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18

Post-larval Capture and Culture of Ornamental Fishes

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Abstract

Post-larval capture and culture (PCC) is a sustainable technique whereby post-larval (PL) fish are collected from plankton in the open ocean without physically impacting the marine environment. Wild reef fish undergo extremely high natural mortality (>95%) during reef colonization and settlement as they transition from the planktonic to the juvenile phase of their life cycle. Post-larval capture collects a tiny proportion of post-larvae prior to this high natural mortality event, impacting minimally on overall plankton biomass. Post-larval culture rears and conditions captured post-larvae into healthy, superbly conditioned fish with a high survival rate. Thus PCC not only reduces environmental and human impacts of devastating wild fish collection methods, it also produces first-class specimens for aquarium hobbyists, a win-win situation for all concerned. Nevertheless, even after a decade of development, PCC is not yet widely implemented. The reasons are many but often unrelated to the technique itself.

Keywords *PCC; sustainability; marine aquarium trade; new species*

18.1 Introduction

Tropical marine animals (mainly fishes but also crustaceans and molluscs) are very highly prized by the Marine Aquarium Trade (MAT). Therefore marine resources are overexploited not only for food species, but also for popular reef species. Over 11 million reef fish and millions of other reef dwellers are taken each year to meet the huge demand of aquarium hobbyists worldwide.

Current market demand leads to extensive wild fish collection, with short-term economic factors usually taking precedence over conservation needs, resulting in major disadvantages for all stakeholders. Hobbyists and traders suffer from poor animal quality, while exporting countries suffer coral reef overfishing, biodiversity loss and habitat destruction; moreover communities form exporting countries suffer economic losses

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and face several risks to their health, and even death, from hazardous fishing methods (Wood, 2001).

Most fishing techniques target juveniles or adults, often breeders, diminishing not only current but also future stocks. The destructiveness of conventional open water fishing for food fish varies according to technique; less destructive methods (e.g. gillnets and long-lining), together with catch restrictions, can help to conserve both stocks and habitat. This is not the case for coral reef fisheries, where many fishermen use harmful chemicals, such as cyanide and dynamite, because these are fast and facilitate the catch of multiple fishes at once (Cartwright *et al.*, 2012). Russ & Alcala (2004) found that 75% of Philippine coral reefs have been damaged by such practices. Not only is there over-fishing, but habitats are also devastated by chemical poisoning or blast damage, leaving nature with no way to recover. It is an undoubted, and somehow inconvenient truth, that the MAT negatively impacts marine biodiversity and human heath, and therefore one of the main challenges facing the MAT today is obtaining specimens that are hardy and economically, as well as environmentally, sustainable.

Governments, conservation organizations, producer communities, dealers and hobbyists have all recognized the role that aquaculture could play in reducing harvesting pressure on wild stock and promoting species conservation (Tlusty, 2002; Koldewey & Martin-Smith, 2010). However, many popular ornamental species do not breed in captivity, and therefore PCC – which harvests wild-caught post-larvae – can significantly increase the number of sustainably-produced species. But does PCC represent a real hope? This chapter provides an overview of the technique, sums-up current PCC deployment and opportunities, and discusses hobbyists' roles and responsibilities.

18.2 PCC *Versus* Fish Life Cycle

Most coastal marine animals (coral reef fish, crustaceans, molluscs) have oceanic larval phases at the beginning of their life cycles (Sale, 1980; Leis, 1991; Leis & Carson-Ewart, 2000) (Figure 18.1). This phase allows them to colonize new habitats, thereby facilitating the species' broad distribution and, consequently, their persistence (Choat & Robertson, 1975; Lobel, 1978; Victor, 1986). Fairly passive during most of this phase, they finally become active in order to seek their new habitat (post-larval stage). The various stages of their life cycle are marked by high mortality, mainly due to natural predation, but also pollution or habitat destruction (Figure 18.2). It has been scientifically demonstrated that during the final colonization phase (when the post-larvae transform into juveniles on the reef habitat (c in Figure 18.2), post-larvae suffer catastrophic mortality rates during the settlement process: more than 90% disappear in the week following colonization (Doherty & McWilliams, 1988, Planes & Lecaillon, 2001; Planes *et al.*, 2002; Doherty *et al.*, 2004). The capture and culture of those post-larvae prior to settlement is called PCC (post-larval capture and culture), a new technique first introduced in 2000 and defined as "*aquarioculture*" when the post-larvae are cultured for sale to the MAT (Delbeek, 2006; Lecaillon & Lourié, 2007).

Eggs, larvae and post-larvae of marine fish and crustaceans are usually considered to be a non-exploitable marine resource, as opposed to juveniles and/or adults, which are actively harvested. Recent publications shed light on the rarely described life stages of those post-larvae (Maamaatuaiahutapu *et al.*, 2006; Junker, 2007; Lecaillon *et al.*, 2012).

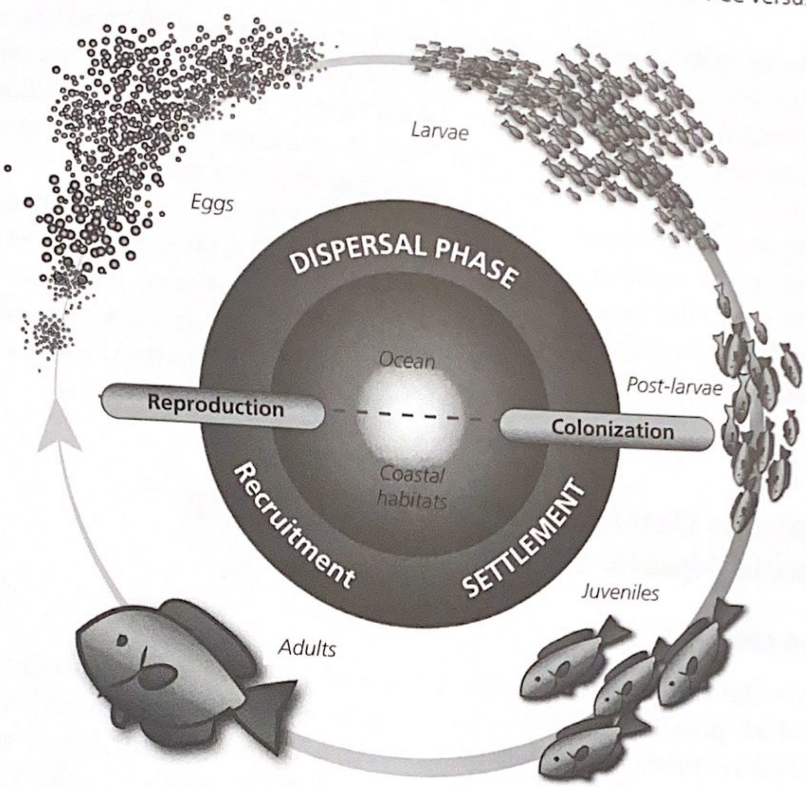

Figure 18.1 Reef fish life cycle (Lenfant *et al*, 2016).

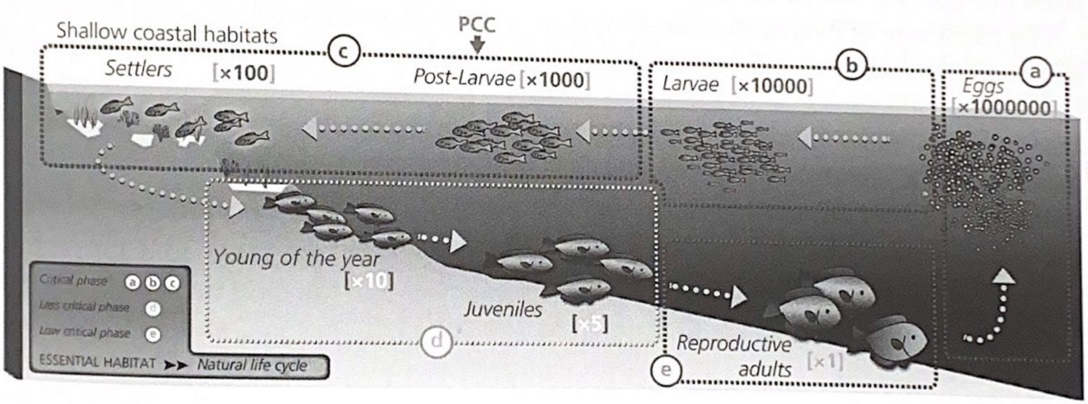

Figure 18.2 Level of mortality within fish life cycle and position of PCC intervention.

Today it is fully accepted that, given the very large number of post-larvae arriving from the ocean, collecting a small percentage of them has a negligible impact, which is also limited in time (Bell *et al.*, 1999, 2009). Thus PCC can effectively exploit a resource that would otherwise be largely and naturally wiped out (Lecaillon, 2004; Lecaillon & Lourié 2007).

Thanks to a range of existing and new collection tools (Lecaillon & Lourié, 2007) and the know-how developed by certain private and public agencies, those post-larval fish can be kept alive, weaned, grown and shipped to supply the marine aquarium trade.

The various inexpensive PCC tools and the different steps required to reach saleable size (sorting, rearing, etc.) are described in various papers (Bell *et al.*, 1999, 2009;

Hair & Doherty, 2003; Lecaillon, 2004; Lecaillon & Lourié, 2007) and are not detailed here. However, PCC technology involves the following major steps: (1) overnight catching of live, healthy and uninjured post-larval fish or crustaceans; (2) identifying and segregating/sorting species which could harm or consume one another; and (3) weaning and growing the fish to a saleable size (average of 3 months).

One of the most important advantages of PCC is that the rearing stage is easy to implement using intermediate technologies, thus reducing the need for technologically advanced and expensive laboratories and hatcheries. Sorted post-larval fish are initially fed with newly hatched *Artemia* (brine shrimp). Fish food granules can then rapidly replace the live food as the fish never develop an appetite for natural reef food. In short, PCC produces pre-conditioned, easy-to-feed marine aquarium animals.

18.3 Features Determining Species Suitability to the Marine Aquarium Trade

18.3.1 Catch Efficiency

Depending on the year, locality, season, wind direction, sea surface temperature, etc., about 30% of all post-larval fish caught is suitable for the ornamental market (e.g. butterflyfish, surgeonfish, colorful damselfish, etc.). Moreover, a further average of 40% can be used for local food fish aquaculture (e.g. rabbitfish, groupers, jacks or snappers). These data are based on experiences over more than one decade and can also differ from one specific site to another.

The catch rate of live, healthy post-larvae is a direct function of the fishing tools used (e.g., hoa net, crest net, light trap, etc.), with certain tools being more suited to specific sites and locations (Lecaillon & Lourié, 2007). However, assuming a site-appropriate choice of tool(s), for PCC to work profitably in a specific location, a combination of the following factors is required:

1) A large number of post-larvae caught alive per night per trap (catch per unit of effort, CPUE). This is directly related not only to the fishing tool used (as noted above) but also to the adult fish assemblage and the overall health of the local habitat. The coral reef fish catch can range from as high as 300 PL/night/trap in a French Caribbean island (Guadeloupe, on-going Zoé project, pers. comm.) down to 20 PL/Night/trap in poor Philippine areas (MAMTI project, pers. comm.).
2) Low internal cost of the fishing activity. This depends on ease of sea access, distance from rearing farm to fishing site, fuel prices and of course local salaries.
3) Easy market access. Direct flights to the main hobbyist markets (USA, Europe and Japan) are essential, as logistical delays can easily damage live animals, regardless of how well they are packed. It is also important to consider freight costs, which usually contribute 30% of the final price of fish arriving in the target markets. In some areas (e.g. French Polynesia), high freight costs were the main reason for the failure to profitably implement PCC.
4) Local political support, as political will and the necessary policies must be in place to help change behaviour and regulate destructive fishing techniques.
5) Availability of attractive and popular species. It is generally assumed that Southeast Asian species are much more colorful and desirable than Caribbean species.

18.3.2 High Quality of Fishes

Opportunities exist mainly in the developing countries of the Coral Triangle (specifically the Philippines, Indonesia and Papua New Guinea, but also East Timor and Solomon Islands), who currently export more than 80% of the wild-caught aquarium fish consumed by the world market (Hoeksema, 2007; Olazul, 2012 in Cartwright *et al.*, 2012). Those countries are not noted for the quality of their exported fish, with mortality rates at times peaking up to 90% between point of collection and final purchase by aquarium hobbyists (Schmidt & Kunzmann, 2005).

The know-how required for the various PCC steps is very well understood and several trials have been successfully carried out (e.g., in the Philippines, Madagascar, Mauritius, Reunion Island, French Polynesia and Fiji), with an astonishingly low mortality rate of less than 2% from point of shipment to one week after reception (Nausicaa Aquarium, pers. comm.). Because an average three months of grow-out are needed to obtain fish of a "small" marketable size (1 month for Pomacentridae but more than 4 months for Chaetodontidae), juveniles become accustomed to human handling and acclimated to elevated levels of fish by-products in their tanks. Their adjustment and acclimatization to the tank environment makes them far less prone to stress and therefore much easier to transport and keep in captivity. PCC aquarioculture also produces immunized and disease-resistant specimens, and thus their acclimatization, freedom from disease and general hardiness improves lifespan in marine aquaria. This in turn enhances demand for such eco-friendly fish while reducing pressure to restock aquaria due to fish mortality.

PCC aquariocultured fishes are considered to be as sustainable and resistant as aquacultured species such as clownfishes and dottybacks. In most cases, captive-bred species are very complementary to PCC species in terms of handling and feeding. Therefore breeders and PCC farmers have the opportunity to pool resources, share fixed expenses and offer a more extensive stock list to the market.

Nevertheless, and despite their many advantages, PCC aquariocultured species must be consistent and attractive.

18.3.3 Consistency

As explained above, PCC catches depend on natural fish recruitment, which is variable in abundance and diversity throughout the year. As shown in Figure 18.3, the over-year recruitment CPUE in Micronesia varies seasonally (Ellis, 2010). During June to August the post-larval catch is very low in some tropical areas, such as Micronesia and the Indian Ocean islands, likely due to low water temperature. These periods are therefore not profitable for PCC. However, from November to April, the CPUE is very high with three months (November, December and May) yielding CPUE of over 100 PL/night/trap.

To deliver a consistent supply of PCC fishes to the market over the entire year, the market needs to be supplied by various fishing sites from different biogeographical regions. The Caribbean region, for example, exhibits the best recruitment with the highest CPUE in July, when the southern Indian Ocean is at its lowest point; in July 2014, the Zoé project caught up to 224 fish per trap with a diversity of 40 species (Igrec Mer/Zoé project, pers. comm.).

While the marine aquarium trade may consider this seasonality to be a disadvantage for the PCC technique, it can be easily offset if PCC producers start exporting (and the

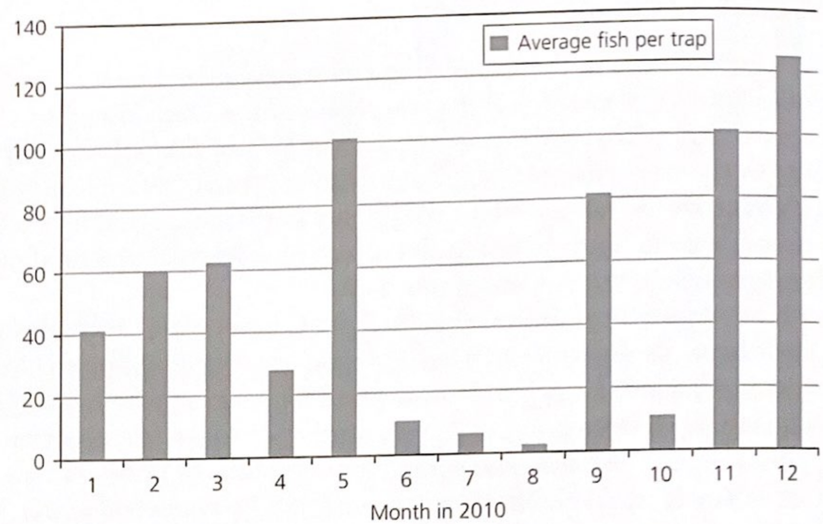

Figure 18.3 Micronesia CPUE over one year (2010). Fish traps used were CARE light traps and crest net.

MAT starts buying) from different sites at different times of the year. For example, *Chromis viridis* can be supplied from the French Polynesian islands or similar islands in the Pacific during the period from June to August and from Mauritius (or similar islands in the Indian Ocean) from October to December. However, if the MAT is to become sustainable it must accept a certain degree of seasonality. If we want PCC-caught yellow tangs we must fish in Hawaii during the natural peak of this species, which occurs from September to November each year with fish being available on the market only 2 to 3 months later.

Such seasonality is not necessarily a disadvantage for the MAT. For example, manufacturers and retailers involved in many other hobbies (such as fishing and hunting) leverage "closed seasons" when people are barred from pursuing their hobby (or aspects thereof) to encourage purchases of expensive items, such as new fishing rods and reels, new guns and bows, training equipment and so on. In the MAT's case, a hobbyist who can't buy new damselfishes until February should be hoping for a nice new aquarium for Christmas (or Hanukkah or Chinese New Year), in order to condition it in time for the arrival of new marine ornamentals.

18.3.4 Species Requested by the Market

Seasonal species composition can be as variable as CPUE. Some species recruit all year round, whereas others only peak once a year. Indeed, the PCC catch rate depends on annual conditions (El Nino *versus* La Niña), season (i.e. temperature of the water) and the inshore fish assemblage. In fact inshore fish species opportunities for PCC vary widely between countries: the French Polynesian archipelago has 633 species of reef fishes, the Marshall Islands up to 827 species and the Philippines a maximum of 2500 species (Myers, 1999).

It is widely but erroneously believed that PCC species do not appear in the top 10 or 20 lists of MAT species. This fallacy is evident from the work by Rhyne *et al.* (2012), where the top species and families of marine fishes entering the US MAT (Figure 18.4 and 18.5). As clearly shown in Figure 18.4 and Table 18.1, pomacentrids lead the list, with species

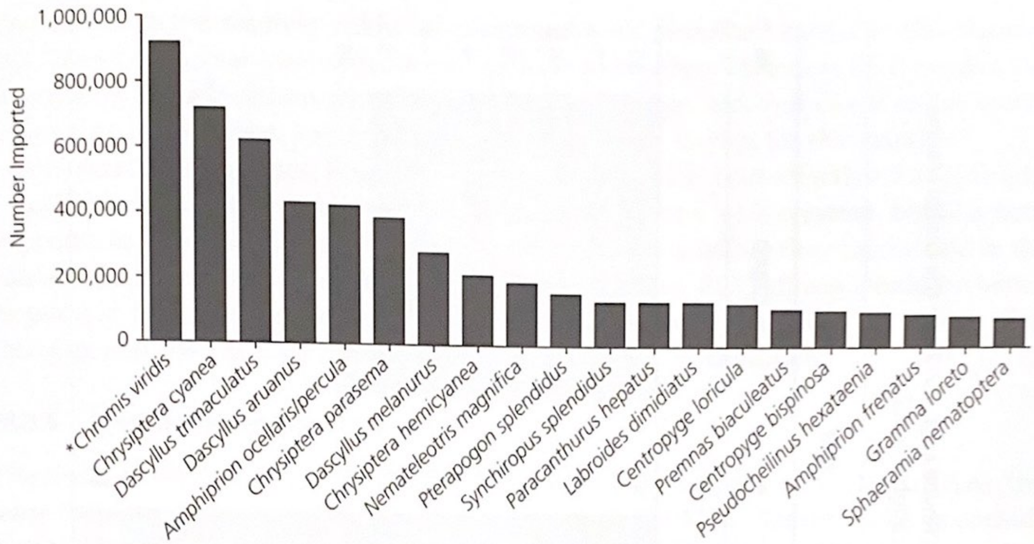

Figure 18.4 Top 20 marine aquarium fish species imported into the United State (from Rhyne *et al.*, 2012). *Indicate species complexes, which could represent more than one species which are all traded under the same name.

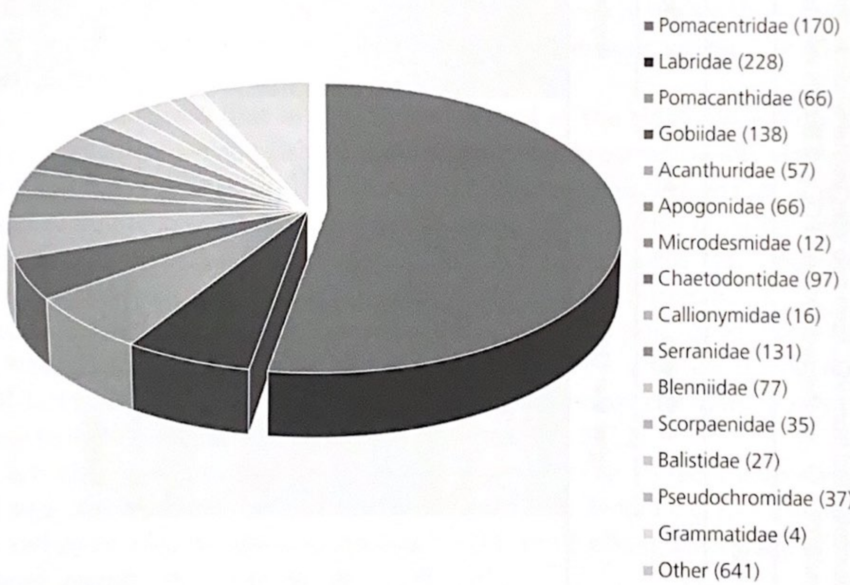

Figure 18.5 Top 10 marine families aquarium fish species imported into the United State (from Rhyne *et al.*, 2012).

such as *Chromis viridis, Chrysiptera cyanea, C. parasema* and *C. hemicyanea, Dascyllus aruanus* or *D. melanurus* being among the top eight species. All of these species (or very similar ones) have already been collected at various PCC sites tested over the last decade. Moreover, if we look at the top ten families (Figure 18.5), the PCC catch is remarkably similar.

Nevertheless, PCC is not a miracle tool – it does not manufacture post-larvae! PCC can only harvest fish species where they are naturally present and at some relative

Table 18.1 Comparison of fish families collected from PCC from two sites versus wild-caught families listed in Rhyne *et al.*, 2012 and the Global Marine Aquarium Database. ■ cells show similarities, ■ cells the specificity of PCC and ■ cells refer to families poorly caught by PCC.

PCC				MAT			
Indian Ocean	%	Caribbean	%	Worldwide	%	GMAD	%
Briot (2012)		Igrec Mer (2014)		Rhyne *et al.*, 2012			
POMACENTRIDAE	43	POMACENTRIDAE	18	POMACENTRIDAE	52	POMACENTRIDAE	45
APOGONIDAE	17	HOLOCENTRIDAE	16	LABRIDAE	8	ACANTHURIDAE	7
GOBIIDAE	5	TETRAODONTIDAE	15	POMACANTHIDAE	7	LABRIDAE	6.5
ACANTHURIDAE	4.5	APOGONIDAE	9	GOBIIDAE	5	GOBIIDAE	6
BLENNIDAE	2	BALISTIDAE	8	ACANTHURIDAE	3	CHAETODONTIDAE	4
HOLOCENTRIDAE	1.8	ACANTHURIDAE	8	APOGONIDAE	2	BLENNIDAE	2.5
BALISTIDAE	1.6	BLENNIIDAE	5	MICRODESMIDAE	2	SERRANIDAE	2.5
SERRANIDAE	1.5	CHAETODONTIDAE	4	CHAETODONTIDAE	2	*OTHERS*	26
CHAETODONTIDAE	1	SYNGNATHIDAE	4	CALLIONIMIDAE	2		
SYNGNATIDAE	0.5	SERRANIDAE	2	SERRANIDAE	2		
LABRIDAE	0.3	DACTYLOPTERIDAE	1	BLENNIDAE	2		
OTHERS	22	*OTHERS*	10	SCORPAENIDAE	1		
				BALISTIDAE	1		
				OTHERS	11		

abundance, as the resident wild reef community. As described earlier in the chapter, PCC sites can also vary widely from one location to another. Therefore PCC needs to be targeted on those locations where the species assemblage and abundance either match existing market needs or can produce viable alternative species for the market.

Even marketable species, however, need to be potentially cost-effective. For example, a significant amount of wrasses (Labridae) can be collected with crestnet, but this family produces very small larvae which need a year of rearing before they can be sold in the market. Because of the comparatively high rearing costs, PCC efforts would be better targeted at less common wrasses that can demand a high market price, rather than common and abundant cleaner wrasses such as *Labroides dimidiatus*.

18.3.5 The Best Site on the Planet?

The closer to the Coral triangle and specifically the Raja Ampat Archipelago (RAA), the more suitable the inshore fish species list for sale to the MAT. Indeed, RAA is considered to have the planet's most biodiverse reefs (Jones & Shimlock, 2002). In November 2009, Ecocean was able to conduct a diagnostic for PCC development over a few days of collection with CARE traps (Lecaillon, 2010). The fishes collected (represented in Table 18.2) were amazingly interesting in terms of both diversity (64 species) and abundance (1739 PL collected in three nights with two CARE traps). The number of fish suitable for sale to the MAT represent 49% of the total catch, with 64% of these species already in demand by the market, including 19% of *Chromis viridis*, the MAT's most highly demanded species.

These results illustrate that if PCC is established in the right place with good reef conditions, and with the right fishing tools, it can provide economically viable opportunities for local communities to produce sustainably caught aquarium fish. The report by Cartwright *et al.* (2012) recommends implementing PCC in combination with a grow-out operation using Micropod™ ocean cages. We recommend this approach to be carried out in combination with the rearing of local food fish species.

In Figure 18.6, we can see the list of families caught from post-larval collection in the Indian Ocean from a 10 years data set from Ecocean (for additional information see Briot, 2012). Pomacentrids represent 43% of the catch and are the main family collected, as they are heavily requested by the MAT (Rhyne *et al.*, 2012).

There is a difference in rank abundance of species in the 16 most abundant families between two islands in the Indian Ocean (Figure 18.7). Thus PCC has the potential to produce and deliver many different species for the MAT taking advantage of the Indian Ocean biodiversity.

18.4 Hobbyist Responsibilities

MAT wholesalers and retailers order and stock species according to hobbyist demand, which is relatively consistent throughout the year and across all major markets for most species. Unfortunately this is a powerful disincentive for the use of sustainable production methods. PCC aquarioculture is affected by seasonality as it relies on fishing for post-larvae at specific times of the year. Therefore, despite the availability of sustainable production methods, the MAT continues to demand wild-caught fish even though

Table 18.2 Fish species collected with CARE light trap during the Conservation International diagnostic.

Families	Scientific name	Qtv
Acanthuridae	*Acanthurus pyroferus*	1
Blenniidae	*Escenius* sp1	4
	Escenins sp2	2
Caesionidae	*Pterocaesio* sp	93
	Pterocaesio sp2	1
Carangidae	*Caranx sexfasciatus*	1
	Scombrides sp	2
Chaetodontidae	*Chaetodon* sp	1
Cirrithidae	*Paracirrithes* sp	2
Holocentridae	*Neoniphon sammara*	21
	Holocentrids sp	11
Labridae	*Stetojulis* sp	4
	Coris sp	2
Lutjanidae	*Macolor niqer*	2
Nemipteridae	Scolopsis lineatus	27
	Scolopsis sp	1
Mullidae	*Parapuneus bifasciatus*	4
Pomacanthidae	*Pomacanthus semicirculatus*	2
Pomacentridae	*Pomacentrus* spp	1
	Amblyglyphidodon tematensis	18
	Pomacentrus coelistis	75
	Dascyllus trimaculats	30
	Dascyllus reticulatus	35
	Pomacentrus chrysurus	35
	Pomacentrus dark spot, red line on	6
	Pomacentrus yellow tail	149
	Pomacentrus yellow tail+ black spot	28
	Chrysiptera talboti	3
	Chrysiptera rex	6
	Chromis viridis	109
	Chromis lepidolepis	55
	Plectroglyphidodon lacrymatus	50
	Neoglyphidodon sp1	1
	Neoglyphidodon sp2	1
	Chromis tematensis	2
	Pomacentrus yellow+ black spot	19
	Pomacentrus moccculensis	12

Table 18.2 (*Continued*)

Families	Scientific name	Qtv
Siganidae	*Siganus spinus?*	16
	Siganus sp2	6
Tetraodontidae	*Canthigaster benneti*	1
	Arothron hispidus	2
Special families	*Triacanthidae/monodactylus?*	1
	Caloplessiops altivelis	1
	Platycephalidae	1
	Pleuronectidae	1

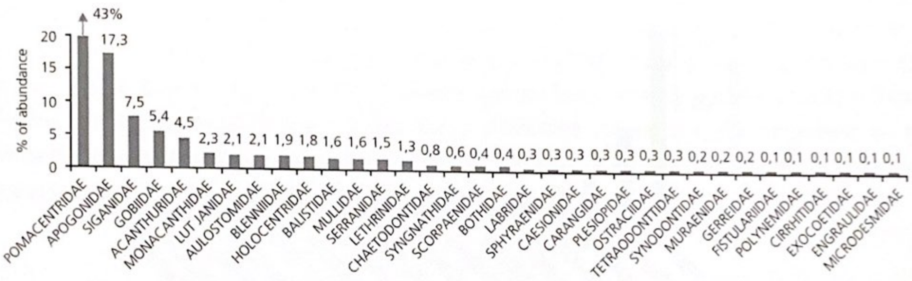

Figure 18.6 Rank-abundance diagram for the 35 families more abundant in the Indian Ocean (four islands grouped).

sustainably reared fish are available. This naturally has a catastrophic impact on reef population assemblages worldwide. For example, the yellow tang (*Zebrasoma flavescens*) is native to Hawaiian reefs and highly valued by aquarium hobbyists. Thousands of yellow tangs are taken by the trade annually. Unfortunately, only recently have yellow tangs been bred in captivity and the species only recruits in sufficient numbers for viable PCC collection from September to November. If every hobbyist wants this species anytime anywhere, the market will never become green, and ironically the high seasonality and predictability of breeding behaviour of such wild fish species actually contributes to the market's unsustainability.

In contrast to wild-fishing for adults, PCC actually leverages the seasonality and predictability of breeding behaviour to reduce its impact to negligible levels, and thus has a great advantage in terms of sustainability. However, PCC fishing is not strongly species selective, and yields quantities of post-larvae species in accordance with the respective species abundance at the fishing site. Thus PCC will invariably collect more damselfishes than angelfishes, because in the wild, damselfishes are much more common. This is not necessarily a disadvantage if hobbyists can be persuaded to adapt their behaviour accordingly. They can play a very positive role in reducing the destruction of the coral reef ecosystem by opening their minds (and wallets) to new original species produced by captive breeding or by PCC aquarioculture. A good example is that of *Chromis nigrura* from the Indian Ocean, which exhibits identical peaceful and unaggressive behaviour to the popular *Chromis viridis* and can be caught sustainably in large numbers at Reunion Island and Mauritius.

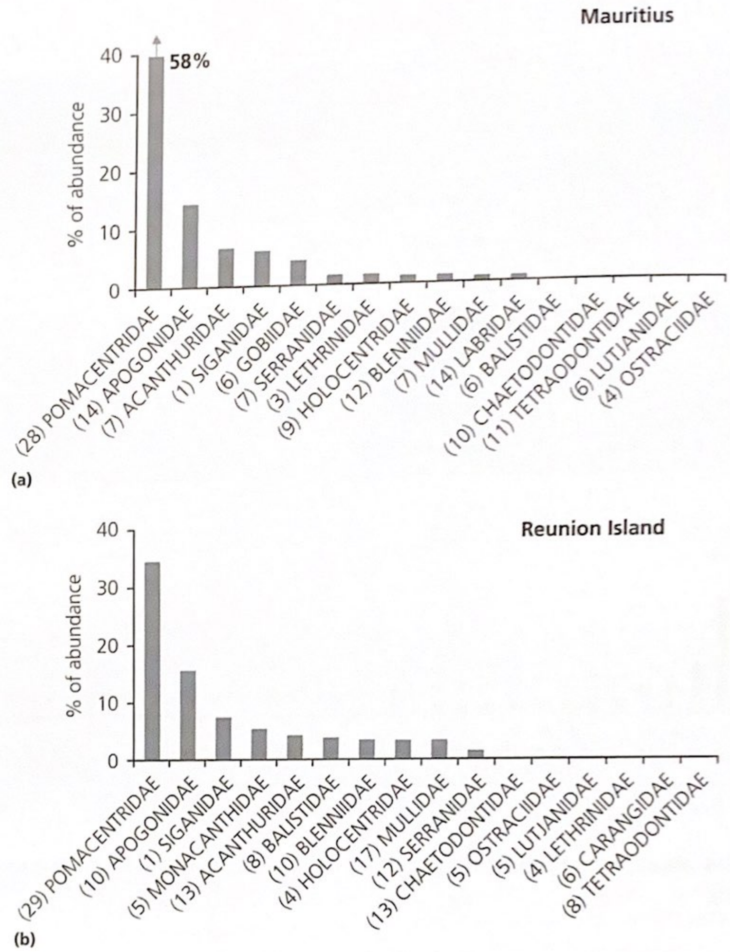

Figure 18.7 Rank-abundance diagram for the 16 first families more abundant in two different Indian Ocean islands. (a) Mauritius and (b) Reunion Island.

For the marine ornamental fish trade to become and remain sustainable, hobbyists must learn to accept a degree of seasonality in the availability of the most popular species, and acquire their new specimens during the appropriate period of the year.

Finally, hobbyists must be prepared to pay for sustainable PCC-caught and captive-bred fish versus unsustainable wild-caught adults. According to the recent Bren School of Environmental Science and Management study (Cartwright *et al.*, 2012), American hobbyists are willing to pay up to 25% more for sustainably caught fish compared to regular wild fish caught. If the MAT is prepared to address this apparent willingness, it will have a direct positive impact on the entire market chain: aquaculture operations and fisherman can increase their income; distributors and retailers can increase their turnover and profit margins; and hobbyists can enjoy higher quality fish with much-reduced mortality. However, the study referred above declared willingness and not an actual behaviour. Despite the best of intentions, when a hobbyist enters an aquarium store with his or her own hard-earned money, the resulting purchasing behaviour may well lean towards cheaper wild-caught fish, even though tank-raised fish are almost certain to stay alive much longer and far less likely to die within a couple of weeks!

It has been clearly demonstrated that both PCC aquarioculture and captive-breeding aquaculture can contribute to the sustainability of the MAT. However, only a profound shift towards sustainability in hobbyist behaviour can actually green the market.

There are actually some precedents for such behaviour change in other areas. For example, sport hunters contributed to the extinction of the passenger pigeon and the near extinction of the American bison, while anglers (sport fishers) were principally responsibility for the near absence of the Atlantic bluefin tuna from the North Sea. However, at least in North America and Northern Europe, hunting and angling organizations are now amongst the most powerful and effective conservation lobbyists, and have themselves voluntarily introduced or proposed legislation for close seasons, catch reductions, size limits and restrictions on equipment used. It could be argued that this change of behaviour, which took place gradually over many decades, was entirely due to self-interest, as both hunters and anglers recognized the impact their behaviour was having on their choice of activity. Nevertheless their behaviour did become far more sustainable.

The major difference between hunters, angers and aquarium hobbyists is that the first two groups were able to experience their environmental impacts directly, in terms of scarcity of game and fish. The aquarium hobbyist, by comparison, is one step removed; he or she may be theoretically aware of the impacts of this hobby, but experiences these impacts only indirectly in terms of increased prices for certain species, and not directly by diving on a devastated reef. Thus more effective measures are required to raise awareness amongst marine aquarium hobbyists about the impacts of their activities and the mitigating strategies available to them.

18.5 PCC Experiences

A successful PCC project must collect a large number of post-larvae to be able to obtain sufficient numbers of the most desirable species for the MAT. In most cases, roughly 40% of the post-larvae collected are suitable for the MAT. However, unlike other fishing methods, the remaining 60% are hardly by-catch. Instead, they are also tank-reared and then aquacultured for two purposes. Firstly, they can supply the local (and occasionally regional) food fish market, thereby reducing commercial fishing pressure on reef species and also contributing to the profitability of the project as side income. Secondly, they can be reintroduced to the coral reef alive for restocking purposes (along with a proportion of the ornamental species where this would be beneficial) or be used for feeding the selected valuable species.

Over the last decade, attempts at building profitable businesses based on PCC have not entirely succeeded. Problems often originated from administrative or political interference or inertia (e.g., Mauritius and Reunion Island), because local stakeholders were not sufficiently involved and motivated (e.g., Madagascar) or because the distance from market, as well as local labor and material costs, were just too high (e.g., French Polynesia, New Caledonia). However, two Southeast Asian projects (Marine Aquarium Market Transformation Initiative – MAMTI and National Fish and Wildlife Foundation – NFWF) came very close to profitability, despite the local marine resource being too overfished in the targeted areas (Bohol Island), the species caught lacking in attractiveness to the MAT and the CPUE being too low (20 PL/night/trap).

In the Indian Ocean, Mauritius and Reunion islands produced excellent stock lists, such as the one obtained in November 2012 from the Eco Fish Mauritius PCC project (see Table 18.3). Up to 50 different species were available, with damselfishes being the

Table 18.3 Stock list example of available fishes and crustaceans from PCC from Mauritius islands in February 2012.

Scientific name	Common english name	Qty
Cardinalfishes		
Apogon apogonides/evermanni	Short-tooth cardinal	4
Apogon cyanosoma	Yellowstriped cardinalfish	80
Apogon kallopterus	Iridescent cardinalfish	4
Apogonichthys perdix	Perdix cardinalfish	170
Damselfishes		
Chromis dimidiata	Chocolatedip chromis	4
Chromis lepidolepis	Scaly chromis	113
Chromis nigrura	Blacktail chromis	615
Chromis viridis	Blue green damselfish	70
Chrysiptera brownriggii/leucopoma	Surge damselfish	168
Chrysiptera glauca	Grey demoiselle	55
Dascyllus aruanus	Whitetail dascyllus	70
Dascyllus carneus	Cloudy dascyllus	4
Dascyllus trimaculatus	Threespot dascyllus	158
Plectroglyphidodon dickii	Blackbar devil	14
Plectroglyphidodon imparipennis	Brighteye damselfish	145
Plectroglyphidodon johnstonianus	Johnston Island damsel	15
Pomacentrus caeruleus	Caerulean damsel	2290
Pomachromis richardsoni	Richardson's reef-damsel	670
Boxfishes		
Arothron nigropunctatus	Blackspotted puffer	2
Canthigaster coronata	Crowned puffer	1
Canthigaster solandri	Spotted sharpnose	1
Canthigaster valentini	Valentin's sharpnose puffer	6
Lactoria cornuta	Longhorn cowfish	2
Lactoria fornasini	Thornback cowfish	1
Ostracion cubicus	Yellow boxfish	1
Blennies & Gobies		
Cirripectes castaneus	Chestnut eyelash-blenny	6
Eviota albolineata	Spotted fringefin goby	26
Exallias brevis	Leopard blenny	3
Surgeonfishes		
Acanthurus nigrofuscus	Brown surgeonfish	1
Acanthurus triostegus	Convict surgeonfish	90

Table 18.3 (*Continued*)

Scientific name	Common english name	Qty
Triggerfishes & limefishes		
Cantherhines pardalis	Honeycomb filefish	3
Rhinecanthus aculeatus	White-banded triggerfish	10
Rhinecanthus rectangulus	Wedge-tail triggerfish	1
Butterflyfishes		
Chaetodon auriga	Threadfin butterflyfish	8
Chaetodon guttatissimus	Peppered butterflyfish	1
Chaetodon lunula	Rancoon butterflyfish	3
Chaetodon trifasciatus	Melon butterflyfish	1
Chaetodon xanthocephalus	Yellowhead butterflyfish	1
Divers		
Corythoichthys schultzi	Schultz's pipefish	10
Epinephelus fasciatus	Blacktip grouper	10
Epinephelus flavocaeruleus	Blue-and-yellow grouper	1
Grammistes sexlineatus	Goldenstriped soapfish	20
Histrio histrio	Sargassumfish	2
Lutjanus kasmira	Common bluestripe snapper	8
Myripristis murdjan	Pinecone soldierfish	3
Parupeneus bifasciatus	Doublebar goatfish	1
Parupeneus macronemus	Long-barbel goatfish	4
Priacanthus sp	Bigeye sp	1
Pterois volitans	Red lionfish	1
Solenostomus paradoxus	Harlequin ghost pipefish	1
Crustaceans		
Stenopus hispidus	Banded cleaner shrimp	10

most abundant. The color and tank behaviour of those species were really attractive but they were unknown to the market, and thus the MAT was not yet ready to accept them. Additionally, the local government failed to provide final authorization for commercial exploitation due to political disagreements. Export freight was also expensive, as local shipping companies and freight forwarders preferred to charge high one-off prices for shipments rather than help develop this sustainable market (and generate a repeat business for themselves) by offering regular freight prices. A PCC project is still operating in Madagascar but, at present, they have no authorization to export.

Some experiences have been more positive. In Hawaii an aquaculture company is collecting post-larvae fish for a local program named "adopt a baby fish" which is designed to raise awareness of marine conservation among local school students. (www.livingartmarinecenter.com). Sustainable Aquatics has proposed using PCC to harvest sustainable fish from the Solomon Islands using crest nets. Conservation International is still looking of money to try developing PCC in the Raja Ampat archipelago, probably the most suitable location of all for this sustainable technology.

Indeed, PCC is an excellent tool with which to educate people, fisherman and even tourists about the state of our coral reefs and to research and better understand this little-known part of the life cycle of coastal marine species.

18.6 Conclusions

In summary, tank-raised fish from post-larval collection offer many benefits both for conservation and for the marine aquarium trade. They reduce the number of wild-caught fish, which in turn decreases the pressure from marine ornamental collectors on coral reef habitats. Even with such a fantastic principle, PCC has not yet become really successful worldwide. As described earlier in this chapter, for PCC to work a combination of local factors and market desire is needed, not all of which are yet in place at the right markets and locations. We also have to cope with unrealistic expectations; some countries have expected PCC techniques to work on reefs and fisheries that have already been overfished to the point of local extinction, when of course it is too late for this method to have any effect. Without genitors, there are no post-larvae, and with reef habitats in poor condition, there are insufficient genitors, so naturally PCC cannot be profitable under these circumstances. When implemented in healthier neighboring areas, however, it can be a valuable source of healthy live fishes for restocking. On the positive side – and as a result of the effort, expense and energy devoted to the development of this technology by a number of very dedicated people – PCC has already been labeled "good practice" by the International Coral Reef Initiative (www.icriforum.org). Organizations such as UNESCO, through its Man and Biosphere (MAB) Programme, have found PCC suitable for building quality economies through the conservation and sustainable use of coastal and marine biodiversity. The overwhelming majority of the technological challenges have already been overcome, and it is now fully feasible to transfer capacity building and technology of the various steps to local communities.

It is only fair to point out that funding for PCC has been somewhat limited – the CRISP project (500 K US$, AFD), the MAMTI project (300 K US$, World bank), a couple of other experiments funded by the NOAA and the French Polynesia Fisheries Department and about a dozen small private investments worldwide. In short, no more than US$ 3 million has been spent on developing PCC in over a decade. In contrast, many decades of research and development have been conducted and millions and even billions of dollars have been spent to overcome the technological barriers to global food fish aquaculture, with many millions more for aquacultured marine aquarium fishes (such as clownfish).

The stakes are enormous – the future survival of our tropical coral reefs! We must invest in this technique because it is fully sustainable and is proven to work when all the requisite factors are in place. We have the know-how and the technological barriers have been overcome. We only lack the necessary political will, a modest amount of funding and the MAT's sincere desire to green itself. If hobbyists can become more aware, if policy makers can make courageous decisions (Tissot *et al.*, 2010) and if institutional donors and governments are willing to invest, PCC can be a powerful tool to help green the MAT and mitigate its impacts.

If not successfully mitigated, these impacts are far more likely to increase than to decline in the foreseeable future. Chinese aquarium hobbyists (and Koreans, Malaysians, Singaporeans, wealthier Indonesians and Filipinos) absolutely adore ornamental freshwater fish and are busy developing a similar passion for marine species. Asia's emerging economies are capable of bringing literally millions of new and acquisitive hobbyists to the global MAT, and thus greening the industry is a priority of the greatest possible urgency. PCC fish – along with other sustainably reared fish – have to become products that hobbyists demand from the MAT because they are not only eco-friendly but also better and more desirable! Consumer demand will green the market far more effectively than any legislation.

To conclude on a positive note, PCC serves to reduce the pressures on adult reef fish by offering access to a new and under-exploited or even unexploited marine resource in tropical seas and developing countries. However, PCC is also suitable for use by advanced nations in temperate seas as an additional economic, conservation and restocking resource (mitigation banking), especially where conventional conservation strategies have already failed. The heavily over-fished Mediterranean and North Sea fisheries are good examples of areas that could benefit from such an approach. Finally, PCC is also an excellent tool to study and understand this little-known part of the life cycle of coastal marine species; research projects using PCC, such as the SUBLIMO LIFE+ Project (www.life-sublimo.fr) are still on-going. Post-larval capture and culture is certainly not the only solution to the overexploitation of demersal marine aquarium trade species, but it is nevertheless a valuable one that directly complements other conservation strategies, such as the development of aquacultured marine aquarium species detailed in this book.

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MARINE ORNAMENTAL SPECIES AQUACULTURE

The global trade of aquatic organisms for home and public aquariums, along with associated equipment and accessories, has become a multi-billion dollar industry. Aquaculture of marine ornamental species, still in its infancy, is recognized as a viable alternative to wild collection as it can supplement or replace the supply of wild-caught specimens and potentially help recover natural populations through restocking.

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