Using coral reef fish larvae: Synopsis of work conducted in French Polynesia

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Introduction

For more than 15 years, the École Pratique des Hautes Études (EPHE – French Applied Higher Studies Institute), in collaboration with French Polynesia's Fisheries Department (SPE), has been studying the reef colonisation phase of fish larvae, and has been working on the sustainable exploitation of post-larvae through an integrated aquaculture approach.

The goal of this paper is to assemble and share the basic knowledge of coral reef fish post-larval harvesting and rearing techniques used in French Polynesia. This overview is not a comprehensive compilation of all data, but rather a presentation of key points identified in the French Polynesian context. We hope, in this way, to present practical and useful information for the development of, on an island scale, sustainable reef aquaculture that is specifically oriented towards the production of live fish for the ornamental fish trade. After reviewing the principles acquired from basic research, we present the issues dealt with by applied research in French Polynesia and explain in detail how the French Polynesian expertise could be promoted.

Knowledge acquired through basic research

The crest net

In the 1980s, in order to describe the zooplankton in reef and lagoon environments in French Polynesia, Jean-Pierre Renon (EPHE) anchored fine-mesh nets on the reef crests or in the shallow channels that connect the ocean and lagoon (locally called *hoa*) of islands such as Takapoto, Hao, Mataiva and Moorea (Renon 1989). The purpose of those nets was to filter the flow of plankton entering the lagoon, which is how the passage of fish larvae and juveniles over the reef are now studied. The study on ichthyoplankton in the reef complex of Moorea[5] was then continued by EPHE. As part of his DEA (upper tertiary studies) and later his doctoral thesis presented in 1992, Vincent Dufour took up Renon's technique of fixed nets, which he called "crest nets" (Dufour 1991, 1994; Dufour and Galzin 1992, 1993). These nets, which for the first time offered the possibility of expressing catch results in terms of larval flow (i.e. the number of specimens caught per meter of barrier reef and per unit of time), proved to be both vital for the dynamics of CRIOBE research on larval reef fish colonisation and the forerunners of the nets used today for aquaculture purposes.

Temporal variations in larval colonisation

Studies on temporal variations in larval colonisation by Dufour (1991), Planes et al. (1993) and Dufour et al. (1996) on Moorea, and Lo-Yat (2002a) on Rangiroa show they are highly cyclical (Fig. 1). Descriptions of these temporal variations are given below.

Nycthemeral cycles. The vast majority of larval colonisation takes place at night. The most credible theory to explain this phenomenon is that nighttime is better for the survival of fish larvae in terms of reef predators.

Lunar cycles. Larval colonisation is higher on moonless nights, and the most productive period for collection is around the new moon. The explanation for this phenomenon is also associated with predation, as dark nights promote the survival of larvae during colonisation.

Annual cycles. Lo-Yat (2002a) demonstrated on Rangiroa that most fish species (72%) have seasonal colonisation cycles lasting a few months a year, whereas 27% of species caught are so-called "mixed" species that colonise throughout the year. Among seasonal species, 58% prefer colonisation during the warm season, from October to May, and only 14% are specific to the cold season. An increase of a few degrees in ocean temperature changes biotic factors (e.g. a plankton bloom = more prey for larvae) and abiotic factors (e.g. an increase in larval metabolic activity = better growth rates), which promote better survival of larval cohorts. These arguments may make it possible to explain the evolutionary trend in most fish species towards reproducing during the warm season.

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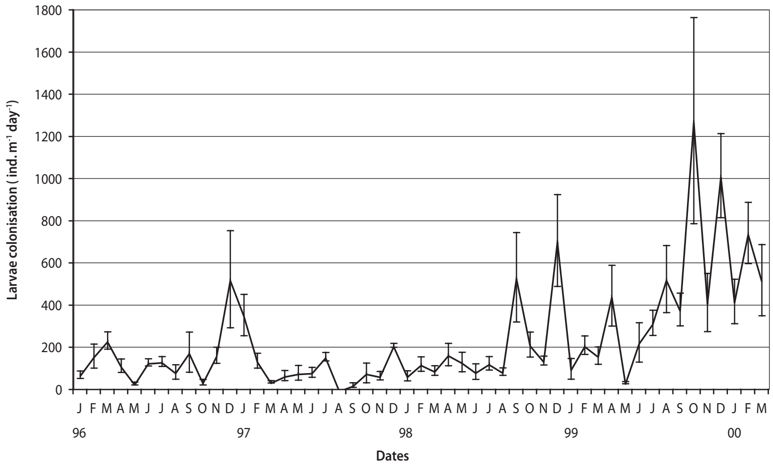

Figure 1. Temporal evolution of larvae colonisation at Rangiroa from 1996 to 2000 (Excerpt from Lo-Yat A. 2002a).

Inter-annual cycles. Colonisation varies widely from one year to another (Fig. 1) and at present, there is no model to predict such variations. The survival of larval cohorts in the ocean is very arbitrary and linked to unforeseeable biotic and abiotic phenomena.

Spatial variations in larval colonisation

A study of variations in larval colonisation was carried out on several different scales on Moorea. Dufour et al. (1996) conducted an experiment using five crest nets that were 8–12 kilometres (km) apart and distributed around the island. This made it possible to show that colonisation was homogenous over all reef crests in Moorea. For certain species, simultaneous peaks in colonisation were observed in sites located 10–30 km apart. In addition, as part of the COVARE (colonisation larvaire et variabilité des stocks de poissons récifaux) mission, six crest nets placed 200 m apart on the northern coast of Moorea (Lecchini et al. 2004) made it possible to validate the homogeneous nature of larval colonisation on a smaller scale by demonstrating the absence of any significant differences in abundance and species richness between traps. Comparable results were obtained by Dufour (1992a,b) with two nets located 10 m apart.

It would appear that larval colonisation, at the level of reef crests on high islands such as Moorea, is homogeneous no matter what the spatial scale is.

In order to compare larval colonisation on reef crests with that in other habitats, Malpot (2005) conducted a study using light-traps on Rangiroa. Three sites (outer slope, pass and lagoon), located 2 km apart, were each equipped with three independent light-traps. The results showed that colonisation was significantly higher in island passes than on the outer reef slope, which seems to indicate that current-related phenomena in the pass favour larval concentration. The lagoon site recorded very low catches, due to the prior settlement of larvae from the ocean. The use of three independent light-traps at each sampling site allowed confirmation of the absence of spatial variation in colonisation on a small scale.

The notion of spatial variation in larval colonisation does not appear, in principle, to be determined by quantitative parameters (e.g. distances between sites) but rather by qualitative criteria (e.g. hydrodynamics and habitat). It has only been recently that the notion of auto-recruitment and connectivity between islands has been studied in greater detail (Planes et al. 2002; Irisson et al. 2004; Almany et al. 2007).

Structure of larval cohorts

Analysis of fish larval catches in French Polynesia, using nets and light-traps repeatedly, shows very low catch diversity. Even when total species richness of catches is high (i.e. a very large number of species), most species are poorly represented and only a few taxa are very abundant (Fig. 2). Annual catches are generally dominated by Pomacentridae (45–55%), Apogonidae (15–20%), Acanthuridae (6–8%) and Holocentridae (4–5%).

Larvae after colonisation

A study by Dufour et al. (1996) made it possible to show, through density estimates (larval abundance at colonisation vs settled adult fish), that out of every 100 larvae that arrive alive on the reef, only 1 to 10 survive to become adults.

In 1998, as part of the COVARE programme, 20 French, American and Australian researchers monitored both the colonisation and mortality of *Naso unicornis* post-larvae during settlement on the lagoon floor on Moorea. This study showed that 61% of the larvae that colonised the lagoon during this period had disappeared by the morning following their arrival, regardless of the size of the cohorts (mortality density-independent). Over the following days, daily cohort mortality was assessed at between 9% and 20%, depending on their size (mortality density-dependant). This vital scientific result (Doherty et al. 2004) demonstrates that harvesting part of the stock of larvae colonising a reef only has a minor impact on the dynamics of the fish population. In this way, the merits of exploiting larvae, instead of adults, as suggested by Yan (2001), Hair et al. (2002) and De Villers (2003), was scientifically validated.

Overview of knowledge acquired through basic research

The basic research carried out in French Polynesia by CRIOBE, with the support of the French and

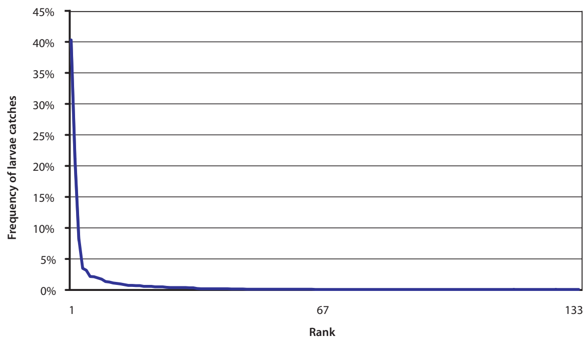

Figure 2. Rank/frequency diagram showing the heterogeneous structure of larval catches on Rangiroa from January 2006 to February 2007. The ranks correspond, in descending order, to the abundance classes of species caught.

French Polynesian governments, has made it possible to summarise the processes (Lecchini and Galzin 2003) and respond to three vital questions regarding the use of larvae for fisheries purposes.

How should larvae be collected? A well-designed crest net is key to properly carrying out research on larval colonisation. It is also a tool that has raised the interest of development agencies such the Etablissement pour la Valorisation des Activités Aquacoles et Maritimes (Aquaculture and Maritime Activities Development Agency – EVAAM), and has allowed applied research to begin, for the first time, the development of a net for the channels through the reef that connect the ocean and lagoon, *hoa*.

Where and when should larvae be collected? The work carried out by CRIOBE and EVAAM made it possible to determine the most favourable time periods for collecting fish larvae in French Polynesia, both overall and also specifically, by analysing the qualitative structure of catches and changes over time. This also allowed the best collection sites to be identified.

Why collect larvae? Crest and *hoa* nets mainly catch specimens in the colonisation phase, just before they are subjected to high rates of mortality from predators. So, catching them to rear in aquaculture facilities has only a very small impact on populations at the site, which ensures the sustainable ecological nature of this activity (Hair et al. 2002).

The French Institute of Research for Development (IRD), in collaboration with EPHE, SPE and the Pearl Farming Department (PRL), is now directing research towards determining the factors that influence larval colonisation on the reef (Lecchini 2004, 2005).

Development of applied research

The various basic research studies mentioned above focused solely on the colonisation phase. This work allowed a theoretical base to be laid with a view to exploiting a new resource (i.e. reef fish larvae). Fish larval stock use and aquaculture development were the natural outcome of this work and have been the subject of several developmental research programmes.

Optimising larval harvesting techniques

The crest net that Dufour used on Moorea to describe changes in larval flow was poorly adapted to production purposes. Its opening was quite small (1.5 m x 0.75 m), it was built out of flimsy materials, and the initial design did not promote the survival of collected samples. A trap designed to supply larvae for aquaculture facilities needs to meet different specifications; for example, it must be robust, as productive as possible, and limit stress on larvae as much as possible. It was at EVAAM on Rangiroa — from 1996 to 2000 — that improvements to the crest net began.

The first modification involved the site where the trap was set up. A reef crest is a particularly exposed area, and its strong hydrodynamics limit the useful life of equipment, and complicate deployment, collection and maintenance of traps. The shallow channels through the reef (*hoa*) through which ocean water enters the lagoon, provides an interesting alternative for setting up nets. Located several hundred meters from the wave impact zone, *hoa* are sites that are easy to use and, more importantly, they concentrate larval flow. This was demonstrated by Malpot (2005) at Rangiroa by comparing catches using a *hoa* net and a crest net (Fig. 3) located upstream. The

Figure 3. Crest and hoa nets on Rangiroa (From Malpot 2005).

hoa net had a larval flow that was 250 times more concentrated than the flow at the crest, while the volume of water filtered was only 26 times greater. These results demonstrate the tendency of certain taxa to swim along the atoll's outer reef flat looking for a passage into the lagoon, and suggest that an isolated *hoa* crossing a long strip of reef acts as a bottleneck for the passage of larvae.

In addition, Yan (2001) and Lo-Yat (2002a) worked on improving the trap itself. Its opening was widened to 2 m x 1 m and its filtering capacity was increased by adding current deflectors. The collectors that the larvae are held in at night were also modified to increase their volume.

Additional improvements have been made by a few private sector companies, covering, in particular, the overall design of the trap to make it easier to handle, especially during the removal of harvested larvae.

While collection techniques in French Polynesia are exclusively based on crest and *hoa* nets, in the 1990s Australian researchers developed collection devices based on light (i.e. light-traps; see Fig. 4). In order to test their efficiency in French Polynesia, and possibly to use them in addition to net techniques, vertical-slot traps were tested by Polti (2001) on Moorea and compared with crest nets. The author showed that nets were significantly more productive than light-traps in terms of total catch abundance and species richness. On Rangiroa, the performances of *hoa* nets, crest nets and nine CARE systems (Lecaillon 2004) were tested by SPE, CRIOBE and Tropical Fish Tahiti (Malpot 2005) over 101 consecutive nights. Results show that *hoa* nets are much more productive than light-traps in terms of total catch abundance and species richness, and that there is no significant difference in terms of larval survival rates between the various traps (Table 1). However, light-traps have the advantage of collecting species that are confined to outer reef slopes, which nets do not catch (i.e. 13.5% of the species caught in the CAREs had never before been collected at Rangiroa) (Malpot 2005). This advantage is limited by the very low number of specimens of these additional species (0.76% of the total number of larvae collected by Malpot using CARE systems in 2005), their low commercial interest, and the often prohibitive operating costs of traps used on outer reef slopes. The low level of effectiveness noted in light-traps and CARE systems on reefs in French Polynesia — where fish populations are abundant, tides are shallow or non-existent and larval colonisation is very dynamic — leaves us perplexed as to the usefulness of this kind of trap for aquaculture projects, in contrast to what has been suggested by Lecaillon and Lourié (2007).

Development research on the rearing phase

The fact that reef fish larvae can be caught alive, using crest nets, led public agencies in French Polynesia to become interested in finding out if the larvae could be farmed. Several studies have been carried out in this area since 1995, by both EVAAM and the public agencies that took over from it, currently SPE, and its private and public partners (i.e. Ifremer, Aquanesia, BoraEcoFish, Tropical Fish Tahiti, and Vai Consulting). Producing small fish for the aquarium market, which is the primary objective of the private sector, and the priority SPE has given to reseeding have, in large part, oriented zootechnical work towards the first two months of rearing. For that reason, most of these studies have covered acclimation of post-larvae to rearing conditions, weaning onto inert feed, and nursery rearing to the point that they are ready to be transferred to cages, released into the lagoon or shipped overseas, depending on the planned outcome.

Table 1. Comparison of performances of hoa nets, crest nets and CARE systems at Rangiroa over 101 consecutive nights from 16 May to 24 August 2004 (taken from Malpot 2005).

Comparison criteria	Hoa net [a]	Crest net [b]	CARE system [c]	Observations
Abundance (mean daily catch ± s.d.)	11,476.7 (±44,622.9)	41.8 (±146.8)	2.7 (±3.7) to 51.4 (±17.6)	*Hoa* net performed better. (F=57.61; p<0.001; df=2. 277)
Species richness (mean daily species richness ± s.d.)	13.2 (±11.5)	5.5 (±4.3)	1.4 (±1.4) to 3.72 (±4.7)	*Hoa* net performed better. (F=41.03 ; p<0.001; df=2,277)
Larval survival	76.9%	75.8%	77.8% to 87.3%	No significant difference (K=2.49; p=0.64 ; df=4)

[a] An extraordinarily large peak of *Epinephelus polyphekadion* was recorded in the *hoa* net. Even when this peak is excluded from analysis, the *hoa* net retains its significant advantages.
[b] The crest net, originally designed for barrier reefs on high islands, was set up at Rangiroa on the crest of an external reef flat at that island. The specific hydrodynamics of this spot may have disturbed how it functioned, which would explain the lack of any significant differences between the performance of the crest net and the best CARE system.
[c] Nine CARE systems were set up at three sites (lagoon, ocean and *hoa*); shown here are the minimum and maximum values among the nine systems.

Figure 4. Aquafish Technology light-trap in Moorea lagoon (taken from Polti 2001.) and Ecocean light-trap (CARE system) in sub-surface waters at Rangiroa (taken from Malpot 2005).

The results indicate species-related variations in the parameters for success. Herbivores have no problem acclimating, and Esnault and Tetuanui (2005) demonstrated, with two Acanthuridae genera (*Acanthurus* and *Naso*), very good survival rates during rearing (> 98% after 60 days). At the same time, three species of Holocentridae, nocturnal zooplankton-eaters in the wild, proved to be very difficult to wean, and repeatedly had daily mortality rates of about 0.5%. Additional work carried out at Tropical Fish Tahiti (de Boishebert 2005) made it possible to confirm the very good survival rates during rearing for *Naso brevirostris* (98% after 63 days) and study how well that species — as well as *Zebrasoma veliferum*, *Chromis viridis* and *Chaetodon auriga* — can be farmed using a protocol described by Durville et al. (2003). The results, which were very encouraging for *Naso brevirostris* and *Zebrasoma veliferum*, were more modest for *Chromis viridis*, which, after a few weeks, developed high heterogeneity in size, perhaps due to overcrowding during rearing or the appearance of dominance phenomena, characteristic of a community with a harem structure. For *Chaetodon auriga*, the early appearance of territorial conflicts limited the zootechnical performances of that species.

In August 2004, the collection of more than 30,000 larvae of the grouper *Epinephelus polyphekadion*, allowed SPE (at the Ifremer station in Vair) to test several environmental factors affecting their survival during rearing (Tamata 2004). It appears that light and the type of settlement substratum (artificial reefs in the tanks) are determining factors, but this study more importantly confirmed the exceptional adaptability of wild grouper post-larvae (particularly cannibal) to farming conditions with a survival rate — quite good for Serranidae weaned on inert feed — ranging from 20–52% after 21 days, while the mean weight went from 0.3–1.5 g.

It is important to point out that the haphazard nature of larval colonisation limits the structured development of zootechnical research programmes. It is, in fact, impossible to anticipate the abundance and taxonomic composition of future catches. Rather than designing experiments in advance, a particular hypothesis is formulated and tested spontaneously when the harvest on a given day yields a statistically useful number of specimens of a species of interest. So, most of the technical progress in rearing has been made empirically, as part of the daily operations of private pioneer farms in this sector. It appears that the success of a production cycle is linked to mastering conventional fish farming factors such as density; homogeneous batches; diet and feeding scheme; environmental conditions such as water turnover, aeration and luminosity; type of habitat; intra- and inter-species relations (although multi-species batches are generally inadvisable); and maintaining strict prophylaxis. Managing these parameters for the 100 or so species farmed on a regular basis constitutes the expertise of French Polynesian farms.

There are few results on the grow-out phase leading to the production of fish for food purposes. Only the study carried out by Martin in 1997 and continued by Yan (2001) at EVAAM on Rangiroa made it possible to record growth performances in tanks for a limited number of lagoon fish and then model them (Table 2). However, rearing conditions during this work were not optimal and the results obtained could probably be improved.

Table 2. Weight gains for eight food species (according to Martin 1997 and Yan 2001). Gains are expressed as changes in the square root of mean weights over time.

Species	$\sqrt{W} = f(t)$	R^2
Acanthurus xanthopterus	y = 0.0506x + 1.521	0.99
Caranx melampygus	y = 0.0441x + 5.2816	0.99
Cephalopholis argus	y = 0.0142x + 0.9182	0.99
Crenimugil crenilabis	y = 0.0205x + 0.6069	0.98
Epinephelus polyphekadion	y = 0.0328x + 2.1778	0.99
Naso annulatus	y = 0.0697x + 1.6804	0.99
Naso brevirostris	y = 0.0222x + 2.5995	0.98
Naso unicornis	y = 0.0279x + 3.5369	0.99

Figure 5 shows interesting weight–growth increases for two Acanthuridae (*Naso annulatus* and *Acanthurus xanthopterus*), which unfortunately are poorly represented, from a statistical viewpoint, in the larval harvest in French Polynesia. As for Serranidae, *Cephalopholis argus* seems to have a slow growth rate and so is only of moderate interest for aquaculture.

For certain species whose post-larvae are several centimetres long at colonisation, and which can therefore be rapidly acclimated and weaned (Bigot 2006), rearing in cages placed in the lagoon (Kerneur 2003) may be an option for reducing production costs and improving zootechnical performances. An initial approach to this technique was taken on Bora Bora by CRIOBE and SPE (Planes et al. 2004) and continued by SPE in partnership with BoraEcoFish (Bigot 2006). The latter study made it possible to compare performances of batches of *Naso unicornis* reared in tanks to batches reared in sea cages. The results showed that there were no significant differences in terms of the batches' survival or conversion indexes, but there was significantly more rapid growth in those batches reared in cages starting from the second week of rearing. An initial comparison of small-scale production costs showed that tank farming costs twice as much as cage farming for a three-month cycle.

Reseeding

Reseeding consists of releasing cohorts of farmed fish on an appropriate part of a reef so that they mix with the existing population. This technique makes it possible to add fish stock to a given fisheries to guarantee adequate resources for all, or else to recreate an adequate stock of genitors so that an overexploited population can once again regenerate and develop. Through SPE, French Polynesia has funded and led all work carried out in this area since 2004, with the goal of this work leading to viable protocols in terms of reseeding for ecotourism or fisheries purposes.

Initial reseeding work, using juveniles from post-larval catches, took place simultaneously on the islands of Moorea and Bora Bora from March to August 2004 (Planes et al. 2004). The main objective was to assess the feasibility of this technique (collection, rearing, release), and determine the constraints and yields. The post-larvae collected using crest nets (Moorea) and *hoa* nets (Bora Bora) were sorted and then sent for rearing in tanks or floating cages for 3–12 weeks. Only those fish species to be used for food or ecotourism purposes were selected for this work. Reared juveniles were then marked with coloured elastomers and released into coral gardens at hotel sites or near traditional fishing areas. Assessment of the effectiveness of reseeding was then done by visual census surveys over a two-week period after their release. The overall project allowed release, at each island, of 1500 specimens for ecotourism purposes and 1000 specimens for fisheries purposes. Of these, 30 species were for ecotourism and 20 species for fisheries. Survival rates showed large differences by species, more than 20 of which were not observed at all, suggesting total elimination of the species through predation and/or emigration, or the inability of researchers to effectively detect these species. In contrast, 19 fish species had encouraging survival rates (> 5%). Among those, four Acanthuridae species had survival rates of 15–50% (i.e. up to 10 times greater than during natural recruitment;

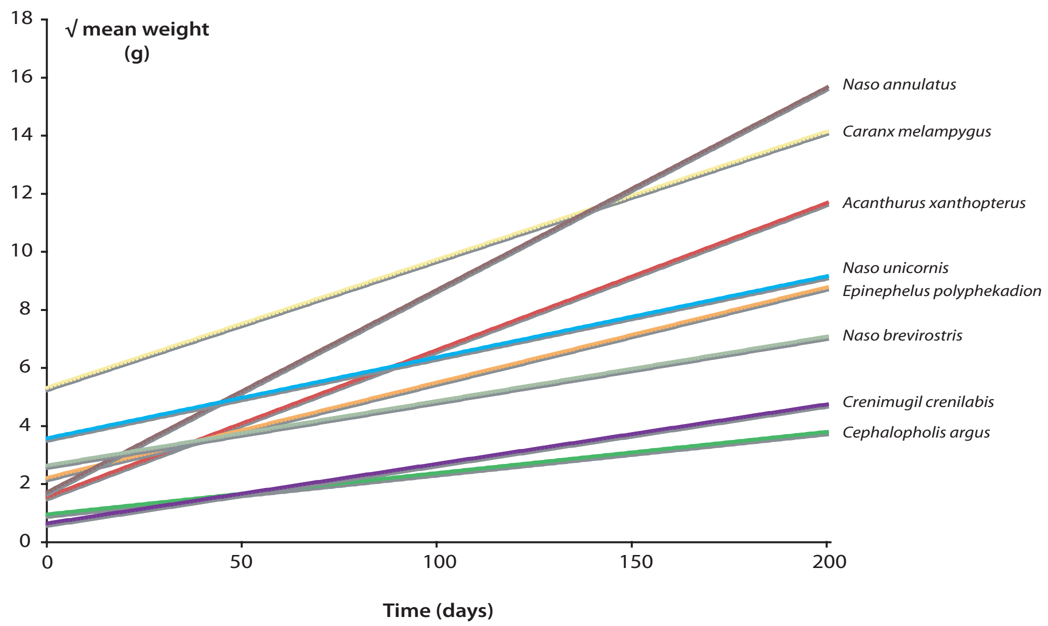

Figure 5. Larval weight development in relation to time: √W = f(t) for eight reef fish species (according to Yan 2001).

Doherty et al. 2004). These results were confirmed on Bora Bora with *Naso unicornis* during a study carried out by SPE in 2006 at the BoraEcoFish farm (Bigot 2006). After a month of rearing, survival rates after release were 14%, demonstrating the influence of the release site on the results.

Identification of constraints during this preliminary study revealed a need to optimise the methodology so as to improve survival. The influence of rearing and release conditions had previously been studied on Rangiroa by SPE and CRIOBE through logistical support to the company Tropical Fish Tahiti (Maamaatuaiahutapu 2005). Factors such as length of rearing time before release, the lunar cycle (time and phase of the moon), the release technique or the length and method of acclimation to the lagoon environment were tested. These experiments were limited to six species from three families. Given the large stocks required for this type of experiment, it was only possible to study a few species: *Chromis viridis* (Pomacentridae), *Acanthurus triostegus* and *Naso brevirostris* (Acanthuridae), *Sargocentron microstoma*, *S. spiniferum* and *Neoniphon sammara* (Holocentridae). During each experiment, specimen survival was assessed through visual census surveys over a period of three days. Only *Acanthurus triostegus* could support marking with elastomers. The results with *Chromis viridis* and *Acanthurus triostegus* revealed optimal survival rates for a rearing period of at least 30 days, transport of the fish in plastic bags to the release site, release at dusk on a natural reef protected by an anti-predator cage, and finally, an acclimation period of three days before cage removal. These very interesting results demonstrate that rearing and release conditions have a significant influence on fish survival and offer new perspectives for study. Observation of *Naso brevirostris* and three Holocentridae species was a failure in all these experiments, undoubtedly because the release sites were not appropriate for these species.

In general, the initial reseeding studies using juveniles from post-larval collection revealed the technique's potential, and offered some interesting prospects in terms of projects to restore damaged sites, given the good results obtained with territorial benthic species such as *Chromis viridis*, a species used for ecotourism that had survival rates of 70% under experimental conditions three days after release. Already, French Polynesian companies offer ecotourism site development services with reseeding species of similar behaviour (i.e. very substrate-specific). The results of these studies also give a glimpse of success over the medium term with reseeding projects for food (fisheries) and ecological purposes through the release of herbivore species caught locally (e.g. *Naso unicornis* or *Naso lituratu),* which could contribute to the elimination of invading seaweeds from the genus *Sargassum,* for example.

Ornamental reef fish sector

About 99% of the worldwide commerce in fish for the reef aquarium trade is based on the collection of wild fish, which has led to often critical levels of fishing pressure on the stocks of exporting countries (Wabnitz et al. 2003). Sustainable use of this resource through the harvest of post-larvae offers an alternative to the traditional harvest of adult fish, which encouraged French Polynesian authorities to study how French Polynesia could become an exporting country. Dufour (1997) conducted the first aquarium trade market study and provided some strategic proposals for French Polynesia. Recognition by the International Coral Reef Initiative in 2001 of larval collection as a "good practice for the protection and management of coral reefs", heightened general interest in the technique and when several "ecological aquarium trade" projects became known, two studies (Biodax 2003; de Villers 2003) were designed to propose a model structure for the future French Polynesian aquarium fish trade sector, with support of the Marine Aquarium Council (Holthus 2003).

On a more technical level, Scourzic's work (1999) was designed to summarise the administrative procedures for shipping live fish from French Polynesia to the European Community, and to set up tests to determine the best transport conditions for fish survival. These results served as a working basis for private sector companies, which then improved their transport protocols in line with feedback from their customers in the United States and Europe. To date, nearly 150,000 fish from post-larval harvests have been exported, with survival rates or more than 95%.

Promoting French Polynesian expertise

In French Polynesia

The experience acquired in French Polynesia over the past 15 years on the scientific, technical and, now, economic aspects of reef fish larval collection, rearing, and market outlets for such larvae has allowed French Polynesian stakeholders, both public and private, to have enough information on hand to define a joint strategy designed to develop a sustainable economic sector. The basic objectives are, obviously, to allow companies to make profits while at the same time protecting fisheries resources and guaranteeing the health of the marketed product.

In 2007, a study carried out jointly by SPE, aquaculture specialists and economists analysed the current situation in two French Polynesian companies, identifying their strong and weak points, and then proposing an update of the development strategy for the "reef aquaculture" sector in French Polynesia. The results showed that production costs at French Polynesian farms do not constitute a primary limiting factor and that affordable improvements to production would allow gains in productivity that would bring production costs below market prices. In fact, it seems that the main factor limiting the development of the two farms analysed was linked to the efficiency of larval collection methods, as *hoa* nets, and even more so, light-traps, generally do not catch enough marketable specimens, particularly in terms of high added value species. The random nature of larval colonisation further complicates rationalisation of a production plan and generates operating overruns.

Research and development should continue with reseeding techniques and techniques for harvesting larvae from target species. Designing a new generation of traps seems to be a decisive step in the development of ornamental or food fish aquaculture projects. Food fish projects currently appear to be limited by the inadequate efficiency of the post-larval capture and culture (PCC) traps available (Pickering et al. in progress).

At the same time, French Polynesian authorities are working on creating a legal framework for this sector. Draft legislation is being studied by SPE's legal specialists and is based on Lo-Yat's (2002b) proposal for setting out the rules of conduct for sustainable harvest and production traceability.

In addition, the Fisheries Department, in partnership with IFREMER (French Institute of Research for Ocean Development), is continuing its research and development work in aquaculture zootechnics on *Platax orbicularis* and in terms of animal health monitoring for farms. Finally, the SPE also has the intention and mission of assisting French Polynesian companies gain better control over these two aspects of production, through the creation of a specialised team in this area.

Elsewhere in the South Pacific

As part of the Coral Reef Initiative for the South Pacific (CRISP) programme, which was initiated by the Agence Française de Développement (www.crisponline.net 2007), Component 2A-1 covers reef fish post-larval harvest and development at a regional level. Its missions are to further basic research, transfer knowledge and train technical staff.

The publication of a guide identifying reef fish larvae in French Polynesia (Maamaatuaiahutapu et al. 2006) is a first step towards sharing French Polynesia's experience (SPE, EPHE and private work) with students, researchers and those conducting projects in the South Pacific. In addition, under EPHE's scientific responsibility, the University of the South Pacific is hosting French students to do basic research work in Suva, Fiji. The topic "Larvae rearing and identification" has been raised, and a PhD student is looking into optimising reseeding methods in natural settings, using juveniles from post-larval collection (Clua 2007). In this context, the expertise that CRIOBE acquired on Moorea has been promoted, and may make it possible to develop sustainable activity in the Pacific region. French Polynesia, a pioneer and leader in reef post-larval harvesting and rearing, could benefit from this technology transfer by accompanying the development of South Pacific island countries, in the form of partnerships between private French Polynesian farms and foreign projects.

Since November 2007, the Aquaculture Section of the Secretariat of the Pacific Community (SPC) has been developing, with support of the French Ministry of Foreign Affairs, an experimental project to harvest and rear reef larvae in Aitutaki, Cook Islands. Coordinated by SPC, this project is being developed as a partnership between the Cook Islands' Fisheries Department and French Polynesia's SPE, and involves the participation of private stakeholders in French Polynesia (Aquanesia and BoraEcoFish).

Because it is based on techniques that have been recognised as ecofriendly, the reef fish larval harvesting and rearing sector, known as "reef aquaculture" in French Polynesia, opens — under certain environmental, technical, socioeconomic and cultural conditions — some interesting possibilities in terms of sustainable development based on:

- exports of high-added value products to the aquarium trade markets,
- lagoon development for eco-tourism, and
- additional farms for food purposes using certain post-larval species that can colonise *en masse*.

Many international agencies such as the WorldFish Center or SPC have seen the value of this. However, in addition to mastering larval harvesting and identification techniques, several conditions must be met in order to allow such sustainable development in Pacific Island countries.

- In terms of the environment, at least a minimum level of information is required regarding spatial and temporal changes, both qualitative and quantitative, in fish larval colonisation at each operating site.
- In terms of the aquarium trade market, recognition must be sought from all stakeholders of the sustainable aspect ("ecofriendly") of this type of harvest and the "farm" quality of the products (and so, their prices) resulting from these techniques.
- In terms of the food market ("food-fish"), well-adapted traps and production protocols must be designed for herbivore species that are *a priori* competitive, such as *Siganus* spp.
- We should continue research and development in order to master the sustainable harvest of other reef species (in the same way as what SPE did with the collection of giant clam spat) by first

targeting those sites that have specific assets that could be promoted.

- Finally, we feel that research and development efforts should focus on fish farming and preventive care, techniques that now are relatively well understood for certain species in French Polynesia.

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