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Chapter 34

The role of sexual coral reproduction in captive population management – a review

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ABSTRACT

Public aquaria increasingly apply sexual reproduction as a tool to managing their coral live stock. Since biological processes are better understood and since techniques are developed to obtain sexual propagules either from captive corals or from the field, sexual recruits may be produced from an increasing number of species. In captivity, larvae can be collected from brooding species on a regular basis; in some cases, larvae of broadcast spawners could be generated during captive spawning events. The control of the settlement process and of the development of early life stages is essential to produce high numbers of juveniles. This paper gives an overview of this rapidly developing field of interest.

INTRODUCTION

For many years, the spontaneous appearance of juvenile corals occasionally observed on rockwork and tank walls in aquaria indicated sexual reproduction in captivity. However, such recruitment could also have been the result of asexual reproduction such as polyp bail-out, polyp balls or asexual planulae (Harrison and Wallace, 1990). Since basic techniques are increasingly available for public aquariums to study sexual coral reproduction, we begin to better understand this mystery and its controls. If an aquarist should envisage to sexually reproduce corals in captivity or to enhance the reproductive success, he/she has to understand and control the fundamental processes: gametogenesis, fertilization, embryogenesis, planktonic larval stages, larval settlement and metamorphosis, and, last but not least, recruitment of juveniles. If this chain of events is interrupted, no reproduction will occur.

In this paper, basic reproductive processes and their control is summarized; an overview on sexual reproduction in public aquariums is given as well as a brief outlook into the future of this rapidly developing field draws chances, challenges and limits.

BASIC PROCESSES AND THEIR CONTROL IN CAPTIVITY

There are two modes of sexual reproduction in corals. 'Brooders' may release settlement competent larvae following internal fertilization. Only sperm cells are released during spawning events whilst eggs stay protected inside the coral polyp. 'Broadcast spawners' release their gametes usually during mass spawning events into the water column where fertilization takes place near the water surface. Most corals studied up to date are simultaneous hermaphrodites (female and male gonads within a polyp), whereas most of the remaining species are gonochoric (one sex per colony). Geographic variation in modes and sex may occur within a species, which may be of great relevance for planning a brood stock (Harrison and Wallace, 1990). If possible, only brood stock from a well known geographic region should be used for captive breeding; otherwise, breeding incompability may occur. Following the advice of Baums (2008), mixing of genotypes from different geographic regions should be avoided, if the captive bred corals might be reintroduced in the natural coral reef in future. Otherwise, local genotypes might be extinct by more opportunistic alien genotypes. Scleractinian corals usually reach maturity species-specifically after 3 to 5 years (Harrison and Wallace, 1990);

however, opportunistic brooders may be fertile after less than one year (Petersen *et al*., 2007). It is important for any captive breeding attempt to give the parental corals space to grow to a minimum size for reaching maturity. Only when a species specific colony size has been reached, gonads are developed (Harrison and Wallace, 1990). Frequent fragmentation might lead to at least partial infertility in corals as shown in a comparative field experiment in *Acropora formosa* (Okubo *et al*., 2007). Oocyte production was disturbed in fragmented corals which partly led to resorbtion of oocytes in the fragmented areas. Sexual reproduction is cost-intensive for corals. Only if the brood stock is healthy, exposed to low or no competition (algae, cnidarians) and has optimum light and water conditions, gametogenesis will occur. Organic food sources are an important energy source for hermatypic corals for producing gametes under aquarium conditions.

Gonads, especially of broadcast spawners, are not present throughout the year; usually they are developed a few months before the actual spawning event. As a consequence, gametogenesis in broadcasters may take a few months, whereas brooders may have shorter gametogenetic cycles with a minimum of around one month. Brooders may have multiple gametogenetic cycles per year, whereas broadcast spawners usually have one annual cycle. The only method to monitor gametogensis in captive corals is histology; however, since this technique is invasive and partly damaging the corals, it will probably only be chosen for larger colonies, which are less affected by a partial damage.

Spawning in broadcasters is usually synchronized by various environmental triggers such as moon cycle and annual water temperatures. It is currently accepted that annual temperature cycles determine the month of spawning, the moon cycle defines the day, and the time of sunset determines the precise hour of spawning in a time frame of minutes (Jokiel *et al*., 1985; Babcock *et al*., 1986; Fukami *et al*., 2003). For specific information on reproductive biology in corals, see Fadlallah (1983) and Harrison and Wallace (1990). Petersen *et al.* (2007a) gives an overview on reproductive modes of coral species that have shown reproductive behaviour in aquaria. Gametes of broadcast spawning species can be collected with plankton netting from specific colonies or from the water surface (Iwao et al., 2002). Collection has to occur within minutes after gamete release since sperm vitality is very limited. Ideally fertilization is carried out in the laboratory using plastic bowls with seawater. Sperm concentration of $>10^6$ cell per ml may lead to fertilization rates of >90 % (Hatta, pers. com.; Petersen, pers. observation; Szmant, pers.com.).

After fertilization, embryos of brooders develop in several days to weeks inside the coral polyp whilst those of broadcast spawners undertake embryogenesis in the water column within 2 to 6 days depending on the species and environmental conditions. The culture of embryos of broadcasters is labour and time intensive. Embryos have to be transferred frequently and gently to fresh seawater for a few days until they reach settlement competency (Petersen, personal observation). Innovative methods such as automized flow-through culture devices are important steps for optimizing cultures (Hagedorn *et al*., unpublished). Contrary, embryogenesis in brooders takes place inside the coral polyp; therefore, no embryo culture is necessary.

After reaching settlement competency, larvae start developing searching behaviour on the benthos in order to find the most ideal location for settlement and metamorphosis. Certain cues such as crustose coralline algae may enhance settlement whereas cyanobacteria and filamentous algae may reduce settlement (Morse *et al*., 1996; Negri *et al*., 2001; Petersen *et al*., 2005). Established corals may inhibit settlement of other coral species (Maida *et al*., 1995). Metamorphosis usually takes place within 24 hours after settlement. Corals tend to settle in a more cryptic microhabitat which gives them shelter and protection from aggressive grazing, predation and competition. Under aquarium conditions, settlement is often limited due to high spatial competition from other corals. Any filtration bares the risk of loosing planktonic larvae. It is much more effective to collect larvae from brooders shortly after their release using plankton netting (Petersen *et al*., 2007). Hereby the parental colony is surrounded by plankton netting that allows water circulation, but holds back any released larvae. If the colony is positioned near the water surface, the top of the sampling device doesn't have to be covered by plankton mesh, therefore, larvae can be easily collected from the water surface using a pipette.

Primary polyps usually measure about 1 mm in diameter and are easily outcompeted by algae or other sessile organisms. Therefore,

once the coral has reached a semi-stable size, it is growing into more (light-)exposed areas. In general in the field, about 60 to 90 % of the early settlers die within the first 3 to12 months after settlement (Sorokin, 1995). Under captive conditions, especially algae and sediments may highly reduce survival and growth of juveniles, whereas predation can be mostly excluded under aquarium conditions. Feeding may play an important role in the early development of coral recruits (Petersen *et al*., 2008). So far, a complete life cycle of a reefbuilding coral in captivity has only been reported for the brooder *Favia fragum* (Petersen *et al*., 2007).

CURRENT STATUS IN PUBLIC AQUARIA

A questionnaire was distributed by the Coral ASP (Aquatic Animal Sustainability Program) of the European Union of Aquarium Curators (EUAC) in 2004 (Petersen *et al*., 2007a). In order to include recent developments, a second questionnaire was distributed by the author in March 2007 through the AquaticInfo list server. Additional information was available through personal communication. Regarding scleractinians, 45 species of 13 families were observed to reproduce in captivity of which 29 species established recruits (see Table 1). A total of 24 public aquariums observed reproductive events; however, 79 % of the total number of species (30 species) were observed to reproduce in two institutions: Reef HQ Townsville, Australia (22 species) and Oceanopolis Brest, France (8 species).

FUTURE OUTLOOK

In general, large-polyped coral species can be hardly propagated through fragmentation compared to branching species. Therefore, besides fragmentation, captive sexual reproduction will be important to stock public aquariums sustainably. However, there are exceptions such as certain species of the genus Euphylia, which can be more routinely fragmented (Janse, pers. com.). Other corals such as *Trachiphyllia geoffroyi* are attractive aquarium corals which currently can not be propagated at all and therefore are purely collected in the field (Carlson, pers. com.; Jones, pers. com.). Last but not least, public aquaria should at least partly aim at establishing potential brood stock and breeding techniques of critically threatened or endangered species which may serve in future as a basis for coordinated breeding programs.

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Table 1: Overview of reproductive events in public aquaria as reported up to date

Species	Temp.	Moon	Generation F1	Generation F2	Manipulation	Institution
Acropora formosa[2]	variable	yes	>100	0	yes	Okinawa Churaumi Aquarium, Japan
Acropora microphthalma[2]	variable	yes	>100	0	yes	Okinawa Churaumi Aquarium, Japan
Acropora nobilis[2]	variable	yes	>100	0	yes	Okinawa Churaumi Aquarium, Japan
Acropora secale	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Acropora valida[2]	variable	yes	0	0	no	Birch Aquarium at Scribbs, USA
Acropora yongei[2]	variable	yes	0	0	no	Waikiki Aquarium, Hawaii
Agaricia humilis[2]	const.	no	<10	0	no	Rotterdam Zoo, The Netherlands
	variable	yes	>100	0	yes	Rotterdam Zoo, The Netherlands
Astroides calycularis[2]	const.	no	>100	0	no	Musée océanographique de Monaco, Monaco
Caulastrea tumida[2]	variable	yes	<10	0	yes	Kushimoto Marine Park, Japan
Cycloseris sp.	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Echinopora lamellosa[2]	const.	yes	<10	0	no	Burgers' Zoo, The Netherlands
	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Euphyllia ancora[2]	variable	yes	0	0	no	Waikiki Aquarium, Hawaii
	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Euphyllia paradisa	const.	yes	<10	0	yes	Oeanopolis, France
Euphyllia glabrescens[2]	variable	no	10-100	0	yes	National Museum of Marine Biology and Aquarium, Taiwan
Euphyllia divisia	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Favia fragum[2]	const.	no	>100	>100	no	Rotterdam Zoo, The Netherlands
	variable	yes	>100	>100	yes	Rotterdam Zoo, The Netherlands
	variable	no	<10	0	no	Columbus Zoo and Aquarium, USA
	const.	yes	10-100	0	yes	Oeanopolis, France
Favia sp.	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Fungia scrutinaria	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Galaxea sp.[2]	const.	no	<10	0	no	Skansen-Akvariet, Sweden
Galaxea fascicularis[2]	const.	yes	<10	0	no	Burgers' Zoo, The Netherlands
Goniopora gigas[2]	variable	yes	0	0	no	Waikiki Aquarium, Hawaii
Heliofungia actiniformis	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Herpolitha limax	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Hydnophora exesa	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Hydnophora rigida	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Merulina ampliata	variable	yes	10-100	0	no	Reef HQ Townsville, Australia

Table 1 (continued): Overview of reproductive events in public aquaria as reported up to date

Species	Temp.	Moon	Generation F1	Generation F2	Manipulation	Institution
Montipora capitata[2]	variable	yes	0	0	no	Waikiki Aquarium, Hawaii
Mycedium elephantotus	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Pachyseris rugosa	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Pavona decussata	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Pocillopora damicornis[2]	const.	yes	>100	0	no	Oceanopolis, France
	const.	yes	10-100	0	no	Tokyo Sea Life Park, Japan
	const.	no	<10	0	no	London Zoo, UK
	const.	no	10-100	0	no	New England Aquarium, USA
	variable	no	>100	0[1]	yes	National Museum of Marine Biology and Aquarium, Taiwan
	variable	no	<10	0	no	Cologne Zoo, Germany
	const.	no	10-100	0	no	Vancouver Aquarium Marine Science Centre, USA
	variable	yes	10-100	0	no	Waikiki Aquarium, Hawaii
	const.	no	10-100	0	no	CineAqua Paris, France
	variable	yes	10-100	0	no	Pittsburgh Zoo & PPG Aquarium, USA
	variable	yes	>100	0	no	Reef HQ Townsville, Australia
Pocillopora verrucosa	const.	yes	<10	0	yes	Oceanopolis, France
Pocillopora sp.[2]	const.	yes	10-100	0	no	Oceanario de Lisoboa, Portugal
Porites astreoides	const.	no	<10	0	no	Rotterdam Zoo, The Netherlands
Porites sp.	const.	yes	<10	0	yes	Oceanopolis, France
Physogyra lichtensteinii	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Sandalolitha robusta[2]	variable	yes	0	0	no	Waikiki Aquarium, Hawaii
Seriatopora hystrix[2]	variable		>100	0[1]	yes	National Museum of Marine Biology and Aquarium, Taiwan
	const.	yes	<10	0	no	Oceanopolis, France
Stylocoeniella guentheri	const.	yes	<10	0	yes	Oceanopolis, France
Stylophora pistillata[2]	variable	no	>100	0[1]	yes	National Museum of Marine Biology and Aquarium, Taiwan
	const.	no	<10	0	no	Musée océanographique de Monaco, Monaco
	const.	yes	<10	0	no	Oceanopolis, France
Symphyllia radians	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Tubastrea aurea	variable	no	10-100	0	no	Zoo Aquarium Madrid, Spain
Tubastrea coccinea[2]	variable	no	10-100	0	no	Waikiki Aquarium, Hawaii
	const.	no	10-100	0	no	Rotterdam Zoo, The Netherlands
Tubastrea sp. 1[2]	const.	no	<10	0	no	London Zoo, UK
Tubastrea sp. 2	const.	no	>100	0	no	National Museums Liverpool, UK
Turbinaria reniformis[2]	variable	yes	0	0	no	Birch Aquarium at Scribbs, USA
	variable	yes	10-100	0	no	Reef HQ Townsville, Australia
Turbinaria peltata	variable	yes	10-100	0	no	Reef HQ Townsville, Australia

1 Mature eggs and sperm, and early embryos present in coelenterons of specimen of F1 generation.
2 Data reported by Petersen *et al*. (2007a).