D2.2 - Technical publication (project results)

Reliable and innovative technology for the realization of a sustainable MARINe And coastal seabed management PLAN

LIFE Environment and Resource Efficiency project
LIFE15 ENV/IT/000391

Start Date: 01/10/2016
Expected End Date: 31/12/2020

Type of Protocol: Public

Delivery date:
29/11/2020

Last update:
27/12/2020

Project partners

	Coordinating beneficiary: TREVI S.P.A. Private Commercial R&D Project Engineer Via Dismano 5819 47522, Cesena – Italy http://www.trevispa.com Contact: Giovanni Preda - gpreda@trevispa.com
	Associated beneficiary: Comune di Cervia Public Body Piazza G. Garibaldi 1 48015, Cervia – Italy http://www.comunecervia.it Contact: Simona Melchiorri - melchiorris@comunecervia.it
	Associated beneficiary: International Council of Marine Industry Associations - ICOMIA Private non-commercial Brigade Pironlaan 132 B-1080, Brussels - Belgium http://www.icomia.com Contact: Albert Willemsen - Albertw@icomia.com
	Associated beneficiary: ALMA MATER STUDIORUM - Università di Bologna Public Body Via Zamboni 33 40126, Bologna – Italy http://www.unibo.it Contact: Augusto Bianchini - augusto.bianchini@unibo.it

Index

Disclaimer

1. Technical publication

Annexes

Disclaimer

This document contains description of the MarinaPlan Plus project findings, work and products. Certain parts of it might be under partner Intellectual Property Right (IPR) rules. In case you believe that this document harms in any way IPR held by you as a person or as a representative of an entity, please do notify us immediately.
The authors of this document have taken any available measure in order for its content to be accurate, consistent and lawful. However, neither the project consortium as a whole nor the individual partners that implicitly or explicitly participated the creation and publication of this document hold any sort of responsibility that might occur as a result of using its content. This publication has been produced with the support of the European Union. The content of this publication is the sole responsibility of MarinaPlan Plus consortium and can in no way be taken to reflect the views of the European Union.

Chapter 1. Technical publication

Since the 15 months of operation of the demo plant concluded in September and many results were achieved and consolidated in the same period, it was not possible to have published and distributed by the end of the year the results of the project in technical publications.

Nevertheless, LIFE MARINAPLAN PLUS project partners submitted two articles to two different magazines, that are:

- *EcoScienza*, that is the official magazine of the Environmental Agency of Emilia-Romagna region. The magazine is in Italian and it is distributed throughout Italy, to both public and private entities that carry out their activities in the environmental field and are holders of technical and / or political responsibilities (local authorities, university and scientific research bodies, police forces, service companies public and private sectors in the energy, water and waste sectors, libraries, teachers, associations, etc.).

- *Terra et Aqua*, that is the official magazine of the International Association of Dredging Companies (IADC). Launched in 1972, Terra et Aqua is a quarterly publication which aims to disseminate knowledge accrued by global dredging professionals as well as solutions to issues facing the industry. Terra et Aqua is distributed free of charge to more than 10,000 readers world-wide and is available to anyone in the dredging industry upon request.

The article for EcoScienza has been accepted and is now in proof editing. The article will be published in the number 5 of 2020, to be distributed in January 2021.

The article for Terra et Aqua has been submitted to the magazine main editor the 1st of December and it is now under review by the editors board.

Annexes

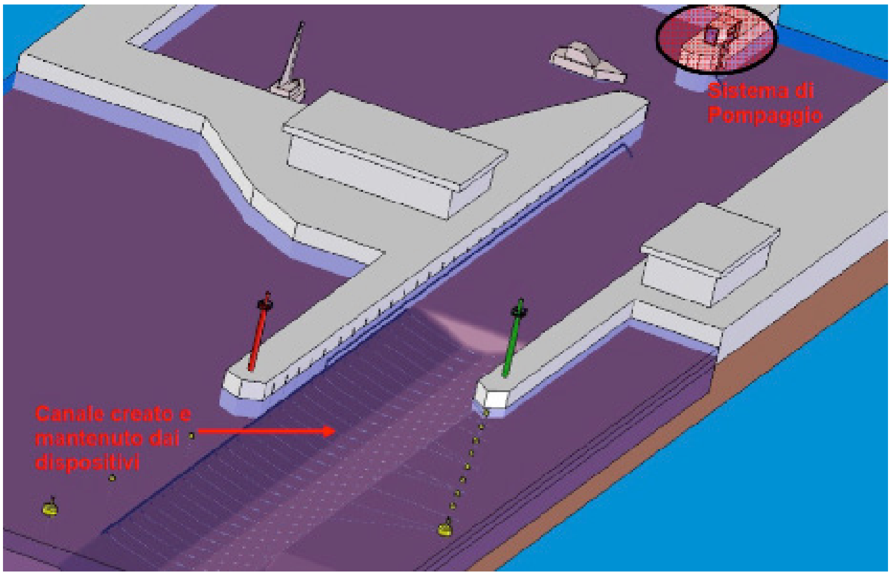
Annex 01	Proof editing version of the technical publication on "*EcoScienza*"
Annex 02	Authors version of the technical publication on "*Terra et Aqua*"

UN IMPIANTO PER UNA GESTIONE PIÙ SOSTENIBILE DEI SEDIMENTI

UNO PROGETTO DI RICERCA CONDOTTO DA PRIVATI E UNIVERSITÀ HA INSTALLATO IL PRIMO IMPIANTO A EIETTORI IN SCALA INDUSTRIALE PRESSO IL PORTO MARINA DI CERVIA (RA). LA TECNICA MANUTENTIVA È VALUTABILE COME PIÙ SOSTENIBILE DA UN PUNTO DI VISTA AMBIENTALE RISPETTO AL DRAGAGGIO DEI FONDALI, INTERVENTO PIÙ COSTOSO E INVASIVO.

A giugno 2019 è entrato in funzione il primo impianto a eiettori in scala industriale presso il Marina di Cervia. L'impianto, costituito da dieci eiettori, è stato realizzato da Trevi Spa nell'ambito del progetto Marinaplan Plus (https://www.lifemarinaplanplus.eu), co-finanziato da Easme (*Executive Agency for Small and Medium Enterprises*) nell'ambito della linea di finanziamento Life. Il progetto, oltre al coordinatore Trevi, vede la partecipazione della Università di Bologna, del Comune di Cervia e di Icomia, che è l'ente internazionale che raggruppa associazioni dell'industria marina provenienti da tutto il mondo.

L'impianto di Cervia è costituito da due moduli indipendenti, ognuno dei quali è composto da una pompa, un filtro autopulente a dischi e un collettore, cui sono collegate le tubazioni di alimentazione di 5 eiettori. Gli eiettori sono dispositivi posizionati sul fondale marino che realizzano una rimozione puntuale del sedimento apportato nella zona da essi controllata, trasportandolo in una zona adiacente ove non costituisce intralcio alla navigazione. Il prelievo del materiale da asportare avviene senza che vi sia alcun organo in movimento sommerso, ma solamente mediante getti di acqua in pressione. L'impianto è residente sul fondale e non costituisce intralcio alla navigazione. Attraverso la composizione di un reticolo di eiettori è possibile intervenire sulla o sulle aree interessate dal fenomeno di insabbiamento. In ***figura 1*** si riporta in sezione e in pianta lo schema di funzionamento di un singolo eiettore. Da ogni eiettore, poi, riparte una tubazione di scarico che procede in direzione sud verso le boe che ne tengono in leggera sospensione l'estremità rispetto al fondo. L'impianto, come mostrato in ***figura 2***, accompagna le condizioni naturali della dinamica dei sedimenti, che opera principalmente da nord verso sud, e



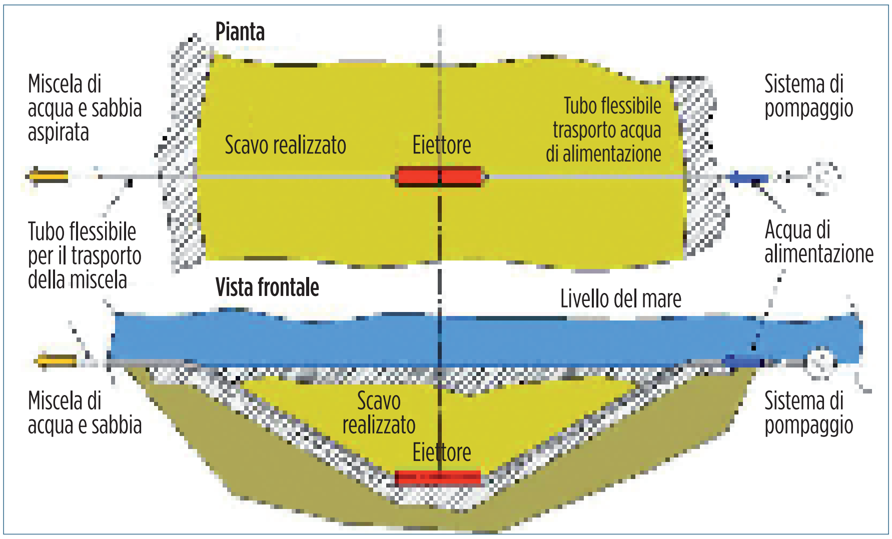


FIG. 1 EIETTORE
Visione in pianta e in sezione di un eiettore.

favorisce, da un lato, il mantenimento del fondale all'ingresso del porto e, dall'altro, restituisce alla corrente dominante parte del sedimento perso a causa dei fenomeni di sedimentazione indotti dalla presenza della struttura portuale. Quindi, la tecnologia a eiettori si configura, anche dal punto di vista normativo, come soluzione alternativa (seppur non concorrente) al dragaggio, poiché realizza uno spostamento del sedimento con bilancio di massa complessivamente nullo nell'area di influenza, ovvero l'impianto trasferisce all'esterno dell'area di influenza tutto il sedimento in ingresso e nulla più.
Nel quadro elettrico è installata l'unità di controllo (plc), gestibile da remoto, che regola l'impianto tramite una logica predefinita. Portate e pressioni operative sono monitorate in continuo, e attraverso gli *inverter* e le elettrovalvole posizionate lungo le tubazioni di alimentazione di ogni singolo eiettore è possibile regolare e bilanciare le portate sulle diverse linee. Lo scopo di tale regolazione è quello di minimizzare i consumi elettrici dell'impianto attraverso la modulazione della portata erogata, in maniera tale da alimentare gli eiettori con la massima portata disponibile solo in presenza di condizioni meteomarine avverse.
L'impianto ha lavorato ininterrottamente da giugno 2019 a settembre 2020, raggiungendo così l'obiettivo del progetto Life, ovvero il monitoraggio delle prestazioni e degli impatti prodotti per un periodo minimo di funzionamento di 15 mesi. L'efficacia è dimostrata dalla capacità che l'impianto ha avuto di mantenere un canale navigabile con fondale minimo di 2,5 m rilevato rispetto al livello del medio mare in uscita dal porto. Per quanto riguarda l'efficienza, i consumi dell'impianto sono risultati superiori alle attese a causa degli inevitabili imprevisti tecnici che si sono presentati. In particolare, a partire da gennaio 2020 e sino a luglio 2020, con un picco nel mese di giugno 2020, la crescita incontrollata di cozze (*Mytilus galloprovincialis*) nelle tubazioni e nei filtri ha notevolmente incrementato le perdite di carico nell'impianto, costringendo le pompe a lavorare con maggiore pressione, a parità di portata, rispetto alle condizioni operative registrate nel 2019. Trevi sta valutando diverse soluzioni tecniche presenti sul mercato per impedire la proliferazione nelle tubazioni di organismi (*fouling*).
Per questo motivo, sulla base dei dati rilevati nel primo periodo di funzionamento dell'impianto, si ritiene di poter valutare il consumo medio di ogni eiettore in condizioni normali pari a 3 kW, ovvero un consumo annuo per i 10 eiettori pari a circa 255.000 kWh.
Per quel che riguarda, invece, le valutazioni in merito agli impatti ambientali, le evidenze preliminari mostrano come le emissioni di CO_2 associate alla prima applicazione industriale su Cervia risultino sostanzialmente comparabili, se valutate con l'approccio Lca, rispetto al metodo tradizionale per la gestione dei sedimenti, ovvero il dragaggio. Nondimeno, occorre sottolineare che l'utilizzo della draga produce anche impatti rilevanti e locali sulla acidificazione e ossidazione fotochimica, nonché la risospensione degli inquinanti eventualmente accumulatisi nel tempo nei sedimenti e l'intorbidimento delle acque, mentre tali impatti sono nulli o trascurabili nel caso dell'impianto a eiettori. Inoltre, nel caso in cui l'impianto

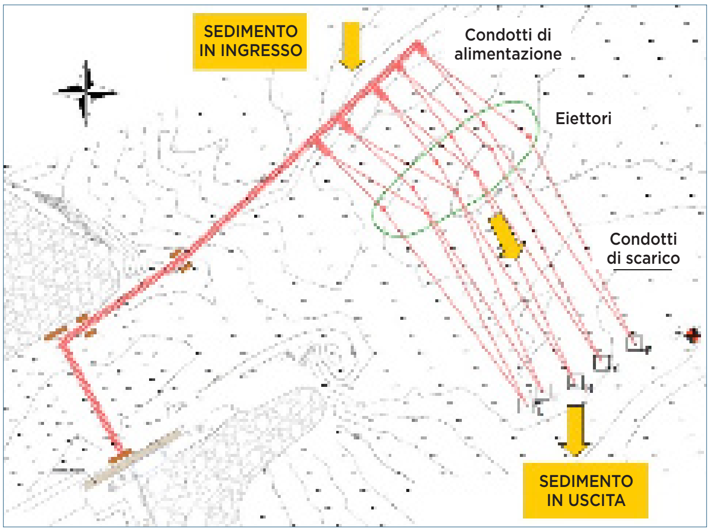


FIG. 2
IMPIANTO DI CERVIA

Principio di funzionamento dell'impianto di Cervia.

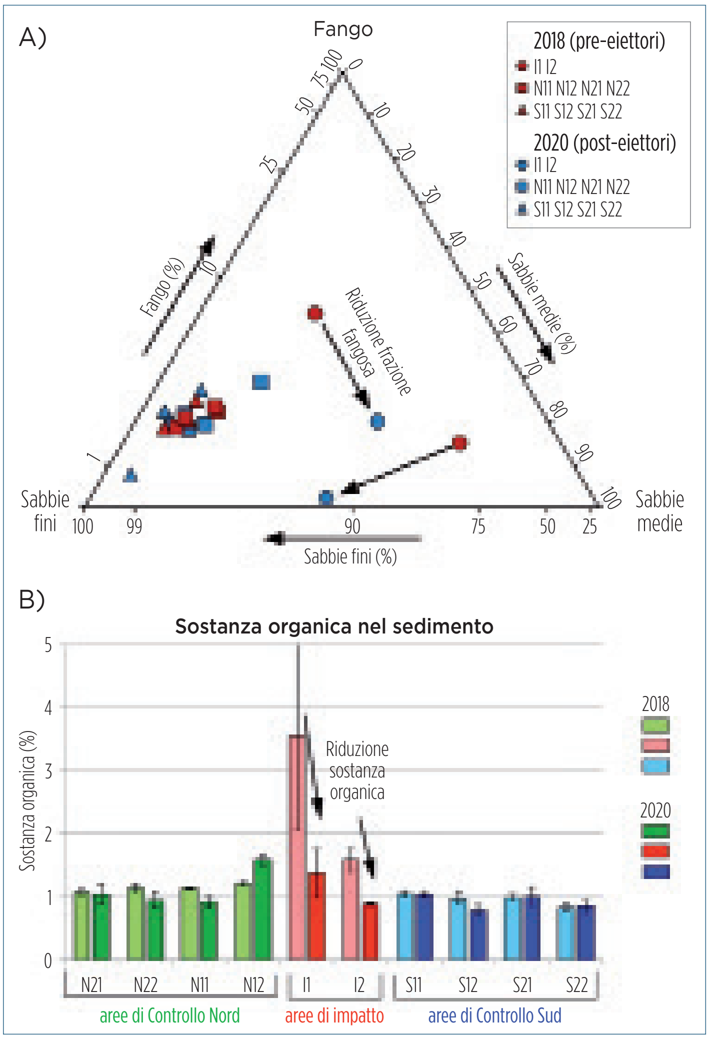


FIG. 3
COMPOSIZIONE SEDIMENTO

A) proporzioni delle frazioni granulometriche. B) percentuale della sostanza organica nel sedimento.

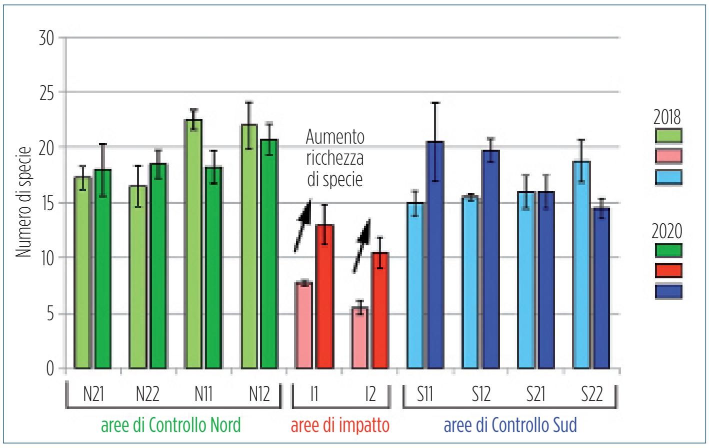


FIG. 4
RICCHEZZA SPECIFICA DEGLI INVERTEBRATI

Numero di specie di macro-invertebrati nelle comunità bentoniche.

a eiettori fosse alimentato con energia elettrica da fonte rinnovabile, vi sarebbe un dimezzamento delle emissioni di CO_2. Infine, l'influenza dell'impianto sull'ecosistema marino è stata valutata attraverso le analisi delle caratteristiche del sedimento (sostanza organica e granulometria) e della diversità e composizione delle comunità bentoniche (comunità del fondo marino), nelle due aree di possibile impatto (I1 = eiettori, I2 = scarichi nelle *figure 3 e 4*) e in aree di controllo poste sia a sud (indicate con S nelle *figure 3 e 4*) sia a nord (indicate con N nelle *figure 3 e 4*) del porto, nei periodi prima (2018) e dopo (2020) l'installazione dell'impianto.
L'uso della nuova tecnologia a eiettori è risultato in una riduzione della frazione fangosa (*figura 3a*) e del contenuto della sostanza organica (*figura 3b*) presenti nel sedimento nelle zone interessate dall'impianto, rispetto ai valori iniziali che erano condizionati dai precedenti dragaggi, avvicinandosi così ai valori medi osservabili per tutto lo studio nelle aree di controllo. La ricchezza specifica dei macro-invertebrati marini (*figura 4*), inizialmente ridotta in prossimità del porto, probabilmente a seguito dei precedenti ripetuti dragaggi, è significativamente aumentata otto mesi dopo la messa in funzione del nuovo impianto, pur rimanendo ancora inferiore a quella media dei siti di controllo. Questi risultati suggeriscono un miglioramento dello stato ecologico dell'ecosistema marino nell'area influenzata dall'impianto già entro un anno nell'area di influenza.
In conclusione, i 15 mesi di funzionamento dell'impianto dimostrativo di Cervia hanno consentito di dimostrare come l'impianto a eiettori costituisca una alternativa ambientalmente sostenibile al dragaggio manutentivo per la gestione ordinaria dei sedimenti in ambito portuale. Inoltre, l'attività di monitoraggio ha consentito di identificare quelle migliorie tecniche che consentiranno alla tecnologia di operare con maggiore affidabilità, riducendo i costi di gestione e manutenzione.

Giovanni Preda[1], Marco Pellegrini[2], Cesare Saccani[2], Massimo Ponti[3], Barbara Mikac[4], Marco Abbiati[4], Marina Colangelo[3]

1. Trevi Spa
2. Università di Bologna - Dipartimento di ingegneria industriale (Din)
3. Università di Bologna - Dipartimento di scienze biologiche, geologiche e ambientali
4. Università di Bologna - Centro interdipartimentale di ricerca per le scienze ambientali (Cirsa)

Title:
An innovative sustainable technology for sediment management in water bodies: final results of the LIFE MARINAPLAN PLUS project

Authors:
Marco Pellegrini, Giovanni Preda, Cesare Saccani, Arash Aghakhani, Barbara Mikac, Massimo Ponti, Marco Abbiati, Marina Antonia Colangelo

Marco Pellegrini is Assistant Professor in Industrial Mechanical Plant at the University of Bologna. He joined the Department of Industrial Engineering (DIN) in 2007 and has both research and teaching experience. The research activities are in the field of sustainable sediment management, renewable energy generation, storage and distribution, health and safety at work. He is author of more than 80 papers in peer-reviewed journals and relevant international conferences.

Giovanni Preda works for Trevi Spa, as R&D Project Manager. Trevi is a worldwide leader in Engineering. For example, some specialties are: foundations, restoration of dams, ports and jetties, tunnels, confinement of contaminated sites, restoration of monuments. After few years as Jobsite Manager, he joined the R&D Department in 2009. He is mainly focused on the development of innovative technologies for sediment management and treatment, environmental dredging, reclamation of contaminated areas, waste management, soil improvement.

Prof. **Cesare Saccani** is Full Professor in Industrial Mechanical Plant at the University of Bologna, Department of Industrial Engineering (DIN). He has a decennial experience in multi-phase flow design, modelling and testing. Coordinator of local unit in several international and national research projects, he is author of over 110 papers on industrial mechanical plants topics, of theoretical and experimental kind, and he is inventor of 10 patents.

Arash Aghakhani is a Ph.D. student at the University of Bologna. He joined the "Future Earth, climate change, and societal challenges" program in 2019. His focuses are mainly on the low carbon systems for climate change mitigation and adaptation, coastal erosion, sediment transport, and renewable energies. His master's degree is in environmental engineering at the University of Bologna.

Barbara Mikac is a marine ecologist, currently research fellow at the Interdepartmental Research Centre for Environmental Sciences (CIRSA) of the University of Bologna. Her research is focused on diversity, structure, dynamics and ecology of benthic communities and natural and anthropogenic impacts on them, distribution and impacts of non-indigenous marine species and diversity and conservation of marine species and habitats. Specialised in ecology, systematic and taxonomy of polychaetous annelids, she described several species new to science.

Prof. **Massimo Ponti** is a marine ecologist, associate professor at the Department of Biological, Geological and Environmental Sciences (BiGeA) of the University of Bologna. President of the Italian association of scientific divers, diving master instructor and vice-president of the Reef Check Italy no-profit association. His research experiences range from temperate to tropical benthic ecology, mainly

	focusing on species diversity, habitat-species interactions, effects of human disturbances and climate change at community and population levels, and biodiversity conservation.

	Prof. **Marco Abbiati** is Full Professor at the Department of Cultural Heritage of the University of Bologna. He is now on leave for having held the position of Science Attaché at the Italian Embassy in Hanoi, Vietnam. He works in the fields of basic and applied marine ecology, environmental management and conservation. He coordinated several research projects funded by the EU, Ministries and private companies.

	**Marina Antonia Colangelo** is a marine ecologist, senior researcher at the Department of Biological, Geological and Environmental Sciences (BiGeA) of the University of Bologna. Her research is focused on the ecology of meio and macrobenthic communities and their role in the subtidal and intertidal ecosystem of sandy coasts with special attention to the response of these communities to natural and anthropogenic disturbance and on response of meiobenthic communities associated with sessile organisms of rocky bottoms in urbanized coasts.

Summary

The project "*Reliable and innovative technology for the realization of a sustainable marine and coastal seabed management plan*" MARINAPLAN PLUS, funded by the Executive Agency for Small and Medium-sized Enterprises (EASME) of the European Commission (EC) within the framework of the LIFE programme, started in October 2016 and finished in December 2020. The project was coordinated by the Italian company Trevi, specialized in civil foundations, and saw the participation as partners of i) the Municipality of Cervia (Italy), which played the role of technology end-user, ii) the University of Bologna, which was responsible for the impact monitoring of the demo installation, and iii) the International Council of Marine Industry Associations (ICOMIA), which acted as main dissemination and communication contributor. The project team received a whole co-financing of 1.45 million Euros to design, realize, operate and monitor the first of a kind demo installation at industrial size of an innovative solution for the sustainable management of sediment in marine infrastructures. The demo plant operated from June 2019 to September 2020 and was able to guarantee navigability of Cervia port entrance for the whole period. The paper shows the preliminary assessment of demo plant results after 15 months of continuous operation and monitoring.

Introduction

The need to remove the deposited material from the water basins is a common feature shared by many ports and channels, since the earliest settlement along coasts and river. Sedimentation characteristics and causes depend mainly on the intensity of seas and rivers currents, which, thanks to the energy of their movement, carry a large amount of sediment that they release due to their interaction with the ports infrastructures. Sedimentation dynamic may vary from location to location, but generally affects and limits the navigability and the related activities.

Normally, the most widely used solution to remove sediment deposits is dredging. Dredging is a well-known, reliable, and diffused technology. Nevertheless, in specific conditions (i.e., smaller marinas and channels) dredging in shallow water requires scaled technologies which are less productive and more expensive than standard configuration. Moreover, dredging is only able to restore the desired water depth but without any kind of impact on sedimentation causes. So, it cannot guarantee sedimentation avoiding over the time. Moreover, dredging operation, usually interfere with other nautical activities and often implies the prohibition of navigation. Dredging also implies high environmental impacts for the marine ecosystem: dredging operations destroy and strongly modify marine habitat related organisms, and can also shuffle contaminants already present in the seabed. Therefore, maintenance dredging operations are often becoming too expensive and/or not allowed by normative framework due to the related environmental impact.

Brief description of the ejectors demo plant

Cervia is a municipality counting about 30,000 inhabitants, located in Emilia-Romagna region coast. The Marina of Cervia is located on the North-East side of the old harbour (Figure 1), reserved for recreational craft, consisting of a dock with eight piers. The Marina has a capacity of 300 boats with a maximum length of 22 m. Cervia harbour is affected by a cyclic problem of inlet sedimentation. Natural sand transport is present alongside the coast line, moving from North to South, as confirmed by regional studies (ARPAE, 2016). The technological solutions adopted until now, including seasonal dredging and/or sand underwater re-suspension by boat propellers, as well as docks lengthening (completed in 2009), have not solved the sedimentation problem. In fact, from 2009 to 2015 about 1.3 million Euro were spent in dredging and sediment handling with propellers (i.e. a mean yearly cost of 185,000 Euro, in Pellegrini et at., 2020).

Figure 1. Cervia position and harbour aerial picture of the study area.

The ejectors plant installed in Cervia has the main objective of guaranteeing navigability at the port inlet while in operation. Cervia demo plant consists of 10 ejectors located at the port entrance as shown in Figure 2. The ejector (Figure 3) is an open jet pump (i.e., without closed suction chamber and mixing throat) with a converging section instead of a diffuser and a series of nozzles positioned circularly around the ejector. Each ejector is placed on the waterbed and transfers momentum from a high speed primary water jet flow to a secondary flow that is a mixture of water and the surrounding sediment. The sediment–water mixture is then conveyed through a pipeline and discharged in an area where the sediment can be picked up again from the main water current (as in Cervia demo plant) or where it is not an obstacle for navigation. Based on preliminary test carried out in 2017 (Pellegrini et al., 2020), it is known that with a primary water feeding flowrate of about 27 m^3/h, a working pressure of about 2.4 bar and a discharge pipeline characterised by 60 metres in length, each ejector is able to convey a peak sand flowrate at the discharge pipeline of about 2 m^3/h (whole discharge flowrate is about 34 m^3/h) and a water pump power consumption of about 3.5 kW. The ejector works on a limited circular area created by the pressurized water outgoing from the central and circular nozzles, whose diameter depends on the sediment characteristics such as, for example, the repose angle. By ejector integration in series and in parallel it is possible to create or to maintain a seaway.

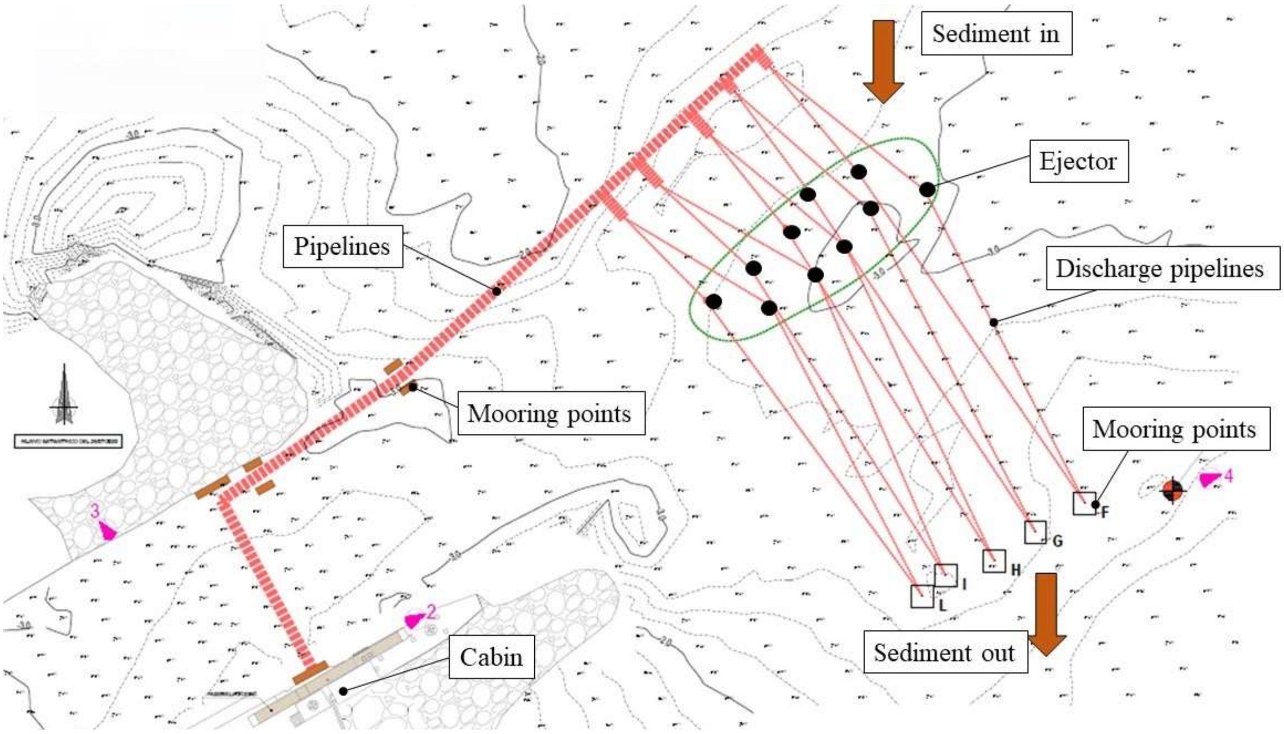


Figure 2. Ejectors location in the demo plant of Cervia.

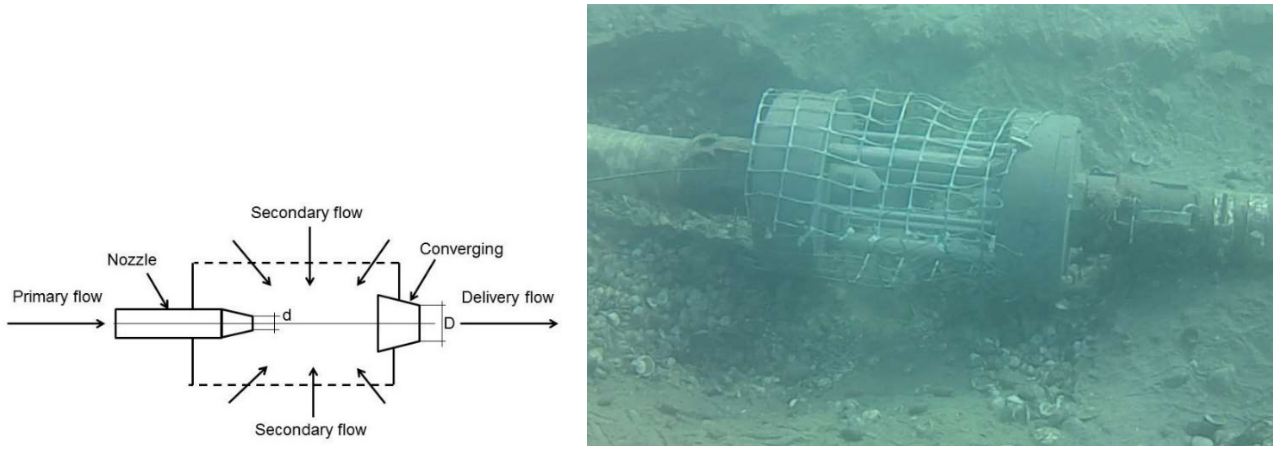


Figure 3. a) Sketch of the ejector, and b) underwater picture of the ejector in operation.

The technology is reliable since, generally speaking, jet pumps have been applied starting from the 1970s for coastal application. Regarding the ejectors technology, it has been developed and tested starting in 2001 by the University of Bologna and the start-up Plant Engineering Srl. In 2005, the first experimental plant (Amati and Saccani, 2005) was realized and tested in the port of Riccione (Italy). In 2012, a second experimental plant (Bianchini et al., 2014; Pellegrini and Saccani, 2017) was realized in the Portoverde Marina (Italy). Both installations have been realized at port entrances and were designed to handle sand. A third experimental installation has been realized in 2018 in Cattolica (Italy), wherein for the first time the ejectors have been applied in the management of silt and clay sediments and installed in a river channel (Pellegrini et al., 2020).

Cervia demo plant also includes a fully automated and remotely accessible pumping station equipped with auto-purging filters. The Piping and Instrumentation Diagram (P&ID) of the pumping plant is schematically shown in Figure 4, where only one ejector line is drafted. There are two pumps, each one feeding five ejectors. Each pumping line has an auto-purging disk filter: the auto-purging cycle is activated once the pressure drop in the filter reaches a certain level. The total pumped water flowrate is controlled by an inverter, while the flowrate for each ejector feeding pipeline is balanced through electrovalves. An air compressor can be used to inject compressed air in the line to easily identify the position of the ejectors on the seabed. The total installed power is about 80 kW. A local meteorological station has been installed to relate plant operation with sea weather conditions.

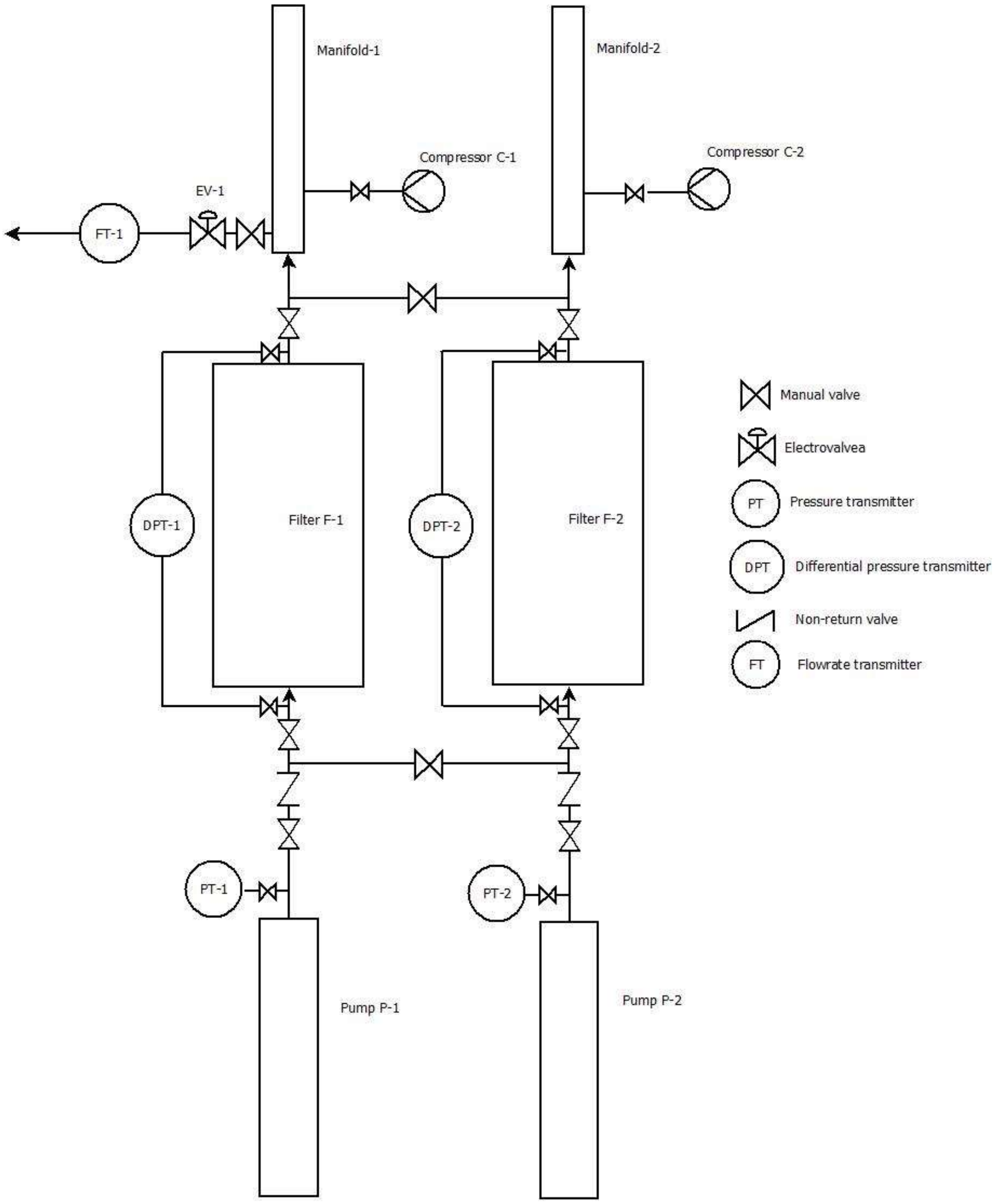


Figure 4. P&ID of the pumping plant.

The main novelty of the MARINAPLAN PLUS project application is that the ejectors plant is designed and is controlled to by-pass the settling sediments, and not to remove them from the seabed. This feature is important in authorisation and permit procedures, since the mass balance in the area wherein the ejectors are installed can be considered as zero, and so the ejectors plant operation should not be equated to maintenance dredging. Moreover, the continuous operation of the ejectors plant reduces to near-zero the environmental impact, since the sediment management follows the nature rhythm.

The monitoring plan

Bianchini et al. in 2018 already demonstrated through a literature review that sand by-passing plant can be more economical than dredging, even if operation and maintenance costs are usually based on estimation more than on real data. One of the main objectives of the MARINAPLAN PLUS LIFE project was to measure the operation and maintenance costs over a consistent period. The efficacy of the demo plant has been monitored through bathymetries in the ejector area, while the efficiency of the demo plant has been assessed through power consumption analysis.

Environmental monitoring activities are fundamental in the MARINAPLAN PLUS LIFE project, since reliable data are crucial i) to evaluate the impact of the demo plant on the marine environment, ii) to compare the impact of the demo plant with that of dredging activities, and iii) to design sustainable sediment management. The environmental impact of sand by-passing systems has never been analysed in detail (Bianchini et al. 2019). Therefore, another interesting novelty of the MARINAPLAN PLUS LIFE project is the assessment of the demo plant impacts on marine benthic and fish communities, due to both sediment reworking and possible noise production. Moreover, the environmental impacts of the realization and operation of the demo plant, projected over 20 years of operation, have been evaluated through the life cycle assessment (LCA) approach.

Project results: navigability guaranteed

Cervia demo plant operated continuously from June 2019 to September 2020, thus achieving the objective of the LIFE project, namely the monitoring of performance and impacts produced for a minimum period of operation of 15 months. Figure 5 summarizes the five operating phases in which demo plant operation can be divided. In the first and second phases, the demo plant operated with a reduced load (25% and 50%, respectively) and manual control: such a control strategy has been necessary to limit pressure and power consumption, since some demo plant devices showed lower performances than the one declared by the suppliers. Then, the demo plant entered the third and fourth phases of operation, in which the full load of the demo plant has been reached. Nevertheless, in this period a growing issue related to mussels (*Mytilus Galloprovincialis*) fouling in the pipes and filters has been detected. The performance of the demo plant was highly affected by fouling, since a reduced water flowrate was available for the ejectors, and a higher pressure was needed, thus dramatically increasing power consumption. That’s why in the fifth phase, only 2 ejectors were in operation.

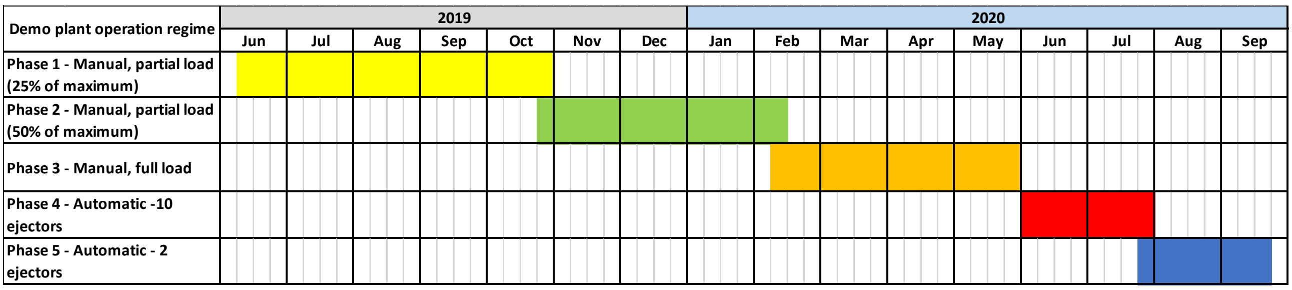


Figure 5. Classification by phases of the demo plant operation in Cervia.

Bathymetries have been carried out through a digital hydrographic ultrasound system with narrow emission cone, preliminary calibration and differential GPS Trimble positioning system; the resulting error is estimated as not exceeding 3 cm. Figure 6 shows the bathymetry before demo plant installation: in Figure 6a there is a detailed colormap of water depth at the port entrance, while in Figure 6b specific areas with water depth higher than 3 m, between 2-2.5 m and lower than 2 m are reported.

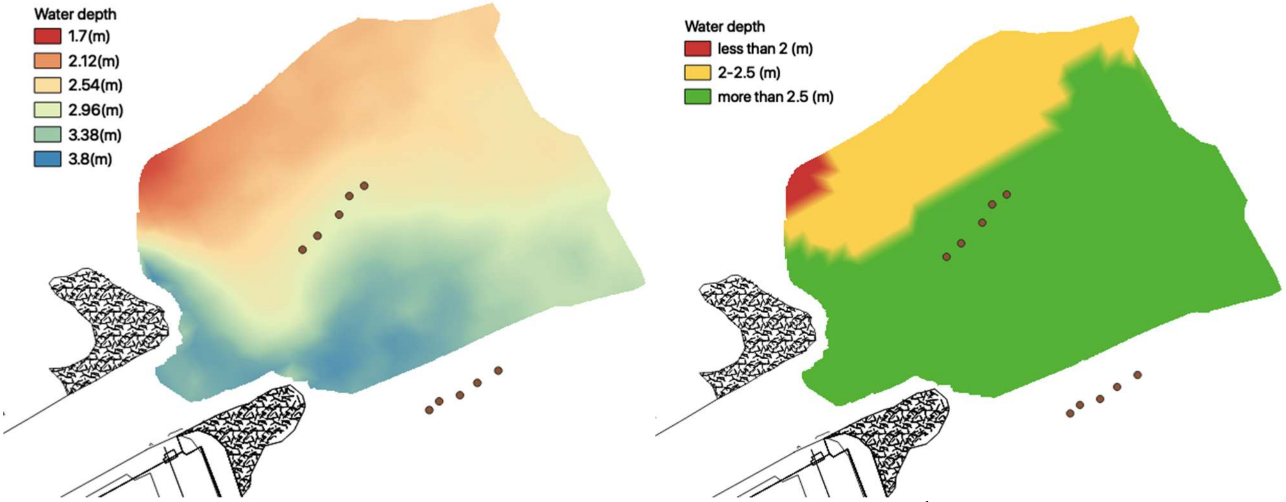


Figure 6. a) Colormap, left side, of water depth at the port entrance on 12th of June 2019; b) Colormap, right side, of water depth for specific ranges (more than 3 m, between 2-2.5 m and lower than 2 m) on 12th of June 2019. The red circles indicate the GPS reference of the mooring points of inlet and outlet ejectors pipelines. The ejectors are installed between the inlet/outlet mooring points, as showed in Figure 2.

Despite the numerous problems encountered, which however have been solved or for which a technical solution has been identified, the effectiveness of the demo plant is demonstrated by the ability of the plant to maintain a navigable channel with a minimum depth of 2.5 m measured with respect to the mid-sea level leaving the port, which is a condition that has never been reached in the past at the beginning of the summer season without dredger operation. Figure 7 is referred to the end of April 2020, i.e. after 10 months of continuous operation. Up to that date the effect of fouling was not critical in terms of effectiveness, even if efficiency was reduced.

Figure 7. Colormap of water depth for specific ranges (more than 3 m, between 2-2.5 m and lower than 2 m) on 30th of April 2020. The red circles indicate the GPS reference of the mooring points of inlet and outlet ejectors pipelines. The ejectors are installed between the inlet/outlet mooring points, as showed in Figure 2.

The final bathymetry of the monitoring period (Figure 8) has been realized on 11th of September 2020, and shows a critical sedimentation between the port entrance and the area of installation of the ejectors, which is anyway not consistent enough to impede navigation. Nevertheless, it should be noted that only two ejectors were in operation from the end of July 2020 due to fouling limitations.

Figure 8. Colormap of water depth for specific ranges (more than 3.0 m, between 2.0-2.5 m and lower than 2.0 m) on 11th of September 2020. The red circles indicates the GPS reference of the mooring points of inlet and outlet ejectors pipelines. The ejectors are installed between the inlet/outlet mooring points, as showed in Figure 2.

With regard to efficiency, the system's consumption was higher than expected: as stated before, starting from January 2020 and up to July 2020, with a peak in June 2020, the uncontrolled growth of mussels in the pipes and filters has considerably increased the pressure losses in the system, forcing the pumps to work with higher pressure, with the same flow rate, compared to the operating conditions recorded in 2019. Various technical solutions alternative to chlorination are under evaluation to prevent the proliferation of organisms in the pipes, like low frequency electromagnetism. For this reason, based on the data collected in the first period of operation of the demo plant and the measured water flowrate for the whole monitoring period, it is possible to assess the average consumption of each ejector in normal conditions equal to 3 kW, i.e. an annual consumption for the 10 ejectors that is approximately 255,000 kWh/year.

The environmental impact assessment

While the effectiveness of the demo plant was already assessed in previous experimental installations, one of the main results of the LIFE MARINAPLAN PLUS project is related to the thorough monitoring of environmental impacts of demo plant operation, which includes i) integrity of seabed sediments and communities, ii) underwater noise, and iii) greenhouse gases (GHGs) and pollutant emissions through LCA.

Possible impacts of the demo plant on sediment characteristics, benthic and fish assemblages need to be assessed simultaneously at a variety of spatial scales, encompassing the full extent of the environmental variability of the area where the ejectors are positioned. Sampling sites are located in one putatively impacted location in front of the port of Cervia and in four control locations, placed 600 m and 1200 m north and 600 m and 1200 m south of the impact location respectively (Figure 9). Two sampling areas (about 800 m^2 each), 20–30 m apart, were defined within every location. In particular, the impact location include two distinct areas, the ejectors (I1) and the outlets (I2). Changes in time of the measured variables at each putatively impacted areas were compared to the whole range of control areas.

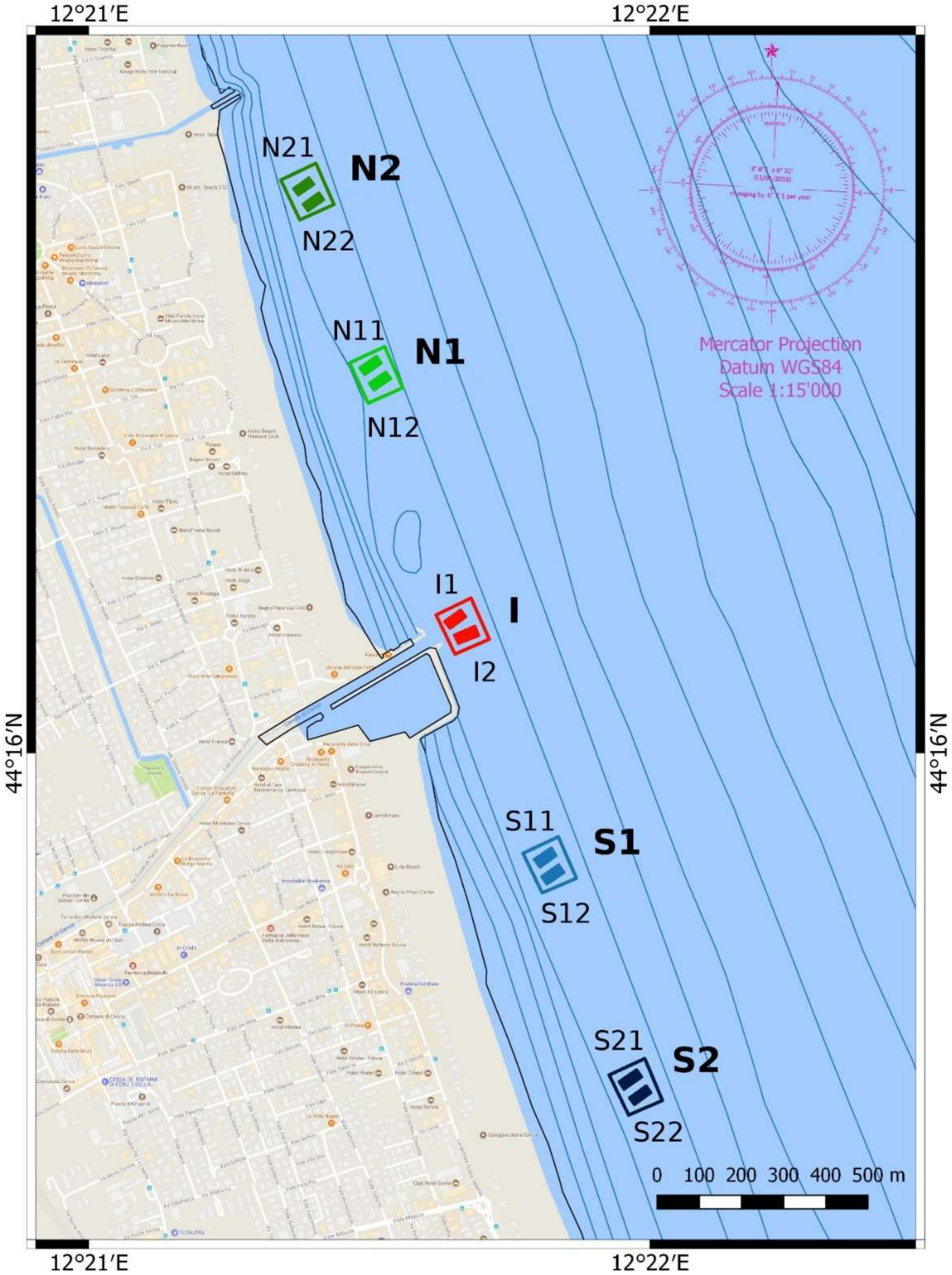


Figure 9. Map of sampling locations (Mercator projection, geodetic datum WGS84). N11 and N12 = areas within location North 600 m (N1), N21 and N22 = areas within location North 1200 m (N2), S11 and S12 = areas within location South 600 m (S1), S21 and S22 = areas within location South 1200 m (S2), I1 and I2 = areas within location impact (I).

The use of the ejectors plant technology resulted in a reduction of the percentage of muddy fraction (Figure 10a) and of the organic matter content (Figure 10b) present in the sediment in the areas affected by the plant, compared to the initial values (samples taken in May 2018) conditioned by the previous dredging, thus approaching the mean values observable throughout the study in the control areas. Species richness of marine macro-invertebrates (Figure 11), initially reduced in the impacted area near the port, probably as a result of the previous repeated dredging, significantly increased eight months after the demo plant was put into operation (i.e. February 2020), although still remaining below the average for control sites. These results suggest an improvement in the ecological status of the marine ecosystem in the area affected by the demo plant within less than one year from the start of the plant operation.

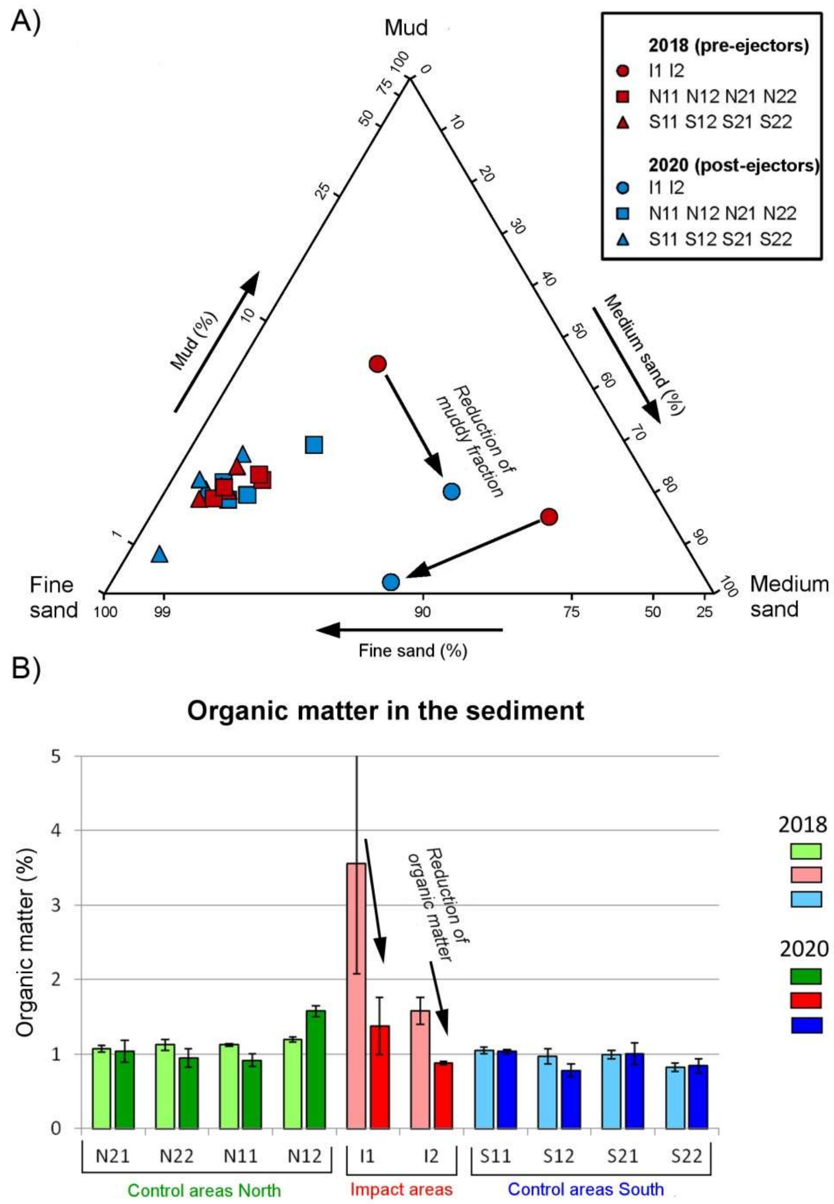


Figure 10. a) Proportions of the sediment granulometric fractions (medium sand > 250 µm; fine sand 250-63 µm; mud < 63 µm); b) percentage in weight of organic matter in the sediment (error bars based on standard error).

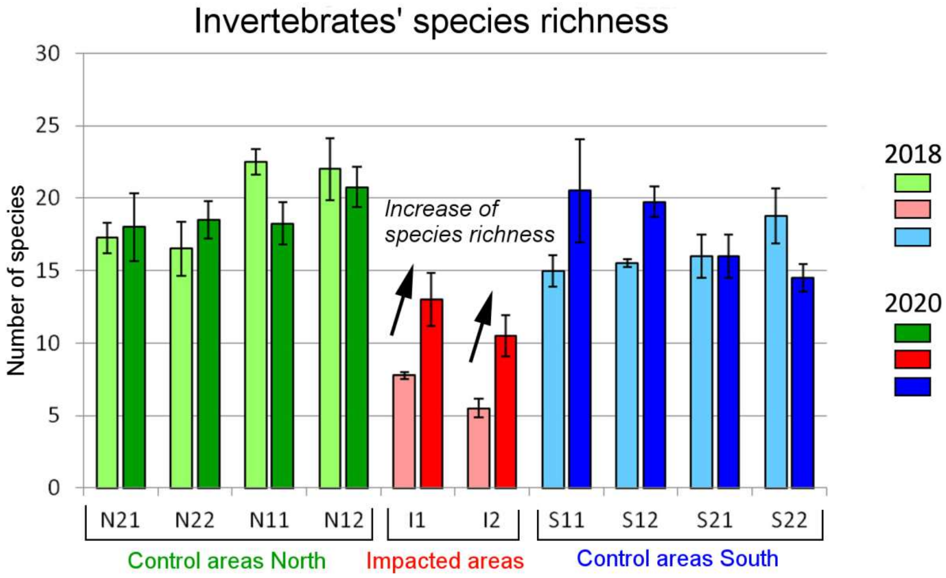


Figure 11. Mean number of macro-invertebrate species per sample in benthic communities (error bars based on standard error).

The impact of the demo plant on underwater noise has been assessed in September 2020. Since specific international standards do not exist yet for the measurement of underwater noise in port environment, the document produced by the National Physical Laboratory (UK) has been taken into account (NPL, 2014). The acoustic measurements were carried out by a specialized operator and by using the SQ26-05 sensor, a pre-amplified hydrophone produced by Sensor Technology. The measurements were carried out on five sampling points (see Figure 12): near the hydraulic pumps, from the quay (B1); 60 m from the hydraulic pumps (B2); about 200 m from the hydraulic pumps and 150 m from point B2 (B5); near the discharge point of the ejectors, or approximately 50 meters from them (M3); about 185 m from point M3 (M4). Furthermore, the measurements have been carried out with the demo plant shut off, and with the demo plant in operation in three different conditions: manual control at two different speeds of the centrifugal pumps, plus automatic control (variable speed of the centrifugal pumps).

Figure 12. Locations of the five measurement points.

The sampling was conducted over 4 days (from Friday to Monday) and planned to perform the measurements during different time slots (day and afternoon). The measurement period, which includes the weekend (Saturday and Sunday), was chosen to be able to observe the effect of the tourist pressure, i.e. of the traffic of motor boats, with respect to the condition that occurs on working days (Friday and Mondays) in which traffic is more limited. While the assessment carried out in sampling points M3 and M4 is related to the impact on open marine environment, the sampling points B1, B2 and B5 have been measured to evaluate the impact of submersible centrifugal pumps for Marina's customers. All the acoustic data were analysed through MATLAB software. For each of the audio files, the average value of the Sound Pressure Level (SPL) in the frequency spectrum 12-20,000 Hz was calculated taking into account the gain level set for the recorder (M), for the pre-amplifier (G) and the sensitivity of the instrument (S), accordingly to equation 1:

$$SPL = 20 \log_{10} (\sqrt{P_x}) + M - G - S \qquad \text{(Eq.1)}$$

where P_x corresponds to the ratio between the digital values of the audio file in .wav format (uncompressed format that guarantees the preservation of a sound identical to the original without quality reduction in the analog-digital transformation that takes place inside the acoustic recorders) and the number of bits set for analog-digital conversion of the signal (16 bit). Particular attention was paid to the analysis of the average value of SPL in the operating frequencies of the hydraulic pumps (30-50 Hz). Where anomalies were found in the measured SPLs, the data were subjected to statistical tests, conducted with the aid of the PAST advanced statistics software to investigate the presence of a statistically significant deviation from the average measured values.

The ejectors themselves had no impact on underwater noise level if compared with the "natural" baseline, while only in the case of monitoring point B1 a difference was found between the noise levels in the recordings made with and without the hydraulic pumps in operation (see Figure 13). Nevertheless, the data were subjected to the Mann-Withney statistical test for non-parametric distributions, to verify, in the presence of ordinal values from a continuous distribution, if two statistical samples come from the same population. The results obtained indicate that the difference between the measurements made with the inactive hydraulic pumps (OFF in Figure 13) compared with the measurements made with the hydraulic pumps on and at different operating status (max, min and automatic control in day #1 and day #2) is not statistically significant ($p = 0.12$, which is greater than the significance value of 0.05) and therefore not attributable solely to the activity of hydraulic pumps. The conclusion is that from the analysis of the acoustic data it emerged that in the port environment the impact of ejectors and hydraulic pumps to the underwater noise is insignificant.

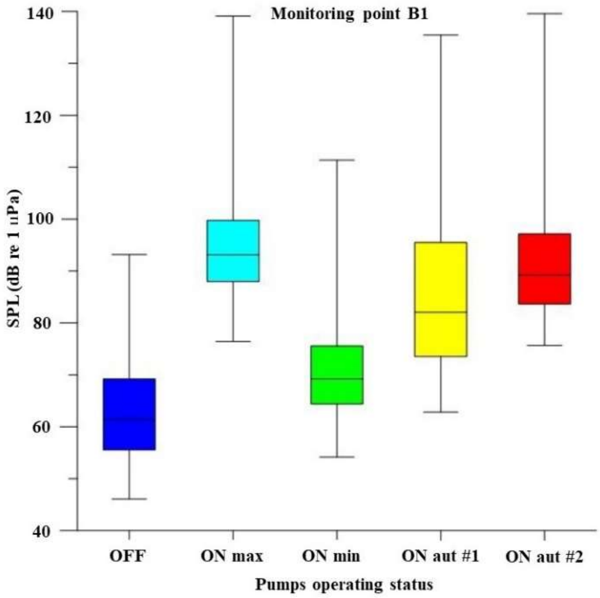


Figure 13. Box-plot of the average SPL values (on the ordinates) for the different operating states of the hydraulic pumps (on the abscissas).

Finally, the impact of demo plant construction and operation on GHGs and pollutant emissions has been assessed through LCA. The choice of system boundaries considered only emissions related to raw materials processing and demo plant operation phases. The other phases of demo plant construction (components manufacturing, transport and assembly) as well as decommissioning phase was not included since in their contribution is considered as negligible. This hypothesis is consistent with available literature data on LCA of pumping station (Jocanovic et al., 2019), which is comparable in terms of components and expected life with the demo plant. The Life Cycle Inventory (LCI) has been performed on the basis of i) bill of materials (BOM) analysis, to identify/classify the components used for the realization of the ejectors plant, of ii) energy consumption in operation, and iii) of components substitution for damaging and/or wear over the years. The estimated life of the demo plant is 20 years. To take into consideration the optimization potential of energy consumption that is estimated on the basis of the 15 months monitoring of demo plant operation in Cervia, the LCA analysis considers two different scenarios for energy consumption:

i) the energy consumption measured during the LIFE MARINAPLAN PLUS project, which is about 530,000 kWh/year, and
ii) the energy consumption optimized, which is estimated in about 147,000 kWh/year.

The estimation of optimized energy consumption is based on the following considerations: the ejectors plant operated almost continuously, and by considering the hours of maintenance and the stop period registered during MARINAPLAN PLUS implementation, it is possible to estimate that the demo plant worked approximately 8400 hour per year, which means a measured mean power consumption per ejector that is 6.3 kW. Nevertheless, by considering the early operation period of the demo plant, which was not affected by fouling, it can be noticed that the mean power consumption per ejector could be about 3 kW, which is coherent with the yearly energy consumption estimated for the optimized scenario. Moreover, the results of monitoring actions highlighted how 5 ejectors instead of the 10 installed should be enough to avoid sedimentation at the port inlet. The area of influence of each ejector is dependant much more on sediment characteristics, like angle of repose, than on ejector efficiency, and long term monitoring has been useful to verify also how each ejector worked by time. So, the final estimation of energy consumption in an optimized configuration considers 5 ejectors with a mean power consumption of 3.5 kW. Operation strategy could be further optimized to reduce energy consumption by ejectors plant shut off in certain conditions, but such a strategy needs to be validated on field.

Material consumption for components damaging and/or wear has been included to consider also the impact of spare parts or components substitution. The hypotheses are based on manufacturers datasheet and the monitoring of 15 months of operation of the demo plant in Cervia:

- marine installation: substitution of 5 meters per year of pipeline;
- inverter: 10 years of expected life-time;
- pump: 10 years of expected life-time;
- pipeline brackets (metallic): 10 years of expected life-time.

Table 1 summarizes the impacts of the ejectors plant construction and operation referred to the functional unit and by considering the two different scenarios previously described. A further emission reduction could be reached if the ejectors plant would be powered by renewable energy.

Table 1. Impacts of the ejectors plant in the two different scenarios by considering the functional unit. NMVOC= non-methane volatile organic compounds.

SCENARIO #1							
Boundary	**Source**	**Environmental impact**					
		CO_2 (kg)	CO (kg)	SO_2 (kg)	NO_x (kg)	PM2.5 (kg)	NMVOC (kg)
Construction	Materials	57,816	33.5	6.7	4.4	1.2	6.5
Operation	Energy	3,498,000	-	-	-	-	-
	Materials	5,202	0.06	0.01	0.0	0.0	0.28
	Total	3,561,018	33.6	6.7	4.4	1.2	6.8
SCENARIO #2							
Boundary	**Source**	**Environmental impact**					
		CO_2 (kg)	CO (kg)	SO_2 (kg)	NO_x (kg)	PM2.5 (kg)	NMVOC (kg)
Construction	Materials	28,908	16.8	3.3	2.2	0.6	3.3
Operation	Energy	970,200	-	-	-	-	-
	Materials	2,601	0.03	0.01	0.00	0.00	0.14
	Total	1,001,709	16.8	3.3	2.2	0.6	3.4

The categories selected to describe the impacts caused by the emissions and the consumption of natural resources at midpoints are Global Warming Potential (GWP), Fine particulate matter formation (PMFP), Photochemical oxidant formation (EOFP and HOFP), terrestrial acidification (TAP). All categories have been assessed accordingly to ReCiPe 2016 (Huijbregts et al., 2016). Figure 14 shows the results of the LCA:

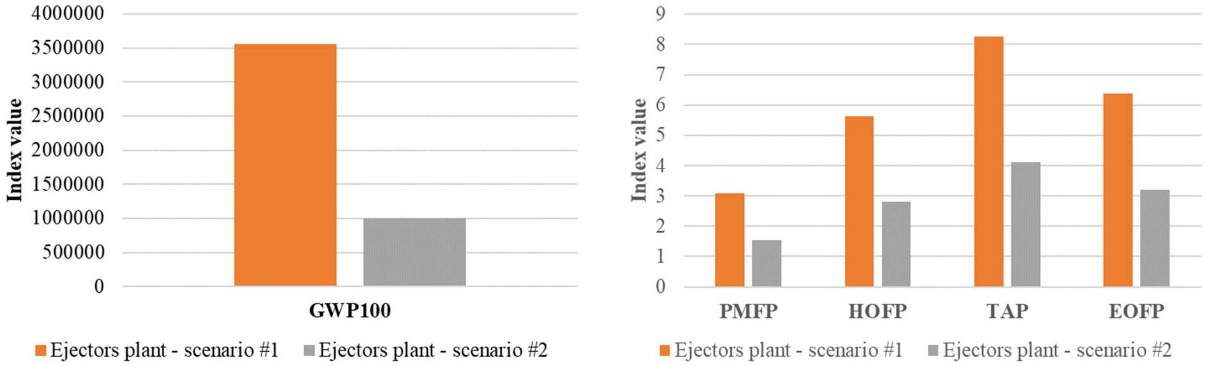


Figure 14. Comparison of midpoint characterization between the two scenarios.

The economic assessment

The primary elements of the economic assessment are BOM analysis (purchasing costs of all the components used for the realization of the ejectors plant), construction site work journal (manpower costs for installation and commissioning and number of hours), energy consumption in operation, costs for components substitution for damaging and/or wear over the years, manpower for maintenance activities.

By considering ejectors plant construction, some equipment has been added, in particular automatic anti-fouling system to prevent pipelines and filters clogging. Moreover, based on the experience, the divers and workers costs have been recomputed by considering the management optimization that could be reached by a better coordination between Trevi purchasing department, Trevi human resources department and sub-contractors in the organization of the construction site. The realization of 5 ejectors plant (optimized configuration) would require 25 days of on-shore activities, plus 10 days of marine activities. To evaluate the benefits for the ejectors plant customer, i.e. Cervia Municipality, the selling price is estimated by adding to Trevi costs i) unexpected events, ii) overheads and iii) profit. The final results is a whole cost for Cervia municipality of 520.000€.

The costs related to ejectors plant operation can be summarized in the following categories: energy consumption and maintenance (components/spare parts cost and manpower). The cost of energy is about 0.21 €/kWh. Based on the demo plant monitoring activities and by considering maintenance optimization which could be reached through i) the installation of an automatic anti-fouling system and ii) more robust and cost effective solutions for the marine installation, it is assumed that 12 days per year of single diver plus 52 hours per year of a worker are enough to guarantee the ordinary maintenance of a 5-ejector plant. Extraordinary maintenance, including substitution of spare parts and main components affected by wear (like pumps or inverters), is computed as a percentage (20%) of the whole yearly operation and ordinary maintenance cost. The final result is an operation and maintenance (ordinary and extraordinary) cost of about 50,000€ per year for Cervia municipality.

Figure 15 shows the simple payback time for the municipality by considering two comparisons with dredging costs: a yearly cost of 185,000 €/year (coherently with historical data) and a yearly cost of 115,000 €/year, which has been computed without including dredging costs for beach nourishment. The investment in the technology results very competitive, with a simple payback time of 4 years in the best scenario. Nevertheless, if a lower advantage is considered for the municipality, which can be read as operation and maintenance cost increasing of the ejectors and/or partial use of dredging equipment for extraordinary maintenance, the investment still results as attractive with 7 years of simple payback time.

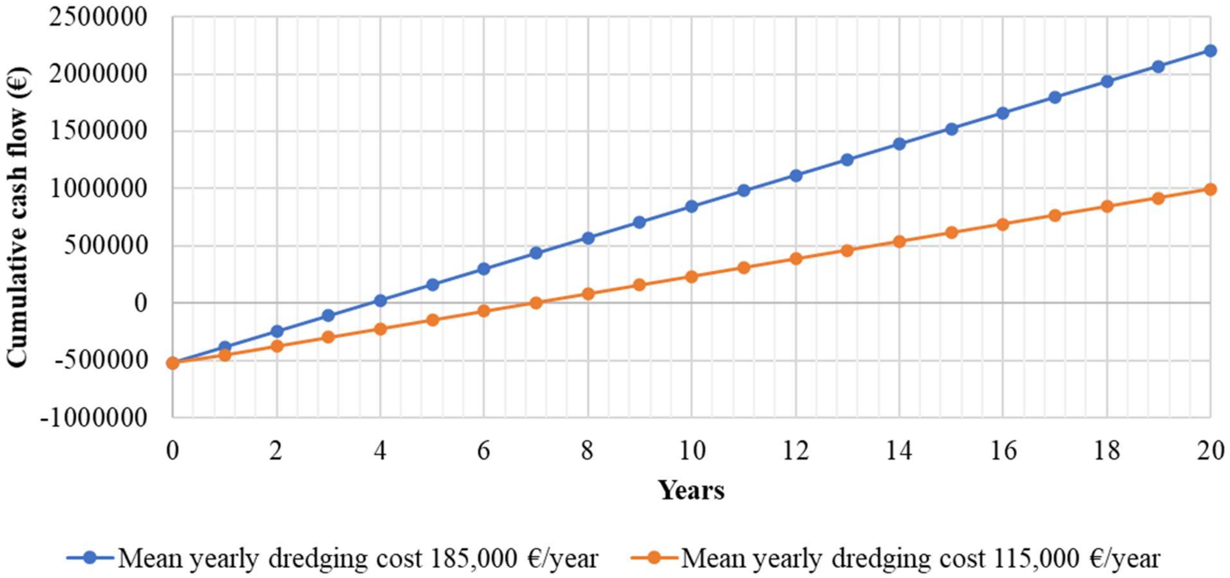


Figure 15. Simple payback time for the municipality of Cervia.

Conclusions

The LIFE MARINAPLAN PLUS project tested and validated an innovative technology for sediment management in water infrastructure. The first industrial size demo plant has been realized at the port entrance of the Marina of Cervia (Italy), with promising results in terms of effectiveness, since the navigability of the port entrance has been guaranteed for the whole operation period of 15 months. Some technical improvements are needed to limit fouling issues, optimize power consumption and maintenance activities. Nevertheless, the solutions to address all the issues arise during the project have been already identified.

Trevi is now committed in the retrofitting of the demo plant, which should be converted to a 5-ejectors plant. Based on monitoring activities carried out during the project, the operation of the plant is expected to reduce sediment management costs for the municipality with a near-zero impact on marine environment (i.e. seabed integrity and underwater noise) and limited impact on GHGs and pollutant emissions.

Trevi is also looking for industrial partners, including dredging companies, to develop business-to-business opportunities related to integration of sustainable and green technologies for ports, as well as the combination with dredging: in the latter case, the matching between ejectors plant and dredging would result as a win-win chance since dredgers can support ejectors plant operation for extraordinary maintenance dredging.

References

Amati G., Saccani C. (2005). Experimental plant for sediment management in harbours' areas (in Italian), *In: Proceedings of the XXXII National Conference on Italian Plant Engineering*, 6-7 October, Rimini, Italy.

ARPAE (2016) *Status of the Emilia-Romagna coast at 2012 - Erosion and defense interventions (Stato del litorale Emiliano-romagnolo al 2012 – Erosione e interventi di difesa, in Italian)*. ISBN: 978-88-87854-41-1.

Bianchini A., Pellegrini M., Saccani C. (2014). Zero environmental impact plant for seabed maintenance, *In: Proceedings of the International Symposium on Sediment Management I2SM*, 17-19 September, Ferrara, Italy.

Bianchini A., Cento F., Guzzini A., Pellegrini M., Saccani C. (2019). Sediment management in coastal infrastructures: techno-economic and environmental impact assessment of alternative technologies to dredging, *Journal of Environmental Management*, 248, DOI: https://doi.org/10.1016/j.jenvman.2019.109332

Huijbregts M.A.J., Steinmann Z.J.N., Elshout P.M.F., Stam G., Verones F., Vieira M.D.M. (2016). ReCiPe 2016 - A harmonized life cycle impact assessment method at midpoint and endpoint level - Report I: Characterization, National Institute for Public Health and the Environment.

Jocanovic M., Agarski B., Karanovic V., Orosnjak M., Micunovic M.I., Ostojic G., Stankovski S., (2019). LCA/LCC Model for Evaluation of Pump Units in Water Distribution Systems, *Symmetry*, 11, DOI: https://doi.org/10.3390/sym11091181

NPL (2014). *Good Practice Guide for Underwater Noise Measurement, NPL Good Practice Guide No. 133*. ISSN: 1368-6550

Pellegrini M., Saccani C. (2017). Laboratory and field tests on photo-electric probes and ultrasonic Doppler flow switch for remote control of turbidity and flowrate of a water-sand mixture flow, *IOP Journal of Physics Conference Series*, 882:012008, DOI: https://doi.org/10.1088/1742-6596/882/1/012008

Pellegrini M., Abbiati M., Bianchini A., Colangelo M., Guzzini A., Mikac B., Ponti M., Preda G., Saccani C., Willemsen A. (2020) Sustainable sediment management in coastal infrastructures through an innovative technology: preliminary results of the MARINAPLAN PLUS LIFE project, *Journal of Soils and Sediments*, 20, DOI: https://doi.org/10.1007/s11368-019-02546-6

Pellegrini M., Preda G., Saccani C. (2020). Application of an innovative jet pump system for the sediment management in a port channel: techno-economic assessment based on experimental measurements, *Journal of Marine Science and Engineering*, 8, DOI: https://doi.org/10.3390/jmse8090686