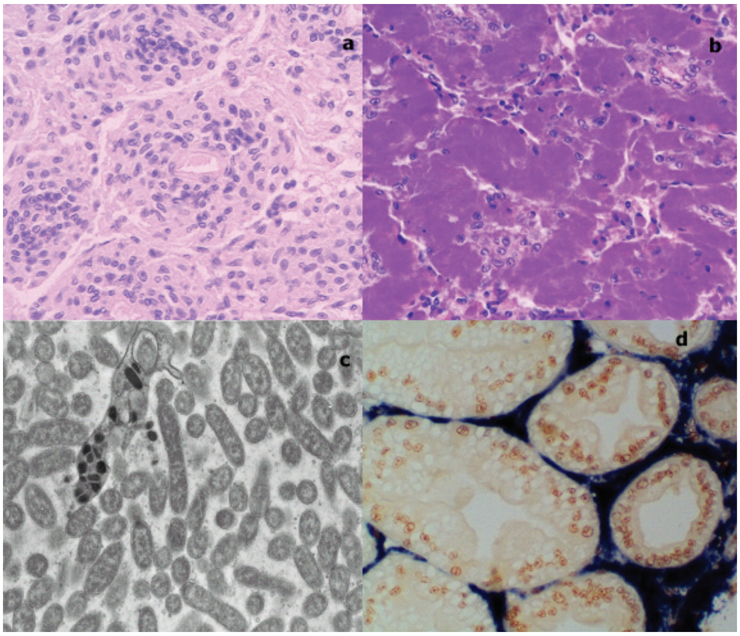
Wild populations of *P. monodon* are sporadically observed with MBV, but seem to have never impacted the production (Le Groumellec, M. and Duraisamy P., pers. comm.). A baculovirus was reported from crab. Similarly a parvovirus infecting the midgut caecum was observed in the wild populations of F. indicus. These findings were made thanks to the pathogen surveillance program, performed originally by Aqualma internal pathology laboratory until 2007, now extended to the whole Madagascar island and integrated with the national surveillance program. Infection by opportunistic bacterial pathogens like common Vibrio spp. infections, other specific Vibrio inducing systemic infections like *Vibrio nigripulchritudo* and a Gram+ micrococcus have also been reported.

Considering all these newly discovered pathogens, a biosecurity policy was first designed at a company level, with the future intention to amplify it to a national level.

Biosecurity strategies – company, country and regional levels

At a company level, compartmentalisation of production systems was already considered at the design stage (Fig. 7). Compartments separate animals at different phases of the production cycle with distinct health status and comfort levels (Zepeda, Jones, and Zagmutt, 2008). Biosecurity measures to prevent introduction of infections from one compartment to the others is assured by implementing control plans that are part of the standard operating

Figure 7 Different steps leading to development of molecular diagnostic tools for endemic pathogens of Madagascar, i.e. for RLB. a) Normal lymphoid organ (LO) tubules, H&E stain b) LO tubules infected with RLB, H&E c) TEM image of RLB in LO and d) positive reaction to *in situ* RLB probe in the hepatopancreas, showing the systemic infection, not affecting the tubules. Photos c & d are from Shrimp Pathology Laboratory, UAZ.



procedure of each compartment. A crisis management procedure is in place to react quickly to disease outbreaks in any of the compartments. Equipments, training of personnel, predefined responsibilities and preparedness are essential component of this crisis management system. Each compartment is audited by independent agencies for certifications (ISO 9001 V 2000; Label Rouge; ACC).

As the domestication centre and larval rearing facility are closed units with more indoor facilities, the production of post larva from domesticated brood stock is done in a more secured environment guaranteeing constant production of SPF seeds for stocking at the farms. All the other inputs used in the hatchery production are sourced from certified suppliers and each lot of inputs undergoes rigorous quality control before being used in the system, and complete traceability records are maintained. Quarantine facilities, filtration and sterilisation of both inlet and outlet water, systematic screening for pathogens at different life stages and control over movement of workers and materials are part of the biosecurity plan.

The grow out farms are semi-closed systems where there is total control of animal movements, but limited control over water flow. They are vulnerable to natural calamities like cyclone and flooding resulting in stress for shrimp and significant changes in the wild fauna (Fig. 8). A continuous monitoring of environmental parameters and surveillance programme is used to manage any potential biosecurity issues arising out of these natural events.

Figure 8 View of typical semi-intensive farms in Madagascar; a) Mahajamba Farm (700 Ha, 3200 tons average per year), Aqualma and b) Besalampy farm (450 Ha, 2000 tons average per year), Aqualma.

Each production site has a dedicated person in charge of biosecurity and animal husbandry issues, who works in coordination with the company's veterinary doctor and central laboratory. They are also in charge of monitoring the wild fauna and potential vector populations in the surrounding environment including the bays. Based on risk analysis, methods are developed to prevent their contact with the reared animals in the ponds. Periodic review of the process helps in constantly improving the biosecurity protocols, critical control points, surveillance programs, contingency plans, emergency harvests and secured disposal and elimination procedures.

The other major issue for Madagascar producers was to keep the status of the island free from the major OIE listed pathogens affecting the shrimp industry worldwide. As the farming industry in western Indian Ocean really started after the devastating WSSV outbreaks in Asia, the industry in the region had sufficient lessons to learn from others mistakes, and thus diseases were perceived as one of the major issues threatening sustainability. Consequently, substantial efforts and investments were made in projects like Aqualma ranging from domestication to separation of various production units to prevent the entry of pathogens and to limit the spread of any potential disease outbreaks. A law was enforced in 2003, prohibiting all entrance of live crustaceans, and fixing rules regarding the rearing conditions and animal welfare in the farms.

By virtue of isolation from other shrimp farming countries and being an island, Madagascar is free from most of the OIE listed pathogens. At country level, Madagascar is eligible to make self-declaration of disease-free zone status based on historical data and a starting epidemiology surveillance program. The Association of shrimp farming and fishing companies in Madagascar (Groupement des Aquaculteurs et Pêcheurs de Crevettes de Madagascar - GAPCM) and the competent authority (Autorité Sanitaire Halieutique - ASH) have been promoting this strategy since several years, through the raising of funds for the newly setup epidemio-surveillance national aquatic pathology laboratory and organizing seminars with an international epidemiology expert to validate the original survey plan and follow-up (Cameron, A., pers. comm.) in order to reach this goal that will benefit to all the operators in the country. To maintain the disease-free status, effective mechanisms in terms of legislation to prevent spread of diseases through trans-boundary movements of aquatic animals needs to be enforced. Adoption of codes of practice, adherence to industry standards set up in association with international groups i.e., WWF and exigencies of clients are some of the ways to assure bio security at national level, which involves the competent authority (Autorité Sanitaire Halieutique - ASH), the concerned Ministry (Ministère des Pêches et des resources Halieutiques) and the Association of shrimp farming and fishing companies in Madagascar (GAPCM) and has a clear regulatory frame (Government of Madagascar, 1990, 2001, 2001; Bis, 2004).

The region still continues to be free of pandemic pathogens that are known to cause devastating epidemics in shrimp farms. As the countries around the Mozambique Channel are far from other major shrimp farming regions of the world, a regional setup similar to the Network of Aquaculture Centres in Asia and the Pacific (NACA) is needed to coordinate with world bodies like OIE and FAO on various issues concerning aquatic animal diseases. The company, deeply conscious of the need to have a common strategy to ensure the biosecurity of this zone, is strongly promoting this regional discussion.

Optimization of rearing conditions and animal husbandry

Once the foundation for domestication of *P. monodon* was established, the objective was then to start the second phase of the domestication process, mostly by designing sustainable and optimized animal breeding techniques. We developed exhaustive rearing protocols that are adapted to our requirements throughout many assays. As this form part of the intellectual property of Unima/Aqualma group, the details cannot be divulged, but the general method used will however be presented, as it is not yet very common in shrimp aquaculture.

In terms of management requirements, the most important aspect of this domestication project is to have a strong discipline on documenting what has been done or tested. All the performances should be recorded in databases in order to analyse and apply a continuous improvement to provide the best conditions to the breeders, respecting animal welfare as far as possible. Working with a tool for quality management also helps, as the interaction of all these aspects is critical (Fig. 9). We propose a modified version of Sniezko's diagram, more adapted in our opinion to its use in private industry. It is very important to distinguish what is controllable from what is not in the environment of the shrimp. All actions performed by the farmer which can reduce stress and improve animal welfare should be identified and put in place. The overall success of all these issues also largely depends on manpower management. We chose to work under ISO 9001:2000 certifications, with written procedures, records on critical points and continuous improvement. All the production steps are audited and certified by a third-party annually. Specific training procedures adapted to local culture were also designed. Under semi-intensive rearing conditions, in ponds without aeration, we obtained satisfactory results (Fig. 10) thanks to a dedicated farm management. Typical performance figures obtained are an FCR of 1,41 for a mean weight at harvest of 30g, with a survival rate of 86 % (stocking weight at 1,52 g).

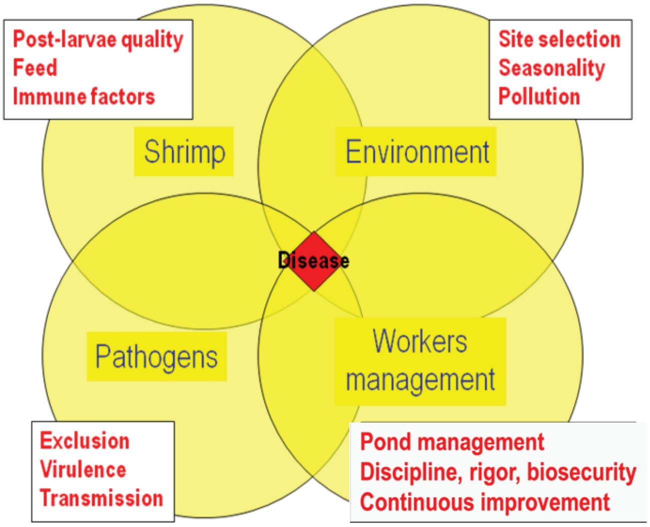
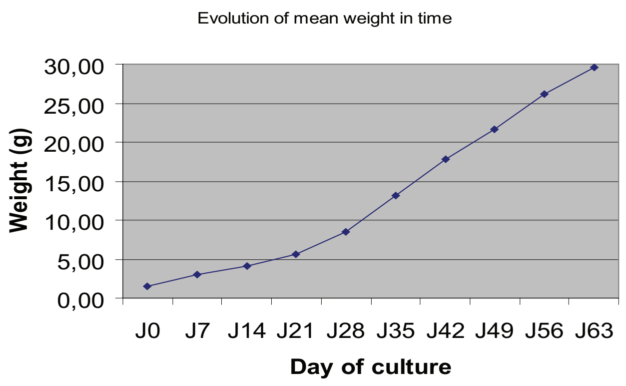


Figure 9 Modified Sniezko's diagram adopted to its use in commercial production

Genetic resource management

The main purpose was to maximize the genetic diversity of the founding population. In order to obtain this diversity, as mentioned elsewhere, the breeders were collected from several locations of Madagascar Island. Considering the number of breeders collected and

Figure 10 Evolution in average body weight in a typical pond condition following typical Madagascan semi-intensive rearing method



selected, the domesticated population was initiated from 198 wild founders, representing more than 99.5% of the genetic variability in the wild population. They were selected from approximately 10,000 breeders, notably according to their sanitary status and their performances.

Moreover, crossing optimization was performed from the beginning in order to minimize inbreeding. Since 2003, the domestication centre functions only with this genetically optimized population: 140 families are reproduced per each generation, divided in 7 sub-cohorts with a rotational mating scheme. The effective population size is maintained over 300, allowing an excellent control of inbreeding, which increases less than 0.2% at each generation, which ensures the sustainability of the genetic management program. The family traceability is maintained over the generation via visible implant elastomer (Northwest Marine Technology, USA). A mild within-family selection for growth is applied to eliminate potential runts.

Figure 11 shows the evolution of growth rate with generations of domestication in *P. monodon*. The growth rate plotted here is the growth from 2 to 30 g in small outdoor ponds, corrected for variations in rearing temperature, and then gives an unbiased estimate of the trend of growth rate (15% per generation of domestication). However, this trend is not corrected for environmental effects other than temperature (i.e. improvements in husbandry techniques, feed, rearing density etc.) and therefore cannot be considered as an unbiased estimate of the genetic gain from domestication, but only as an upper limit of such an estimate.

The future of this genetic program is expected to be based not only on quantitative genetics, but also by using molecular tools to trace parentage (suppression of the separate rearing phase before tagging). It is an undergoing work in collaboration with a research team. Mass selection can also be performed, notably to better evaluate the heritability of growth in this population and for rapid improvement of this trait. In the long term, disease resistance and fertility improvement could also be included in the breeding goal.

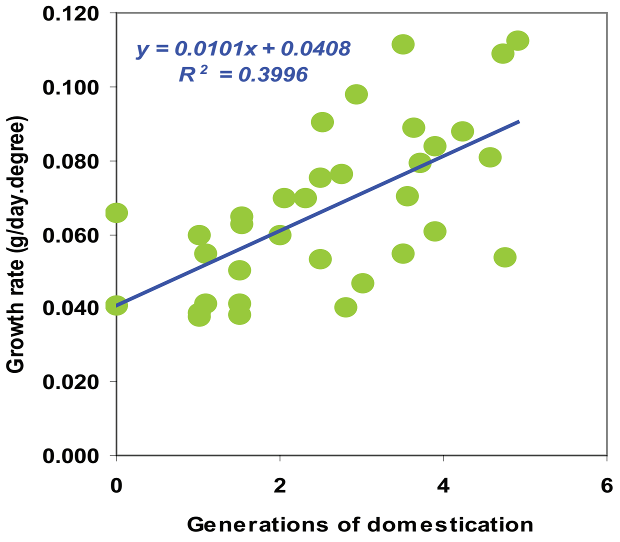


Figure 11 Evolution of growth rate with increasing generations of domestication in SPF *P. Monodon* from Madagascar, during the first five generations.

Building databases and traceability records
Once the computer databases were built, we developed interfaces for different users, including the technicians, biologists, economists, logisticians and managers. Portability of these different databases through links results in obtaining complete traceability from founding populations to finished products including all the inputs used in the production process. Complete traceability is necessary to address our clients' enquiries about the causes of incidents, and therefore call back exercises are performed frequently. Software has been developed to help the sellers to extract information from the databases and to be able to track every batch produced.

Process and product certifications
In order to evidence these achievements and to be able to value those commercially, it has been decided to initiate product certifications.

Decision was to stress out the quality of the finished product through a famous standard called "Label Rouge", where the quality and its consistency are asserted by blind tests performed by third party. Along with very strict and detailed standards regarding the rearing methods and continuous control procedures, it assures that the consumer will consistently get a superior quality product. This required an involvement of all supply chain actors, as the certification covers all steps of production, from broodstock management to marketing, thus requiring a holistic and integrated approach.

In parallel, efforts made on respecting high standards regarding environmental and social issues were distinguished by a close partnership with the World Wildlife Fund.

In the recent years, our production sites were thus audited and certified by Aquaculture Certification Council (ACC), and continued to be for Label Rouge, WWF and several food safety standards like IFS and BRC.

CONCLUSION

We successfully domesticated *P. monodon* from Madagascar 10 years ago, and produced over 30,000 tons of superior quality head-on shrimp for European markets since then. The domesticated SPF shrimp population allowed us to produce consistently despite our open semi-intensive model that is highly susceptible to environmental changes, using better biosecurity and management control. This was notably achieved through the extensive use of ISO 9001:2000. Being fully integrated vertically allows us to provide complete traceability, therefore to obtain famous certifications, hence our products carry multiple labels like the "Label Rouge" in France, which was completed by the development of a private partnership with WWF to communicate on Aqualma's environmental and social respectful management. The genetic management program is sustainable, providing animals with good performance and future selection programs look promising. The involvement of the private sector - along with other stakeholders - in research and development, and its importance in leading biosecurity measures can also be stressed out from our experience, when initiating a shrimp industry in an new country.

We are also looking at opportunities to share experience and acquired know how with partners who have common values of long term sustainable business for mutual benefits. One objective is to assess the potential of this domesticated stock to perform well under different rearing conditions (notably the current Asian rearing model).

We used domestication program and biosecurity as elements of a sustainable strategy, by reducing impacts of shrimp culture on its environment (no catches of wild breeders, no disease dissemination). The shrimp industry has been responsible so far for the worldwide spread of many crustacean pathogens. It can be viewed as a failure, and shows that we must be pro-active and promote alternative strategies.

The domestication is required for all species in aquaculture in order to sustain at industrial level. This also helps to control the sanitary level of the reared populations, to stabilize, to optimize and then to improve their rearing performance through selective breeding. This should be done while respecting the basics of genetics to limit inbreeding. Each domestication process should be adapted to the farmers' will and needs.

Like with terrestrial animals in the past, aquaculture species should soon be fully domesticated, specific pathogen free and genetically managed in closed conditions. We plead for the development of local domestication programs, allowing each region to promote its own strains and own breeding methods, leading to the emergence of several "races" for each species reared (shrimp, crabs, etc.). In order to achieve this, we will need a strong multi-disciplinary effort through all stakeholders and researchers (physiology, physiopathology), and this should be pro-actively promoted by international organizations like FAO and OIE as major actors in regional integration strategies and providers of trainings for capacity building, for crustacean aquaculture to become really sustainable.

Moreover, the biggest danger of shrimp aquaculture in the near future is in our opinion what is currently happening with domesticated *Litopenaeus vannamei*, as it leads to worldwide uniformity and ease of production. Pressure from the market in terms of price induces drop in quality, and consequently a change in the mind of the consumer, now seeing shrimp as a commodity product. This has already caused serious economical problems to the farmers, especially in less developed countries, unable to compete with these falling prices. Product diversity, quality of finished products, eco-friendly and sustainability driven certifications are some of the alternatives to this disastrous trend, and we intend to promote this alternative strategy of development for crustacean aquaculture.

REFERENCES

Anantasomboon, G., Sriurairatana, S., Flegel, T.W. and Withyachumnarnkul, B. 2006. Unique lesions and viral-like particles found in growth retarded black tiger shrimp *Penaeus monodon* from East Africa. *Aquaculture* 253: 197-203.

Bilio, M. 2007. Controlled reproduction and domestication in aquaculture. Part I. Aquacult. Eur. 32: 5-14.FAO/NACA/UNEP/WB/WWF. 2006. International Principles for Responsible Shrimp Farming. Network of Aquaculture Centres in Asia-Pacific (NACA). Bangkok, Thailand. 20 pp. Bangkok, Thailand. 20 pp.

Government of Madagascar. 1990. Law 90-033, December 21st 1990 regarding the respect of shrimp farms' environment.

Government of Madagascar. 1997. Law 97-012, June 06th 1997. Modification of shrimp farms' environment impact assessment.

Government of Madagascar. 2001. Law 2001 – 020, October 4th 2001 regarding the development of a sustainable and responsible aquaculture.

Government of Madagascar. 2001 Bis. Order 93-022 regulating fisheries and aquaculture.

Government of Madagascar. 2004. Law 2004-015, August 19th 2004. Modification of shrimp farms' environment impact assessment.

Krabsetsve, K., Cullen, B.R. and Owens, L. 2004. Rediscovery of the Australian strain of infectious hypodermal and haematopoietic necrosis virus. *Diseases of Aquatic Organisms* 61: 153–158.

Nunan, L.M., Noble, B., Le Groumellec, M. and Lightner, D.V. 2003. Experimental infection of *Penaeus vannamei* by a rickettsia-like bacterium (RLB) originating from *P. monodon*. *Diseases of Aquatic Organisms* 54: 43–48.

Nunan, L.M., Poulos, B., Redman, R., Le Groumellec, M. and Lightner, D.V. 2003. Molecular detection methods developed for a systemic rickettsia-like bacterium (RLB) in *Penaeus monodon* (Decapoda: Crustacea). *Diseases of Aquatic Organisms* 53: 15–23.

Pullin, R.S.V., Williams, M.J. and Preston, N. 1998. Domestication of crustaceans. *Asian Fisheries Society* 11: 59-69.

Tang, K.F.J., Poulos, B.T., Wang, J., Redman, R.M., Shih, H. and Lightner, D.V. 2003. Geographic variations among infectious hypodermal and hematopoietic necrosis virus (IHHNV) isolates and characteristics of their infection. *Diseases of Aquatic Organisms* 53: 91–99.

Tang, K.F.J., Navarro, S.A. and Lightner, D.V. 2007. PCR assay for discriminating between infectious hypodermal and hematopoietic necrosis virus (IHHNV) and virus-related sequences in the genome of *Penaeus monodon*. *Diseases of Aquatic Organisms* 74: 165–170.

Tang, K.F.J., Redman, R.M., Pantoja, C.R., Groumellec, M.L., Duraisamy, P. and Lightner, D.V. 2007. Identification of an iridovirus in *Acetes erythraeus* (Sergestidae) and the development of in situ hybridization and PCR method for its detection. *Journal of Invertebrate Pathology* 96: 255–260.

Tang, K.F.J., Pantoja, C.R. and Lightner, D.V. 2008. Nucleotide sequence of a Madagascar hepatopancreatic parvovirus (HPV) and comparison of genetic variation among geographic isolates. *Diseases of Aquatic Organisms* 80:105-112.

Toubiana, M., Guelorget, O., Bouchereau, J. L., Lucien-Brun, H. and Marques, A. 2004. Microsporidians in penaeid shrimp along the west coast of Madagascar. *Diseases of Aquatic Organisms* 58: 79–82.

Zepeda, C., Jones, J.B., and Zagmutt, F.J. 2008. Compartmentalization in aquaculture production systems. *Rev. sci. tech. Off. Int. Epiz*., 27 (1): 229-241.