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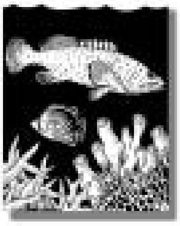

Aquacultural suitability of post-larval coral reef fish

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Introduction

Previously, aquaculture mainly consisted of the intensive rearing of commercially valuable carnivorous species for the food market. Some high-yield operations have proved harmful for the environment (Kautski et al. 1998) or of doubtful profitability (Naylor et al. 2000). In the future, the focus is likely to shift either to new species, such as herbivores or detritus feeders, which occur lower down the food chain, or to the development of new activities, such as fish production for recreational fishing, natural stock rehabilitation and the breeding of species for laboratories or aquaria. These potential prospects in marine resources are at present underexploited, especially in tropical latitudes. Some small-scale farming activities represent, for the moment, only a small output in terms of tonnage, but they can nevertheless prove highly profitable. This, for example, is the case with ornamental fish production, which can be a significant economic activity (Tauji 1996; Dufour 2002).

Mastery of breeding techniques is not always necessary and some aquacultural operations now use young specimens caught at sea that are then transferred to farms (Deniel 1973; Rimmer 1998). In the Mediterranean, the Italians traditionally harvest juvenile mullet, sea-bream and European seabass in an area stretching from Turkey to Morocco, rearing them in the "valli" of the Adriatic (Barnabé 1991). This is also similar for the milkfish, *Chanos chanos*, as Far Eastern fishers have been acquiring specialised knowledge for more than a century through capturing young specimens, which are then transferred to farming units (Smith 1981). In Japan, juvenile amberjack, *Seriola quinqueradiata*, caught in the open sea under floating seaweed masses, are used for subsequent rearing in cages (Kuronuma and Fukusho 1984). This method is still very widely used to supply production units. This kind of fishing is cheap and easy, but the harvests vary from year to year and one poor season could jeopardise a whole year's output (Lequenne 1984).

Recently, aquacultural experiments have also taken place with coral reef fish caught in their natural environment at the post-larvae stage (Dufour 2002; Durville 2002); that is, at their final stage of larval development, which, for most species, corresponds to the stage when they migrate from the pelagic environment to the reef. These catches have been made possible by the development of new techniques such as the crest net (Dufour 1992; Riclet 1995) and light trap (Milicich 1992; Hendricks et al. 2001). On Reunion Island, many specimens were caught using these techniques during a study on the colonisation of the islands' reef flats by fish post-larvae (Durville et al. 2002). Concurrently with that study, and in order to understand how well these coral reef fish might adapt to the requirements of fish farming at this particular stage

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of their development, a number of species were placed in captivity.

Materials and methods

Choice of species studied in captivity

The choice of species was guided by the results of the catches. Each time it was possible to catch more than 30 specimens of the same species during a given sampling period with the crest net, the fish were placed in the nursery tanks. This lower limit of 30 specimens was considered adequate to obtain statistically valid results and corresponded to the number of fish liable to be caught over the same period and therefore theoretically of the same age. Twelve species representing eight different families were selected in this way (Table 1).

The technical resources used in rearing

The fish caught in this study were post-larval; that is, specimens close to metamorphosis. At this stage of development, they no longer have reserves and feed in their immediate environment; their fins are formed and they swim actively (Leis and Trnski 1989). To rear them, we therefore chose conventional techniques, similar to those used in intensive hatchery rearing. The selected fish were placed in glass tanks with a net volume of 0.2 m^3 (1.2 x 0.4 x 0.5 m). The "load" at the beginning of the experiment, that is, the biomass in fresh weight per unit volume, varied from 2.5 to 1125 g m^{-3}, depending on the species. In order not to exceed a critical threshold, set at 1500 g m^{-3}, the rearing of the bigger specimens was done in rectangular polyester tanks of 2 m^3 net volume (2 x 1 x 1.2 m). The constantly replenished seawater (open circuit) was directly pumped from the surrounding environment at a rate of 5 to 10 renewals per day. A rudimentary filtering system using synthetic foam was installed. The water was constantly agitated by an air supplier and diffuser. Natural light was used and did not exceed 500 lux. The bottoms of the tanks were partly siphoned off daily in order to remove the bulk of the waste. The tanks were emptied and cleaned every 28 days, after removing the fish. The high water renewal rate and the low stocking density in the tanks were designed to create an optimal environment for the fish.

The feed had to meet many requirements, the most important of which were that the size of the pieces should be suitable for the size of the fishes' mouths and that the formula should cover the nutritional needs of the fish. Major research work has been carried out in recent years to develop artificial feeds for small specimens such as juvenile marine fish. Whatever the food, whether natural or artificial, the requirements do not change greatly (Barnabé 1991): the fish need proteins, lipids, occasionally carbohydrates, minerals, vitamins and growth factors (Guillaume et al. 1999). Farmed specimens in this study, at the post-larval stage, were sufficiently developed to accept artificial feeds (Barnabé 1988; Foscarini 1988), but an acclimatisation stage called "weaning" has proved necessary. During this transitional phase of 7 to 10 days, which is not taken into account in the growth data, fresh feeds based on living nauplii of *Artemia salinas* and pieces of shrimp and fresh fish, readily absorbed and high in energy (New 1986), were gradually replaced by an artificial feed in the form of extruded pellets (Biomar brand), specially formulated for young marine fish. Processing by dehydration and pressure at high temperature gives this feed better digestibility and better assimilation. It is composed of proteins (52%), lipids (15%), ash (9%) and fibre (1%), plus vitamins A (20,000 IU kg^{-1}), D3 (2500 IU kg^{-1}) and E (200 mg kg^{-1}), and in most cases covers the fishes' main food requirements. Food was distributed by automatic dispensers on a non-stop basis over eight hours, which improved feeding for the relatively undomesticated species whose feeding behaviour is easily disrupted. Also, the juvenile fish, which have a very low absorption capacity and a

Table 1. Families, species, authors and adult diets (after Vivien 1973) of post-larvae captured from reef flats and studied in rearing tanks. Classification is based on taxonomy.

Family	Species	Author	Adult diet
Monodactylidae	*Monodactylus argenteus*	Linné 1758	Omnivorous
Gerreidae	*Gerres acinaces*	Bleeker 1854	Carnivorous
Pomacentridae	*Stegastes nigricans*	Lacepède 1802	Omnivorous
Pomacentridae	*Chromis viridis*	Cuvier 1830	Carnivorous
Pomacentridae	*Dascyllus aruanus*	Linné 1758	Carnivorous
Pomacentridae	*Chrysiptera glauca*	Cuvier 1830	Omnivorous
Labridae	*Stethojulis albovittata*	Bonnaterre 1788	Carnivorous
Scaridae	*Scarus sordidus*	Forsskål 1775	Herbivorous
Mugilidae	*Valamugil cunnesius*	Valenciennes 1836	Omnivorous
Acanthuridae	*Zebrasoma desjardinii*	Bennet 1835	Herbivorous
Acanthuridae	*Naso unicornis*	Forsskål 1775	Herbivorous
Balistidae	*Rhinecanthus aculeatus*	Linné 1758	Carnivorous

rapid digestion, need constant feeding (Guillaume et al. 1999).

Inspection periods and monitoring of fish development

The development period was seven periods of 28 days, thus a total of 196 days. In intensive aquaculture, this period of approximately six months corresponds to the transition of juvenile fish to the growing phase (Frelin 1994). Every 28 days, the fish were anaesthetised before being counted, weighed and measured. The anaesthetic used was clove oil mixed with seawater at a dilution of 0.05 ml L^{-1} (Durville and Collet 2001). This process considerably reduces the risk of disease induced by stress, injury or accident due to handling (Keene et al. 1998). Certain biological parameters were chosen in order to estimate the survival, growth and resilience of specific coral reef fish species. A number of indices regularly used in fish farming (Guillaume et al. 1999) were calculated, enabling us to discuss the responses of the post-larvae and juveniles placed in captivity.

- The specific survival rate (SR): This is the most important parameter in terms of the study's overall results. For each species, the number of fish was counted every 28 days; from this, the survival of each species for the whole experimental period was monitored by calculating the specific survival rate, that is, the percentage of live individuals compared with the original number of specimens introduced to the farm.

- The daily feed ration (R): In young specimens, this is usually between 1% and 5% of the biomass (Lequenne 1984). In our work, this daily ration, initially set at 3% of the biomass, was rebalanced and adjusted on a daily basis depending on the results of observations. It was reduced by 10% when food was left over in the bottom of the tanks or increased in daily increments of 10% until the fish were fully fed. The daily feed ration was recorded every 28 days. It represents the amount of food ingested daily and is expressed as the weight of the food (dry weight) as a percentage of the biomass (fresh weight) at a given time, t.

- The conversion index (CI): This is the relationship between the weight of dry feed consumed and the fresh weight gained (Barnabé 1988), also referred to as the conversion rate (or food conservation ratio). It was assessed for each species every 28 days. It is widely used in aquaculture for the purpose of optimising the quantity of food given in relation to the growth of the animal.

- Growth observed in captivity: At the beginning of the rearing period (t^0), after weaning, fish were individually weighed and measured in order to obtain their initial weight (fresh ungutted weight, expressed in grams, called here W) and their initial length (standard length, expressed in mm, called here SL). Subsequently, weights and lengths were measured every 28 days. Fish were not fed on the day they were measured.

- The specific growth rate (SGR): This is defined as the daily weight gain of the fish expressed as a percentage of its weight at time t (Priede and Secombes 1988). It was calculated for each species after 196 days of experimentation.

- The length–weight relationship: For the great majority of species, weight development in relation to length follows a theoretical equation of the power type (Pauly 1997) and can be expressed in the form: $W = a \cdot SL^b$. For each species studied, the parameters "a" and "b" were computed over the rearing period, as was the coefficient of determination (R^2) for each curve. The closer this coefficient is to 1, the more the weight change in relation to length follows this theoretical curve.

- The coefficient of variation (CV) of the weights: This was calculated for each species every 28 days. It is expressed as a percentage and represents the variability in the weights of the different fish as compared to the mean. The lower and/or more stable this is in relation to time, the more the studied batch will tend to become homogeneous and the more the species can be considered as capable of acclimatising to the artificial environment.

Results

Survival of the species in captivity

For two species (*Gerres acinaces* and *Stethojulis albovittata*), very low survival rates were recorded during the initial rearing periods and their rearing could not be completed. The observations made on these species are therefore incomplete and probably biased by unsuitable captivity conditions. They will not be taken into account in the remainder of this paper. For the other 10 species, the method used made it possible, after more than six months of rearing, to obtain survival rates varying from 60% (*Scarus sordidus*) to 92% (*Monodactylus argenteus, Stegastes nigricans*) (Table 2). Despite the very small size (6.5 ± 0.7 mm) and probable fragility of *Monodactylus argenteus* post-larvae, this species had one of the best survival rates. In comparison, *Zebrasoma desjardinii*, which had larger, apparently more resistant post-larvae (21.6 ± 2 mm), had a lower survival rate (87% after 196 days). Survival is therefore thought to be more dependent on the species than on the initial size at which the rearing process was started.

The most fragile phases are the initial rearing periods, with survival rates for *Scarus sordidus* and *Chromis viridis* of 78% and 80%, respectively, after only 28 days of rearing. For each species, the survival rate tended to increase and stabilise at between 90% and 100% after about 100 days of captivity. As survival rates increased with age of the fish, one can assume that the acclimatisation to rearing conditions and the resilience of individual specimens are a function of time. It should also be noted that some cases of mortality were observed to be one-off events due to various technical shortcomings (water or air supply) or occurred after an abrupt temperature drop (tropical climate disturbance). Some of these mortalities therefore could have been avoided.

Feeding fish in captivity

The feed ration

The feed ration varied over time and, apart from external factors that may have influenced food intake (temperature, stress, disease, environment), it was directly proportional to the weight of the fish. Table 3 gives the daily feed ration over time for the 10 species studied. It varied from 3.1% to 20% of the biomass at the beginning of growing out (t^0), whereas at the end of the experiment (t^{196}) it had dropped to 1.5% to 5% of the biomass. For all species, the daily food requirements were therefore proportionately higher during the initial juvenile phases and gradually diminished with the growth of the individual.

An analysis of needs according to species shows that the greatest inter-specific variability in the daily feed ration occurred at the beginning of the experimental period, especially in small low-weight species such as *Monodactylus argenteus* and *Scarus sordidus*. This could mean that the quantitative needs, expressed in relation to the biomass, are inversely proportional to the weight of the fish during the juvenile period; in other words a low-weight species would have relatively greater food needs than a larger species.

Conversion index

The conversion index (CI), which represents the amount of food necessary to increase weight by one unit for each rearing period, varied according to species and growth period, from 0.9 to 10

Table 2. **Percentage of fish surviving over a 196-day rearing period and initial number of fish (IN).**

Time (days)	*Monodactylus argenteus* IN = 50	*Gerres acinaces* IN = 50	*Stegastes nigricans* IN = 50	*Chromis viridis* IN = 30	*Dascyllus aruanus* IN = 30	*Chrysiptera glauca* IN = 30	*Stethojulis albovittata* IN = 50	*Scarus sordidus* IN = 50	*Valamugil cunnesius* IN = 50	*Zebrasoma desjardinii* IN = 30	*Naso unicornis* IN = 30	*Rhinecanthus aculeatus* IN = 30
0	100	100	100	100	100	100	100	100	100	100	100	100
28	94	74	100	80	83	100	52	78	100	93	93	97
56	94	27	94 *	77	83	93	8	66	94	87 *	93	90
84	92	14	94	67	83	93	0	62	94	87	93	90
112	92	0	94	67	83	90	0	60	94	87	93	90
140	92	0	94	67	80	87	0	60	94	87	87	87
168	92	0	92	63	80	87	0	60	94	87	87	87
196	92	0	92	63	77	87	0	60	90 *	87	87	87

* Technical failure partly explained the drop in the survival rate.

Table 3. **Daily feed ration: weight of food (dry weight) as a percentage of biomass (fresh weight) at time t.**

Time (days)	*Monodactylus argenteus*	*Stegastes nigricans*	*Chromis viridis*	*Dascyllus aruanus*	*Chrysiptera glauca*	*Scarus sordidus*	*Valamugil cunnesius*	*Zebrasoma desjardinii*	*Naso unicornis*	*Rhinecanthus aculeatus*
0	20.0	3.6	4.2	3.6	5.7	20.0	14.9	6.5	3.1	4.7
28	6.8	5.1	8.1	6.6	4.8	5.0	8.2	4.3	2.3	3.9
56	4.2	6.3	5.7	5.0	4.6	6.8	4.7	3.4	2.1	3.7
84	2.1	4.8	6.1	4.0	3.8	7.9	4.3	2.8	3.0	2.7
112	1.8	4.2	6.3	4.1	4.0	7.2	4.3	2.5	3.2	2.8
140	1.5	4.0	5.6	4.1	3.6	5.0	3.8	2.7	3.7	2.9
168	1.5	3.5	5.4	4.1	2.8	3.6	3.1	2.6	3.5	3.1
196	1.5	3.1	5.0	4.1	3.1	3.1	3.1	2.6	3.4	3.3

Table 4. **Conversion indices over time for the 10 species studied and mean conversion indices (mean CI) for the 196-day period.**

Time (days)	*Monodactylus argenteus*	*Stegastes nigricans*	*Chromis viridis*	*Dascyllus aruanus*	*Chrysiptera glauca*	*Scarus sordidus*	*Valamugil cunnesius*	*Zebrasoma desjardinii*	*Naso unicornis*	*Rhinecanthus aculeatus*
0	-	-	-	-	-	-	-	-	-	-
28	0.9	3.0	2.0	3.0	2.0	1.3	1.8	1.5	1.1	2.1
56	0.9	2.3	5.0	4.0	2.5	2.5	1.4	1.6	1.4	3.0
84	0.9	2.2	7.0	5.0	2.0	2.5	1.4	2.2	2.1	1.7
112	1.0	3.0	8.0	5.0	5.0	3.6	1.7	2.3	3.1	2.2
140	1.0	3.1	4.5	3.5	2.3	2.5	1.9	2.8	3.4	2.7
168	1.4	2.4	10.0	8.0	2.8	1.7	1.9	2.9	3.9	5.3
196	1.5	2.6	6.5	9.0	4.3	2.0	2.5	3.0	3.9	7.0
Mean CI	1.1	2.7	6.1	5.4	3.0	2.3	1.8	2.3	2.7	3.4

Table 5. **Linearised growth functions, showing the evolution of the square root of the mean weights over time for the 10 species studied, with coefficients of determination (R^2).**

Species studied	Linearised growth function	Coefficient of determination, R^2
Monodactylus argenteus	Y = 0.60x – 0.57	0.99
Stegastes nigricans	Y = 0.24x + 0.07	0.98
Chromis viridis	Y = 0.09x + 0.24	0.99
Dascyllus aruanus	Y = 0.09x + 0.25	0.98
Chrysiptera glauca	Y = 0.25x + 0.19	0.99
Scarus sordidus	Y = 0.17x – 0.19	0.93
Valamugil cunnesius	Y = 1.01x – 0.99	0.98
Zebrasoma desjardinii	Y = 0.48x + 0.50	0.99
Naso unicornis	Y = 0.93x + 1.94	0.99
Rhinecanthus aculeatus	Y = 0.32x + 0.69	0.98

(Table 4). This index is obviously of greater interest in terms of rearing when its value is small, because it means significant growth with low food input, but it also shows the adaptation of the species to a particular type of food. The more the species can take advantage of the food distributed, the lower the conversion index. The species that demonstrated a good mean conversion index over the 196-day rearing period were *Monodactylus argenteus*, *Valamugil cunnesius* and *Zebrasoma desjardinii*. The first species had a conversion index even lower than 1 during the first rearing period; that is, the weight gain was greater than the food input. This phenomenon has been observed in tilapia, catfish and wolf fish, with conversion indices as low as 0.9 (Barnabé 1991). In addition, as *Monodactylus argenteus* was very small at the beginning of rearing (6.5 ± 0.7 mm at t^0), it is quite possible that this fish could have fed on all the nutritional matter present in the continuously renewed tank water. The species that showed a higher conversion index were *Dascyllus aruanus* and *Chromis viridis*, with means of 5.4 and 6.1, respectively, over 196 days. This could indicate poor adaptation to the rearing conditions.

Growth of fish in captivity

Calculation of growth curves from mean weights

The growth of a fish can be simply defined as weight gain over time. Changes in the mean weights over time for the 10 species studied followed a series of ascending curves generally similar to the power type, with coefficients of determination (R^2) greater than 0.95 (Figure 1). A square-root type conversion enabled us to linearise these data and thus standardise and compare the results (Table 5). The slopes of the straight lines obtained, which represent the rate of growth as compared to the initial weight, were between 0.09 and 1.01. The species with the fastest growth rates were *Valamugil cunnesius*, *Naso unicornis* and *Monodactylus argenteus*. Those with the slowest growth rates were *Dascyllus aruanus* and *Chromis viridis*, which can be taken to confirm the previous results pointing to difficult adaptation on the part of the latter two species.

Specific growth rate

Over a short period such as the one used in the study (196 days of rearing), the increase in biomass

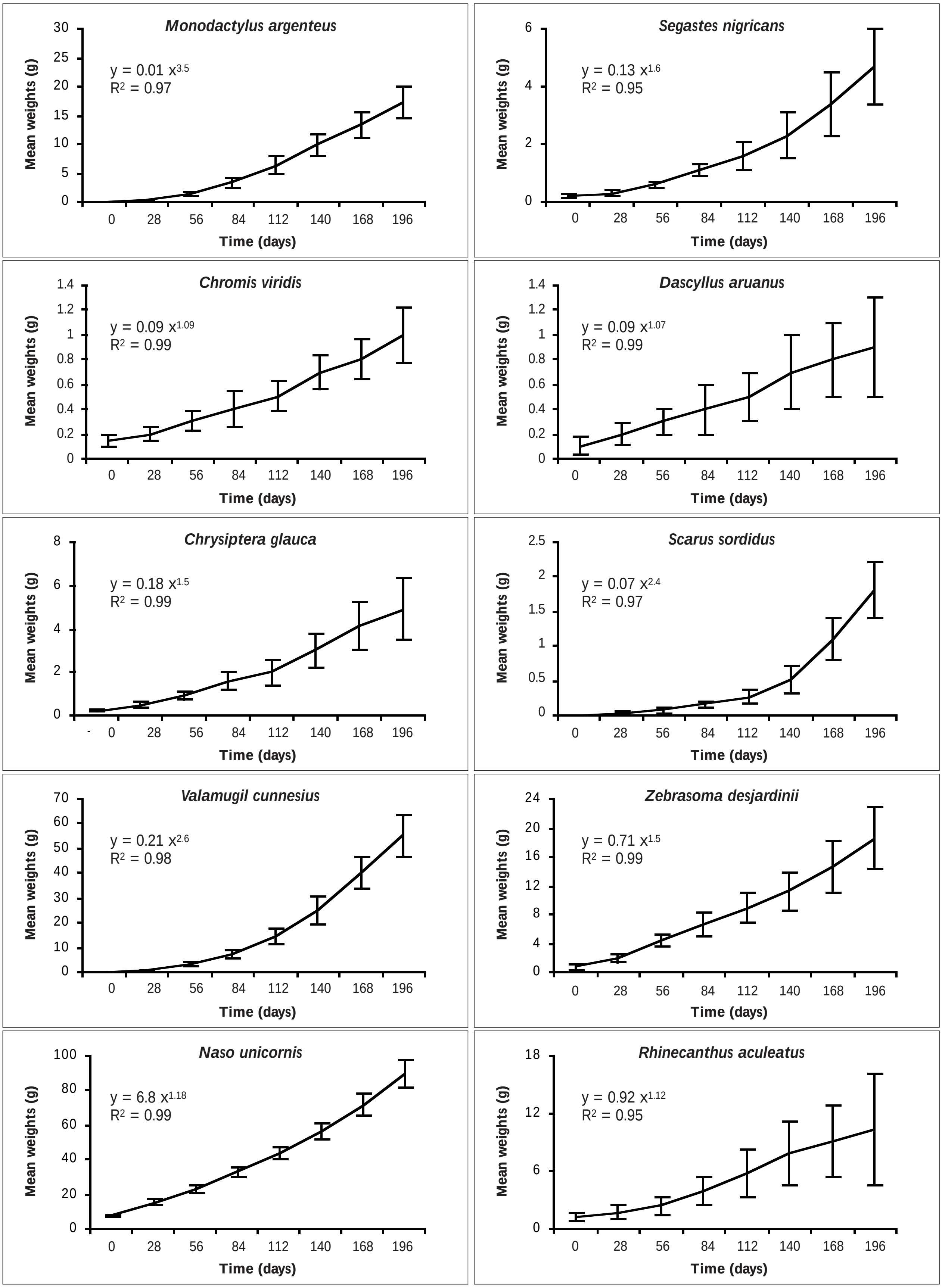

Figure 1. Evolution of mean weights with time, for the 10 species studied; also shown are the equation of the curve and the coefficient of determination (R^2).

can be considered as a linear function of time, which enables us to define a specific daily growth rate (Figure 2). The results obtained for the various species ranged from 0.9% to 3.8% daily weight gain. Those with the best specific growth rate were *Monodactylus argenteus* (3.8%), *Valamugil cunnesius* (2.6%) and *Scarus sordidus* (2.6%). *Chromis viridis* had the lowest rate (0.9%).

Length–weight relationships obtained under aquacultural conditions

It is generally acknowledged that the weight (W), of a fusiform fish is proportional to the cube of its length (SL). The equation can be written in the following form: $W = a \cdot SL^b$, in which the parameter "b" is close to 3 (Pauly 1997). It can be verified that this formula is applicable to the majority of species studied, except *Dascyllus aruanus* and *Chromis viridis*, which gave different results (Table 6). The weight of these species could be very low in comparison to their size, which could, as indicated previously, indicate that these fish did not follow a normal development process under the farming conditions.

Resilience of the species studied

Barnabé (1991) uses the term "resilient" to describe the ability of a species to survive and grow in conditions different from those of its natural environment, to tolerate handling (sorting, treatments) and various deteriorations in farming conditions. This capacity can be judged by monitoring the coefficient of variation (CV) of the weights for each rearing period. If the CV diminishes proportionately and / or stabilises, it can be concluded that the animals are adapting appropriately to the farming conditions. This was the case with *Monodactylus argenteus, Valamugil cunnesius, Zebrasoma desjardinii* and *Naso unicornis* (Fig. 3), whose coefficients of variation were stable at about 10% to 20% of the mean after some six months of rearing. With other species, the variation from the mean figures were greater (40% for *Rhinecanthus aculeatus* and 30% for *Chrysiptera glauca*) or showed variations from the mean that were highly variable depending on time, as was the case for *Scarus sordidus*, *Chromis viridis*, *Dascyllus aruanus* and *Stegastes nigricans*. This denotes heterogeneous and discontinuous growth within the

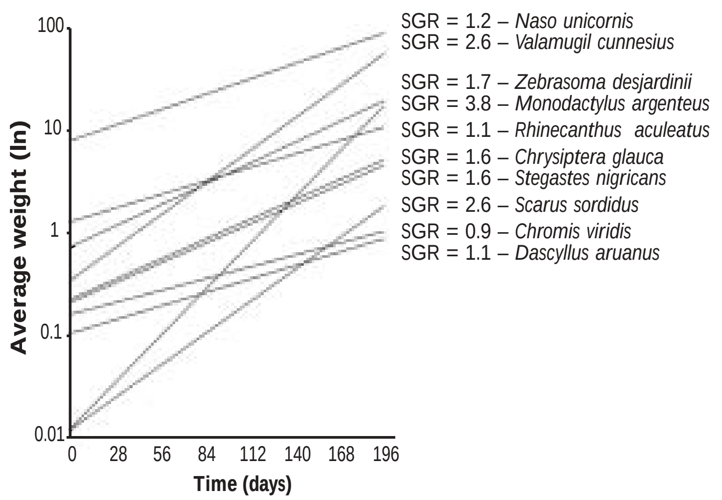

Figure 2. **Linearised growth curves, expressing the growth of the 10 species studied and their specific growth rate (SGR), expressed in per cent per day.**

Table 6. **Number of specimens sampled and parameters "a" and "b" in the length-weight relationship $W = a \cdot SL^b$ for the 10 species reared (the fresh weight is expressed in g and the standard length in cm), with the coefficient of determination (R^2).**

Species	Number of specimens weighed and measured	Parameter a	Parameter b	Coefficient of determination, R^2
Monodactylus argenteus	374	0.046	2.96	0.99
Stegastes nigricans	380	0.036	3.16	0.97
Chromis viridis	176	0.074	2.30	0.87
Dascyllus aruanus	201	0.118	1.61	0.80
Chrysiptera glauca	223	0.090	2.41	0.93
Scarus sordidus	277	0.031	3.03	0.97
Valamugil cunnesius	380	0.025	2.95	0.99
Zebrasoma desjardinii	213	0.067	2.89	0.97
Naso unicornis	220	0.066	2.82	0.98
Rhinecanthus aculeatus	218	0.136	2.45	0.95

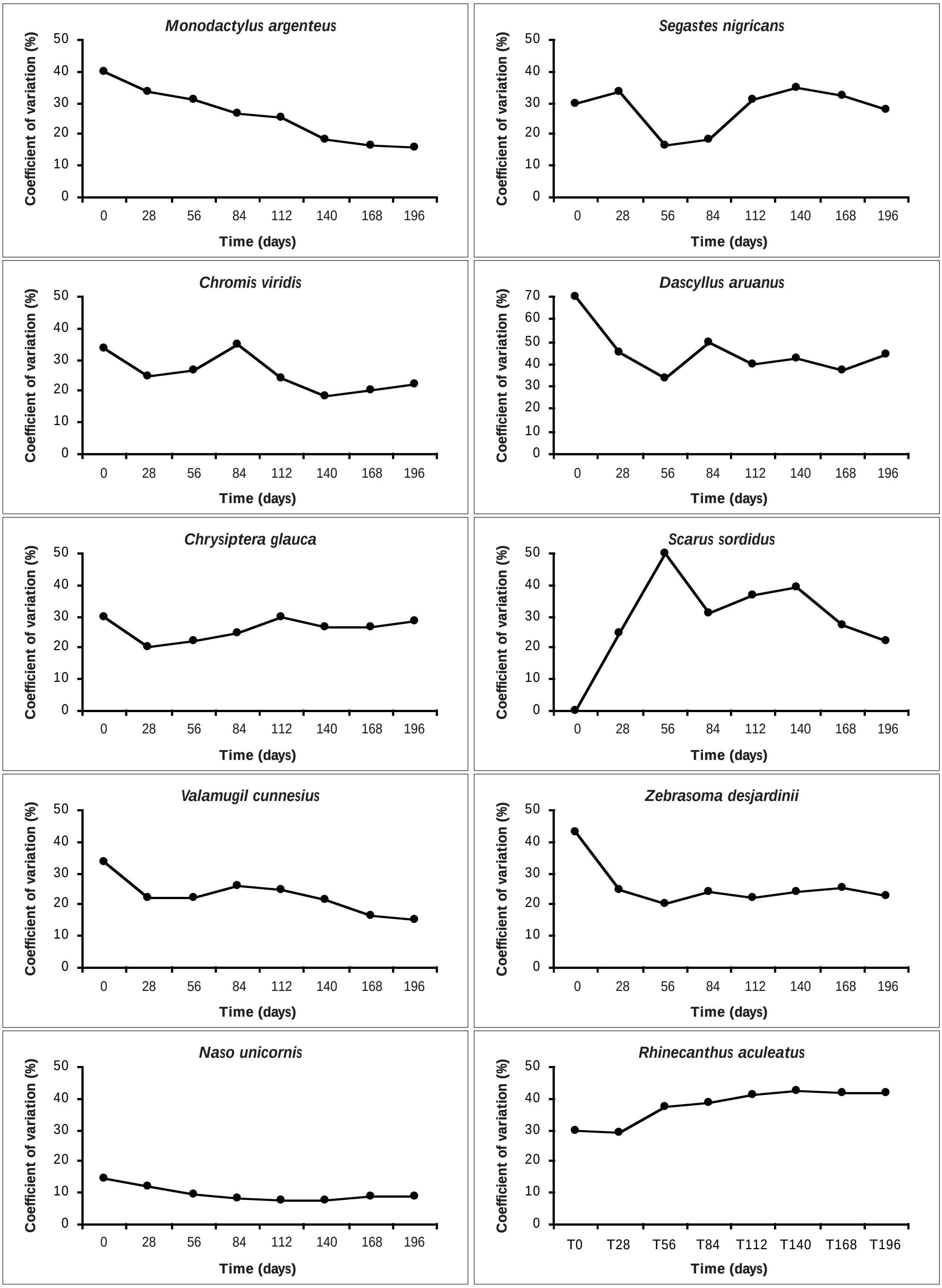

Figure 3. **Evolution of the coefficient of variation (CV) over time for the 10 species studied.**

group and therefore points to a degree of difficulty on the part of these fish to adapt to the experimental conditions.

Discussion

Survival of post-larvae in captivity

Ongrowing is a specific term in aquaculture referring to the stage during which fry weighing just a few grams are fed up to a weight of several dozen grams (Frelin 1994), which was generally the case in this study. The fundamental differences between ongrowing and growing concern, in particular, the susceptibility and fragility of juvenile fish to the biotic or abiotic environments. There is a very clear gradient, an increase in resilience and resistance from the very fragile larval phase to the adult phase (Barnabé and Lecoz 1987). Where marine fish are concerned, there are no precise data on survival at the various stages of growth. In farming conditions, the more fragile larval stages do not exceed a 70% survival rate, whereas at the adult and juvenile stages, 90% survival rates are routinely recorded, reaching as high as 98% with the Salmonidae, for example (Laird and Needham 1989). The purpose of our experiment was to assess the adaptation of certain species of coral reef fish to farming conditions using post-larvae captured in the natural environment. Apart from the aspects of growth and state of health of the fish that are difficult to assess, the survival rates show unambiguously how well these animals adapted to captivity. Of the 12 species studied, only two, *Gerres acinaces* and *Stethojulis albovittata*, showed high mortality rates at the very start of the rearing process and could not be kept alive beyond 84 days. The other 10 species were reared with survival rates varying from 60% to 92% after more than six months of captivity. Generally speaking, a result of greater than 70% is routinely obtained during the rearing phase, but it can be much higher and reach values close to 90% with certain coral reef fish species (Job et al. 1997). It would therefore be possible to use post-larval reef fish in farms and obtain survival results close to those achieved by the species regularly used in aquaculture.

Diet of coral reef fish post-larvae and juveniles

The feeding experiment results are only given on an indicative basis and could be used as a basis for more comprehensive studies on the food needs of young coral reef fish. It proved relatively easy to acclimatise and wean post-larvae caught in the natural environment. The diet that was used essentially covered the food requirements of carnivorous fish, although, of the species selected, three are considered at the adult age to be strict herbivores (*Scarus sordidus*, *Zebrasoma desjardinii*, *Naso unicornis*). They nevertheless rapidly adapted to a diet based on extruded protein-rich pellets. Some authors, such as Lassuy (1984), have observed that *Stegastes nigricans* could be carnivorous when juvenile and subsequently herbivorous. Others, however, such as Lefevre (1991), have observed that most young fish in the natural environment, especially the Acanthuridae, Siganidae and Pomacentridae, adapt early to an adult diet, although the feeding habits from the pelagic life stage remain important, with the constant presence of a large number of copepods in the stomach. The fish are therefore thought capable of major dietary adaptation at the juvenile stage. It remains to be demonstrated whether these feeding habits can be maintained in the long term within a production-oriented setting and whether this forced adaptation is reversible.

It is known that the metabolic activity of fish is inversely proportional to its size. Small fish show more rapid growth in terms of daily weight gain and their protein needs are very high. We therefore naturally observed that the daily food ration varied depending on the size of the fish raised. In our study, the ration was very high early in the experiments, reaching 20% of the biomass with some species (*Monodactylus argenteus*, *Scarus sordidus*). It then seemed to stabilise, whatever the species considered, around a mean value of 2% to 4% of the biomass, after some 100 days of rearing. Although our results were obtained using only one type of feed, similar values are commonly found in the feeding tables for conventional aquacultural species and may therefore be considered valid for coral reef fish at the juvenile stage.

The conversion indices or conversion rates are of interest in terms of production when they are less than 3, as with trout, salmon, bream, wolf fish, turbot and eel. They are unfavourable with values from 4 to 8, as with tuna and amberjack (Barnabé 1991). The purpose of our experiment was not to obtain low conversion indices, but to gather data on the biology and adaptation capacities of coral reef fish. Low conversion indices were, nonetheless, observed with *Valamugil cunnesius*, *Zebrasoma desjardinii* and *Scarus sordidus*. As adults, these fish weigh up to several kilograms. Although further experiments on diet are necessary in order to validate our results, these species could perhaps become potential candidates for some form of aquaculture use. For other species, which may be less rewarding in terms of food–growth conversion, it may be that the diet was unsuitable. Low growth rates and high conversion indices, as with *Dascyllus aruanus* and *Chromis viridis*, may indicate that these fish were underfed or that they had difficulty absorbing the food offered. The natural diet of these fish essentially comprises zooplankton (Vivien 1973), which are rich in fatty acids (Sargent et al. 1989). Types of food other than those chosen in this experiment might therefore be more suitable for these species.

Growth of post-larvae and juveniles in captivity

An understanding of the growth of the various species is a basic requirement for research on population dynamics. Among other things, it provides the theoretical weight of a specimen at a given age and therefore makes it possible to assess the biomass of a species or group of individuals. For the 10 species considered in the study, the mean weight curves showed functions similar to the power type. In this study, they related only to a very limited period in the development of fish at the juvenile stage. It is therefore normal to obtain substantial weight gain, which subsequently levels off with age and becomes close to a sigmoid function, such as described in the models of Gompertz or Von Bertalanffy (Muller Fuega 1990).

The specific growth rates, which make it possible to more accurately assess the growth potential of the fish, in this study showed a certain amount of variability depending on the species considered. The best rates, indicating rapid growth, were obtained by *Valamugil cunnesius* (2.6%), *Scarus sordidus* (2.6%) and especially *Monodactylus argenteus*, which had a growth rate of 3.8% per day over a period of more than six months, indicating the favourable performance of this species in terms of juvenile growth. Routinely recorded values in aquaculture are between 0.5% and 3% (Barnabé 1991), and specific growth rates this high are rarely achieved. Values of 4% to 5% have been obtained with juveniles of *Morone saxatilis*, but only under particular experimental conditions (Harmon and Peterson 1994).

The data obtained on the weight and size of fish during growth allowed the determination of length–weight relationships, which are important in fishery science, particularly for estimating the biomass from length measurements. Such measurements are often obtained during fishery sampling and therefore concern adult fish of commercial interest. This study provides some information on length–weight relationships at stages of development that have not been the subject of much previous research. The "a" parameter depends on the range of measurements used and therefore the growth period considered; it is difficult to interpret comparisons made between studies. On the other hand, the "b" parameter, even if it is not calculated with the same type of length data, does give an idea of the fish's development. If it differs much from 3 (less than 2.5 or more than 3.5), it can be considered as doubtful or based on too short of a length measure (Carlander 1969; Pauly 1997). Estimates of this constant, obtained in our study for the 10 species placed in aquacultural conditions, can be compared with data obtained for wild fish from various coral reefs (Table 7). A certain similarity between the various results is recorded, except perhaps for *Dascyllus aruanus*, *Chromis viridis* and *Rhinecanthus aculeatus*, which show a much lower weight than the fish observed in the natural environment. This can be taken to confirm that the species do not develop properly under the proposed farming conditions.

Concerning the resilience of the 10 species of post-larval coral reef fish studied, at least four (*Monodactylus argenteus, Valamugil cunnesius, Zebrasoma desjardinii* and *Naso unicornis*), tolerated the farming conditions quite well, whereas *Dascyllus aruanus*, *Chromis viridis* and *Scarus sordidus* showed adaptation difficulties. Other species, such as *Rhinecanthus aculeatus* and *Chrysiptera glauca*, showed individual weight deviations that increased with time. This is the predictable reaction of territorial fish, where one part of the group, comprised of dominant individuals, always grows more quickly than the others (Barnabé 1991). To limit this effect, periodic sorting is generally carried out in fish farming to separate fish with differing lengths or weights.

Conclusion

Generally speaking, our understanding of the first stages of development of tropical marine fish is still limited. This study provides some elements on the biology of a number of species on which little research had been done, and at stages of development that are poorly understood. The fact that we worked on new species and used a range of techniques under specific conditions made it possible to test, to experiment with and to improve rearing protocols. Barnabé (1991) remarks that, when particular methods are used for certain species, it is likely that they will prove effective for others also.

The purpose of this research project was to assess the adaptation capacities and aptitude for aquaculture of a number of coral reef fish species, starting from post-larvae captured in their natural environment. The best evidence that a species is suitable for farming is successful early rearing. Its ability to feed properly and to grow and survive in artificial conditions demonstrates definite acclimatisation capacities. This is the case for ten of the 12 species studied, for which the 196-day rearing period was successfully completed. Some, such as *Valamugil* *cunnesius* and *Naso unicornis*, may have farming characteristics suitable for food production, because they are large fast-growing fish with low conversion rates. Others, such as *Monodactylus argenteus*, *Stegastes nigricans*, *Zebrasoma desjardinii* and *Rhinecanthus aculeatus*, show high survival rates and might therefore also be suitable for use for a range of other production purposes.

Generally speaking, the ultimate goal of research on fish in captivity is to understand their biological cycle; this is particularly difficult for most marine fish, which undergo one or more very small larval stages, during which they are highly sensitive to external factors. It is for these reasons that few species are currently farmed with complete predictability, especially coral reef fish. This study shows that the rearing of post-larval coral reef fish is possible under conventional intensive farming conditions, which opens up new prospects in many areas such as aquaculture, research and aquarium-keeping. This practice may make it possible to produce fish from post-larvae captured at sea under controlled conditions (Williams 1996; Bell et al. 1999). Some authors also recommend systematic measures for the purpose of increasing reef productivity: the post-larvae captured would be immediately placed in farming facilities and reintroduced later into the natural environment, thus considerably increasing their chances of survival (Dufour and Galzin 1992; Beets and Hixon 1994).

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Table 7. **Comparison of studies of the parameters "a" and "b" in the length–weight relationship $W = a \cdot SL^b$, for identical species and same-genus species.**

Species studied or species of the same genus	Number of specimens measured	Measurement range (cm)	Type of length*	Parameter a	Parameter b	Study location	Author(s) and date
Monodactylus argenteus	374	0.6 – 9.0	SL	0.046	2.96	Reunion	Durville (this study)
Monodactylus argenteus		2.0 – 18.5	FL	0.033	2.92	New Caledonia	Letourneur et al. (1998)
Stegastes nigricans	380	1.3 – 5.8	SL	0.036	3.16	Reunion	Durville (this study)
Stegastes nigricans		0.7 – 12.6	TL	0.022	3.08	Reunion	Letourneur (1998)
Stegastes nigricans		2.5 – 12.5	FL	0.168	2.36	New Caledonia	Letourneur et al. (1998)
Chromis viridis	176	0.9 – 3.3	SL	0.074	2.30	Reunion	Durville (this study)
(related sp. - *C. atripectoralis*)		3.5 – 9.0	FL	0.020	3.21	New Caledonia	Letourneur et al. (1998)
Dascyllus aruanus	201	0.9 – 4.1	SL	0.118	1.61	Reunion	Durville (this study)
Dascyllus aruanus		2.3 – 9.0	TL	0.028	3.03	Reunion	Letourneur (1998)
Dascyllus aruanus		2.4 – 6.5	FL	0.071	2.63	New Caledonia	Letourneur et al. (1998)
Chrysiptera glauca	223	1.1 – 5.5	SL	0.090	2.41	Reunion	Durville (this study)
Scarus sordidus	277	0.6 – 4.6	SL	0.031	3.03	Reunion	Durville (this study)
(related sp. - *S. frenatus*)		10.6 – 29.5	SL	0.027	3.06	Australia	Choat and Axe (1996)
(related sp. - *S. ghobban*)		6.8 – 49.5	FL	0.016	3.04	New Caledonia	Letourneur et al. (1998)
Valamugil cunnesius	380	2.2 – 16.6	SL	0.025	2.95	Reunion	Durville (this study)
Valamugil cunnesius			SL	0.016	2.88	South Africa	Van Der Elst (1981)
Zebrasoma desjardinii	213	1.9 – 7.6	SL	0.067	2.89	Reunion	Durville (this study)
(related sp. - *Z. veliferum*)		4.0 – 26.5	FL	0.033	2.85	New Caledonia	Letourneur et al. (1998)
Naso unicornis	220	4.9 – 14.2	SL	0.066	2.82	Reunion	Durville (this study)
Naso unicornis		18.5 – 60.0	FL	0.021	2.98	New Caledonia	Letourneur et al. (1998)
Naso unicornis		6.5 – 10.8	TL	0.032	2.78	Reunion	Letourneur (1998)
Naso unicornis		5.0 – 45.7	SL	0.085	2.84	Australia	Choat and Axe (1996)
Rhinecanthus aculeatus	218	1.6 – 7.7	SL	0.136	2.45	Reunion	Durville (this study)
Rhinecanthus aculeatus				0.017	3.10	Micronesia	Smith and Dalzell (1993)

* SL = standard length, FL = fork length, TL = total length

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