Community-based coral aquaculture in Madagascar: A profitable economic system for a simple rearing technique?

Gildas Georges Boleslas Todinanahary [a,b,*], Thierry Lavitra [a], Herinjatovo Hardinat Andrifanilo [a], Nicolas Puccini [d], Philippe Grosjean [c], Igor Eeckhaut [a,b]

[a] Polyaquaculture Research Unit, Institut Halieutique et des Sciences Marines (IH.SM), University of Toliara, Route du Port Mahavatse II, P.O. Box 141, 601 Toliara, Madagascar
[b] Biologie des Organismes Marins et Biomimétisme, University of Mons, 6, Avenue du Champs de Mars, Pentagone 2B, 7000 Mons, Belgium
[c] Ecologie Numérique des Milieux Aquatiques, University of Mons, 6, Avenue du Champs de Mars, Pentagone 3D, 7000 Mons, Belgium
[d] Faculté Warocqué d'Economie et de Gestion, University of Mons, 17, Place Warocqué à, 7000 Mons, Belgium

ARTICLE INFO

ABSTRACT

Since a couple of decades, coral aquaculture has been developed in many countries to face an increasing live coral market and to support conservation of endangered natural coral reefs. To evaluate the potentiality of community-based coral aquaculture in Madagascar, we experienced suitable farming techniques using the species *Acropora nasuta* and *Seriatopora caliendrum*. Survival and growth rate of the nubbins were monitored during wet, warm and dry, cold seasons. To determine economical feasibility, the coral market was investigated and the yields were also calculated using the technical, biological and social parameters of the production. Coral nubbins were reared *in situ* at appropriate conditions. Coral nubbins reared during the wet, warm season showed a final survival rate of $67 \pm 6\%$ and $57 \pm 4\%$ respectively for *A. nasuta* and *S. caliendrum*, while in the dry, cold season, the survival rates were of $85 \pm 7\%$ and $69 \pm 1\%$ respectively. *A. nasuta* had a significantly higher survival rate than *S. caliendrum* during both seasons. During the wet, warm season, growth rates were $0.46 \pm 0.16\%$ d^{-1} and $0.54 \pm 0.16\%$ d^{-1} respectively for *A. nasuta* and *S. caliendrum*. In the dry, cold season, *A. nasuta* had $0.63 \pm 0.18\%$ d^{-1} of growth rate, while *S. caliendrum* grew $0.65 \pm 0.15\%$ d^{-1}. Significant difference was observed between both species during the wet, warm season, but not during the dry, cold season. Furthermore, both species grew faster during the dry, cold season. These results are in the range of reference values for corals. The activity can be profitable from 25 coral nubbins sold per month. Profit can already be perceived from the second year and a total of more than EUR 27,000 earned after 5 years of developing project, for an initial investment of EUR 1978. Marine animals wholesale companies and biodiversity conservation NGOs seem to be the appropriate clients for this form of aquaculture on Madagascar.

Statement of relevance: This paper provides new form of coral aquaculture: the community-based coral aquaculture. The socially and environmentally responsible production of coral is among the benefits of this new economically viable form of aquaculture.

1. Introduction

Coral culture also known as coral aquaculture or coral[1] farming is the rearing of corals for commercial purposes (Ellis and Sharron, 1999; Department of Fisheries of Western Australia, 2009; Albert et al., 2012), reef restoration (Ng et al., 2012) or for drug discovery (Leal et al., 2013). It could provide an effective tool to restore coral reefs (Bowden-Kerby, 1999; Martin et al., 2005; Hernández-delgado et al., 2014) that are declining worldwide (Food and Agriculture Organization, FAO, 2005-2015).

In the Southwest region (SWR) of the Indian Ocean, notably in Madagascar, several studies have reported the impacts of fisheries (Bruggemann et al., 2012), tourism activities, climate change and coral bleaching (McClanahan et al., 2007; Eriksson et al., 2012). Several conservation programs have been established in the Western Indian Ocean (WIO) Region by public research institutions and non-governmental organizations (NGOs). In Madagascar, conservation policies have focused on the creation of marine protected areas (MPAs) as a tool for fisheries management. Over 60 marine reserves have been created with fishing communities and Government, the fishery and marine science Institute and NGOs (Wildlife Conservation Society (WCS), Blue Ventures, Reef Doctor and Conservation International) (Todinanahary et al., 2013). In 2008, the concept of community-based aquaculture was introduced to the traditional fishermen in Madagascar who previously had no alternative

* Coresponding author.
E-mail addresses: gildas.todinanahary@ihsm.mg, todinanaharygildas@gmail.com (G.G.B. Todinanahary).

[1] The term "coral" in this work refers to the scleractinians also known as hard corals.

livelihood to fishing. Community-based aquaculture started with the launch of sea cucumber (*Holothuria scabra*) farming through a newly created company "Madagascar Holothurie SA" (MHSA) with the aim of reducing fishing pressure on wild communities (Laroche and Ramananarivo, 1995; Rasolofonirina and Conand, 1998; Rasolofonirina, 2004; Lavitra, 2008; Lavitra et al., 2009). Seaweed farming (*Kappaphyccus alvarezii*) in Madagascar began in the late 1980s, where culture tests demonstrated the feasibility of algae farming. Since a few years, at least 7 private operators interested in seaweed farming have tried, with varying success, to develop commercial productions. In the SWR, the "COopérative de PEche FRIgorique de Toliara" (COPEFRITO — www.copefrito.com) Company, in partnership with Blue Ventures and the fishery and marine science institute (IH.SM) of the University of Toliara involved over 400 seaweed farmers living over 200 km off the SWR shores and the company currently exports products to Europe (Eeckhaut, pers. com.; Tsiresy et al., 2015).

Since 2008, community-based sea cucumber farming and seaweed culture have increased in both size and production volumes as a result of research and development projects involving fishermen communities, private companies, NGOs and public institutions. These stakeholders continue to work together within a working platform of community-based polyaquaculture that they constitute. In 2012, the Polyaquaculture Research Unit (PRU — http://www.polyaquaculture.mg) project was initiated (Tsiresy et al., 2012) to develop polyaquaculture in the coastal villages of Madagascar, as alternative financial resources to fishing and gathering of wild organisms (Pascal et al., 2013). The research focused on improving sea cucumber and seaweed farming, as well as investigating the feasibility of other aquaculture initiatives such as coral aquaculture, and potential integration into communities.

Coral aquaculture has been practiced since the 1990s (Department of Fisheries of Western Australia, 2009) at different scales in France, The Netherlands, Germany, China, Dominica, Fiji, Indonesia, Israel, Marshall Islands, Philippines, Singapore, United Republic of Tanzania, United States of America (USA), Puerto Rico, Palau, Solomon Islands and Japan and Australia (CITES, 2002). Techniques vary in function of latitude and farming scale but in tropical and subtropical countries, corals are generally cultivated in the field (Ellis and Sharron, 1997; Albert et al., 2012). In temperate countries coral aquaculture is often land-based (Wijgerde et al., 2012, Leblud et al., 2014a) and corals are reared in aquariums (Kangas and Walter, 1996; Berges et al., 2001; Atkinson, 2010). In both cases, the farming method is commonly based on the cuttings technique where small branches of corals or coral nubbins (Leblud et al., 2014b) of about 5 to 10 cm are cut from mother colonies and secured on hard surfaces. The size of the nubbins depends on the goal and the final destination of the reared coral.

Corals can tolerate a wide range of environmental conditions but they usually do not appreciate sudden changes in parameters (Osinga et al., 2011). Thus in ex-situ culture, it is essential to maintain the water conditions at the tolerated range and ideally at optimal values for the corals (Leblud et al., 2014a). In addition, the operational costs for ex-situ coral culture are very high and the cost of the production of a coral can reach over € 30 (Osinga et al., 2011). The advantage of in-situ coral farming is that it is not necessary to control the water parameters when it is performed in the appropriate site. Therefore, the cost of the production of a coral remains less than €1 (Lal and Kinch, 2005).

Since 1990, coral aquaculture continued developing but about 24 years later, farmed corals (including captive bred and captive born specimens) represent <20% of the global live coral trade (CITES, 2016). In 2014, the total trade volume exceeded 120,000 specimens that were farmed both in aquariums and in the field (CITES, 2016). The market for farmed corals remains important in volume knowing that more that 80% of the traded corals are collected from the wild. The growing coral market is essentially dominated by the USA but is also present in Canada and mostly in Europe (Green and Shirley, 1999; CITES, 2016).

There is very little information about community-based coral aquaculture practice. Villagers maintain most of the coral farms in the Solomon Islands (Albert et al., 2012), in Indonesia (Raymakers, 2001), in the Marshall Islands, in Palau or in Fiji (Delbeek, 2008). Then, the farmed corals are bought and exported by private companies that perform the coral preparation in land-based aquariums (Lal and Kinch, 2005). These countries constitute the principal producers and exporters of live corals (CITES, 2016). In the Indian Ocean, coral farming is modestly developing (e.g., in Mauritius, Nazurally and Rinkevich, 2013). In Madagascar, in-situ coral farming was started in 2008 by the private society IBIS Madagascar but their production stopped a few years later due to logistical problems (pers. obs.). Another private company, the Marine Aquaculture of Nosy Be performs coral aquaculture both in-situ and ex-situ but they are limited to the production of soft corals (Menzel, pers. com.).

In this paper, we analyse the potential of coral aquaculture for fishermen in villages of Madagascar. The main objective of the study is to identify a simple coral rearing technique, which is appropriate and accessible to fishermen and farmers in the coastal villages of the country. This paper also assesses the economic feasibility of a coral farming livelihood based on a business model.

2. Materials and methods

2.1. Analysis of biological, ecological and technical feasibility

2.1.1. Studied species

Acropora nasuta (Dana, 1846), and *Seriatopora caliendrum* (Dana, 1846) were used for all the experiments (Fig. 1). Species were initially identified using the in-situ Coral finder identification guide (Kelley, 2011), followed by an in-lab skeletal morphology analysis using the 3 volumes of "The corals of the worlds" (Veron, 2000). Finally, DNA sequencing was performed to confirm and correctly identify these species (unpublished data). The gene cytochrome oxydase subunit 1 (COI) of each species was sequenced and compared to GenBank (http://www.ncbi.nlm.nih.gov/genbank/) published sequences using Basic Local Alignment Search Tool (BLAST) to find out the nearest taxa.

2.1.2. Selection of the farming site

Experiments were performed at the village of Sarodrano (S23°30′35″, E43°44′4″) (Fig. 2) which is a fishing village located at the tip of an arrow-shaped dune of sand at the southern boundary of the lagoon of Toliara. This village is surrounded by a complex of coastal and marine ecosystems: at the south by the dunes and mangroves of Ambanilia, and the fringing reef of Sarodrano that runs along the arrow and separates the village from the estuary of the Onilahy River; in the east by a large area of seagrass and channels that opens on the higher limit of the intertidal zone with some mangrove species; in the North by internal reefs (Belaza, Dimadimatsy, Mareana among others) and the lagoon of the Bay of Toliara; and in the west by the southern tip of the Great Reef of Toliara and the reef complex of Nosy Tafara. These coral reefs are of diverse typology: barrier reef, inner reef, outer reef, fringing reef, and reef patch (Clausade et al., 1971).

To choose the best farming site, we first performed rearing tests at 3 stations of different depth measured at low tide of full moon: the stations A (0.4 m), B (0.6 m), and C (1 m) (Fig. 2). The station D corresponds to natural coral reef where mother colonies were collected. Four coral tables containing forty coral nubbins (~5 g dry weight) of the species *A. nasuta* per station were installed. The rearing test was performed during January/February where the highest water temperatures were observed and where heavy rains occurred, leading to the largest changes in salinity. Coral survival was determined weekly during 4 weeks after nubbins installation.

Fig. 1. A: Fixation of the nubbin of the cement support prior to immersion. B: Installed coral farming table. C and D: *Acropora nasuta* and *Seriatopora caliendrum* from the experimental coral aquaculture at Sarodrano.

Among the tested stations, station C appeared to be the most appropriate for coral aquaculture. Survival rates of 57%, 63% and 96% were observed at stations A, B and C, respectively, one week after coral nubbins installation. The water motion at station C explained this result.
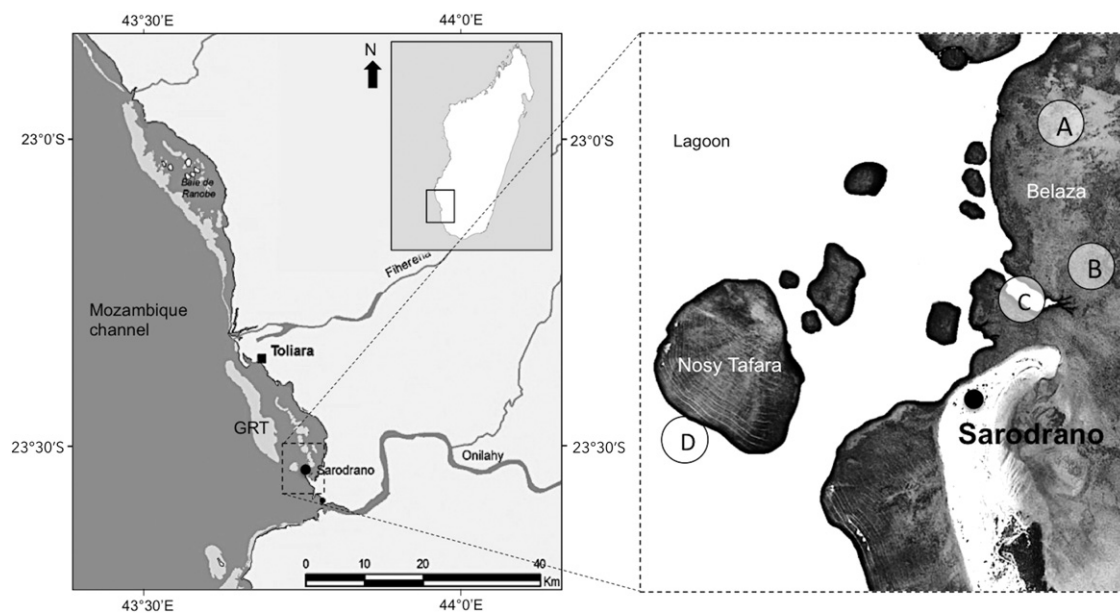
Fig. 2. Location of Sarodrano village and experimentation sites. Farming tests were performed at stations A, B and C. D is the station where mother colonies were collected. White background on the right figure represents the open sea, while, dark backgrounds the coral reefs.

The current regime at this station is more similar to the site where mother colonies originate (station D on Fig. 2; Pichon, 1978). The depth is too low during low tides at stations A and B. This exposed the coral nubbins at high temperature (>30 °C) during 1 to 3 h, once or twice a day which negatively affected their growth rate, induced bleaching and, at worst, death (Forsman et al., 2011). Only station C was taken forward and all subsequent results refer only to this station. It is located 5 min by pirogue from the village of Sarodrano. The station was at the outer limit of the degraded reef flat of patch reef of Belaza, by 1 m depth (measured during the low tide of full moon). Located on an intertidal zone, the water current regime is mainly tidal, with 4 daily movements during ebb tide (2) and rising tide (2) (Pichon, 1978). The current is particularly intense during 1 h prior and after the low tide of full and new moons.

At station C, temperature was measured hourly using Hobo data loggers from which data were downloaded and calculated using the ONSET HOBOware Pro version 3.7.0 (Onset Computer Corporation, 2002-2014); salinity, pH and total alkalinity were measured daily using a refractometer, pH meter (sensION+, precision = 0.01) and YSI-9300 Direct-Read Photometer (precision = 20 μmol·l^{-1}). Sedimentation rate was also measured during 10 days per season. Four sediment traps were installed using the method suggested by Rogers et al. (1994). Accumulated sediment was collected and dried at 60 °C during 24 h. Weight measurements were performed with an electronic balance (Sartorius BP221S, precision = 0.1 mg). The measurement of sediment rate was repeated twice during one season.

2.1.3. Coral aquaculture technique

2.1.3.1. Experimental design. Four coral tables 80 cm long and 40 cm wide were used to rear each species. The plates of the tables were hard iron mesh of a mesh size of 10 cm, and painted with rustproof paint. Each table of 40 cm in height was placed on the sandy bottom, at 1 m depth (measured at full moon). We cut coral nubbins of ca. 5 g dry weight (see growth measurement and skeletal calculation below) from the mother colony using cutting pliers and fixed them on a cement support using elastic thread. Each cement support was placed tightly on the table mesh. A total of 40 nubbins per table, produced from the colony collected in station D (Fig. 2) were installed. One different mother colony was used for each table. The experiment was performed during 6 months in the wet, warm season (November–April) and was repeated during the dry, cold season (May–October). The whole experiments were performed with 4 farmers from the village of Sarodrano. The farmers performed the installation of the tables, the collection of the mother-colonies, the preparation and the installation of the coral nubbins, with logistic and scientific support from the researchers. During the experiments, the farmers undertook the maintenance of the aquaculture facilities, while the researchers were in charge of scientific monitoring and observations. This form of organization is typical for community-based aquaculture (Pascal et al., 2013).

2.1.3.2. Survival and growth measurements. The number of lost and dead coral nubbins was assessed every month. Untied nubbins were counted as dead unless they could be retied on the support and did not present physical damage or bleaching. Growth was measured monthly on 10 nubbins of each species using the buoyant weight method. Each measured nubbin was fixed on a plastic tube that is detachable from the cement support to allow measurement and easy reattachment on the cement support after measurement. Weighing was performed by suspending the nubbin, which was immersed in seawater, to a hook connected to an electronic balance (Sartorius LE623P, precision = 1 mg). Salinity and temperature of the seawater in which the nubbin was immersed during the measurement were measured to calculate the density. The buoyant weight was converted into skeletal weight using the formula detailed by Jokiel et al. (1978) that considers the density of the water and of the skeleton (Davies, 1989). Growth rate over

the experimentation periods was calculated using the exponential growth formula described in Osinga et al. (2011).

2.2. Analysis of the economic potential

2.2.1. Analysis of the market

To identify the main accessible and potential clients for Madagascar coral farming, a survey of 20 questions was performed using the survey monkey online tool (http://www.surveymonkey.com). It consisted mainly of quantitative and qualitative economic questions (corals demand and selling: quantity, composition, origin, size and prices), but also considered biological aspects (species and colour, bio-ecological constraints in transport and conditioning) (see details of the questions in Supplementary material 1). Twelve coral farming/trade stakeholders were targeted. The present analysis is based on the answer of 3 main categories of stakeholders, from which an overview of the coral market and coral prices could be determined: A — coral farming and wholesale company, B — public zoo and botanic park and C — aquarium shop (coral retailer). Complementary information was obtained from aquaria, aquarium shops web portal, personal communications with aquarium shop and public aquarium managers and from the literature. Obtained data was classified and calculations performed throughout the value chain of coral production and market. We also collected information from a few coral reef conservation NGOs to define their interests and their activities with respect to coral and coral aquaculture. Finally, detailed data on the global market for corals was downloaded from the CITES trade data dashboards to characterize the farmed corals trade including the trade volume, list of species, list of importing and exporting countries and the source of traded corals. The analysis of these characteristics allowed an assessment of the effectiveness and viability of coral farming, of the accessibility of the global coral market and of the potential clients of community-based coral aquaculture.

2.2.2. Calculation of the yields

Each level of the value chain (Fig. 3) was evaluated financially. The costs of materials, services and human resources were identified. The following parameters obtained from our biological analyses were used for the yield calculations. They were based on 57% of survival rate during rearing (the lowest observed during the tests) and 90% after transportation to the client. They also consider practical aspects and the methods used. The first percentage was estimated according to the experiments with farmers and the second from a real assay where coral nubbins produced by the farm where packed and sent by airmail. The total duration of the transport, from collection of coral nubbins to unpacking was 27 h. The community-based aspect and the scale of the farming were also considered.

Production parameters

- We selected 8 farmers; each maintaining 6 coral tables containing 40 nubbins each. We take into account 6 tables per farmer to consider the practical aspect of the farming. We consider 8 farmers in the calculations as it fits the range of pilot farmers starting new community-based aquaculture in the villages of Southwest Madagascar.
- A coral nubbin reaches a valuable size after 8 months of rearing. Here we conservatively consider attaining the L size (Table 2) after 8 months, even if the experiment duration was 6 months and L size was obtained after 6 months.
- A production of 240 coral nubbins per month per farmer is reached from the 8th month. At the beginning of a coral production cycle, it should be considered that only 6 coral tables of 1 farmer per month are installed by all of them to promote their training and increase the ability in preparing and installing coral nubbins.
- 25% of the production is reintroduced to the natural coral reef and ~10% are used as a source of new nubbins.
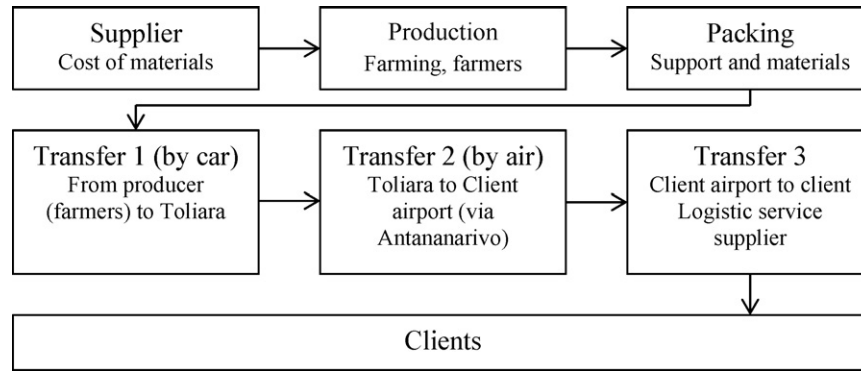
Fig. 3. Value chain of the coral production from Madagascar.

Exportation parameters

- A packed coral nubbin weighs 820 ± 20 g. The volume of seawater in the transportation bag is approximately 800 ml.
- A transportation container can contain a maximum of 30 nubbins with a total weight of 24.6 kg.
- 84 coral nubbins per month are exported and the client pays 76 survived nubbins. These numbers are estimated from the production parameters and from the stated survival rates in the literature (Delbeek, 2008).

The human resource parameters are based on the effective salary and income of the people concerned in 2015 and in considering coral farming only as a complementary activity. All people involved in this form of aquaculture already work in one of the community-based working platform members (Pascal et al., 2013)

- 8 farmers maintain the above production of corals. Each farmer is paid MGA 50,000 per month (~15 EUR).
- 1 technician for exportation tasks is paid 100,000 MGA (~30 EUR).
- 1 secretary in charge of client relations and the administrative aspects of the production is paid 600,000 MGA (~170 EUR).

2.3. Statistical analysis

All the statistical analysis was performed using the R software (R Core Team, 2014). Descriptive statistics were calculated first. Normality of the data was determined using a Shapiro-Wallis test and homogeneity of the variance was calculated using Levene's test. In this study, no transformation was needed. Significance of difference in means was determined using one-way ANOVA and t-test, at a confidence level of 5%.

3. Results

3.1. Biological, ecological and technical feasibility

The measured sedimentation rate at station C was 0.55 ± 0.28 mg·cm^{-2}·d^{-1}. The average values for temperature, salinity and pH of the water were significantly different between the wet,

warm season, and the dry, cold season (Table 1). In wet, warm season the salinity was lower while total alkalinity and pH showed higher values compared to the dry, cold season (Table 1). The annual variation of these parameters is presented in Fig. 4.

Coral nubbins reared during the wet, warm season showed a final survival rate of $67 \pm 6\%$ and $57 \pm 4\%$ respectively for *A. nasuta* and *S. caliendrum*, while during the dry, cold season, the survival rates were $85 \pm 7\%$ and $69 \pm 1\%$, respectively (Fig. 5). *A. nasuta* had a significantly higher survival rate than *S. caliendrum* during both seasons ($p = 0.029$ and $p = 0.003$, respectively). The survival rates of both species were significantly lower in the wet, warm season ($p = 0.006$ and $p = 0.002$ for *A. nasuta* and *S. caliendrum*, respectively). In addition, >80% of the observed mortality was represented by untied coral nubbins. This implies the lower survival rates mentioned above. Recalculated survival rates (excluding untied nubbins) were $92 \pm 3\%$ and $86 \pm 4\%$, respectively for *A. nasuta* and *S. caliendrum* in wet, warm season, and $97 \pm 2\%$ and $91 \pm 7\%$ in dry and cold season. Nevertheless, the differences between species and between seasons were conserved.

During the wet, warm season, growth rates were $0.46 \pm 0.16\%$ d^{-1} and $0.54 \pm 0.16\%$ d^{-1} for *A. nasuta* and *S. caliendrum*, respectively. In the dry, cold season, *A. nasuta* grew at $0.63 \pm 0.18\%$ d^{-1}, and *S. caliendrum* at $0.65 \pm 0.15\%$ d^{-1} (Fig. 6). Significant differences were observed between both species during the wet, warm season ($p = 0.030$), but not during the dry, cold season ($p = 0.51$). Furthermore, both species grew faster during the dry, cold season. Significant differences were observed both in *A. nasuta* ($p < 0.001$) and *S. caliendrum* ($p = 0.001$). Analysis of the growth rate results also showed that *A. nasuta* can double its weight in ~160 days, while *S. caliendrum* doubled its weight in ~100 days.
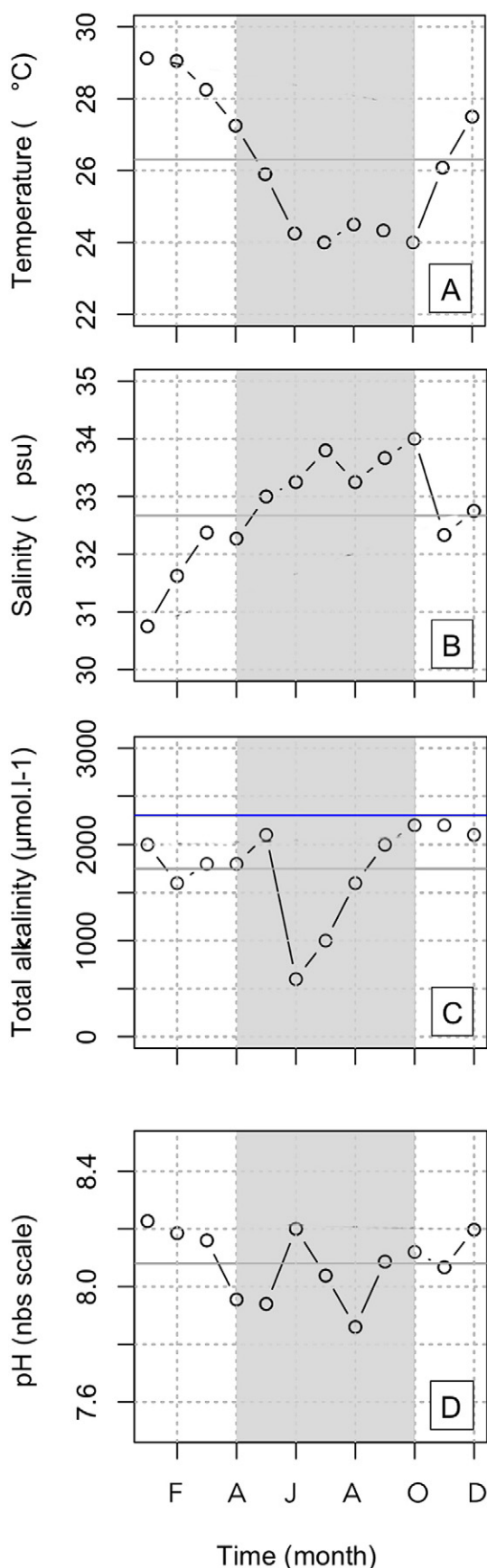
3.2. Economical potential

3.2.1. Investment and profitability

Here we propose a business that requires an initial investment of € 1978 and an annual charge of € 15,246 including variable and non-variable costs. Based on 76 coral nubbins sold per month, the total cost per nubbin is € 21.56, including a non-variable cost of € 12.61 and a variable cost of € 8.95 (Table 3). An amortization of € 836 per annum is estimated. We suggest € 25 as the minimum price in this project but in this case we prudently consider a selling price of € 30. Thus, the project gets € 8.44 of margin per coral nubbin. That

Table 1
Seasonal mean temperature, salinity, total alkalinity and pH of the water at station C (4 measurements per month).

	Temperature (°C)	Salinity (psu)	Total alkalinity (μmol·l^{-1})	pH (nbs scale)
Wet, warm season	27.8 ± 1.1	32.0 ± 0.7	1915 ± 223	8.13 ± 0.15
Dry, cold season	24.7 ± 1.5	33.4 ± 1.2	1582 ± 652	8.03 ± 0.13
Annual average	26.3 ± 2.1	32.7 ± 1.2	1748 ± 496	8.08 ± 0.15
Difference between seasons (p value)	<0.001	<0.001	0.26	0.018

Fig. 4. Annual distribution of temperature (A), salinity (B), total alkalinity (C) and pH (D) of the water during rearing experiments (mean of 4 measured values per month) at station C. Additional measurements were performed during the monitoring of survival and growth of the coral nubbins. The grey areas correspond to the dry, cold season of Madagascar (May to October). Grey lines define the annual average value of each parameter. Blue line in C shows the reference value of total alkalinity of seawater in coral reef ecosystem (2300 µmol·L^{-1}, Leblud et al., 2014a,b).

determines the minimum selling price to € 21.56, which correspond to the total costs per nubbin. The selling price to exportation of € 30 is 25% less expensive than the cheapest price of the species in this experiment. Reference prices were from the major coral wholesalers in Europe and were considered at the exchange rate of July 2015 (Table 2).

Provisional result accounts per year estimated in Table 4 consider that during the first year, exportation is only performed after 8 months, after which the production of 240 nubbins per month can be easily reached. In this case study, the Earning Before Interests and Taxes (EBIT) is of − € 6938 the first year and € 11,350 from year 2 and each following year. Thus, the net result (reduced of 30% of taxes) reaches € 7945 during cruising rhythm of the coral aquaculture project (Table 4). Table 5 proposes the financial flux of the project during 5 years from its implementation. It takes into account the initial investment and includes the annual amortization, as it is not a disbursed amount. Profit can already be perceivable from the second year. The project can earn more than € 27,000 after 5 years, assuming that the inflation is 0% and the price of the products does not change.

In addition, calculations showed that the activity is profitable from 25 coral nubbins sold per month (Fig. 7). According to the appropriate and adopted business model, with 25% of safety margin, we project that at least 30 coral nubbins per month should be sold to ensure a viable activity. For a production of >100 corals per month, profit reaches € 1600 (per month). That is constantly increasing according to the efficiency of the coral aquaculture technique and the adopted business management.

3.2.2. Analysis of the potential clients

Even if the coral market seems to be evident and open (Raymakers, 2001; Reksodihardjo-Lilley and Lilley, 2007), the main obstacle in community-based coral farming in Madagascar is finding and reaching clients. Very little information on the coral market exists and contacting potential clients is not easy. The profitability depends on the type of buyer of the farmed corals. Therefore, a few scenarios could be proposed for selling corals, especially from Madagascar (Table 6).

Scenario 1 consists of selling the farmed corals to a European lead distributor (wholesaler). The European leader in importation, acclimation and distribution of fishes, invertebrates and aquarium plants from around the world is based in France. This well-established, ISO 9001 certified company distributes tropical and Mediterranean species, both wild and from aquaculture, to resellers, wholesalers, and public aquariums.

In Scenario 2, aquarium shops (retailers) are considered as potential clients. They buy the corals either from the European lead distributor or directly from exporters in the major producing countries at varying price. For S. caliendrum, they pay ~€ 30 per coral of L size (Osinga et al., 2011; investigations performed by authors). We identified 14 potential retailers in three European countries, Belgium, France and The Netherlands. Each contacted company showed interest in receiving corals but indicated that they could only receive a small quantity of corals per month. Hence, Scenario 2 entails a niche market with two main parameters: selling expensive but uncommon coral species; and promoting equity in the production system.

In Scenario 3, the farmed corals are sold to luxury hotels and touristic aquaria. This scenario assumes that luxury hotels create their own marine or land-based aquaria, and that the equitable coral aquaculture system of the project shall improve the status and prestige of the hotels. This advantage is essential to some hotels, whose colossal infrastructure
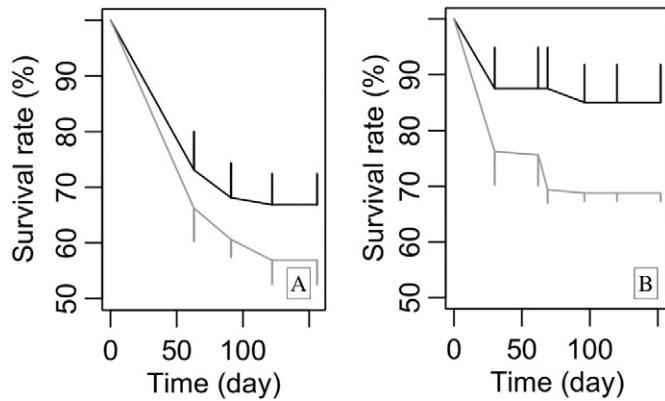
Fig. 5. Evolution of survival rates of *A. nasuta* (black lines) and *S. caliendrum* (grey lines) during farming. A: wet, warm season; B: dry, cold season.

Table 2
Example price range (€) of *Acropora*, *Pocillopora* and *Seriatopora* species according to size and colour of the coral nubbin.

Genus	Colour	XL size (10–15 cm and more)	L size (7–10 cm)	M size (4–7 cm)	S size (3–4 cm)
Acropora	Blue, green and bright colored	120–150	90–120	40–90	
Acropora	Violet		40–90		
Pocillopora	Rose	80–150	40–80		
Pocillopora	Green and yellow		40–80		
Seriatopora	Rose	80–150	40–80	30–40	20–30
Seriatopora	Yellow		40–80		

developments are criticized as non-ecological and non-respectful of human rights. Challenges concern not only the cost of the implementation but also the effective management of a private installation, especially when it is installed in open water. Hotels near the production site and in neighbouring countries have, because of the short distance, the advantage of low transportation costs. The adoption of such a niche market system can be an advantage for a pioneering production system.

Scenario 4, biodiversity conservation by NGOs, relates coral farming to the possibility of financial support in the context of natural coral reef restoration. Three international and two local NGOs aimed at the protection of coral reefs were contacted for the case study, and their potential as a client or partner was analysed. The American NGO Coral Reef Alliance (Coral Reef Alliance, 2015) aims to support the local population to benefit socially, culturally and economically from coral reef conservation. Their actions focus on education and sensitization, and not much on coral reef repopulation. The Global Coral Reef Alliance (GCRA) and Reef Check, on the other hand, work for coral reef conservation and management through coral aquaculture and are potential clients for the coral aquaculture sector. These NGOs create partnerships between the local communities and government, universities and private companies to efficiently manage coral reefs. This has led to the creation of new MPAs and improvement of existing ones in Asia and Oceania. Coral reef conservation is linked to sustainable management of the fishery, including the participation of the local communities in decision-making about fisheries. The approach is based on four elements: low cost of the corals, involvement of local communities, long-term monitoring and scientific research. This last option makes the Reef Check programs a potential client in Scenario 4. The local NGOs suggested in this scenario are Reef Doctor and Blue Ventures, both
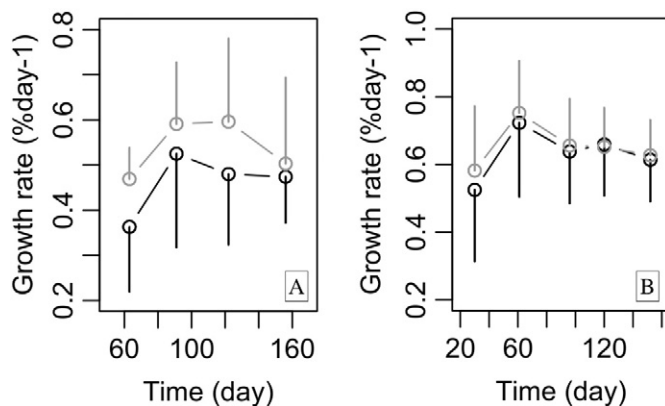
English NGOs aimed at marine conservation and located in Ifaty and Andavadoaka, respectively in the SWR. These NGOs work for a responsible management of marine areas and fisheries. Their activities include education and sensitizing of the local communities on behalf of fishery management, but also social aspects such as health, conflict and family planning.

4. Discussion

Madagascar has >2400 km^2 of coral reefs along 1400 km of coast (Cook et al., 2000). Most reefs in the SWR of the country have the same geomorphological structure as those close to where the present work was performed, including the presence of barrier reefs, fringing reef and patch reef in shallow water (Clausade et al., 1971). In addition, optimal sites for sea cucumber and marine red algae aquaculture were conditioned by the presence of a reef allowing the formation of a lagoon and calm water in the intertidal zone. Accordingly, villages in the SWR and the North regions of Madagascar, where sea cucumber and seaweed farming are implemented, present ideal characteristics for coral aquaculture.

The rearing experiments performed during the present study showed promising results for coral aquaculture. The growth rates observed in the present study were in the range of reported values for these species (0.4 to 1% d^{-1}, Grosjean, pers. com.; Leblud et al., 2014a,b). *S. caliendrum* grew faster than *A. nasuta* but showed lower survival due to the fragility of its branches. These parameters can be considered in controlling the production rhythm by, for example, using bigger or smaller coral branches to grow. They should also be considered when significant loss of coral nubbins or slower growth occur as a result of cyclones, or sudden changes in river flow, resulting in extreme sedimentation (Sheridan et al., 2014), temperature rise or salinity decrease. Anthropogenic activities also constitute an important risk of coral loss: fishing using gill nets, trampling by fishermen during low tide fishing, or pollution from neighbouring cities, and even theft and willful destruction of coral aquaculture infrastructure.

Availability of coral species also constitutes an important parameter for a coral farming project. *Acropora* is the most demanded by both wholesalers and retailers. For wholesalers, the most prized species belong to the genera *Montipora*, *Seriatopora*, *Turbinaria* and *Caulastraea* while for retailers, the most requested species are *Porites*, *Euphylia*, *Plerogyra*, *Cataphyllia*, *Fungia* and *Helofungia*. Colour and size of the coral nubbin is also decisive for price: the more brightly colored the coral, the more expensive it is. The most valuable group includes the green and blue colour morphs while violet and rose corals of the same size are less expensive (Table 2). The brightness and fullness of the colour is the most influencing parameter: two corals of the same species, size and colour may have a different price according to the intensity of their colour. Trade registrations of CITES (2016) correspond to the species list given by the investigated coral importers. The top twenty most traded genera recorded by CITES include, in descending order of quantity, *Acropora*, *Euphyllia*, *Montipora*, *Caryophyllia*, *Goniopora*, *Hydnophora*, *Pocillopora*, *Turbinaria*, *Caulastraea*, *Seriatopora*,

Fig. 6. Average growth rate (± SD) of cultivated coral nubbin: (A) wet, warm season, (B) dry, cold season. The growth rates were based on 10 measurements for *A. nasuta* (black lines) and *S. caliendrum* (grey lines), during both seasons.

Table 3
Summary of costs analysis of the value chain (€).

	Total cost per coral nubbin	Initial investment	Annual charges	Annual amortization
Materials and equipment	0.22	352	476.24	71.62
Coral aquaculture staff and administration	11.12	1000	4527.42	200
Packing	0.45	625.71	309.07	146.29
Transportation (exportation)	9.77	0	9932.96	0
Total	21.56	1977.71	15,245.69	835.93

Plerogyra, *Stylophora*, *Trachyphyllia*, *Porites*, *Agaricia*, *Lobophyllia*, *Fungia*, *Tubastraea*, *Dendrophyllia*, *Heliofungia*. This list represents corals exclusively from aquaculture. The high coral species diversity in Madagascar constitutes an advantage (Pichon, 1978; Obura, 2012; Veron et al., 2015). Madagascar has also some endemic species (Veron, 2000; Maharavo, pers. com.) that might be an additional value to the offer from coral farming.

To better understand the analysis of the potential clients and before suggesting the suitable type of buyer of the farmed corals, it is necessary to review the main positive and negative points of each scenario. The activities of the European lead distributor (Scenario 1) request highly controlled aquarium facilities and well-established logistic services. Such facilities and services are very expensive and the operational costs can reach more than € 11 m^{-2} day^{-1} (1 m^2 aquarium can host up to 100 colonies of ~100 g that correspond to the size of a fist and the L size presented in the present paper; Osinga et al., 2011). Consequently, the production cost can reach € 25 to more than € 30 per coral (for *S. caliendrum*, Osinga et al., 2011). This means that they must buy corals from the exporter countries for less than € 25 and limit their importation to maintain a profitable activity. Besides, this company owns a farm in the Pacific islands with its own logistic services, allowing them to maintain their activities competitive and viable. It also performs several activities not in relation with corals. The suggested selling price of the coral farming project from Madagascar is too expensive to be attractive to this company and such kind of distributor.

Selling the corals directly to aquarium shops is a solution (Scenario 2). A community-based coral aquaculture as in Madagascar should be attractive for these clients because it is socially and environmentally responsible. It also supports equity among the producers. Yet, as these shops have the appropriate facilities, they can easily replant the imported coral species in their aquaria, which may lead to a decreasing demand. Secondly, the supply side of the market is oligopolistic as opposed to the perfect competition of the demand side, meaning that there are few big providers to satisfy a large demand of buying companies. The relatively small supply from Madagascar will barely penetrate this custom-made market. Solution could be to produce particularly prized species that are not or hardly available elsewhere and to be a privileged partner to few companies with low price of the proposed coral species.

In Scenario 3, the main obstacle is the difficulty of reaching clients. In addition, very high quantities of corals will be demanded in a relatively short period of time. The production might not be sufficient in an early-established project. On the other hand, such a project is extremely risky

for the hotels. A big investment is needed in creating the reserve or the aquaria, yet the economic returns will be perceived much later.

The advantage of Scenario 4 is the emphasis on social and environmental responsibility and the community-based aspects of the proposed coral aquaculture project. However, the dependence on only these NGOs is not sustainable. Furthermore, NGOs involve volunteers for their activities and financial support is not secured. With >60 coral reef reserves in Madagascar, especially in the SWR (56 reserves after Todinanahary et al., 2013), the activities of the NGOs align well with the coral aquaculture program proposed in the present paper. Financial support is the main obstacle in this scenario as it suggests that 100% of the produced corals are transplanted to the natural coral reef. This can imply a limitation of the price of each coral nubbins and consequently the income for the farmers.

For all the scenarios, the geographical location of the client determines the efficiency of the coral shipping. It is known that to get >90% of post-transportation survival, the duration of the coral transport including the preparation and transit time, should not exceed 30 h (Delbeek, 2008). To sell corals from Madagascar, buyers from the Indian Ocean region (South Africa, Swaziland, Sri Lanka) and Europe (France, Denmark, Greece, Netherlands, Sweden, Germany, Ireland, Switzerland) are suggested. These countries belong to the registered importers of live corals (CITES, 2016) and are <15 h flight from Madagascar. The USA, Japan, Mexico, Brazil and Canada in descending order also belong to the top 10 importers of live corals before Singapore, Hong Kong, New Zealand, China and Costa Rica. These countries do not constitute interesting destinations for farmed corals from Madagascar as the flight duration usually exceed 20 h and they are much closer to the experimented coral producers and exporters such as the top five Marshall Islands, Indonesia, Taiwan, Solomon Islands and Tonga.

Scenario 1 (selling to the European lead distributor) is the only scenario that does not fit the objectives and the adopted philosophy of the coral aquaculture presented in the present paper. Scenario 3 is difficult to establish due to the high quantity required, but it can be considered for long-term purposes when the project is well established. Combination of Scenarios 2 and 4 (with aquarium shops and biodiversity conservation NGOs) seems to be appropriate for the community-based coral aquaculture in Madagascar. They can buy the corals at the suggested price and their rhythm of importation fits with the small-scale production.

In Madagascar, community-based coral aquaculture is technically and environmentally feasible. The common coral farming techniques are adaptable to the coastal villages of the country, using locally available materials for coral aquaculture tables and hard supports to fix coral nubbins. The activity can be fully profitable at a small-scale

Table 4
Result accounts of the yield calculations.

	Year 1 (€)	From year 2 (€)
Sales turnover	9144	27,432
Exploitation charges	16,082	16,082
– Annual charges of production	15,246	15,246
– Annual amortization	836	836
Earning Before Interests and Taxes (EBIT)	−6938	11,350
Taxes (30%)	0	3405
Net result	−6938	7945

Table 5
Financial flux of the proposed coral aquaculture project (€).

Year	Gain	Cumulative gain
0	−1978	−1978
1	−6102	−8079
2	8781	702
3	8781	9483
4	8781	18,264
5	8781	27,045

Table 6
Comparative summary of advantages and disadvantages of each scenario.

|	Advantages	Disadvantages
Scenario 1: European lead distributor	Experience improvement and services	Loss of community-based character
	Use of well-established systems	Loss of independence and scientific research aspect
		Expensive
Scenario 2: Aquarium shops (Pet shops)	Ethical (new approach from Madagascar)	Oligopolistic offer and pure competition?
	New provenance of the corals	Coral replanting feasible by the clients
		Limited offer
Scenario 3: Luxury hotels	Participation to reef protection	Target difficult to reach
	Innovative target for the sector	Too much requested quantity
	Improve the image of the clients	Unwillingness
	Low transportation fees for nearing hotels	
Scenario 4: Biodiversity conservation NGOs	Respect of the ethical	Dependence not secured
	Experience improvement	

production if partnerships with appropriate clients (aquarium shops and coral reef conservation NGOs) can be set up. Relatively low initial investment is needed and amortization of the investment could be quick. The integration of the coral aquaculture within existing production systems like the polyaquaculture work platform is suggested (Pascal et al., 2013). It allows the small-scale production to be economically profitable and viable in the long term with social and environmental benefits.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.aquaculture.2016.07.012.
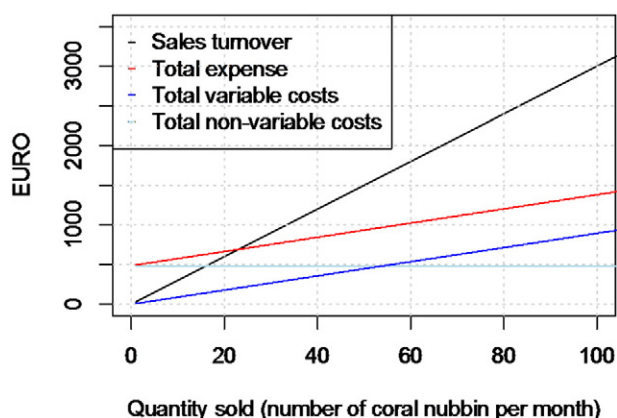
Fig. 7. Break-even point of the proposed coral aquaculture project. Profit is represented by the difference between sales turnover (black line) and total expenses (red line).

References

Albert, J.A., Trinidad, A., Boso, D., Schwarz, A.J., 2012. Coral reef economic valuation and incentives for coral farming in Solomon Islands. Policy Brief. CGIAR Research Program on Aquatic Agricultural Systems, Penang, Malaysia (AAS-2012-14).
Atkinson, M., 2010. Elemental composition of commercial seasalts. J. Aquaric. Aquat. Sci. 3 (2), 39–43.
Berges, J., Franklin, D.J., Harrison, P.J., 2001. Evolution of an artificial seawater medium: improvements in enriched seawater, artificial water over the last two decades. J. Phycol. 37 (6), 1138–1145. http://dx.doi.org/10.1046/j.1529-8817.2001.01052.x.
Bowden-Kerby, A., 1999. Coral culture and transplatation — methods for use in coral reef restoration, fisheries enhancement, and commercial coral aquaculture. Report, Sea Grant College Program (21 pp).
Bruggemann, J.H., Rodier, M., Guillaume, M.M.M., Andréfouët, S., Arfi, R., Cinner, J.E., Pichon, M., Ramahatratra, F., Rasoamanendrika, F.M.A., Zinke, J., McClanahan, T.R., 2012. Wicked social–ecological problems forcing unprecedented change on the latitudinal margins of coral reefs: the case of Southwest Madagascar. Ecol. Soc. 17 (4), 47. http://dx.doi.org/10.5751/ES-05300-170447.
CITES, 2002. Coral Production Systems – Report of the Coral Working Group. 18th Meeting of the CITES Animals Committee, San Jose, Costa Rica.
CITES, 2016. CITES Trade Database. CITES Secretariat.
Clausade, M., Gravier, N., Picard, J., Pichon, M., Roman, M.L., Thomassin, B., Vasseur, P., Vivien, M., Weydert, P., 1971. Coral reef morphology in the vicinity of Tuléar (Madagascar): contribution to a coral reef terminology. Téthys Supplément 2, 1–74.
Cook, A., Ratomahenina, O., Ranaivoson, E., Razafindrainibe, H., 2000. Chapter 60. Madagascar. In: Sheppard, CRC (Ed.), Seas at the millennium: an environmental evaluation. Regional chapters: The Indian Ocean to the Pacific. 2. Pergamon, Amterdam, pp. 113–131.
Coral Reef Alliance, 2015. Coral 2015 Annual Report. Coral Reef Alliance, Broadway, USA (24 p).
Dana, J.D., 1846. United States exploring expedition during the years 1838–1842. Zoophytes 7: 1–740. Lea and Blanchard, Philadelphia (http://www.sil.si.edu/digitalcollections/usexex/navigation/ScientificText/USExEx19_08select.cfm).
Davies, P.S., 1989. Short-term growth measurements of corals using an accurate buoyant weighing technique. Mar. Biol. 101, 389–395.
Delbeek, J.C., 2008. Collecting and Shipping Live Coral: Techniques, Tips and Headaches. Advances in Coral Husbandry in Public Aquariums. In: Leewis, R.J., Janse, M. (Eds.), Public Aquarium Husbandry Series 2, pp. 363–373.
Department of Fisheries of Western Australia, 2009. Aquaculture of coral, live rocks and associated products. Aquaculture Policy. Fisheries, Fisheries Management Paper No. 245 (ISSN 0819–4327).
Ellis, S., Sharron, L., 1997. The culture of soft corals for the marine aquarium trade. CTSA Publication no 137.
Ellis, S., Sharron, L., 1999. The culture of soft corals (Order: Alcyonacea) for the marine aquarium trade. CTSA 137 (73 pp).
Eriksson, H., Wickel, J., Jamon, A., 2012. Coral bleaching and associated mortality at Mayotte, Western Indian Ocean. Western Indian Ocean J. Mar. Sci. 11 (1), 113–118.
Food and Agriculture Organization (FAO), 2005-2015. World inventory of fisheries. coral reefs: environments under threat. Issues Fact Sheets. Text by J.J. Maguire. FAO Fisheries and Aquaculture Department [Online]. Rome. Updated 27 May 2005 ([Cited 7 May 2015],http://www.fao.org/fishery/topic/14781/en).
Forsman, Z.H., Kimokeo, B.K., Bird, C.E., Hunter, C.L., Toonen, R.J., 2011. Coral farming: effects of light, water motion and artificial foods. J. Mar. Biol. Assoc. U. K. 1–9 http://dx.doi.org/10.1017/S0025315411001500.
Green, E., Shirley, F., 1999. The Global Trade in Coral. World Conservation Monitoring Centre. World Conservation Press, Cambridge UK (60p).
Hernández-Delgado, E.A., Mercado-Molina, A.E., Alejandro-Camis, P.J., Candelas-Sánchez, F., Fonseca-Miranda, J.S., González-Ramos, C.M., Guzmán-Rodríguez, R., Mège, P., Montañez-Acuña, A.A., Maldonado, I.O., Otaño-Cruz, A., Suleimán-Ramos, S.E., 2014. Community-based coral reef rehabilitation in a changing climate: lessons learned from hurricanes, extreme rainfall, and changing land use impacts. Open J. Ecol. 4, 918–944. http://dx.doi.org/10.4236/oje.2014.414077.
Jokiel, P.L., Maragos, J.E., Franzisket, L., 1978. Coral growth: buoyant weight technique. In: Stoddart, D.R., Johannes, R.E. (Eds.), Coral reefs: research methods. UNESCO monographs on oceanographic methodology, Paris, pp. 529–542.
Kangas, P., Walter, A., 1996. Mesocosms and ecological engineering. Ecol. Eng. 6 (1–3), 1–5 (http://linkinghub.elsevier.com/retrieve/pii/0925857495000585).
Kelley, R.A., 2011. Indo Pacific Coral Finder 2nd Edition. Published by BYOGUIDES, Townsville, Australia.
Lal, P., Kinch, J., 2005. Financial assessment of the marine trade of corals in Solomon Islands. Report, Canada South Pacific Ocean Development Programme Phase II C-SPODP II (32p).
Laroche, J., Ramananarivo, N., 1995. A preliminary survey of the artisanal fishery on coral reefs of the Tulear region (Southwest Madagascar). Coral Reefs 14, 193–200.
Lavitra, T., 2008. Caractérisation, contrôle et optimisation des processus impliqués dans le développement postmétamorphique de l'holothurie comestible Holothuria scabra (Jaeger, 1833) (Holothuroidea: Echinodermata). [Thesis], Université de Mons-Hainaut. (180 p).
Lavitra, T., Rachelle, D., Rasolofonirina, R., Jangoux, M., Eeckhaut, I., 2009. Traitement et Commercialisation Des Holothuries Dans La région de Toliara, Au Sud-Ouest de Madagascar.
Leal, M.C., Calado, R., Sheridan, C., Alimonti, A., Osinga, O., 2013. Coral aquaculture to support drug discovery. Trends Biotechnol. 31 (10), 555–561. http://dx.doi.org/10.1016/j.tibtech.2013.06.004.
Leblud, J., Moulin, L., Batigny, A., Dubois, P., Grosjean, P., 2014a. Technical note: artificial coral reef mesocosms for ocean acidification investigations. Biogeosci. Discuss. 11, 15463–15505. http://dx.doi.org/10.5194/bgd-11-15463-2014 (2014).

Leblud, J., Batigny, A., Grosjean, P., 2014b. Ecophysiological changes of hermatypic scleractinians facing ocean acidification: studies in original chemostats and artificial mesocosms. [Thesis], University of Mons, Belgium. (258p).

Martin, S., Main, K.L., Leber, K.M., Vaughan, D., 2005. Developing culture techniques to conserve coral reefs in the Florida Keys. Progress Report, Mote Technical Report # 1087.

McClanahan, T., Ateweberhan, M., Graham, N.A.J., Wilson, S.K., Ruiz Sebastián, C., Guillaume, M.M.M., Bruggemann, J.H., 2007. Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. Mar. Ecol. Prog. Ser. 337, 1–13. http://dx.doi.org/10.3354/meps337001.

Nazurally, N., Rinkevich, B., 2013. A Questionnaire-based Consideration of Coral Farming for Coastal Socio-economic Development in Mauritius. Western Indian Ocean J. Mar. Sci. 12 (1), 47–56.

Ng, C.S.L., Zhen Ng, S., Chou, L.M., 2012. Does an ex situ coral nursery facilitate reef restoration in Singapore's waters? Contrib. Mar. Sci. 2012, 95–100.

Obura, D., 2012. The diversity and biogeography of Western Indian Ocean reef-building corals. PLoS One 7 (9), e45013. http://dx.doi.org/10.1371/journal.pone.0045013.

Onset Computer Corporation, 2002-2014. ONSET HOBOware Pro: Software for HOBO Data Loggers and Devices. Version 3.7.0.

Osinga, R., Schutter, M., Griffioen, B., Wijffels, R.H., Verreth, J.A.J., Shafir, S., Henard, S., Taruffi, M., Gili, C., Lavorano, S., 2011. The biology and economics of coral growth. Mar. Biotechnol. 13, 658–671. http://dx.doi.org/10.1007/s10126-011-9382-7.

Pascal, B., Eeckhaut, I., Lavitra, T., Dubois, P., Lepoint, G., Grosjean, P., Todinanahary, G.G.B., Tsiresy, G., 2013. A multidisciplinary research programme to ensure sustainable coastal livelihoods in Madagascar. 21st International Seaweed Symposium, April 21–23 2013, Bali, Indonesia.

Pichon, M., 1978. Recherches sur les peuplements à dominance d'anthozoaires dans les récifs coralliens de Tuléar (Madagascar). Atoll Res. Bull. 222, 1–447. http://dx.doi.org/10.5479/si.00775630.222.1.

R Core Team, 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria (URL http://www.R-project.org/).

Rasolofonirina, R., 2004. Reproduction et développement de l'holothurie comestible Holothuria scabra (Jaeger 1833), Holothuroidea: Echinodermata [Thesis], Free University of Bruxelles. 175 p.

Rasolofonirina, R., Conand, C., 1998. Sea cucumber exploitation in the Toliara region of SouthWest Madagascar. SPC Beche-de-mer Inf. Bull. 10, 10–13.

Raymakers, C., 2001. Review of trade in live corals from Indonesia. Report, TRAFFIC Europe (46 pp).

Reksodihardjo-Lilley, G., Lilley, R., 2007. Towards a sustainable marine aquarium trade: an Indonesian perspective. SPC Live Reef Fish Inf. Bull. 17, 11–19.

Rogers, C.S., Garrison, G., Grober, R., Hillis, Z.-M., Franke, M.A., 1994. Coral Reef Monitoring Manual for the Caribbean and Western Atlantic. National Park Service, Virgin Islands National Park, p. 114 pp.

Sheridan, C., Baele, J.M., Kushmaro, A., Fréjaville, Y., Eeckhaut, I., 2014. Terrestrial runoff influences white syndrome prevalence in SW Madagascar. Mar. Environ. Res. 101, 44–51. http://dx.doi.org/10.1016/j.marenvres.2014.08.003.

Todinanahary, G.G.B., Rakotoarinivo, W., Tsiresy, G., Lavitra, T., Eeckhaut, I., 2013. Coral reefs of the south-western region of Madagascar: 56 local based management reserves. Eighth Ninth WIOMSA Scientific Symposium, at Maputo, Volume: 8 http://dx.doi.org/10.13140/RG.2.1.2024.2089.

Tsiresy, G., Todinahary, G.G.B., Lavitra, T., Razanakoto, I., Dubois, P., Lepoint, G., Pascal, B., Eeckhaut, I., 2012. Development of a promising polyculture farming involving the sea cucumber Holothuria scabra and the red algae Kappaphycus alvarezii in the south west of Madagascar. 14th International Echinoderm Conference. Belgium, Brussels.

Tsiresy, G., Todinanahay, G.G.B., Lavitra, T., Dubois, P., Lepoint, G., Eeckhaut, I., 2015. Seasonal occurrence and morphological description of the stages observed in the life cycle of the efa (epiphytic filamentous algae) Polysiphonia Sp., parasite of the farmed seaweed Kappaphycus alvarezii in Madagascar. 9th WIOMSA Scientific Symposium, Port Edward, South Africa.

Veron, J.E.N., 2000. Corals of the World. Volume 1–3. Australian Institute of Marine Science.

Veron, J.E.N., Stafford-Smith, M., DeVantier, L., Turak, E., 2015. Overview of distribution patterns of zooxanthellate Scleractinia. Front. Mar. Sci. 1, 81. http://dx.doi.org/10.3389/fmars.2014.00081.