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Submarine coupled multi-filtration pump

TERESA MADURELL*, ALEJANDRO OLARIAGA AND JOSEP-MARIA GILI

INSTITUT DE CIÈNCIES DEL MAR (CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS, CSIC), PG MARÍTIM DE LA BARCELONETA 37-49, BARCELONA 08003, SPAIN

*CORRESPONDING AUTHOR: tmadurell@icm.csic.es

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The submarine coupled multi-filtration pump (SC-pump), a zooplankton pump system for quantitative sampling coupled with a submarine, is described. The device is battery-powered by the submarine auxiliary engine and has a wide range of potential applications. The SC-pump efficiently collected replicate zooplankton samples associated with cold-water corals and provided reliable estimates of density for major groups of abundant zooplankton encountered in the vicinity of corals (mean 259 $\pm$ 173 ind. m^{-3}). A performance test of the SC-pump compared with conventional net catches (WP2 net) considering overall faunal composition showed effective sampling of the fauna associated with cold-water corals.

KEYWORDS: zooplankton pump; cold-water corals; Northwestern Mediterranean

INTRODUCTION

Cold-water corals are considered an important habitat for larval fish and crustaceans, in the same way as shallow water corals in terms of provision of habitat and diversity of associated fauna (Jensen and Frederiksen, 1992; Rogers, 1999; Reed, 2002; Henry and Roberts, 2007). They act as potential places of refuge, breeding and feeding of many deep-sea species, including commercially important fish (Husebo *et al.*, 2002; Krieger and Wing, 2002; Costello *et al.*, 2005; Ross and Quattrini, 2007; D'Onghia et al., 2010). However, little is known about the invertebrate communities associated with cold-water corals, due in part to practical difficulties in capturing these organisms because of depth, structural heterogeneity and three-dimensionality of the reefs. In coral mounts, data from acoustic-Doppler profiles have revealed a significant circadian vertical migration only 100 m above the bottom, attributed to zooplankton (Davies *et al.*, 2010). Measurements of the density of bioluminescent deep pelagic zooplankton have also been used to evaluate the influence of benthic hotspots associated with topographic structures like underwater mountains, cold-water corals and mud volcanoes (Craig *et al.*, 2010). However, no evidence was found of increased pelagic bioluminescent zooplankton in the vicinity of cold-water corals for logistical reasons. Thus, sampling was conducted several meters above the bottom, not in the vicinity of corals (Craig *et al.*, 2010). However, direct observations with remotely operated vehicles (ROVs) and submersibles have shown abundant zooplankton around the corals.

Direct observation of cold-water corals also shows that they are capable of capturing and eating prey such as zooplankton (Mortensen, 2001; Freiwald, 2002). These observations are supported by indirect evidence from stable isotope analysis and lipid biomarkers (Duineveld *et al.*, 2004; Kiriakoulakis *et al.*, 2005; Carlier *et al.*, 2009; Dodds *et al.*, 2009; van Oevelen *et al.*, 2009), indicating that zooplankton is an important food source for cold-water corals. Recent laboratory experimental work with *Desmophyllum dianthus* also shows the importance of

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zooplankton in the physiological processes of cold-water corals (Naumann *et al.*, 2011). However, there is a major gap in our understanding of zooplankton availability for benthic feeders and therefore there is a critical need for sampling fauna associated with deep-water corals.

Suction sampling has been used extensively on rocky bottoms and coral reefs to sample effectively cryptic mobile invertebrates (e.g. Rützler *et al.*, 1980; Taylor *et al.*, 1995; Heidelberg *et al.*, 2004, 2010; Holzman *et al.*, 2004; Yahel *et al.*, 2005a). Diverse zooplankton pumps have been developed according to target species and the type of environments or substrates; yet, they are predominantly deck operated from the surface (see review by Powlik *et al.*, 1991; Sameoto *et al.*, 2000; Nayar *et al.*, 2002). New technological and engineering approaches to overcome depth-related sampling difficulties have led to new pumping systems becoming available to use in specific areas of the deep-sea (e.g. Buhl Mortensen and Mortensen, 2004; Mullineaux *et al.*, 2005; Carlier *et al.*, 2009, 2010; Zimmer, 2009).

The need for sampling the fauna associated with cold-water corals led us to the development of a submersible pump system. Here, we describe a pump system to quantify zooplankton associated with cold-water corals that is coupled with a submarine. This device, the SC-pump (submarine coupled multi-filtration pump) has the potential to sample zooplankton aggregations in the vicinity of corals and difficult to access areas and to generate replicates. In this paper, we describe the design of the pump, its handling procedure in the field and some initial results to encourage further development and application of the SC-pump for the study of difficult to sample zooplankton. A performance test was carried out by comparing catches of the SC-pump with those of a standard WP2 net, which represents the zooplankton abundance of the surrounding waters.

METHOD

SC-pump design description

The pumping system consists of a series of elements mounted on a square polyvinyl chloride (PVC) base, 50 × 80 cm (10 mm thick). Three 90-mm diameter acrylic cylinders each one containing a small plankton net of 500 μm mesh size were mounted on the PVC base (Figs 1 and 2A). Each net has a 2.8 L collector with a codend of 30 mL volume where the sample is preserved (concentration of the sample into the codend does not take place until the net is drained, ensuring the good condition of the organisms collected). On the top of each cylinder, a non-return valve was installed (Fig. 1A–C). These valves, together with a series of PVC tubes, form the aspiration area of the SC-pump (Fig. 1). At the lower part of the cylinders, three other valves (Fig. 1D–F) are located and connected forming a duct through which the water is pumped through the flow meter (Fig. 1). To select the sampling cylinder that will be used, two manual triggers (1 and 2 in Fig. 1) are located on the right side of the system (Fig. 1). The triggers are connected with the valves through a series of springs, pulleys and stainless steel wires (Fig. 2A). The triggers can be released by means of a hydraulic arm or any other kind of linear activators.

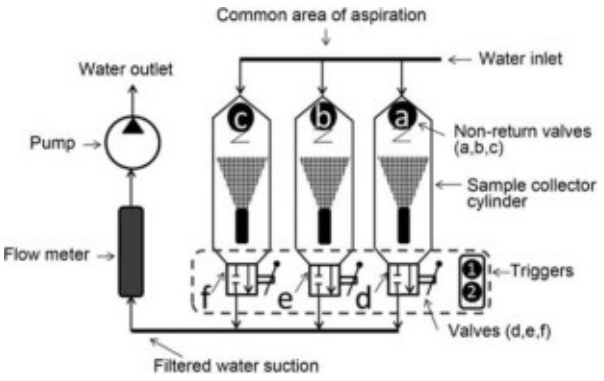

Fig. 1. Schematic illustration of the SC-pump showing the location of the valves, sampling cylinders, triggers, flow meter and pump (pumping system). The SC-pump designed and constructed by A. Olariaga.

Within the framework of the project LIFE + INDEMARES sampling cruise INDEMARES II, the SC-pump system was used coupled to the JAGO submarine (Fig. 2B). One of the auxiliary engines of JAGO was modified and used for pumping, constituting the suction power of the SC-pump system. The engine was equipped with PVC housing that acted as a funnel for water displacement (Fig. 3). Due to the location of the pump (Fig. 1, see location of the pump), at the end of the SC-pump system, the sample is collected before the water passes through the engine and the animals can be kept in good conditions.

SC-pump operating description

One of the most important features of the SC-pump is the capability to collect replicate samples. The SC-pump system works following a sequence of procedures that are summarized in Table I. The sequence that needs to be followed to collect the three sequential samples involves six steps. The procedure involves the condition of the pump (switch on/switch off); the triggers 1 and 2 (armed/disarmed) and the valves d, e and f (open/

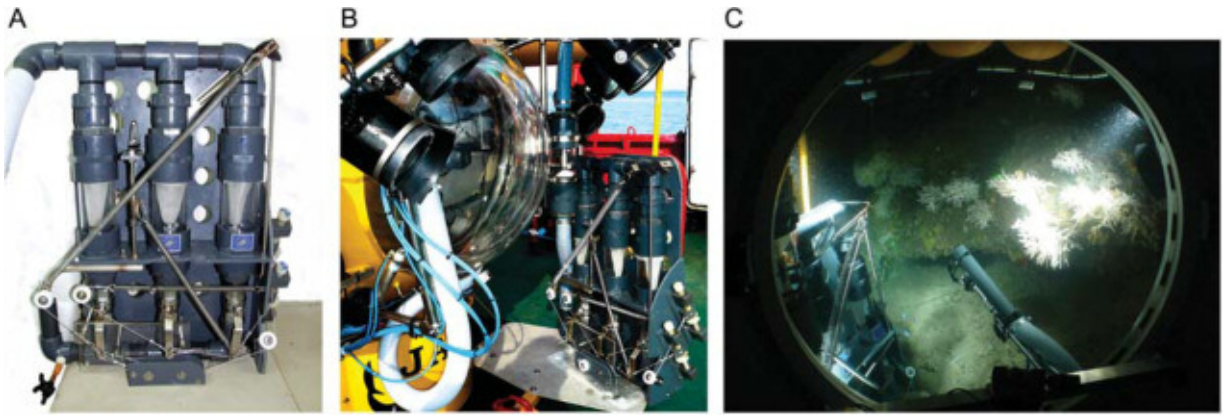

Fig. 2. Photograph of (**A**) SC-pump; (**B**) mounted on the JAGO submarine (IFM-GEOMAR) with detail of triggers connected to the valves through springs, pulleys and stainless steel wires and PVC hose coming from the engine funnel (on the right side of the JAGO submarine) and (**C**) in operation (with light switched on to take the picture).

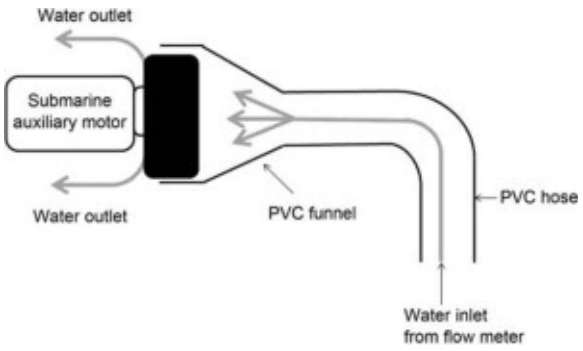

Fig. 3. Zoom image of the pumping system (pump in Fig. 1): submarine engine, funnel and PVC hose.

closed). All combinations and results (system filtering or not filtering) are shown. During the INDEMARES II expedition, the triggers were activated by means of the hydraulic arm of the JAGO submarine.

To select the sampling area, a 50-mm diameter suction hose was placed in the desired position using the same hydraulic arm used for releasing the triggers (Fig. 2C).

Performance test

The performance of the sampler was tested on fauna associated with cold-water corals in the Cap the Creus canyon (Western Mediterranean) at ca. 233 m depth (Table II). Samples were collected during daytime around cold-water corals on rocky substrates. After localizing a sampling spot, the submarine remained still in position with all lights turned off for 5 min, after which we started to filter (all filtrations were performed without any light). Consistent with our sampling objectives, we switched off the light to avoid visual avoidance, visual attraction and dense zooplankton concentrations. Each pump sample lasted for ~10 min, with an average volume filtered of 1.14 m^3. Collectors were fitted with a 500-μm mesh size. A total of six samples were collected from three different dives (Table II). To test the performance of the pump, a WP2 net (57 cm diameter, 500 μm mesh size, with closing device) and equipped with a flow meter was used to sample zooplankton, by horizontal-oblique hauls to obtain samples close to the bottom. A total of three horizontal WP2 net tows of 10 min were performed in the same area during daytime (Table II).

All samples were preserved in 4% formalin and identified later in the laboratory with a binocular stereoscope. All individuals collected were counted and identified to the lowest possible taxonomic level. Differences were tested between taxonomic group composition and their relative abundances, and all groups were included in the analyses.

Statistical methods

A Mann–Whitney *U*-test was performed to identify significant differences between the mean total densities of all zooplankton taxa captured by the two methods and for differences in diversity measures between the pump and net samples. Non-parametric tests were performed with STATISTICA 6.0®. Faunal composition estimated by the two methods was examined with multi-dimensional scaling (MDS) techniques, based on the Bray–Curtis similarity on previously standardized and $\log X + 1$ transformed data using PRIMER®. A similarity matrix was ordinated into a non-metric MDS. Differences between pump and net samples were examined using analysis of similarity percentages ("ANOSIM test") that estimates R,

Table I: Sequence of sampling that needs to be followed for the collection of the three replicate samples

Step	Pump	Trigger 1	Trigger 2	Valve d	Valve e	Valve f	System filtering	Replicate
1	Switched off	Armed	Armed	Open	Closed	Closed	No	
2	Switched on	Armed	Armed	Open	Closed	Closed	Yes	1
3	Switched off	Disarmed	Armed	Closed	Open	Closed	No	
4	Switched on	Disarmed	Armed	Closed	Open	Closed	Yes	2
5	Switched off	Disarmed	Disarmed	Closed	Closed	Open	No	
6	Switched on	Disarmed	Disarmed	Closed	Closed	Open	Yes	3

Table II: Location and details of sampling stations for both the SC-pump and the WP2 net

Station number	Sampler	Date	Depth (m)	Longitude	Latitude	Filtration time (min)	Volume (m^3)
34 M1	SC-pump JAGO 1128	11 June 2010	239	42.393	3.317	15	1.34
34 M2	SC-pump JAGO 1128	11 June 2010	240	42.393	3.317	12	1.22
34 M3	SC-pump JAGO 1128	11 June 2010	240	42.393	3.317	10	1.11
38 M1	SC-pump JAGO 1129	12 June 2010	223	42.364	3.340	10	1.06
40 M2	SC-pump JAGO 1030	12 June 2010	233	42.394	3.311	11	1.07
40 M3	SC-pump JAGO 1030	12 June 2010	231	42.394	3.311	10	1.07
51	WP2	14 June 2010	300	42.390	3.318	10	153.51
52	WP2	14 June 2010	287	42.387	3.321	10	193.74
53	WP2	14 June 2010	258	42.368	3.321	10	173.63

Table III: Mean abundance (ind. m^{-3}) and SD of main taxonomic groups identified for both samplers SC-pump (six replicates) and WP2 net (three replicates) and statistical significance (n.s., not significant)

			Mann–Whitney test		
Groups	SC-pump pump (mean ± SD)	WP2 net (mean ± SD)	*U*	*Z*	*P*-level
Polychaeta	0.59 ± 1.13	0.11 ± 0.06	—	—	n.s.
Decapoda larvae	3.71 ± 6.54	1.16 ± 0.28	—	—	n.s.
Stomatopoda	—	<0.01	—	—	n.s.
Euphausiids adults	41.35 ± 72.74	0.10 ± 0.08	0	2.324	0.020
Euphausiids larvae	27.41 ± 42.35	1.33 ± 1.02	0	2.324	0.020
Amphipoda	5.83 ± 8.53	0.01 ± 0.01	—	—	n.s.
Isopoda	1.71 ± 3.76	—	—	—	n.s.
Mysidacea	2.81 ± 4.69	0.03 ± 0.02	—	—	n.s.
Copepoda	172.49 ± 155.93	7.11 ± 0.92	0	2.324	0.020
Ostracoda	0.16 ± 0.38	0.09 ± 0.03	—	—	n.s.
Chaetognata	0.71 ± 0.84	0.33 ± 0.03	—	—	n.s.
Siphonophora	—	3.06 ± 1.16	0	−2.761	0.006
Medusae	2.58 ± 3.12	0.02 ± 0.03	—	—	n.s.
Ophiuridae	—	0.00 ± 0.01	—	—	n.s.
Appendicularia	—	0.03 ± 0.05	—	—	n.s.
Fish larvae	—	0.02 ± 0.01	0	−2.777	0.005
Fish eggs	—	0.23 ± 0.02	0	−2.777	0.005

the degree to which species composition differed between samplers. Similarity of percentages ("SIMPER") was applied to identify taxa that could potentially discriminate between both samplers. In all cases, statistical significance was set *a priori* at $P < 0.05$.

RESULTS

The taxonomic groups and densities of zooplankton found in samples collected by the SC-pump and the WP2 net are shown in Table III (species list is provided in Supplementary data, Table S1). Eleven taxa were found in the SC-pump catch (Table III) with an average of 259 ± 173 ind. m^{-3} collected in six samples. Three groups made up 90% of the total zooplankton abundance caught with this sampler, copepods and adults and larvae of euphausiids. In contrast, 15 different taxa were collected with the WP2 net (Table III). Four groups made up to 93% of the total abundance of zooplankton caught with the WP2 net, copepods, siphonophora, decapoda larvae and euphausiid larvae. An

average of 13.6 ± 1.4 ind. m^{-3} was collected in three samples. Zooplankton taxa abundance estimated using the SC-pump was significantly higher than that estimated using the WP2 net (Table III) for copepods, adults and larvae of euphausiids, whereas siphonophora, fish larvae and fish eggs were significantly more abundant in the WP2 net samples.

All diversity measures were significantly higher in WP2 net samples except for evenness that was similar for both samplers fauna (Table IV; Mann–Whitney test, $U = 0$, $Z = -2.32$, $P < 0.02$ in all cases).

The multivariate statistical analysis showed significant differences in species composition between the two methods. The MDS based on the density matrices of different zooplankton groups showed a clear separation between the two groups of samples (Fig. 4). The discrimination of both groups was also revealed by the ANOSIM test (global $R = 0.889$, $P < 0.012$). SIMPER analysis showed that four groups contributed to 64% of the average similarity of the SC-pump samples (copepods, adults and larvae of euphausiids and amphipods to 93%), while copepods, siphonophora, decapoda larvae, euphausiid larvae, chaetognaths and fish eggs contributed 90% to the average similarity of WP2 net samples.

Table IV: Diversity indexes (S, total number of groups; d, species richness margalef; J′, Pielou's evenness; H′ (log_{10}), Shannon index)

Sample	S	d	J′	H′ (log_{10})
SC-pump 38M1	4	0.651	0.4465	0.2688
SC-pump 40M2	9	1.737	0.3071	0.2931
SC-pump 40M3	9	1.737	0.5611	0.5354
SC-pump 34M1	6	1.086	0.6072	0.4725
SC-pump 34M2	5	0.869	0.2428	0.1697
SC-pump 34M3	7	1.303	0.3756	0.3174
WP2 net St53	12	2.389	0.6105	0.6589
WP2 net St51	12	2.389	0.5234	0.5649
WP2 net St52	13	2.606	0.5077	0.5655

Fig. 4. Non-metric MDS ordination of the SC-pump and WP2 net samples.

DISCUSSION

The SC-pump is an effective gear to collect zooplankton fauna associated with cold-water corals. The main advances compared with other submersible pumps (e.g. Sebens *et al.*, 1992; Yahel *et al.*, 2002) are that the SC-pump enables *in situ* quantitative sampling with replicates along a submersible dive. Moreover, the pump is easy to use, mechanically operated, not deck-dependent and not very cumbersome in size and there is limited damage of the organisms collected. All these features are usually disadvantages in previous zooplankton pumps (Taggart and Leggett, 1984; Møhlenberg, 1987; Powlik *et al.*, 1991; Sebens *et al.*, 1992; Yahel *et al.*, 2002); therefore, the SC-pump represents a significant improvement. The major limitation is maybe the small volume filtered by the SC-pump (0.1 m^3 min^{-1}). Nevertheless, this limitation is minor when zooplankton densities are high (Taggart and Leggett, 1984; Harris *et al.*, 1986; Møhlenberg, 1987; Sameoto *et al.*, 2000).

The total abundance of zooplankton (259 ± 173 ind. m^{-3}) collected by the SC-pump was higher (20-fold greater) than that estimated using the WP2 net. This observation implies dense concentrations of particular species or groups of zooplankton dwelling by the corals and confirms the potential of the SC-pump for sampling fauna associated with corals, when compared with surrounding waters. No comparable data exist for zooplankton assemblages and cold-water corals, but a parallel study on crustacean fauna associated with gorgonian corals from 330 to 500 m depth in the Northeast Channel off Nova Scotia yielded less number of species; however, this study sampled small volumes (Buhl-Mortensen and Mortensen, 2004). Compared with recent estimates of meso- and microzooplankton in shallow water coral counterparts (ca. 3500–4500 ind. m^{-3}; Heidelberg *et al.*, 2004, 2010) and Mediterranean gorgonians (ca. 1500 ind.m^{-3}; Coma *et al.*, 1994; Rossi *et al.*, 2004), our estimates are conservative, but our concentrations refer only to macrozooplankton (>500 μm). In shallow coral reefs, meso- and microzooplankton distribution depends on predation and behavior, and composition differs with increasing distance to the reef (Holzman *et al.*, 2004; Motro *et al.*, 2005). Recent studies on zooplankton communities in shallow water coral reefs also suggest complex dynamics

related to their diel vertical migrations (Heidelberg *et al.*, 2004; Yahel *et al.*, 2005a,b). Thus, detailed description of the zooplankton community assemblages living by coral reefs, and their temporal and spatial patterns are necessary to understand their ecological importance to cold-water reef ecosystems.

Despite the higher abundance of the fauna associated with cold-water corals compared with the surrounding waters (WP2 catches) their diversity was lower. The differences in the taxonomic composition observed are due to the absence of characteristic pelagic groups like siphonophora, decapoda larvae and fish larvae in the SC-pump samples. Visual avoidance of the pump is an issue for certain fish larvae, large zooplankton and rapid swimmers (e.g. Taggart and Leggett, 1984; Harris *et al.*, 1986; Powlik *et al.*, 1991). However, other aspects discussed in the literature are attraction or avoidance by noise, which seem to differ depending on the taxon considered (Simpson *et al.*, 2011). Additionally, differences in taxonomic composition are also due to the differences in total volume sampled. Where catches with WP2 nets and pumps are comparable, differences were found in composition and population dynamics, mainly different size classes of larvae (e.g. Taggart and Leggett, 1984; Harris *et al.*, 1986).

At the species level (Supplementary data, Table S1), the dominant copepod species identified from the SC-pump samples *Diaxis pygmaea* is a suprabenthic species commonly found up to 300 m depth (Razouls *et al.*, 2005–2012), whereas the dominant calanoid copepod species found in the WP2 samples *Calanus helgolandicus* is an important component of oceanic zooplankton that also inhabits in deep waters (Bonnet *et al.*, 2005). Similarly, the dominant euphausiid *Nyctiphanes couchii* (both adults and larvae) is a common species in macrozooplankton samples, which are concentrated on the sea bottom during daytime (Casanova, 1970) and was caught by both samplers, though with higher densities with the SC-pump. From the remaining taxa identified (Supplementary data, Table S1), it is also apparent that both samplers caught characteristic vertical migrators found in oceanic macrozooplankton samples; however, samples from the SC-pump showing a more suprabenthic component than those from the WP2, which are more characteristic of the water column. These differences in faunal composition from both samplers confirm the effective sampling of fauna associated with corals and thus with great potential to better understand benthic-pelagic coupling.

In conclusion, we have designed a portable suction sampler that can be used conveniently to collect multiple quantitative samples. We have successfully used it to sample fauna associated with corals. Sampling performance of the device was tested by comparison with WP2 net catches that represent the fauna of surrounding waters. The SC-pump provided reliable estimates of density for the main groups of zooplankton. Preliminary data on near-bottom zooplankton densities within cold-water corals revealed that the associated fauna is not that diverse but abundant, with characteristic suprabenthic species. More sampling efforts should be made to confirm our results, probably increasing the sample volume, which would likely yield higher diversity. The SC-pump can be used for collecting samples in difficult to access depth areas and by extension in a variety of challenging marine habitats with both hard and soft bottoms. With minor modifications to engine power, the equipment could also be adapted to operate in other sampling situations with ROVs and submersibles.

SUPPLEMENTARY DATA

Supplementary data can be found online at http://plankt.oxfordjournals.org.

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