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Establishment of a Global Coral Biobank: Implementation of the protocols from coral collection to long distance shipping and long-term maintenance in public aquariums

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ABSTRACT

The World Coral Conservatory (WCC) has initiated a pioneering global biobank to conserve coral species in response to accelerating reef degradation. This paper reports on the first coral collection mission at Aldabra Atoll, Seychelles, undertaken during the Monaco Explorations Indian Ocean expedition in October 2022. Fifty-eight colonies, representing 21 species, were successfully collected, transported, and distributed across European aquariums. We detail the methodologies for coral collection, transport, and in-tank maintenance, ensuring genetic diversity and coral health preservation.

Post-arrival monitoring revealed an 88 % survival rate over an 18-months period, despite challenges such as bleaching and bacterial infections. The success of this mission validates the feasibility of long-term coral conservation in aquaria and sets the stage for future expeditions and advanced genetic research.

1. Introduction

The conservation of coral reefs has become a global priority in response to the rapid degradation of these ecosystems due to climate change and human-induced pressures (Hoegh-Guldberg et al., 2023). Coral reefs, which support unique marine biodiversity, are critically threatened by rising ocean temperatures, ocean acidification, and widespread bleaching events, such as the fourth Global Coral Bleaching Event which has been devastating for coral reefs in 2023 and 2024 (Reimer et al., 2024). These threats could result in the loss of numerous coral species, highlighting the urgent need for innovative conservation strategies, such as ex-situ biobanking efforts.

The World Coral Conservatory (WCC) was established as a global network dedicated to the *ex-situ* conservation of coral species. This initiative is spearheaded by the Oceanographic Institute, Prince Albert I of Monaco Foundation and the Scientific Centre of Monaco, in partnership with the Prince Albert II of Monaco Foundation. Leveraging the infrastructure of public aquariums worldwide, the WCC aims to maintain and propagate diverse coral species. This initiative integrates science, conservation, education, and reef management, aiming to preserve coral biodiversity, enhance ecosystem resilience, and support reef restoration efforts (Zoccola et al., 2020).

At the heart of the WCC's mission is the use of advanced techniques such as assisted evolution, cryopreservation, and controlled breeding. These techniques, designed to preserve the genetic diversity of coral species and to develop corals that are more resilient to future environmental changes will be keys of the future scientific programs implemented as a second step of the WCC initiative. By creating a "Noah's Ark"

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for corals, the WCC provides a platform for research and the preservation of coral species in the face of rapidly shifting ecological conditions.

The WCC represents a comprehensive and innovative effort to counteract the impacts of climate change on marine ecosystems by focusing on the long-term conservation of coral species. By leveraging international collaboration and scientific expertise, the WCC is poised to contribute significantly to the preservation of coral biodiversity, ensuring that these ecosystems can adapt to future environmental challenges.

The long-term objective of the WCC is to host corals from most of the regions where corals live. Although various regions would have offered a higher diversity, The World Coral Conservatory's inaugural coral collection mission, also designed as a "proof of concept", took place at Aldabra Atoll, Seychelles, taking advantage of the opportunity offered to several scientific teams, by the Monaco Explorations Indian Ocean expedition in October 2022. This mission, conducted in collaboration with the Seychelles Island Foundation, initially aimed to collect 27 different coral species, prioritizing the collection of multiple specimens to maximize genetic diversity and resilience. This article outlines the protocols used throughout the collection process, from the selection of coral colonies to their transport and acclimatization in public aquariums across Europe.

Following this expedition, the collected corals were successfully delivered to four European public aquariums: Burgers'Zoo in Arnhem (Netherland), Nausicaa in Boulogne sur mer (France), Oceanopolis in Brest (France), and the Oceanographic Institute of Monaco (Monaco). These facilities will play a key role in maintaining the corals, allowing for continued research, education, propagation, and conservation activities as part of the WCC's broader mission.

2. Material and methods

2.1. Coral collection process

The aim of the WCC is to collect as many species as possible in various regions of the world, privileging critically endangered, local and/or endemic species every time it is possible, to finally have a wide representation of coral species existing around the globe. Based on the studies of Stoddart (1984) and Stobart et al. (2002, 2005), our coral collection mission initially targeted ten coral genera, encompassing 27 species, on the western side of Aldabra Atoll with 2–3 colonies per species, to ensure a minimum genetic diversity, and allow further scientific work. The target defined at 80 species was the result of the combination of several criteria, including: the number of interesting species available in the area for the program, the space available in each partners facility to host the corals, and the maximum number of collected colonies allowed by the Seychelles authorities. The team consisted of five specialized divers: a coral taxonomist responsible for species identification, two aquarists ensuring the corals' health from collection to shipment, a photographer/videographer documenting the entire process, and a biologist managing logistics and molecular sampling.

The collection process involved seven scuba dives and one snorkeling session. For this preliminary mission, dive sites were selected by our local collaborators at the Seychelles Islands Foundation (SIF) based on their knowledge of accessible and representative outer reef areas. All dive sites were located exclusively on the outer reef slope of the atoll, but they were deliberately spread out geographically to maximize the potential for sampling genetically distinct populations, particularly when encountering the same species at different sites. Although the mission aimed to collect 80 coral colonies, 58 colonies were successfully gathered, with an average of 3 specimens per species. This shortfall was largely due to the strict selection criteria applied, which considered not only the targeted species but also colony size and abundance at each dive site. Size thresholds were set at a minimum of 10 cm in diameter to maximize survival rates in the long-term process, and at a maximum of 20 cm to ensure good conditions during transport and minimize the impact on the reef. Additionally, CITES permits obtained before the expedition restricted the collection to pre-approved species, limiting the total number of colonies collected.

Fig. 1A. Aquarist drilling a colony of Lobactis scutaria to install the RFID chip.

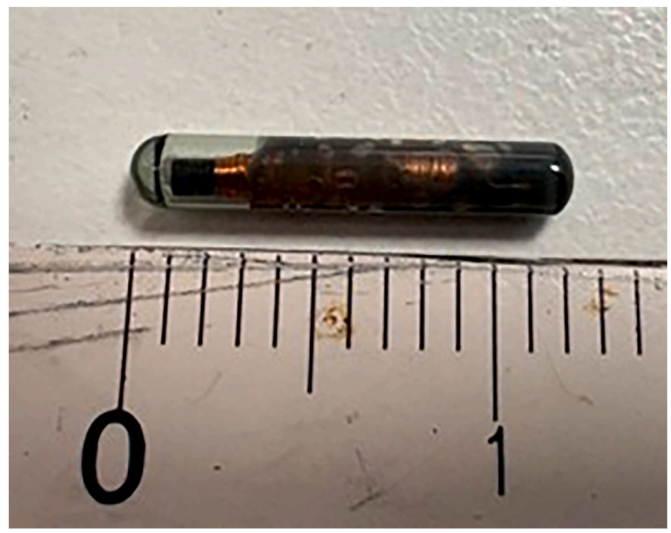

Fig. 1B. Precise view of the chip.

Several permits were necessary before we were authorized to collect the corals on Aldabra's reef. A Research Agreement was signed between the Seychelles Island Foundation (SIF) and the WCC for live corals sampling. In addition, Export CITES permits were mandatory to allow the shipment out of the Seychelles. Those permits were delivered by the Ministry of Agriculture, Climate Change and Environment prior to the collecting dives.

For each collected colony, detailed information was meticulously recorded, including the depth, substrate type, and GPS coordinates. These data, along with the final destinations of each coral colony, will be publicly available through the WCC's data portal. The success of this mission relied heavily on the diverse expertise within the team, ensuring every aspect - from taxonomy to transport - was handled with appropriate care. The corals species were identified based on the WORMS (World Register of Marine Species) reference data base.

Once collected, the corals were carefully placed in a basket and transported to the surface using a lift bag. A surface safety diver would then retrieve the basket and immerse the corals in several 50-L seawater-filled containers (three to five colonies per container, depending on their size). After the dive, the corals were lifted onto the vessel for further processing.

Onboard, each coral was measured, photographed, and tagged. To ensure precise identification and tracking throughout transport, each

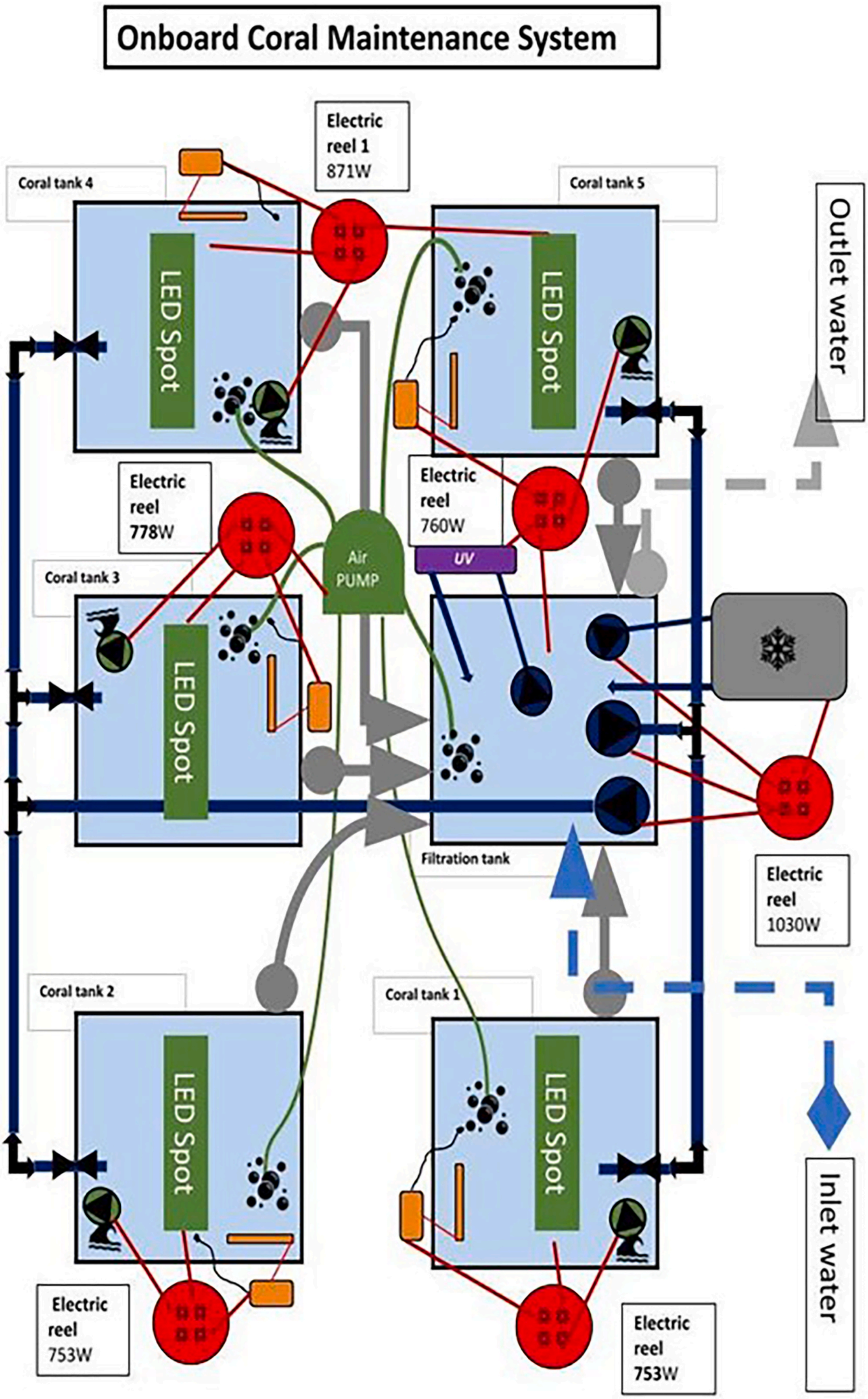

Fig. 2A. Onboard coral maintenance system.

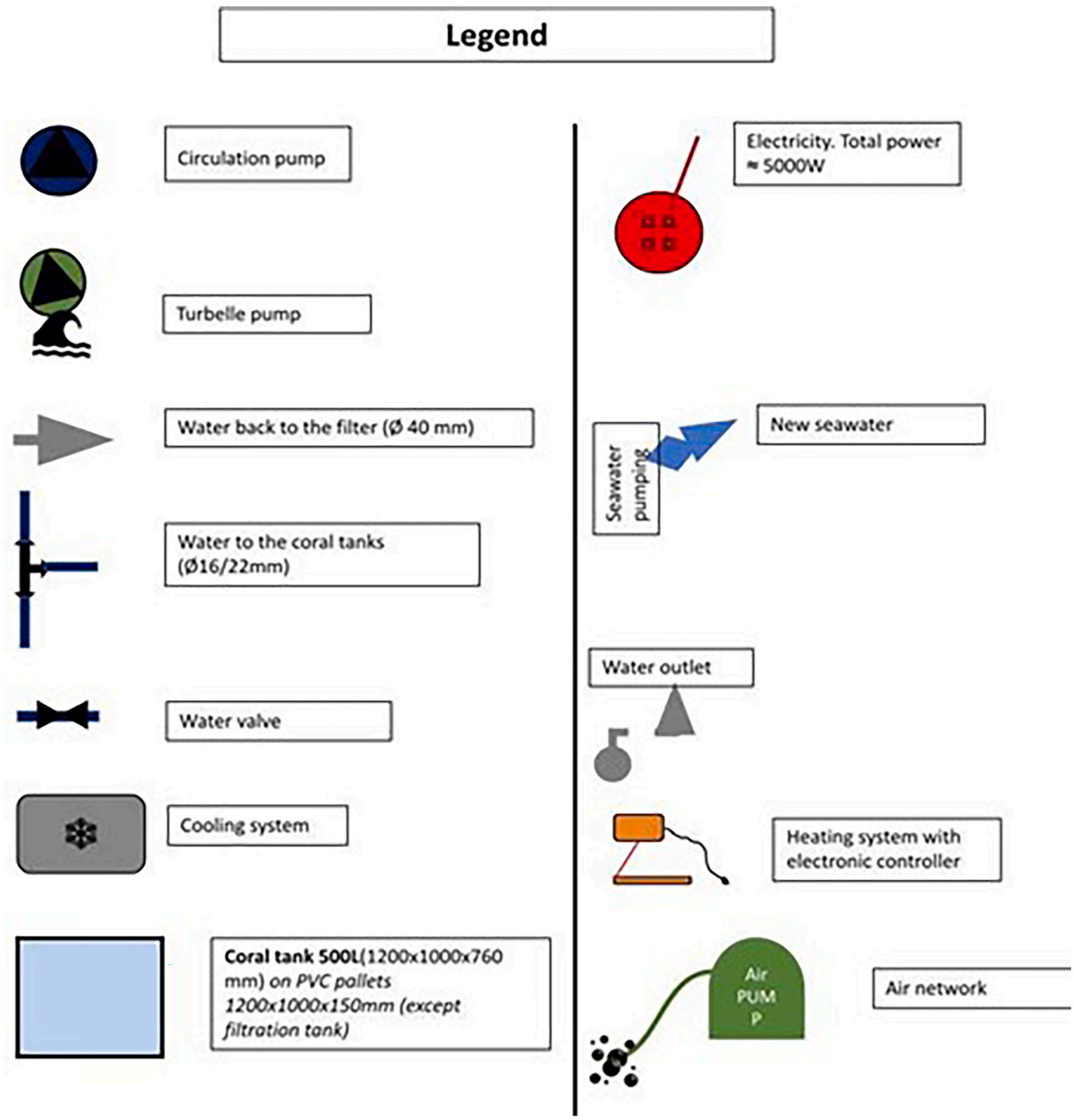

Fig. 2B. Legend.

coral received an RFID chip (Avid Identification Systems, Inc. CA, USA) embedded within its skeleton. Holes of 2.5–3 mm were drilled into the coral skeleton to accommodate the chip (see Fig. 1A and 1B), which was then secured using a two-component epoxy paste (Aquarium System) to prevent displacement. RFID chips were selected instead of conventional ones due to their long-term readability and reduced risk of detachment. Regular ones can easily become unreadable if algae or coral tissue colonize them.

2.2. Onboard storage and transport

The first coral colonies were transferred onto the vessel on October 19th, 2022, with the final colonies added on October 25th, 2022. Following the completion of the collection, the vessel departed from Aldabra and sailed to Mahé, the main island of the Seychelles, to offload the corals. The vessel arrived in Mahé on October 29th, 10 days after the first colony had been collected.

Once retrieved from the reef, the coral colonies were placed in an onboard system (see Figs. 2, 3A and 3B) consisting of five dedicated 500-L tanks, installed on the vessel's back deck. An additional technical tank was used for filtration and temperature control, featuring Universal EHEIM 3400 pumps, a cooling system (Teco TK 3000), and a UV reactor (Vitronic OASE 55 W). Each of the five coral tanks was equipped with 15 m^3/h current pumps (EcoDrift 15.3- Aquamedic), air diffusers, and LED lighting (Aquarius plant 90 plus - Aquamedic) with a 12:12 photoperiod. The light intensity was measured as photosynthetically active radiation (PAR), ranging between 50 and 150, customized for optimal coral health.

Water recirculation within each tank was maintained at a rate of 200–300 % per hour. Additionally, approximately 16 % of the total water volume (500 L out of 3000 L) was renewed daily using freshly filtered seawater. This water was filtered through a 100-μm filter bag and treated with active charcoal before being introduced into the system, ensuring optimal water quality for the corals throughout the transport.

Electricity for the system was supplied directly by the vessel. To prevent potential damages from heavy waves, a specific frame constructed from plastic netting and PVC pipes was placed at the bottom of

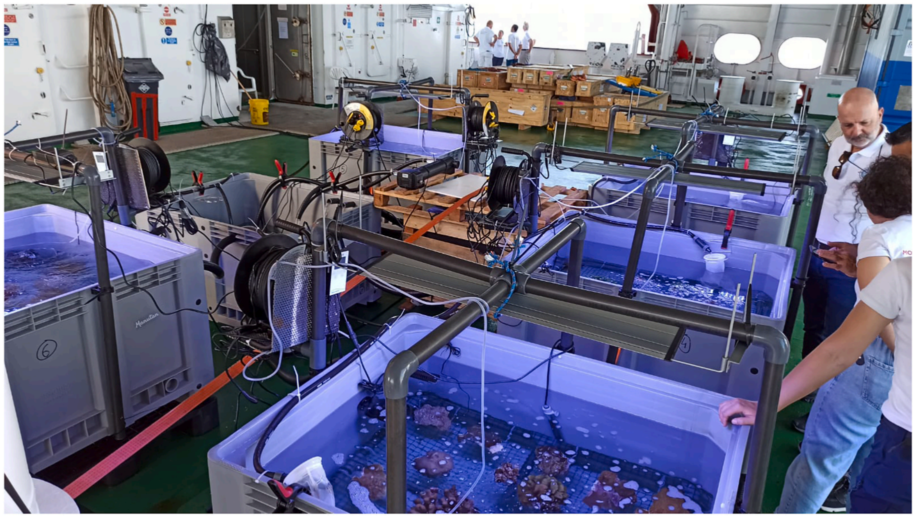

Fig. 3A. Onboard coral maintenance system consisting of five 500-L tanks and a filtration tank, installed on the back deck of the vessel for coral storage and water quality control during transport.

Fig. 3B. Large view of the installation on the deck.

Fig. 4. Protective frame constructed from plastic netting and PVC pipes, designed to secure corals in the tanks and prevent potential damage from wave action during transport. The coral colonies were only placed on the net, without being attached to it.

each tank to securely hold the corals in place (Fig. 4).

Daily monitoring of physico-chemical parameters was carried out to ensure the corals were kept under ideal conditions throughout the operation. Key parameters such as temperature, oxygen saturation and pH were measured using a portable multiparameter device (Hach Lange 40d), while alkalinity, ammonia, and nitrite levels were monitored with rapid test kits (Salifert). The average values of these parameters during the onboard storage are presented in Table 1.

Upon arrival in Mahé, the main island of the Seychelles archipelago, the coral colonies were transferred to a 6000-L circular tank (see Fig. 5) at the Seychelles Fisheries Authorities (SFA). This tank was supplied with locally sourced seawater, filtered using glass media with a water change rate of 50 % per hour. The physico-chemical conditions of the tank were closely monitored: temperature was maintained at 29 °C, pH 8.03, salinity at 33 g/L, ammonia at 0.63 mg/L, and phosphate at 0.51 mg/L. The corals were held in this system for six days, following the same water quality monitoring protocol, before being packed for air transport to Europe.

Table 1
Average values of key water quality parameters monitored during onboard coral storage.

Temperature (°C)	pH	O_2 (% sat)	Alkalinity (mEq/l)	NH_4 (mg/l)	NO_2 (mg/l)
25.6	8.10	100.97 %	2.646	0	0

2.3. Packing and air transport

Safe packing is mandatory for long trips of live corals in Styrofoam boxes. A specific protocol, adapted from the work of Craggs et al. (2018), was thus implemented to maximize survival rates upon arrival. Each coral colony was placed in double plastic bags, with individual packing for each colony. Smaller colonies (<15 cm in diameter) were packed in 4–5 L of water, while larger colonies (>15 cm in diameter) required 6–8 L. These plastic bags were then placed inside Styrofoam boxes, with one large colony per box or up to three smaller colonies per box. Additional protective layers of cardboard were used as the final outer packaging.

To maintain optimal oxygen saturation rate during transport, pure oxygen was injected into the water inside each plastic bag to reach a ratio of $^2/_3$ water- $^1/_3$ oxygen before sealing.

The key parameters to be maintained at acceptable levels during transport were oxygen saturation, pH, alkalinity, and temperature. Temperature control was achieved by placing two heat packs inside each Styrofoam box, ensuring that the air temperature remained between 25 and 30 °C throughout the journey. Activated charcoal (2g per bag) was added to absorb any organic compounds released during transport. Additionally, a specific volume of controlled water was prepared at the SFA facilities to fill the transport bags. The water was conditioned to match the required parameters: a temperature of 25 °C, pH of 8.15, and alkalinity of 3.21 mEq/L. Sodium bicarbonate powder was added to the water to adjust alkalinity (33 mg/L $NaHCO_3$ to increase 0.4 mEq/L). Once the parameters were stabilized in the tank, the water was used to fill the transport bags.

Before packing, the coral colonies were briefly removed from their holding tanks to induce mucus production, with the aim of minimizing further production of mucus, and associated water pollution during transport. This mucus was then washed off by dipping the colonies in a separate tank containing the prepared transport water. After this process, each colony was carefully placed in its respective plastic bag, which was already filled with the prepared water. Branching corals such as *Acropora* were attached upside-down to Styrofoam rafts using rubber bands to prevent contact with the plastic bags during transport.

The coral packing process was completed at the SFA facilities on the morning of November 2nd, 2022. Once packed, the coral boxes were transferred to the airport for loading. After a 10-h flight, the necessary customs clearance was completed, and the boxes were then dispatched by truck to three destinations: Oceanopolis (Brest, France), Burgers' Zoo (Arnhem, Netherlands) and Nausicaa (Boulogne sur mer, France).

Corals finally arrived at Nausicaa 37 h after packing, at Oceanopolis 41 h later, and at Burgers' Zoo (Arnhem) 42 h after packing. The shipment of corals destined for Monaco required a re-export CITES permit, and the transfer was completed ten days after their initial arrival in Brest.

2.4. Water quality and coral health status monitoring in culture tanks

Daily monitoring of water quality parameters, including pH, temperature and salinity was conducted to ensure optimal conditions for coral health. Macro- and trace elements were measured monthly using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) at the Fauna Marin Laboratory in Holzgerlingen, Germany.

Light intensity in the tanks was measured and adjusted regularly, according to changes in coral coloration. The color chart (see Fig. 6) allowed the aquarists to document the color changes over time. If the colonies started to show signs of bleaching, the light intensity was immediately decreased. This step, usual for aquarists used to keep corals in aquarium, was crucial in ensuring that the light conditions remained appropriate for the different species' growth and health. The same monitoring protocol was applied in the four aquariums.

Coral health status was assessed daily, and any unusual changes or issues were discussed among the four participating aquariums during regular online meetings. To track growth, colonies were photographed at regular intervals, enabling precise comparisons over time. Growth monitoring also included a color chart for visual assessment of coral health and vitality.

2.5. Data management

All coral colonies were registered in the web-based ZIMS (Zoological Information Management System) software from Species 360 (Minneapolis, USA). This system allows each partner to access comprehensive data on the colonies, including original collection locations, the collection dates, CITES permit numbers, and any transfers between facilities.

Water quality data, obtained from the ICP-OES tests, were managed through a custom-designed web platform implemented by Fauna Marin for the WCC. This platform provides dedicated access to each partner's results and enables comparisons of water quality parameters across the various WCC tanks, fostering standardized monitoring practices across facilities.

3. Results

3.1. Coral collection on the reef

As explained in section 1.1, the goal was to collect 80 colonies across 27 species. However, challenges in locating some of the targeted species led to the successful collection of 58 colonies representing 21 species. Table 2 provides detailed data for each colony collected, including environmental and health-related information. Photographs were taken from various angles to document the colonies' health and their surrounding environment at the collection sites (Fig. 7).

3.2. On arrival

Upon arrival at their destinations, the water parameters in the transport bags were immediately checked. The 14 colonies sent to Burgers' Zoo (Arnhem), the farthest destination, had an average pH of 7.3 (± 0.3), a temperature of 25.3 °C (± 0.6 °C), and salinity 35.6 g/L.

Although the above-mentioned parameters were in an acceptable range, some colonies displayed signs of stress upon arrival. Specifically, *Acropora valida* in Burgers' Zoo, *Pocillopora eydouxi* in Nausicaa as well as *Stylophora palmata* in Nausicaa and Oceanopolis, exhibited a brown color and unpleasant odor, indicating health issues.

After conducting water quality checks, the colonies were rapidly transferred into pre-prepared tanks with systems tailored to each aquarium's infrastructure. The variation in equipment and tank setups

Fig. 5. Transfer and installation of coral colonies into the 6000-L tank at the Seychelles Fisheries Authority (SFA) facility, where they were acclimated before further transport.

across the partner facilities was considered an opportunity to share technical insights among the partners. Table 3 provides a summary of the technical characteristics of the holding tanks at each location.

3.3. Eighteen months after the Corals' Arrival in the Aquariums

Eighteen months after the initial collection, the majority of the coral colonies remained in good condition, with a survival rate of 88 %. Only seven colonies did not survive (one *Acropora valida*, one *Gardineroseris planulata*, two *Isopora palifera*, two *Pocillopora eydouxi*, one *Stylophora palmata*), likely due to the stress encountered during transport and acclimatization as their health condition was already critical upon arrival, and they were lost during the first months. Nevertheless, all 21 collected species were still represented in the biobank, either by maintaining healthy fragments from the original colonies or through dispersal of colonies across different aquariums.

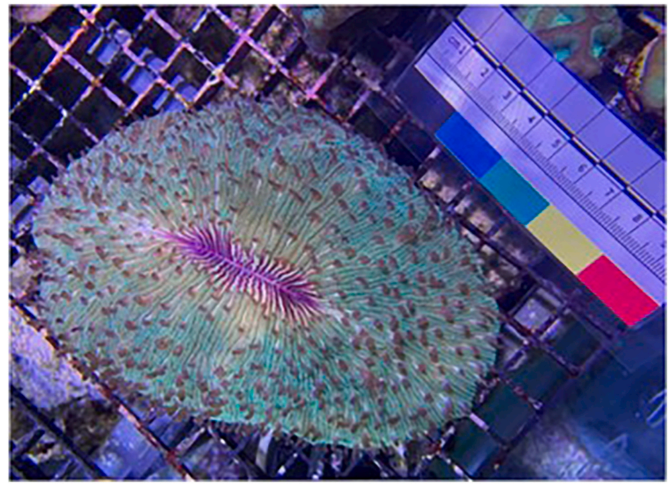

Fig. 6. Lobactis scutaria - Size and color monitoring chart to facilitate color comparison between the facilities.

Growth rates varied significantly across species and individuals. Some colonies, such as *Acropora valida* in all facilities, *Tubastrea micranthus* in Monaco, and *Galaxea fascicularis* in all facilities, doubled in size during the 18-months of aquarium maintenance (see Fig. 8A and B). Other species, such as *Coscinaraea* cf. *monile* in Monaco, showed little to no growth.

3.3.1. Significant health challenges

Several colonies encountered significant health issues after arriving at their final destinations probably due to their size. The *Stylophora palmata* transported to Nausicaa never recovered and died within the first week. The *Isopora palifera* slowly declined in Burgers'zoo and Monaco, likely due to the stress of transport, and finally died after prolonged bleaching from the base of their branches in spring 2023.

Aside from the mortalities likely caused by the prolonged transport, the aquarist teams encountered several challenges in maintaining the health of the remaining coral colonies.

Among the health challenges observed, *Isopora palifera* at Oceanopolis exhibited symptoms suggestive of "ulcerative white spot disease" (Fig. 9A–B). Although no specific pathogenic agent was identified, the presence of filamentous bacteria was suspected. As a result, the colony was treated with a potassium permanganate ($KMnO_4$) solution at a concentration of 1 g/L in osmosis water. This non-specific treatment is commonly used in aquariology to sanitize coral colonies when the infectious agent is not clearly identified. The solution was applied to the tank at a dose of 1 ml/L for 45 min, leading to noticeable improvements in the following weeks.

Additionally, *Lobactis scutaria* at Nausicaa experienced tissue loss and bleaching. Initial treatments with iodine (Betadine), a non-specific disinfectant, at a concentration of 1 ml/L for 5 min slowed the progression of the tissue loss, but the condition continued to deteriorate. A subsequent broad-spectrum commonly used antibiotic treatment with Doxycycline (1,7 mg/L for 5 days) successfully halted the tissue loss. However, the coral's tissue did not regenerate to cover the skeleton. Instead, the colony began producing dozens of anthocauli (tiny clones of the original colony), which were collected and grown in a separate tank.

Table 2
Detailed list of coral colonies collected from the reef, including species identification, collection site, depth, substrate type, and associated environmental data.

Genus		Species	Collection date	Latitude	Longitude	Depth (m)	Substrate	Dive site
Acanthastrea		*echinata*	2022-10-22	−9.37050000	46.2229166666667	5.8	Rock	3
Acanthastrea		*echinata*	2022-10-23	−9.46975000	46.2233333333333	5.4	Rock	4
Acanthastrea		*echinata*	2022-10-24	−9.39180555555556	46.1994722222222	18.6	Rock	6
Acropora		*valida*	2022-10-19	−9.39180555555556	46.1994722222222	16.0	Rock	1
Acropora		*valida*	2022-10-22	−9.37486111111111	46.2055555555556	8.6	Rock	2
Acropora		*valida*	2022-10-23	−9.46975000	46.2233333333333	10	Rock	4
Coscinaraea	cf	*monile*	2022-10-19	−9.39180555555556	46.1994722222222	16.8	Rock	1
Coscinaraea	cf	*monile*	2022-10-23	−9.46975000	46.2233333333333	9.2	Rock	4
Coscinaraea	cf	*monile*	2022-10-24	−9.39180555555556	46.1994722222222	18.3	Rock	6
Cyphastrea		*microphthalma*	2022-10-23	−9.40180555555556	46.2033888888889	6.5	Rock	5
Cyphastrea		*microphthalma*	2022-10-24	−9.46975000	46.2233333333333	14.7	Rock	7
Dipsastrea	cf	*favus*	2022-10-19	−9.39180555555556	46.1994722222222	14.6	Rock	1
Dipsastrea	cf	*favus*	2022-10-22	−9.37486111111111	46.2055555555556	11.5	Rock	2
Dipsastrea	cf	*favus*	2022-10-22	−9.37050000	46.2229166666667	5.7	sand	3
Echinophyllia		*aspera*	2022-10-24	−9.46975000	46.2233333333333	19.4	Rock	7
Echinophyllia		*aspera*	2022-10-24	−9.46975000	46.2233333333333	17.4	Rock	7
Echinopora	cf	*gemmacea*	2022-10-22	−9.37486111111111	46.2055555555556	12.1	Rock	2
Echinopora	cf	*gemmacea*	2022-10-23	−9.40180555555556	46.2033888888889	6.4	Rock	5
Echinopora	cf	*gemmacea*	2022-10-24	−9.39180555555556	46.1994722222222	15.3	Rock	6
Favites		*flexuosa*	2022-10-22	−9.37486111111111	46.2055555555556	8.3	Rock	2
Favites		*flexuosa*	2022-10-22	−9.37050000	46.2229166666667	5.7	Rock	3
Favites		*flexuosa*	2022-10-23	−9.46975000	46.2233333333333	9.4	Rock	4
Galaxea		*fascicularis*	2022-10-19	−9.39180555555556	46.1994722222222	15.6	Rock	1
Galaxea		*fascicularis*	2022-10-22	−9.37486111111111	46.2055555555556	13.1	Rock	2
Galaxea		*fascicularis*	2022-10-22	−9.37050000	46.2229166666667	5.7	sand	3
Gardineroseris		*planulata*	2022-10-19	−9.39180555555556	46.1994722222222	7.2	Rock	1
Gardineroseris		*planulata*	2022-10-22	−9.37486111111111	46.2055555555556	11.5	Rock	2
Goniastrea		*edwardsi*	2022-10-22	−9.37486111111111	46.2055555555556	11.5	Rock	2
Goniastrea		*edwardsi*	2022-10-22	−9.37050000	46.2229166666667	7.5	Rock	3
Goniastrea		*edwardsi*	2022-10-23	−9.46975000	46.2233333333333	9.9	Rock	4
Isopora		*palifera*	2022-10-19	−9.39180555555556	46.1994722222222	5.9	Rock	1
Isopora		*palifera*	2022-10-22	−9.37486111111111	46.2055555555556	9.7	Rock	2
Isopora		*palifera*	2022-10-22	−9.37050000	46.2229166666667	6.0	Rock	3
Leptastrea		*purpurea*	2022-10-19	−9.39180555555556	46.1994722222222	8.5	Rock	1
Leptastrea		*purpurea*	2022-10-22	−9.37486111111111	46.2055555555556	12	Rock	2
Leptastrea		*purpurea*	2022-10-22	−9.37050000	46.2229166666667	5.9	sand	3
Leptastrea		*purpurea*	2022-10-23	−9.46975000	46.2233333333333	10.5	Rock	4
Leptoseris		*mycetoseroides*	2022-10-22	−9.37050000	46.2229166666667	6.7	Rock	3
Leptoseris		*mycetoseroides*	2022-10-23	−9.46975000	46.2233333333333	4.4	Rock	4
Leptoseris		*mycetoseroides*	2022-10-24	−9.39180555555556	46.1994722222222	18.8	Rock	6
Lobactis		*scutaria*	2022-10-22	−9.37486111111111	46.2055555555556	11.1	Rock	2
Lobactis		*scutaria*	2022-10-24	−9.46975000	46.2233333333333	13.8	Rock	7
Lobactis		*scutaria*	2022-10-24	−9.46975000	46.2233333333333	13.2	sand	7
Pavona		*chiriquiensis*	2022-10-22	−9.37486111111111	46.2055555555556	15.9	Rock	2
Pavona		*chiriquiensis*	2022-10-22	−9.37050000	46.2229166666667	6.6	Rock	3
Pavona		*chiriquiensis*	2022-10-23	−9.40180555555556	46.2033888888889	7.5	Rock	5
Pocillopora		*eydouxi*	2022-10-23	−9.46975000	46.2233333333333	7.8	Rock	4
Pocillopora		*eydouxi*	2022-10-24	−9.46975000	46.2233333333333	11.6	Rock	7
Pocillopora		*eydouxi*	2022-10-24	−9.46975000	46.2233333333333	11.6	Rock	7
Stylocoeniella	cf	*armata*	2022-10-23	−9.46975000	46.2233333333333	10.3	Rock	4
Stylocoeniella	cf	*armata*	2022-10-24	−9.39180555555556	46.1994722222222	12.6	Rock	6
Stylophora		*palmata*	2022-10-23	−9.40180555555556	46.2033888888889	6.2	Rock	5
Stylophora		*palmata*	2022-10-23	−9.40180555555556	46.2033888888889	6.5	Rock	5
Stylophora		*palmata*	2022-10-25	−9.46302777777778	46.2207222222222	5	Rock	8
Tubastraea		*micranthus*	2022-10-22	−9.37050000	46.2229166666667	8.5	Rock	3
Turbinaria		*reniformis*	2022-10-19	−9.39180555555556	46.1994722222222	15.2	Sand	1
Turbinaria		*reniformis*	2022-10-23	−9.46975000	46.2233333333333	10.5	Rock	4
Turbinaria		*reniformis*	2022-10-23	−9.40180555555556	46.2033888888889	5.9	Rock	5

Fig.10A and 10B

3.3.2. Fragmentation

One of the primary objectives of the World Coral Conservatory is to establish a Noah's Ark of living corals within a global network of public aquaria. To ensure the representation of all collected species in the WCC pool, fragments were propagated from the original colonies and distributed among the four aquarium partners. The aim was for each facility to house at least one representative of each of the 21 species.

4. Discussions

Nearly Two years after the first WCC coral collection trip, several positive outcomes have emerged. The high survival rate of the collected corals, the significant growth observed in most of the original colonies, the successful production and exchange of fragments between partner institutions, and the regular, effective sharing of data and experience among technical teams all confirm the success of the Aldabra collection trip organized during the *Monaco Explorations* mission. Additionally, the general good health status and the successful treatment of disease outbreaks confirm the adaptability of the corals in their host aquariums. Further genetic analyses will also help to better appreciate this adaptability, for example the transcriptome assembly, will allow to explore the expression of genes related to stress response, symbiosis, and biomineralization. These precious data will provide foundational resources for studying the molecular mechanisms underlying coral resilience and

Fig. 7. The 5 diving sites (dive 1 to 7) and the snorkeling site (dive 8) during the collection mission on Aldabra Atoll, Seychelles.

Table 3
Technical characteristics of the holding tanks.

Public Aquarium	Tank	Volume (L)	Filtration	Light	Water movement	Water source
Oceanopolis	OC-1	1000	Protein skimming + calcium reactor + algae reactor	Neptune Led spots Pro Led 200 W Corallien DMX	Ecodrift 20.3 + 15.3 + 8.3	Natural sea water
Burgers'Zoo	BZ-1	4000	Protein skimming	Aqua Illumination - Hydra 64 HD LED	Multiple Tunze Turbelle stream 6085 (8000 L/h)	Artificial salt Tropic marin
	BZ-2	300	Flow through from large coral reef aquarium (details Janse et al., 2008)	Philipps - Coral care LED Gen 2–170 W	Tunze Turbelle stream 6085 (8000 L/h)	Artificial salt Tropic marin
Oceanographic Institute of Monaco	M-1	750	Flow through system	No direct light	1 x Tunze Turbelle 6105	Natural sea water from the Mediterranean sea
	M-2	50	Flow through system + 2 protein skimmers + UV reactor	Neptune Led 200 W	4 x Tunze Turbelle 6105	Natural sea water from the Mediterranean sea
Nausicaa	N-1 N-2	900 900	Flow through system with: Aquamedic zeolith, antiphos Fe, Protein skimming and UV reactor	Aquamedic Led FA 200 flex (x2)	Tunze Turbelle stream 6125	Artificial salt Aquaforest

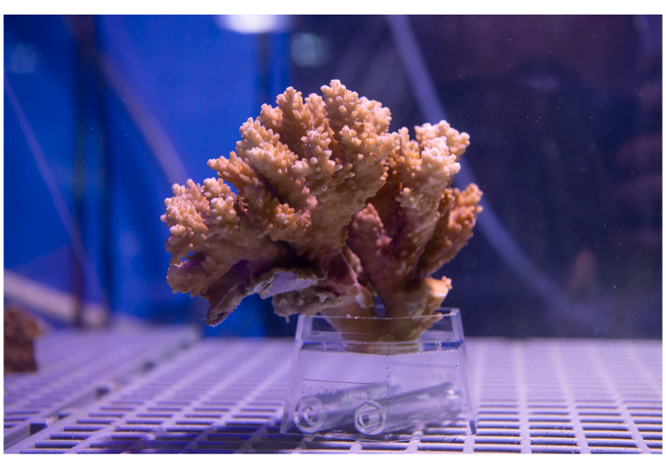

Fig. 8A. Acropora valida on arrival.

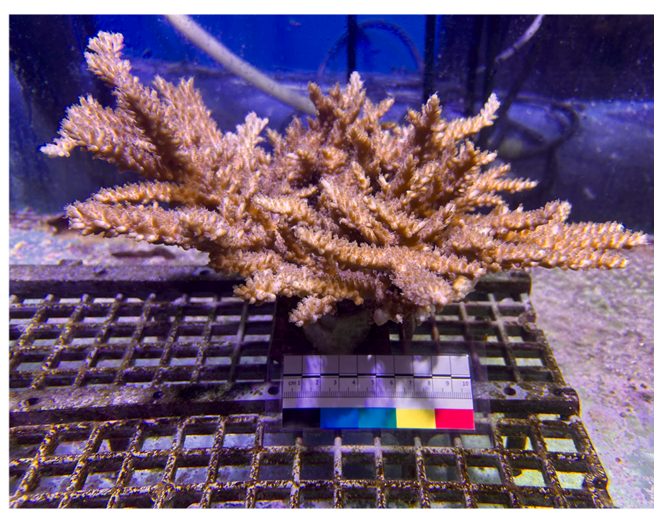

Fig. 8B. Acropora valida eighteen months later (Monaco aquarium).

adaptability.

In parallel, ITS2 metabarcoding is performed to identify the Symbiodiniaceae communities associated with each coral colony. This analysis will help determine the diversity and potential specificity of the symbiotic dinoflagellates, which is a key component of their thermal tolerance and adaptive potential. Combined, these analyses will help assess the baseline genetic and symbiotic diversity of Aldabra corals, and eventually monitor how these attributes change over time in ex-situ conditions. This will enable us to evaluate their adaptability to the host aquaria environments and contribute to the development of best practices for long-term coral conservation under controlled conditions.

The packing procedure, though largely based on prior experience,

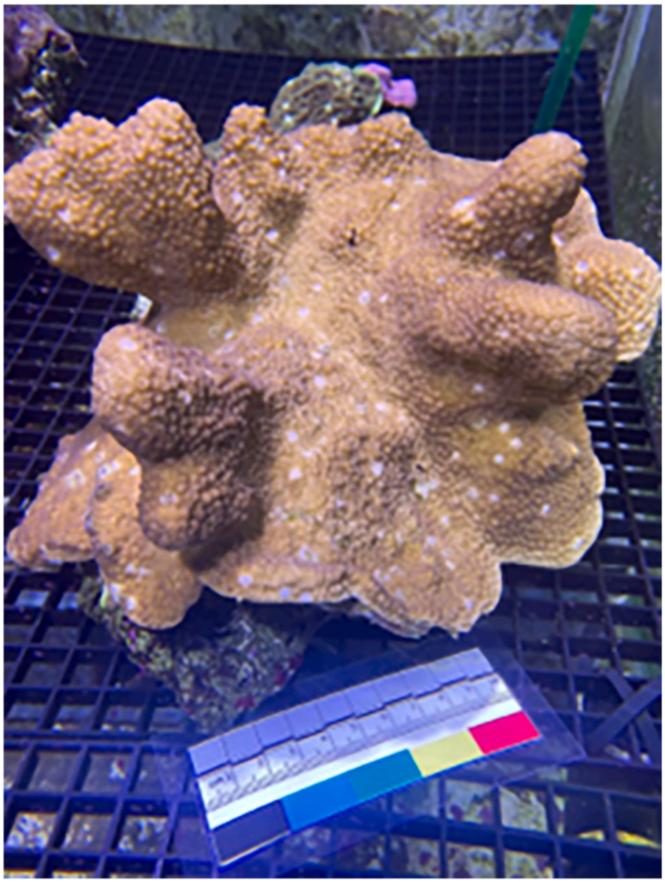

Fig. 9A. Isopora palifera displaying suspected symptoms of Ulcerative White Spot Disease.

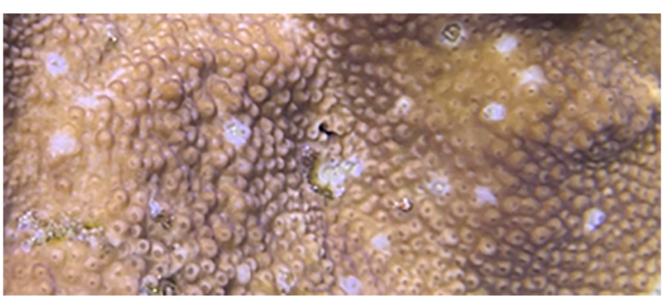

Fig. 9B. Close view.

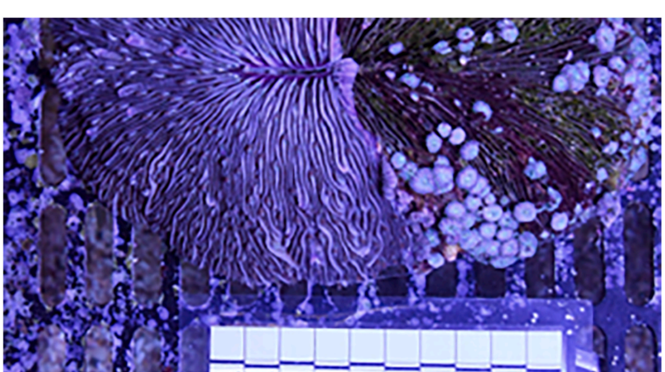

Fig. 10A. Lobactis scutaria showing tissue loss.

Fig. 10B. Lobactis scutaria and the production of anthocauli.

was enhanced by the methodologies described by Craggs et al. (2018), especially in relation to de-sliming the corals and preparing transport water in a separate tank. These improvements played a significant role in ensuring the survival of the corals during their long journey.

Transporting live corals for more than 40 h is a known and documented challenge. As anticipated, certain species, particularly Pocilloporidae, exhibited signs of stress during transport. Based on our observations, colony size appears to be a critical factor in transportation success. We recommend that coral colonies intended for long-distance shipment, particularly Pocilloporidae species, should measure less than 10 cm in diameter to reduce stress and improve survival rates. Another crucial factor during transport was the use of sodium bicarbonate to mitigate pH drops. Despite this intervention, pH levels decreased from 8.15 to 7.3 during transport, highlighting the need for careful monitoring and prompt corrective actions to maintain coral health throughout the process. We also recommend that ammonia levels in the transport water be closely monitored in future shipments. High alkalinity in transport bags may increase the risk of converting ammonium to toxic ammonia, potentially harmful to the corals.

Accurate data collection and monitoring are crucial for this kind of conservation program. Based on the outcomes of this first collection trip, we plan to implement more precise protocols for parameters (use of ICP tests when possible), photographs (with a color and size chart, taken from a standardized distance), and measurements (weight, height and diameter) in future missions to further optimize the process.

This mission in Aldabra was technically very challenging as there was no land-based facilities to keep the corals during the collection days. One of the outcomes of the Aldabra mission is the experience we acquired in keeping corals in good condition, for several days, far away from any existing facility. This for sure can be useful in the future. The system we had to implement on the ship has proven to be very efficient and adapted, but we know that future collection trips will probably be easier, from a logistical point of view. When aquaculture or aquarium facilities exist near the collection sites, they will have to be used, to simplify the process and secure the storage of the colonies before moving them to their destination.

The development and use of platforms such as ZIMS and the Fauna Marin Lab have greatly improved the quality of data management and analysis. These tools enable real-time data sharing and comparisons between partners, and we believe they are mandatory to the success of this type of conservation project.

5. Conclusion and perspectives

This pilot project demonstrates the potential and success of expanding the number of coral species and genotypes with well-documented provenance in an *ex-situ* conservation setting. The successful collection and maintenance of corals in aquariums lay the groundwork for further scientific research, and future shipments will build on this foundation.

In the future, a comprehensive genetic analysis is planned, incorporating metatranscriptomics, metagenomics, and 16S and ITS2 sequencing, as outlined by Belser et al. (2023). This approach is inspired by the Tara Pacific expedition (Planes et al., 2019), which focused on three coral species. With the World Coral Conservatory, the goal is to extend this research to a broader range of species, emphasizing molecular phylogenetics through the assembly of coral transcriptomes. This will provide deeper insights into the evolutionary relationships among coral species. Additionally, a detailed study of the associated bacteriome and symbiotic dinoflagellates will be conducted using 16S, ITS2, and metagenomic analyses.

Unfortunately, during this expedition, we could not obtain the necessary CITES permits for *in situ* molecular sampling. Securing these permits for future expeditions is crucial, as it will allow for critical comparisons between the bacteriome and symbionts at the time of collection and those observed in corals raised in aquariums. Such comparison is essential for understanding the environmental impacts on coral health (Galand et al., 2023).

Based on the success of this first mission and the very good results of coral maintenance in a public aquarium network, the WCC plans to conduct additional collection trips in targeted regions worldwide. These future missions will focus on increasing the diversity of species and colonies hosted in the WCC biobank. The expansion of the global network of public aquarium partners is also a key priority to fully implement the WCC initiative and achieve its conservation goals.

CRediT authorship contribution statement

Olivier Brunel: Writing – review & editing, Writing – original draft, Supervision, Project administration. **Dominique Barthelemy:** Writing – review & editing, Writing – original draft. **Max Janse:** Writing – review & editing, Writing – original draft. **Renaud Herbert:** Writing – review & editing, Writing – original draft. **Nienke Klerks:** Writing – review & editing, Writing – original draft. **Maureen Midol:** Writing – review & editing, Writing – original draft. **Bruno Piguet:** Writing – review & editing, Writing – original draft. **Christophe Cavelli:** Writing – review & editing, Writing – original draft. **Silvia Vimercati:** Writing – review & editing, Writing – original draft. **Frauke Fleischer-Dogley:** Writing – review & editing, Writing – original draft, Project administration. **Annabelle Constance:** Writing – review & editing, Writing – original draft. **Didier Zoccola:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Olivier BRUNEL reports financial support, article publishing charges, and travel were provided by Monaco exploration. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Collecting corals was the first necessary step but maintaining them in optimal condition over the long term in aquarium tanks is a daily challenge for the aquarists working for the four partners. Their passion and attention are keys to success and must be acknowledged.

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Data availability

Data will be made available on request.

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