

## Technical Report

# Transportation Techniques for Massive Scleractinian Corals

Dirk Petersen,<sup>1,2\*</sup> Michaël Laterveer,<sup>2</sup> David van Bergen,<sup>3</sup> and Maureen Kuenen<sup>4</sup>

<sup>1</sup>Department of Hydrobiology, Institute of Ecology, University of Essen, Essen, Germany

<sup>2</sup>Rotterdam Zoo, Rotterdam, The Netherlands

<sup>3</sup>Curaçao Sea Aquarium, Curaçao, Netherlands Antilles

<sup>4</sup>Marine Awareness Center, Curaçao, Netherlands Antilles

Transportation techniques for scleractinian corals have been described mainly for fragments and small colonies. As part of a recent study on captive sexual reproduction of the Caribbean species *Montastrea annularis* and *Diploria strigosa*, we transported relatively large (max. diameter of 21 cm), heavy (max. weight of 9,200 g) colonies of both species from Curaçao, Netherlands Antilles, to Rotterdam, The Netherlands. A new transportation technology was applied whereby the corals were transplanted to specially designed PVC crosses to provide stabilization during transport. In two transports (November 2001 and February 2002), 100 colonies were transported submerged, in a shipping time of > 35 hr. The survival rate measured 2 weeks after transport was 100%. Four and 8 months after transport, respectively, two colonies of *D. strigosa* died without any obvious cause. In November 2002 we observed an outbreak of Dark Spots disease (DSD) affecting two-thirds of the colonies of *M. annularis*. Although the colonies did not show any symptoms when they were collected, the disease most probably was transferred when the coral were transported from the field to the laboratory. The presented method is appropriate for transporting large, heavy corals—especially for scientific purposes. In general, species-specific properties, colony size, and transportation time determine which transportation method should be applied. In the future, there may be a shift toward transports of

Grant sponsor: German Federal Environmental Foundation (DBU).

\*Correspondence to: Dirk Petersen, Rotterdam Zoo, P.O. Box 532, 3000 AM Rotterdam, The Netherlands. E-mail: d.petersen@rotterdamzoo.nl

Received for publication March 28, 2003; Accepted May 9, 2003.

DOI 10.1002/zoo.10127

Published online in Wiley InterScience (www.interscience.wiley.com).

fragments, coral larvae, and primary polyps to reduce collections in the field. *Zoo Biol* 23:165–176, 2004. © 2004 Wiley-Liss, Inc.

**Key words:** *Diploria strigosa*; *Montastraea annularis*; ex situ; transfer; public aquarium; conservation

## INTRODUCTION

Displays of live scleractinian corals in open- and closed-system aquariums have increased tremendously in the last decade due to major improvements in husbandry techniques [Carlson, 1987; Yates and Carlson, 1993; Atkinson et al., 1995; Adey and Loveland, 1998; Borneman and Lowrie, 2001; Delbeek, 2001]. The successful husbandry of corals requires an adequate supply of healthy, undamaged colonies. This necessitates not only a careful selection of colonies regarding their general condition, but also the use of an appropriate technique to transport colonies from the field to aquariums or other facilities, such as research institutions. The literature regarding the transportation of corals contains little information on colony sizes and survival rates. In this work we provide a summary of what is currently known regarding the transportation of corals. Two general techniques have been described: the “submerged method” [Carlson, 1987; Delbeek and Sprung, 1996; Carlson, 1999] and the “dry method” [Bronikowski, 1982; Delbeek and Sprung, 1996; Carlson, 1999].

The transportation of corals immersed in saltwater is termed the “submerged method.” A colony is placed into a double bag (one bag inside another bag) and enough fresh saltwater is added to cover the coral completely. The bag is then filled with pure oxygen to keep the oxygen level high and to stabilize the bag shape during transport. The ideal proportion is one-third water and two-thirds oxygen. Finally, the bag is closed with two rubber bands and placed in an insulated box (styrofoam) for shipment.

The “dry method” is mainly used to ship small fragments (3–10 cm long) [Carlson, 1999] (Delbeek, personal communication) or relatively small colonies weighing <0.5 kg (Carlson, personal communication). The corals are transported in a moist environment without being submerged at all. Each specimen is wrapped in wet plastic strips and placed in a plastic container to avoid damage from shipping. Saltwater is added and then drained so that only a few milliliters remain, which creates a moist environment. Before the containers are closed and packed in styrofoam boxes, oxygen is added. For a detailed description on packing procedures, see Carlson [1999] and Delbeek and Sprung [1996].

Carlson [1999] described successful commercial transports of whole colonies (<15 cm in diameter) using the submerged method. A medium weight per live coral in commercial transports of 166.4 g (min. 27.8 g, max. 1703.0 g) has been estimated by Green and Shirley [1999]. An effective way to ship whole colonies is to put the coral upside down in the transport bag. The colony is fixed to a floating body that prevents it from touching the sides of the bag and causing leakage or tissue damage [Delbeek and Sprung, 1996; Carlson, 1999].

Methods for transporting large coral colonies (>2,000 g) have not yet been described. The Monaco Aquarium shipped stony corals weighing >10 kg from the

Red Sea (Djibouti) to Monaco (Ounaïs, personal communication). Corals from the genera *Acropora*, *Stylophora*, *Pocillopora*, *Lobophyllia*, *Platygyra*, *Favia*, and *Favites*, and from the hydrocoral *Millepora* spp. were collected by the Monaco Aquarium during a mission in 1989 to the Gulf of Tadjoura. The biggest colonies were approximately the size of a cooling box (50 × 50 × 50 cm) and weighed > 10 kg.

They were transported by a dry method similar to that described above for smaller corals. The colonies were placed in plastic bags instead of plastic containers. For branching species, polyester foam was additionally put inside the bags to protect the branch tips from damage. Small quantities of water and oxygen were added. The corals were transported to Monaco (39 hr from packing to unpacking), placed in a quarantine tank overnight to eliminate mucus, and then transferred to a Jaubert system [Jaubert and Gattuso, 1989] with adequate lighting and water quality. Survival rates of 70% and 50% were observed after the first week and the first month, respectively, after shipping.

One reason for the lack of information regarding the transportation of heavy scleractinians may be that most transports involve relatively small colonies [Green and Shirley, 1999]. The collection of larger colonies from the field for commercial purposes and to supply public aquariums is generally not favored in the context of coral reef conservation. However, for research purposes, it is sometimes necessary to collect larger colonies from the field or to transport colonies between institutions. The transportation of heavy colonies presents several problems. The tissue of the colonies can be damaged by the weight of the skeleton when it is placed on live parts of the colony. The sharp edges of the skeleton and substrate can damage transport bags and cause leakage. The use of floating bodies to prevent the coral from touching the bag (especially the bottom of the bag) becomes ineffective when the colonies weigh more than 1,000 g (personal observation).

As part of a research project on the captive reproduction of scleractinian corals in closed-system aquariums (Sexual Coral Reproduction (SCORE) Project [Petersen et al., 2002]), we planned the shipment of 100 adult colonies of the massive Caribbean species *Diploria strigosa* and *Montastraea annularis* from Curaçao, Netherlands Antilles, to Rotterdam, The Netherlands. To be able to study reproductive behavior, we had to ensure that the collected corals had already surpassed a species-specific minimum colony size indicating that they had reached maturity [Szmant, 1986; Soong, 1992]. Therefore, we estimated a colony size of 20 cm as the minimum diameter per colony. With the goal of avoiding damage and minimizing stress to the colonies, we developed a new technique to transport massive stony corals.

## MATERIALS AND METHODS

### Prestudy

To determine whether the dry method would be useful for the transport of massive stony corals, a transport simulation was conducted 4 months prior to the real transport.

Two colonies each of *Diploria strigosa* and *Montastraea annularis* were collected in the shallow fringing reefs in front of the Curaçao Sea Aquarium in August 2001. The colonies were packed immediately after they were brought ashore, using the method described by Delbeek and Sprung [1996], with some modifications.

A double plastic bag was put in a styrofoam box. Wet paper was placed on the bottom of the bag to make a soft bed, and then a layer of wet plastic strips was added. The colony was placed on top. All remaining space around the colony was filled with wet plastic strips. Before each bag was closed, 100 ml of saltwater and 30% oxygen (Nitrox) were added. The boxes were stored in an air-conditioned room (25°C) for 21 hr. The colonies were then unpacked and transferred to an open-system aquarium to monitor behavior and survival.

## Species

*Diploria strigosa* is a common Caribbean species that forms massive colonies (several decimeters to >1 m in diameter). *Montastraea annularis* is a common Caribbean species that is frequently found in shallow reef areas. It forms massive, lobed, dome-shaped colonies of several meters in diameter. Both species were identified following Humann [1996] and Veron [2000]. Special regard was given to the reclassification of the species complex of *Montastraea annularis* by Szmant et al. [1997].

The colonies were carefully chosen according to their general condition and colony size. Only colonies in excellent condition, which showed no mechanical damage, bleached areas, or ectoparasites, were collected. Only one lobe per colony of *M. annularis* was collected.

## Preparation for Transport

All of the colonies were collected from a depth of 5–10 m at the exposed fringing reefs in front of the Curaçao Sea Aquarium several weeks prior to transport. The colonies were broken off the substrate with a hammer and chisel. To avoid causing damage to live tissue by direct contact, rubber gloves were worn during all handling activities. The corals were transferred by divers to a calm spot in the shallow reef near shore at a depth of 6 m, where the colonies were stored until the day of transport. On the day of collection, they were prepared for stabilization during storage and transport in the following way: One colony after the other was brought ashore and placed in a plastic tub that contained about 50 liters of fresh saltwater. To stabilize the colonies for transport, plastic screws, to which a cross could be fixed, were cemented onto their basal plates. In the following paragraph we describe this procedure (see also Figs. 1 and 2).

During the entire procedure, one person holds the coral upside-down, using two flat sponges. Each sponge is put in a plastic bag to create a smooth surface and thus avoid any irritation to the coral by direct contact with the sponge. The colony is held upside-down in such a way that the basal plate is just emerging from the water. The weight of the colony must be equally distributed on the relatively high surface area of the sponges to prevent any tissue damage and reduce stress reactions. A second person prepares a pure, viscous mix of fresh water and Portland cement at a ratio of approximately 1:5. In general, Portland cement dries quickly in saltwater and can develop a permanent saltwater-resistant connection between all sorts of material. Depending on the surrounding temperature, it can dry in <10 sec. The adhesive property increases gradually, and after 1 week the chemical reaction is complete. The cement is used to fix plastic U-shaped screws onto the dead skeleton of the colony. Depending on the size of the colony, two to four screws are used, facing each other (this type of screw is normally used to fix electric cables in

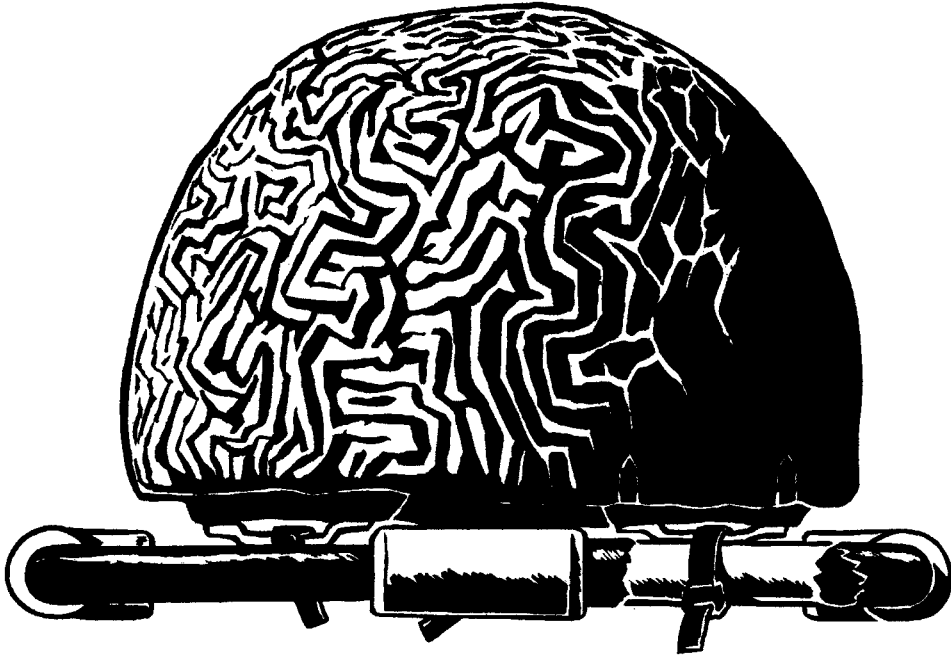


Fig. 1. Side view of a brain coral (*Diploria strigosa*) fixed on a PVC cross. The coral is positioned so that no live tissue touches the cross or the plastic bag. The drawing is semitransparent on the right side to emphasize the connection between the cross and the coral (Leen Zuydgeest, Rotterdam Zoo).

buildings). When the screws are fixed, a slight opening is left between the basal plate of the colony and the upper part of the screw. A tie wrap is subsequently inserted through this opening so that the colony can be fastened to an object. After the screws are fixed, the colony is put back into the sea for at least 24 hr to let the cement harden. If this is not done, both the cement and the screws will break off the colony. Each colony is then fixed to a PVC cross that is surrounded by a piece of polypropylene hose, thus forming a ring similar to a steering wheel. This construction is referred to as the "cross." The diameter of the cross should be larger than the diameter of the colony. Each colony is fastened to a cross, using the cemented screws and tie wraps, by two divers. The corals are fixed to the center of the cross in such a way that the edges of the colonies do not overlap the cross. Finally, the colonies are transferred again to the reef until the day of transport.

### Transport and Acclimation Procedure

The colonies were packed separately in double plastic bags. They were completely submerged by fresh saltwater (ca. 5–10 L), and pure oxygen (100%) was added in a ratio (oxygen : water) of 1:3–1:4. The colonies were shipped in styrofoam boxes by air cargo from Curaçao to The Netherlands. They were unpacked immediately after arrival at the Rotterdam Zoo and were slowly acclimatized to the aquarium water. During the first hour, 200 ml of water (2–4% of the transport

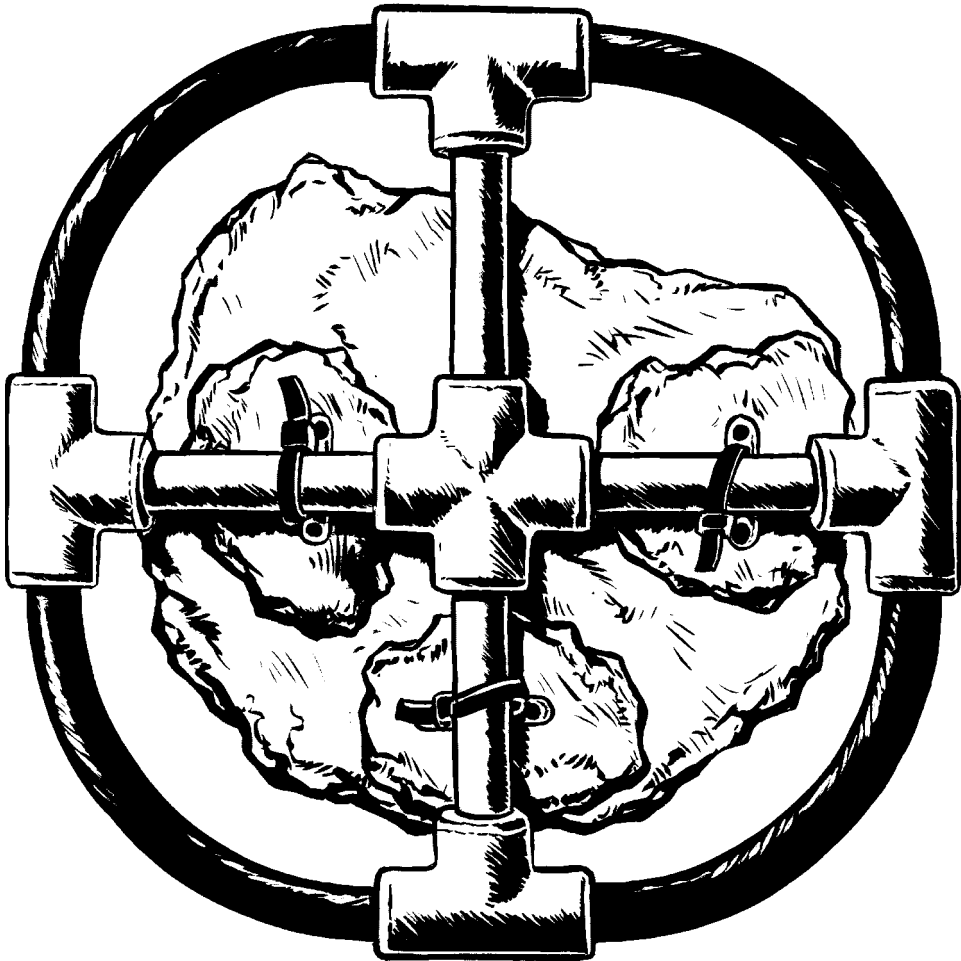


Fig. 2. View from the underside of the coral. Depending on the surface structure of the coral skeleton, a minimum of two (usually three) connections to the cross were necessary to fix the colony for transportation (Leen Zuydgeest, Rotterdam Zoo).

volume) were added every 10 min. After 1 hr, 400 ml of water were added every 10 min. After 2.5 hr, the corals were transferred to the experimental tanks.

Two transports were carried out (November 2001 and February 2002). We estimated the size of each coral colony was by measuring the length and width of the basal plate, and the height of each colony. The weight of each colony was also recorded.

## RESULTS

### Prestudy

The first four colonies that were collected and used for the transportation simulation (dry method) showed a pale area after they were transferred to the

aquarium in Curaçao, probably where the tissue had touched the bottom of the bag. Although this pale area did not necessarily lead to death, we could observe tissue necrosis.

### Collection, Preparation, and Transport

A total of 50 colonies per species were collected. *Diploria strigosa* easily breaks off the substratum at the colony edge without any tissue damage. The lobes of *Montastrea annularis* can be cut off the substratum a few centimeters below the live tissue of the colony. If the colonies were not fastened to the PVC crosses, the corals were relatively unstable and tended to tumble over when current or surf motion increased. Unavoidably, some colonies tumbled over between the time they were collected and fastened to the crosses. They were carefully examined for any tissue damage. In most cases, the damages healed before transportation started. Not a single colony fastened to a cross tumbled over—even when the surf motion was medium to strong. Portland cement is very effective and easily manufactured. It provides a permanent, stable connection between the colony and the screws after 24 hr (in tropical waters of about 25°C). By using the cross as a handle, even the heaviest colonies (> 7,000 g) could be handled above the water surface without the screw connection breaking off. The cement must be mixed carefully, however; otherwise it can disintegrate after a few months.

The collection of each colony, its preparation for transport (fixing screws and crosses), and packaging (by two or three experienced persons) took approximately 45–60 min. In November 2001 and February 2002, 20 and 30 colonies of each species, respectively, were transported.

The November 2001 transport took 35 hr, and the February 2002 transport took 37 hr (from packing until unpacking). In November 2001 the transport water had a salinity of 36.0‰ and a temperature of 26.2°C; in February 2002 the salinity was 36.3‰ and the temperature was 25.3°C. In November 2001 the salinity of the aquarium water was 35.3‰ at a temperature was 26.5°C; and in February 2002 the salinity was 36.0‰ at a temperature of 26°C.

### Colony Size

The colonies were measured and weighed after 3 months of acclimatization in the aquarium tanks. For *Diploria strigosa*, the average length was 18.3 cm (min. 12.4 cm, max. 22.8 cm), the width 16.5 cm (min. 11.2 cm, max. 21.0 cm) and the height was 13.3 cm (min. 9.1 cm, max. 22.0 cm). The average weight per colony was 3,622 g (min. 2,112 g, max. 9,200 g).

The lobes of *Montastrea annularis* had an average length of 14.0 cm (min. 9.1 cm, max. 19.1 cm), width of 11.1 cm (min. 6.2 cm, max. 15.0 cm), and height of 14.4 cm (min. 10.2 cm, max. 20.7 cm). The average weight per colony was 2,843 g (min. 1,810 g, max. 4,395 g).

### Posttransport Survival Rates

A posttransport survival rate of 100% was measured 2 weeks after transportation. No damages were visible. During the first transport in November 2001, several colonies of *Diploria strigosa* were only partly submerged during the transport. This drop in the water level resulted from the use of inappropriate filling material in between the bags. The nonsubmerged tissue areas were pale and covered

by a thick layer of mucus. During the following day, the pale areas disappeared and the tissue recovered completely. The survival rates after 8 and 4 months, respectively, for the transports in November 2001 and in February 2002 were 96% for *Diploria strigosa* and 100% for *Montastrea annularis*, for a total survival rate of 98%.

### Further Development

Some colonies of both species (usually those with a ball-like shape) showed in the longer term a slow necrosis of those tissue areas that were not directly exposed to the light source ( $1 \times 400 \text{ W } 10 \text{ K HQI per m}^2$ , distance of lamps to water surface = 40 cm, mean distance of colonies to water surface = 20 cm,  $450 \pm 100 \mu\text{E m}^{-2} \text{ s}^{-1}$  light exposure at the top of the colonies). This necrosis stopped after the shaded parts disappeared, leading to a stable tissue cover. The colonies with a flatter and more pyramid-like shape did not show any tissue necrosis. To avoid disturbing the colonies, growth (as determined by the weight of the colonies) was not monitored. In both species, slow growth was indicated by the edges emerging from the surrounding, dead skeleton (estimated at 3–5 mm per year under optimal conditions). We observed a slow but constant decrease of alkalinity from 3.3 to 1.8 meq  $\text{l}^{-1}$  until November 2002. After the calcium carbonate supply was optimized by the use of larger calcium reactors and the addition of calcium chloride/sodium hydrogen carbonate, we calculated a current consumption rate of 4,000 g per month per experimental tank (water volume = 2000 l) to keep the calcium above 400 mg  $\text{l}^{-1}$  and the alkalinity at 3.2–3.5 meq  $\text{l}^{-1}$ . These tanks contained 30 massive coral colonies, including other species (e.g., *Siderastrea siderea* and *Porites astreoides*), and approximately the same amount of smaller species (mostly *Favia fragum* and *Agaricia humilis*).

In November 2002 we noticed an outbreak of a syndrome that has been termed Dark Spots disease (DSD) [Gil-Agudelo and Garzón-Ferreira, 2001; Gil-Agudelo et al., in press]. Within 1 month, two-thirds of the *Montastraea annularis* colonies were infected with DSD and showed dark pigmented spots that grew rapidly, leading to tissue necrosis. To prevent a further increase of DSD, we interrupted the temperature simulation and decreased the water temperature gradually from 28°C to 25°C. The simulation was aimed at inducing captive spawning events. After the disease was eliminated, we started the simulation again in February 2003. We did not observe reproduction in *M. annularis* and *D. strigosa* in 2002, but we did note a regular release of planulae in *Favia fragum* and *Agaricia humilis* from November 2001 up to the present date.

### DISCUSSION

The results show that the presented technique is an appropriate method for transporting heavy coral colonies over a large distance, for a period of > 30 hr. All of the colonies survived and there was no visible damage. The deaths of two colonies of *Diploria strigosa* that occurred several months after transport cannot be directly correlated with the transport itself. Both colonies suddenly bleached for no obvious reason and died within a few days. However, the outbreak of DSD may have resulted from transferring the pathogen with the transported corals in the aquariums (see below).

In comparison with the conventional submerged and dry methods (as described above), the current method requires a careful and a relatively time-intensive (15–20 min to fix three screws and one cross to a colony) preparation of the colonies prior to transportation. In addition, at least one person is needed to assist during the fixing of the screws and crosses. Portland cement increases the pH of saltwater after it is manufactured; therefore, the freshly fixed corals have to be kept in a relatively large volume of water to prevent pH changes. We fixed the last cement plugs to the corals 2 days before transport and did not observe any negative reaction of these corals after they had been in a relatively small volume of water for >30 hr. However, potential pH fluctuations should be considered when Portland cement is applied in closed and semi-open systems with a limited water exchange. In this context, we emphasize the importance of mixing the cement carefully with water to achieve a medium viscosity. Only a homogenous mixture of water and cement can guarantee a proper and long-lasting attachment of the screws to the colony. If they are not properly prepared, the cement plugs may decompose several months later, as we observed in some of the colonies.

To keep the colonies submerged, 3–5 liters of saltwater had to be added to each plastic bag, which increased the transportation costs. To reduce the weight, and therefore shipping costs, it is possible that the corals could be transported using the dry method, in addition to being fixed on the crosses to ensure no direct contact between the colonies (in the transport box) and the bottom of the bag. This idea was not tested in the present study, although the results of the prestudy indicated it was feasible if direct contact of the tissue with the bottom of the bag could be avoided. Another observation in favor of the dry method is that unsubmerged parts of the colonies showed no visible damages after acclimation. Bronikowski [1982] and Carlson [1999] suggested that the total transport time for the dry method should be <20 hr, and no large temperature changes should occur during transport. With the dry method, there is no water (which functions as a temperature buffer) surrounding the coral. However, the experience of the Monaco Aquarium (Ounaïs, personal communication) shows that it is possible to transport large colonies using the dry method, even for transportation times of 39 hr.

Whether corals should be transported by the dry or the submerged method may also depend on the species. Borneman (personal communication) suggests that the dry method should be used for species that produce a lot of mucus, in order to avoid increased bacteria growth during transport and thus prevent large oxygen consumption and high concentrations of metabolic toxins in the water. He further recommends that trials should be conducted with tetracycline or similar antibiotics, which reduce bacteria growth, to find out more about the influence of microbes on transport conditions and survival rates.

The use of antibiotics may be important in eliminating and avoiding the transfer of potential pathogens that can not be easily detected, as was the case with DSD in the present study. DSD has been increasingly observed in the Caribbean [Gil-Agudelo et al., in press]. Although DSD was present in some colonies of *Montastraea annularis* at the collection site, none of the collected colonies showed any abnormal pigmentation. We noticed a small dark spot in one colony of *M. annularis* in August 2002, 5 months after its collection, and did not observe any major increase until October 2002. In October/November, the spots increased rapidly and new colonies were infected daily. Finally, we had to move all of the

infected colonies (two-thirds of the stock) to a separate tank, and conduct a major water exchange (80%) to stop the disease in the experimental setup. In addition to the relatively high temperature (28°C), we had to assume that other factors, such as insufficient water movement and low alkalinity, might have contributed to the outbreak. Therefore, we optimized these factors. The pathogen causing DSD has not yet been clearly identified. For further details on our observations regarding DSD, see Gil-Agudelo et al. [in press]. In general, more research on coral diseases, and adequate quarantine procedures and medical treatments are necessary to prevent outbreaks such as those in the present study.

In a previous study, Bronikowski (1982) drilled holes into the colony skeletons to fix them with screws to the rock framework in exhibit tanks. Thinking this simple method might also be useful in preparing massive colonies for transport, we attempted to use it in the current study; however, it resulted in heavy mucus production, mesentery filament ejection, and even tissue damage and broken colonies. Species with massive, dense skeletons were very difficult to drill, even when we used diamond drills. Moreover, screws stuck in these holes often broke off the colony during handling.

Special attention should be given to temperature changes during transport and acclimation. Jones (personal communication) uses ice or heat blocks, depending on the shipping route used, to avoid an increase or drop in temperature. He also recommends giving the receiver of the shipment as much information as possible about the environmental conditions the corals have been exposed to prior to transport. We adjusted the aquarium water before the arrival of the corals to the temperature and salinity of the collection site. Nevertheless, we observed a temperature decrease of 1–2°C in the transport bags during the acclimation procedure due to a relatively low room temperature. This temperature drop could only be stopped by adding more aquarium water to the corals per time unit. In addition to the corals, we shipped other aquatic animals (mainly grazing organisms for the experimental tanks), resulting in a total of 100 boxes per shipment. Depending on the total quantity of a transport, special attention should be given to formulating a detailed plan—especially for packing and unpacking procedures—to avoid any problems in time management. In the present case, more than 15 people helped with both packing and unpacking to minimize handling time.

We still keep the colonies fixed to the crosses in the experimental tanks. This allows us to handle the colonies easily without touching the coral itself. The PVC crosses provide a stable basis for a permanent placement on horizontal surfaces in aquariums.

In conclusion, deciding which transportation method to apply depends mainly on species-specific properties (e.g., mucus production) and the colony size, and partly on the maximum expected transportation time. In future transports of live corals for commercial, educational, or research purposes, there will probably be a shift away from field-collected specimens toward captive-propagated corals for coral farms, public aquariums, research facilities, and commercial uses [Rinkevich and Shafir, 1998; Delbeek, 2001; Petersen and Tollrian, 2001]. This may result in an increased use of the dry method for transports of cultured fragments. Recent studies have shown that it is possible to transport coral larvae over large distances, which can be used to supply species that are difficult to fragment [Petersen and Tollrian, 2001] (Petersen et al., unpublished data). Furthermore, newly settled primary polyps have

shown high survival rates after intercontinental transports (unpublished data). In the future, the transfer of fragments, planulae, and primary polyps will not only reduce transportation costs and ensure a supply for public aquariums and commercial trade, it will also enable us to establish an international framework of breeding centers for in situ and ex situ conservation [Petersen and Tollrian, 2001; Petersen et al., 2002].

The setup and maintenance of stable inland breeding stock will further require the safe and gentle transfer of mature colonies from the field to breeding facilities, as well as between facilities. For massive species in particular, relatively heavy and large colonies are necessary to initiate reproductive events in captivity [Szmant, 1986]. Appropriate transportation and handling techniques are therefore essential to minimize stress and damage to parental colonies, and prevent a lack of fecundity.

## CONCLUSIONS

1. Large and massive coral colonies require special preparations for long-distance transportation.

2. The presented method can minimize the effects of stress and yield high posttransport survival rates (up to 100%). However, the preparation of the colonies prior to transport is more time-intensive compared to other techniques.

3. The choice of an appropriate transportation method depends generally on the size of the colonies, species-specific properties, and the expected duration of transport.

4. Field-collected corals must be carefully checked before transport to avoid any transfer and introduction of parasites or pathogens. In this regard, further research on coral pathology is necessary.

5. Collecting adult corals in the field is particularly important for breeding and other research purposes, which can not be carried out using captive-propagated corals. Any transports involving reef-building corals must be in accord with the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora.

## ACKNOWLEDGMENTS

We thank Krista Vermeulen for her excellent assistance during the collection, preparation, and transport of the colonies. Without the tremendous help of numerous volunteers from the diving schools Animal Encounters and Ocean Encounters, Curaçao, Netherlands Antilles, the packing of the corals would not have been possible. Eric Borneman, Bruce Carlson, Charles Delbeek, Sam Jones, Nadia Ounaïs, and two anonymous reviewers are acknowledged for providing information and useful comments. The unpublished data of Nadia Ounaïs and Pierre Gilles were very helpful in our research. We thank Fernande Hazewinkel for assisting with the layout of the manuscript, and Leen Zuydgeest for drawing the illustrations. We are very grateful to the CITES authorities of The Netherlands and Curaçao, Netherlands Antilles, for permitting the collection and transport of the corals, and to KLM Royal Dutch Airlines for handling the transport from Curaçao to The Netherlands.

## REFERENCES

- Adey WH, Loveland K. 1998. Dynamic aquaria: building living ecosystems. London: Academic Press. 498 p.
- Atkinson MJ, Carlson B, Crow GL. 1995. Coral growth in high-nutrient, low pH seawater: a case study of corals cultured at the Waikiki Aquarium, Honolulu, Hawaii. *Coral Reefs* 14:215–23.
- Borneman EH, Lowrie J. 2001. Advances in captive husbandry and propagation: an easily utilized reef replenishment means from the private sector? *Bull Mar Sci* 69:897–913.
- Bronikowski Jr EJ. 1982. The collection, transportation, and maintenance of living corals. In: Proceedings of the AAZPA Northeastern Regional Conference in Toronto, Ontario, Canada. p 65–70.
- Carlson BA. 1987. Aquarium systems for living corals. *Int Zoo Yearb* 26:1–9.
- Carlson BA. 1999. Organism responses to rapid changes: what aquaria tell us about nature. *Am Zool* 39:44–55.
- Delbeek JC. 2001. Coral farming: past, present and future trends. *Aquar Sci Conserv* 3:171–81.
- Delbeek JC, Sprung J. 1996. *Das Riffaquarium: Ein umfangreiches Handbuch zur Bestimmung und Aquarienhaltung tropischer wirbelloser Meerestiere*. Coconut Grove: Ricordea Publishing. 544 p.
- Gil-Agudelo DL, Garzón-Ferreira J. 2001. Spatial and seasonal variation of the Dark Spots disease in coral communities of the Santa Marta area (Colombian Caribbean). *Bull Mar Sci* 69:619–29.
- Gil-Agudelo DL, Smith GW, Garzón-Ferreira J, Weil E, Petersen D. Dark spots disease and yellow band disease, two poorly known coral diseases with high incidence in Caribbean reefs. In: Rosenberg E, editor. *Coral health and diseases*. Heidelberg: Springer (in press).
- Green EP, Shirley F. 1999. The global trade in coral. World Conservation Monitoring Centre. Cambridge: World Conservation Press. 70 p.
- Humann P. 1996. Reef coral identification: Florida, Caribbean, Bahamas. 3rd ed. Jacksonville: Paramount Miller Graphics. 239 p.
- Jaubert J, Gattuso JP. 1989. An integrated nitrifying-denitrifying biological system capable of purifying seawater in a closed circuit system. In: Deuxième Congrès International d'Aquariologie 1988, Monaco. Bulletin de l'Institut Océanographique, Monaco, no. 5. p 101–6.
- Petersen D, Tollrian R. 2001. Methods to enhance sexual recruitment for restoration of damaged reefs. *Bull Mar Sci* 69:989–1000.
- Petersen D, Laterveer M, van Bergen D. 2002. SECORE–Steinkorallen-Projekt: Internationales Projekt zur Steinkorallen-Vermehrung. *Deutsche Aquar Terrar* 55:36–9.
- Rinkevich B, Shafir S. 1998. Ex situ culture of colonial marine ornamental invertebrates: concepts for domestication. *Aquar Sci Conserv* 2:237–50.
- Soong K. 1992. Colony size as a species character in massive reef corals. *Coral Reefs* 12:77–83.
- Szmant AM. 1986. Reproductive ecology of Caribbean reef corals. *Coral Reefs* 5:43–54.
- Szmant AM, Weil E, Miller MW, Colon DE. 1997. Hybridization within the species complex of the scleractinian coral *Montastraea annularis*. *Mar Biol* 129:561–72.
- Veron JEN. 2000. *Corals of the world*. Vol. III. Townsville: Australian Institute of Marine Science. 490 p.
- Yates KR, Carlson BE. 1993. Corals in aquaria: how to use selective collecting and innovative husbandry to promote coral conservation. In: Richmond RH, editor. *Proceedings of the 7th International Coral Reef Symposium*. Vol. II. Mangilao: University of Guam. p 1091–5.