From fundamental to applied research: The history of the Indian Ocean Trepang company

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The beginnings

The "pre-history" of the Indian Ocean Trepang company begins with the fundamental research performed by the teams of Prof Jangoux, who directed marine biology laboratories at two Belgian universities – the University of Mons (UMons) and the University of Brussels (ULB). The labs in Brussels and Mons were specialised in echinoderm research, and many aspects of this animal group were (and still are) investigated. Various doctoral dissertations related to sea cucumbers emerged from these laboratories (e.g. Coulon 1994; Jans 1993; Rasolofonirina 2004; Becker 2007; Lavitra 2008; Léonet 2010; Plotieau 2012; Caulier 2016; Claereboudt PhD in progress) and, more recently, at UMons, some PhD theses on aquaculture and village farming (Todinanahary 2016; Tsiresy 2016a) (Table 1).

These two labs also had a well-established tradition of studying tropical marine invertebrates. Indeed, in the early 1970s, Prof Bouillon from the Brussels lab founded the King Léopold III Biological Station on the island of Laing in Papua New Guinea. The Laing station was founded in 1972 and directed by Prof Bouillon up until his retirement in 1993. Prof Jangoux succeeded him, and then in 1997, the station closed. This closure guided Prof Jangoux to develop a field lab elsewhere in the tropics with the aim of conducting both environmental and applied research in marine biology. The idea was to exploit the potential of two well-distributed Indo-Pacific echinoderm species that are of both ecological importance and aquacultural interest: the sea urchin *Tripneustes gratilla* and the sea cucumber *Holothuria scabra*. The other idea was to carry out the research in close collaboration with the Belgian labs where "high tech" analyses could be performed.

The research phases

Thanks to his relationship with Chantal Conand, a longtime friend, the meeting between Prof Jangoux and Prof Mara (at the time, director of the Institute of Marine Science at Toliara, University in Madagascar) was possible. Taking advantage of the good relations and common scientific interests of the two professors, a common research project was proposed to the Belgian Cooperation for Development (CUD, currently ARES-CDD). The project was accepted and started in 2000 for a four-year period (Fig. 1). The aim was to build a hatchery on the site of the Malagasy Institute where reproduction, larval development, metamorphosis and early benthic life would be studied for the selected species. Two doctoral research theses were carried out, one on the sea urchin *Tripneustes gratilla* by Devarajen Vaïtiligon (from Mauritius) and the other on the sea cucumber *Holothuria scabra* by Richard Rasolofonirina (from Madagascar). Dr Vaïtiligon continued his career in Australia, Malaysia, Papua New Guinea, and Mauritius working in sea urchin and sea cucumber aquaculture. Dr Rasolofonirina joined the team of the Malagasy Institute and still works there as a professor and scientist. The hatchery was named "Aqua-Lab". Its main section consisted of a 120 m^2 air-conditioned building containing six rooms for growing seaweed, rearing larvae, caring for genitors, and undertaking microscopic and computer analyses (Fig. 2). The room devoted to larval rearing was divided into two parts dedicated to sea urchins and sea cucumbers. The tanks of the hatchery (300 L) were connected to a saltwater pumping station where the reservoir fills up at high tide and the water is poured into a 30 m^3 settling ponds. Decanted water was filtered and sterilised by repeated applications of UV before being used in the larvae rearing tanks. Regarding *Holothuria scabra*, the hatchery was functional in 2001, and produced at that time a few thousands of 1-mm-long juveniles (<1 g ww).

Building on this success, a second project was proposed to the CUD. This time, the project, which only concerned sea cucumbers, was presented by Prof Jangoux, Dr Eeckhaut and Prof Rabenevanana (Prof Rabenevanana succeeded Prof Mara as director of the Institute) (Fig. 2). The goal was to create a pre-grow-out site made of ponds dug into the earth and a grow-out site made of enclosures at sea. However, the project also had to exceed pure research and it was proposed to study the possibility of creating a private company in which coastal fishing villagers would be involved. The project began in 2005 and ended in 2008. A doctoral grant was funded and awarded

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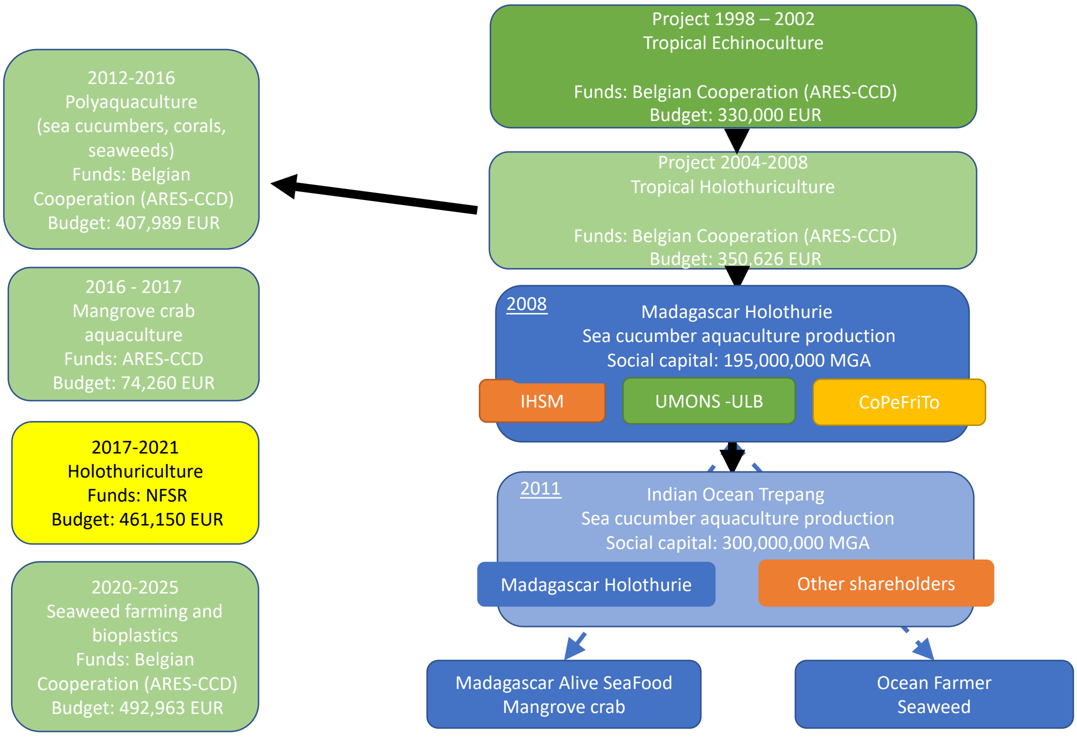

Figure 1. Representation of the different phases of the development of sea cucumber aquaculture in Madagascar and its indirect developments from the research part (top) to the industrial part (bottom). In green are represented the "oriented" research projects supporting village farming, including the development of sea cucumber farming, in yellow are the "fundamental" research projects, in blue are the companies created. Small frames inside large frames are the private and academic shareholders of companies.

to Thierry Lavitra who finished his PhD in 2008; Dr Lavitra then became part of the team at the Institute. (He became director of the Institute from 2013 to 2016, joined the Ministry of Fisheries and Fishery Resources from 2016 to 2018, and is now a professor at Toliara University and a member of the Institute's scientific staff).

This 2005–2008 project made it possible to build pre-growing ponds (nursery) on a larger site – the Belaza site – 25 km from Toliara (Fig. 2). In 2008, at the end of the project, the Belaza site was equipped with a laboratory, dormitories, a house for senior executives, 10 concrete pools of 32 m^2 each, and 600 m^2 of enclosures at sea that were designated to accommodate up to 1200 individuals of marketable size (> 20 cm long;> 300 g ww) (Fig. 2). The main problem in the production of sea cucumber juveniles was the impossibility of inducing *in vitro* the maturation of fully developed oocytes and, therefore, to fertilise them. A year before (2007), an international patent relating to the *in vitro* fertilisation of sea cucumbers was filed (Jangoux et al. 2007). This patent stems from the 2000–2004 research of Dr Rasolofonirina who discovered that ovary-extracted oocytes from *Holothuria scabra* could complete their meiosis and, therefore, be fertilised after having been incubated in an extract of *Tripneustes gratilla* (sea urchin) spawns (Léonet et al. 2009; Eeckhaut et al. 2012). Léonet et al. 2019) demonstrated that the maturation-inducing agent is a protein – thioredoxin – with a strong effect on the redox (reduction–oxidation) potential of oocytes and their environment. This was an important discovery because it made it possible to obtain fertilisable oocytes outside the reproduction period of *H. scabra* and, thus, the production of very large numbers of juveniles intended to develop in the above presented ponds. It also made it possible to have an alternative to the thermal shocks that are traditionally applied to sea cucumbers to obtain embryos. A patent of this type had definite advantages for the development of an industrial project: it had undoubtedly made it possible to create a legal framework without which large investors would certainly not have participated in the creation of the production company Indian Ocean Trepang.

Madagascar Holothurie and Indian Ocean Trepang

With the research carried out and the patent in place, a spin-off company was born (Eeckhaut et al. 2008). It was probably this phase of moving from applied research to building a company that was the most complicated. Only the pugnacity of the researchers and the choice of competent and motivated

[4] MGA 195,000,000 = ~EUR 42,530 or ~USD 51,577 as of 30 January 2021

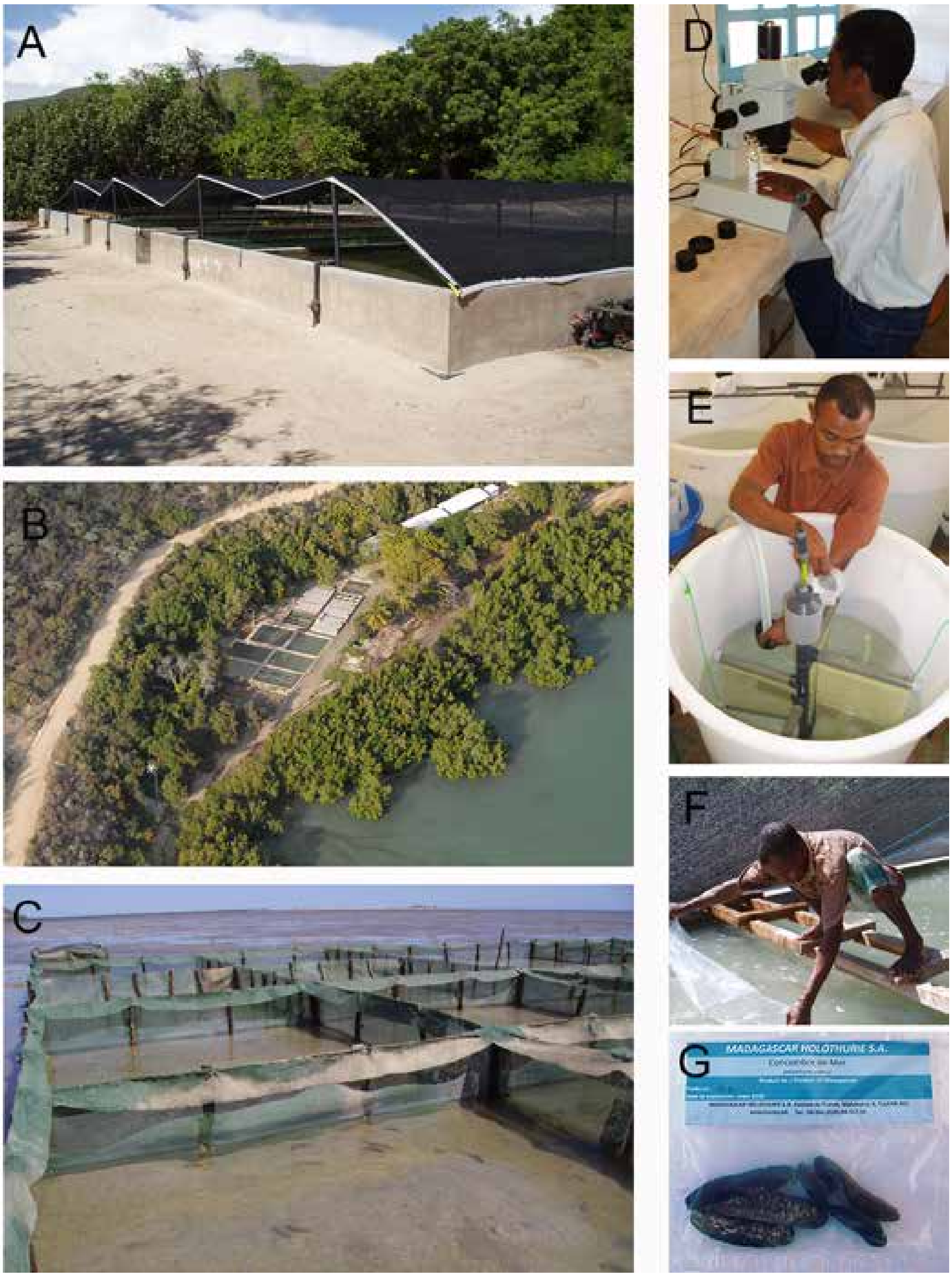

Figure 2. The research phase and the pilot-scale company Magasacar Holothurie. A) Concrete ponds on the site of Belaza used for testing the pre-growing of *Holothuria scabra* during the research phase; B) aerial view of the site of Belaza during the pilot-scale phase (several ponds were added to the concrete ponds to reach 1000 m^2 of surface area in total; C) the first sea pens located in front of Belaza; D) Dr Richard Rasolofonirina during his PhD in the hatchery "Aqua-Lab"; E) the technician Pascal preparing tanks in the Aqua-Lab hatchery; F) the technician John transferring *H. scabra* juveniles in the ponds of Belaza; G) First samples of *H. scabra* delivered to potential buyers in Asia.

private partners enabled this phase to be completed. On 22 April 2008, "Madagascar Holothurie" was created with a capital of MGA 195 million[4] in which the private company Copefrito and three universities (UMons, ULB and the Institut Halieutique et des Sciences Marines) were shareholders (Fig. 1). The exclusivity (first international then in Madagascar) of the use of the patent was purchased by Madagascar Holothurie. One of the company's objectives was to demonstrate the feasibility after three years of obtaining an annual production of around one hundred thousand juveniles with the existing hatchery and to estimate the average annual productivity of the hatchery and nursery phases and grow-out at sea. The capacities of the hatchery and nursery have been increased for this. The Belaza site nursery was then equipped with 1000 m^2 of ponds and the surface area of the at-sea enclosures reached a few hectares in area (Fig. 2). With the support of Madagascar Holothurie, the non-governmental organisation partners TransMad and Blue Venture both obtained ReCoMAP (Regional Program for the Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean) funding from the Indian Ocean Commission to test and develop for three years, the village farming of *H. scabra* in southwestern

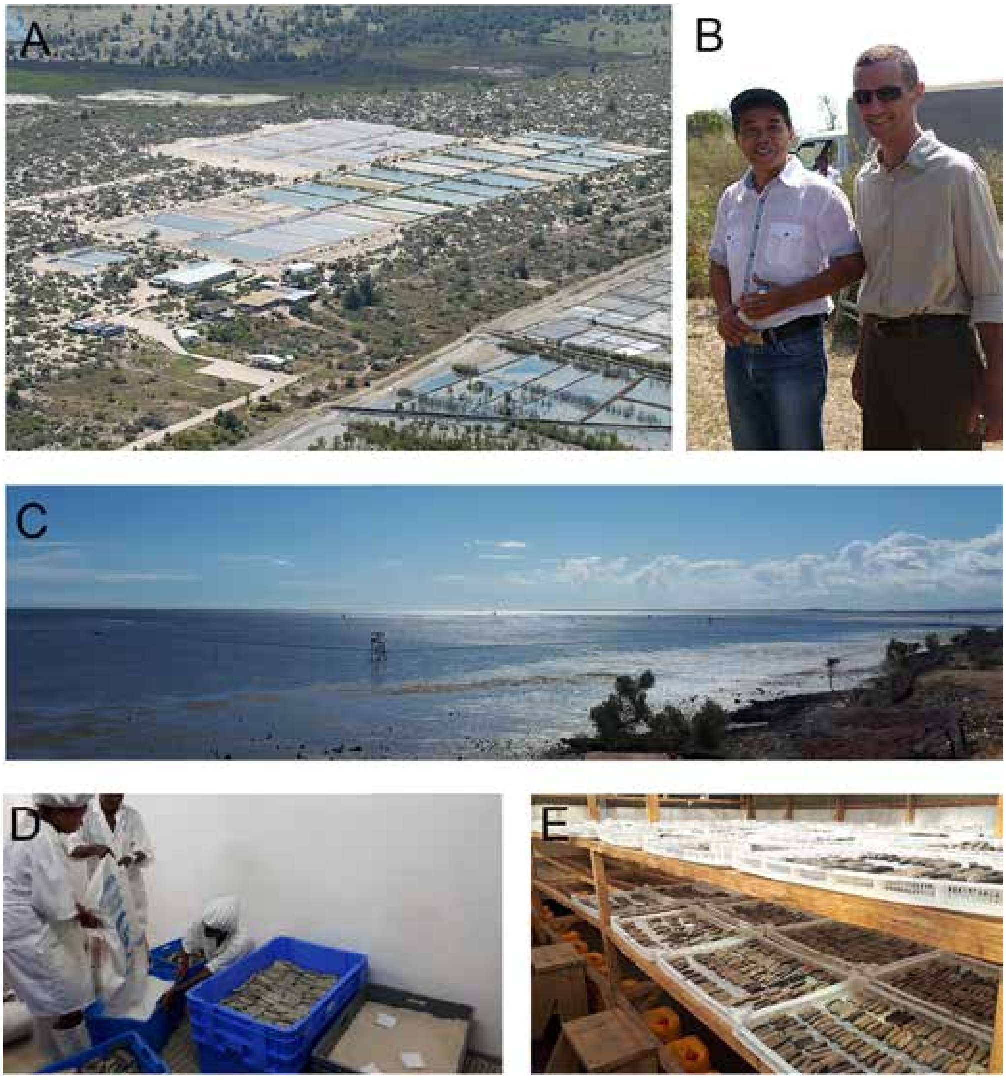

Figure 3. Indian Ocean Trepang, the industrial phase. A) Aerial view of Indian Ocean Trepang (IOT), showing the hatchery building and ponds of 1000 m² each; B) two of the actors of the success story, Olivier Avalle (right) who was the first Director of IOT, and Man Wai Rabenevanana (left) one of the promotors of the research phase; C) the Mangrove site, a 100 ha site of *Holothuria scabra* growing sea pens; D and E) the factory where *H. scabra* are processed into trepang.

Madagascar over an area over 300 km long. Madagascar Holothurie was, and still is, the supplier of *H. scabra* in the grow-out produced by coastal villagers.

With the first trials of Madagascar Holothurie, the Indian Ocean Trepang (IOT) company was created on 8 October 2011 with Madagascar Holothurie, Copefrito and Madagascar Sea Food as the main shareholders (Fig. 1). The acceptance of a PSI project (private sector investment) from the Dutch Ministry of Foreign Affairs, and a French investment fund (Investors and Partners) made it possible to provide the necessary funding for the project, totaling an initial investment of EUR 1.25 million. A production of 33 tons (dw) was expected in the business plan from 2013. A new hatchery of 500 m² was built on a new site, Ankaloha, 10 km south of Tulear (Fig. 3). Adjoining the hatchery, a nursery was created now equipped with around 50 ponds of 100 m² (for juveniles coming out of the hatchery), and 50 other ponds of 1000 m² (for the largest juveniles) (Fig. 3). Much of Ankaloha runs on solar energy. In addition, the bay of Sarodrano acts as a grow-out site. Named the "Mangrove" site, it currently includes 101 ha of enclosures (Fig. 3). A second site, Andamilamy, north of Tulear, was created in 2018 and currently includes 96 ha of growing area. A trepang factory and the offices of the IOT company are located in the free zone in the port of Tulear. IOT currently employs 227 people, including 143 permanent staff who are divided into the following departments: hatchery, nursery, seapens, factory, logistic, security, maintenance and administration and direction. The big jobs in terms of personnel are seapen maintenance (38.7% of personnel) and security (23.3% of personnel). Security includes 40% of the company's full-time people.

The fattening of *Holothuria scabra* in enclosures is, therefore, done partially according to the "company farm" model (company employees paid for the grow-out work) but also according to the "village farming" model (assisted villagers paid for production). Currently, village farming includes 37 ha of enclosures at sea. This area of enclosures represents 226 farms: 145 of 2000 m² each with one household, and 81 of 900 m^2 each with two households. In all, village farming currently affects 307 households, a household roughly corresponding to a family of fishing villagers. Currently, village farming is very beneficial in terms of publicity for IOT but much less beneficial in terms of financial profitability. Without counting export costs, an *H. scabra* costs the company USD 2.02 each, broken down as follows: purchasing adults = USD 1.04; factory and logistics costs = USD 0.26; cost of juvenile production = USD 0.72. These combined costs all greatly decrease profitability.

Problems, solutions and interests for private and public partners

The start of IOT was not easy, with investors wanting a return on their investment within five years. Founded in 2011, the company only managed to export 3.4 tons (dw) of trepang in 2017, reaching 7 tons (dw) in 2020 when, for the first year, it reached an adequate financial break-even point. The problems encountered were various, among them, high salary costs, overestimation of profitability of the three phases (hatchery, nursery and grow-out), and a completely unknown up-scaling effect at the start. One of the mistakes was to transpose the profitability of the three phases at the start to the new, much larger economic model. For example, the profitability of the magnification obtained during the first studies in enclosures where the enclosures were of the order of 100 m^2 were transposed to the enclosures of 10,000 m^2. As a result, the profitability obtained by IOT enclosures at the start was 22% instead of the expected 50%. This poor performance over the years has been analysed and improved on. It is now known that this low performance was due to six main causes: 1) too small of a size of transferred juveniles, 2) predation (mainly by crabs), 3) diseases (mainly skin ulceration diseases), 4) too high of a growing density, 5) temperature stress (mainly cold), and 6) thefts. Thefts constituted the most obvious negative impact of the development of sea cucumber aquaculture in Madagascar and, in particular, the lack of security that near the grow-out sites. Dahalo, or “zebu thieves” from the interior of the country, with the help of some bad intentioned coastal locals, have repeatedly stolen sea cucumbers from the enclosures. It happened that Dahalo bands of more than 50 people looted the enclosures, and community members asked the IOT company to call the Malagasy gendarmerie to solve this problem, which resulted in scuffles involving weapons and arrests.

Alongside the direct benefits obtained by private partners, we can also observe beneficial developments obtained by these partners which, without their departure into the world of sea cucumber aquaculture, would not have existed (Fig. 1). Copefrito was, from the start, the central private partner in the development of sea cucumber aquaculture in Madagascar. This company exports seafood, mainly fish and cephalopods (squid, octopus), which are collected by villagers around Tulear. The entry into sea cucumber aquaculture strengthened the conviction of the private partner in the positive development of village aquacultures. Thus, in 2017, Ocean Farmers became a company outside Copefrito (Fig. 1). This company cultivates the red algae *Kappaphycus alvarezii* and, through village farming, it now produces and exports some 1000 tons of dried algae. It works closely with village communities (algae farmers) where 1700 households (around 3500 villagers) are now involved in growing seaweeds in several dozen villages. In 2015, Madagascar Alive Sea Food – a spin-off company of Copefrito – began cultivating mangrove crabs (*Scylla serrata*) (Fig. 1). This company is still in the development phase.

Contrary to what one might think, the direct financial impact of the patent on universities (ULB, UMons and Institut Halieutique et des Sciences Marines being the legal holders of the patent), laboratories and inventors has been very low. As an example, from the EUR 60,000 provided by a license established initially between the universities and the license applicant to have the exclusivity of the patent, only EUR 10,000 were paid, which is mainly due to the successive revisions concerning this license following the difficulties the company had in breaking even. Of these EUR 10,000, the rule established in Belgian universities stipulated that they take back 40% for the costs of the constitution of the patent (the patent cost the universities more than EUR 50,000, mainly in notarial fees and translation costs). The remaining 60% are divided into three equal sums for the three universities, which remunerate then their laboratories and their researchers according to internal rules. At UMons, the “three-thirds” rule is in force, whereby the budget is divided into three – between university, laboratory and researchers-inventors. Out of these EUR 10,000, the researchers-inventors have each received some EUR 300 to date.

For university laboratories and researchers, the indirect benefits represent the main benefits generated by the history of sea cucumbers in Madagascar (Fig. 1). Thanks to the success of Indian Ocean Trepang, funds for scientific research and for sustainable development have been raised. In 2012, the Belgian Development Cooperation (ARES-CCD) funded a five-year project supporting the development of village polyaquaculture (sea cucumbers, seaweeds, corals). In 2016, ARES-CCD financed a two-year project supporting the development of mangrove crab aquaculture, and in 2019 a five-year project supporting the production of degradable algae-sourced bioplastics. The Belgian National Fund for Scientific Research financed many fundamental researches on reef ecology and, in 2017, a five-year project on the biology of *Holothuria scabra*.

The three pillars of university actions are the development of fundamental, focused and applied researches for the reasoned development of our society, the provision of high-quality education by integrating this research into the courses given to students and researchers, and concrete effects (direct and indirect) of research results in civil society. The history of sea cucumber aquaculture in Madagascar is a fine example of academic research and the establishment of direct application in civil society.

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Table 1. PhD theses and resulting scientific articles relating to aquaculture research on *Holothuria scabra* in Madagascar, and PhD theses on related topics

Doctor of Biological Sciences	PhD theses	Scientific articles related to sea cucumbers (or organisms that could be coupled with sea cucumber farming) resulting from a PhD thesis
Richard Rasolofonirina (2004); ULB Funds: ARES-CCD	Reproduction et développement de Tholothurie comestible *Holothuria scabra* (Jaëger, 1833) (Holothuroidea: Echinodermata).	Rasolofonirina R. and Jangoux M. 2005a; Rasolofonirina R., Vaïtilingon D., Eeckhaut I. and Jangoux M. 2005
Pierre Becker (2007); UMons Funds: FRIA - NSFR	Biologie des symbioses en milieu marin : caractérisation et éthiologie des lésions tégumentaires chez deux espèces d'échinodermes d'intérêt économique.	Becker P., Gillan D.C., Jangoux M., Rasolofonirina R., Lanterbecq D., Rakotovao J. and Eeckhaut I. 2004
Thierry Lavitra (2008a); UMons Funds: ARES-CCD	Caractérisation, contrôle et optimalisation des processus impliqués dans le développement postmétamorphique de *Holothuria scabra* (Jaeger, 1833) (Holothuroidea : Echinodermata)	Lavitra T., Rachelle D., Rasolofonirina R., Jangoux M. and Eeckhaut I. 2008; Lavitra T., Rasolofonirina R., Jangoux M. and Eeckhaut I. 2009a; Lavitra T., Rasolofonirina R., Grosjean P., Jangoux M. and Eeckhaut I. 2009b; Lavitra T., Fohy N., Gestin P.-G., Rasolofonirina R. and Eeckhaut I. 2010a; Lavitra T., Rasolofonirina R. and Eeckhaut I. 2010b
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