

1 **Author's response**

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3 The manuscript has been subjected to extensive changes according to the suggestions and
4 comments of the two referees. We hope that in the current version the paper is now suitable
5 for publication on Ocean Science (OS). The changes performed on the text are reported step-
6 by-step below.

7

8 **Referee #1**

9

10 Comments from Referee

11 This manuscript presents and describes the Civitavecchia Coastal Environment Monitoring
12 System (C-CEMS). The system integrates several components such as fixed stations, in-situ
13 surveys, satellite observations and numerical models to forecast, evaluate and face pollutants
14 dispersion. Two applications of C-CEMS are presented here: 1) Bacterial dispersion in
15 bathing areas and 2) evaluation of dredged sediments dispersion on Sites of Community
16 Importance (SCI) where *Posidonia oceanica* exist. In my opinion, the topic and the results
17 obtained in this manuscript are relevant for its contribution to achieve a Good Environmental
18 Status (GES) within the MSFD and for its implications for coastal environments and society.
19 In my opinion, the manuscript is well written, well documented and its methodology and
20 results are supported by previous work of the authors. For these reasons, I believe that this is a
21 study of good quality that I can recommend for its publication.

22 Author's response

23 The authors appreciate that their work is suitable for the publication in OS according to the
24 Referee#1.

25

26 Comments from Referee

27 Page 1601 lines 7-24. For me is not clear from the text if the “Data processing and
28 standardization” was applied only to the data from fixed stations or to all data produced. If it
29 is only applied to the data from fixed stations I think this should be included in the
30 corresponding subtitled “Fixed stations”. If it is not please clarify better here.

31 Author's response

32 “Data processing and standardization” has been reduced and integrated to “Fixed Station”,
33 reported on page 7 in the lines interval 26-32 and on page 8 to the line 19.

1 Comments from Referee

2 Page 1602 lines 3-19: Please add the temporal resolution of your satellite observations. Daily?
3 For me it is not clear from the text if the authors have used algorithms previously developed
4 for the extraction of Chla and TSM using SEADAS or local ones for CASE II waters. Please
5 clarify and add a little more of information about the algorithms used. I suggest the authors to
6 rewrite the paragraph and try to not mix sensors, products and methodologies.

7 Author's response

8 The satellite observations are daily downloaded and processed, when available. As also
9 suggested by the referee#2 the paragraph "Satellite Observations" has been rewritten
10 highlighting the data processing chain and the algorithms used to calculate TSM and
11 Chlorophyll a concentrations.

12 This information is reported on page 9 and on page 10 in the lines interval 1-10. The new
13 references related to this argument are included in the:

- 14 • page 21 in the lines interval 20-22 (Cristina et al., 2015);
- 15 • page 24 in the lines interval 20-22 (Pichel et al., 2001);
- 16 • page 25 in the lines interval 7-9 (Santoleri et al., 2008);
- 17 • page 25 in the lines interval 1-3 (Qin et al., 2007);
- 18 • page 25 in the lines interval 4-6 (Ruddick et al., 2006);
- 19 • page 24 in the lines interval 17-19 (Ondrusek et al., 2012);
- 20 • page 21 in the lines interval 23-26 (Cui et al., 2014);
- 21 • page 22 in the lines interval 16-19 (Drusch et al., 2012).

22

23 Comments from Referee

24 Page 10607 lines: 3-7: I would appreciate here a little bit more of information about that
25 consist the in situ samplings, what type of information was registered and how the thematic
26 maps were created. Or in other case, please give a reference where the reader can find this
27 information. How this in situ information was used or is going to be used? Authors show that
28 the suspended sediments can reach zones of *Posidonia oceanica*, have they studied some
29 change in these meadows?

30 Author's response

31 The health status of *Posidonia oceanica* meadows located in the two SCIs has been evaluated
32 by shoot density descriptor. This parameter was acquired by scuba-diver in the late Spring of
33 2013 following the method reported in Buia et al. 2003. The thematic map is then obtained

1 spatially interpolating the data collected in the two areas. The authors has previously studied
2 the changes in these meadows due to suspended solid concentration.

3 This information is reported in the:

- 4 • paragraph 4.2 (“Dredged sediments dispersion on *Posidonia oceanica* meadows”),
5 page 14, lines interval 24-32;
- 6 • paragraph 5 (“Discussion”), page 17, lines interval 11-13;
- 7 • “References”, page 20, lines interval 4-6 (Buia et al., 2003).

8

9 Comments from Referee

10 I would suggest the authors add at least one *scale and North arrow* to have a reference. Fig. 1.
11 I would recommend the authors to add a map of Italy here. Thus the reader could locate the
12 study area within the Italian region at a first glance. Fig. 7. It is difficult to read the legends of
13 these figures, especially B. I suggest making these figures and legends larger.

14 Author's response

15 The scale bar and the North arrow have been reported in Figure 5 (a and b), 6 (a and b) and 7
16 (a and b). The map of Italy has been included in the Figure 1 and the legends of the Figures 7a
17 and 7b have been zoomed. The captions of Figure 1 and 7 have also been changed.

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19 Comments from Referee

20 Page 1603 line 8-9: Eliminate “we solved the”

21 Author's response

22 “we solved the” has been removed

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1 **Referee #2**

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3 *Comments from Referee*

4 There are many potential good things about this paper that are still missing and include:

5 (1) conveys a good deal of relevant factual information

6 (2) update references relevant and useful for the topics especially dealing with the MSFD

7 (3) the resource management for coastal issue is timely and important but not well addressed
8 (is not even considered the MSP Framework Directive (Directive 2014/89/EU)

9 (4) the author(s) could convey familiarity with the Mediterranean region in question not only
10 to the local scale,

11 (4) EO processing are not in the good-to-excellent range.

12 I think there are some serious flaws in the paper structures that makes the presentation really
13 difficult to follow. The problem is that the reader comes away from the paper wondering what
14 the paper is about. Somehow the assemblage of words, sentences, paragraphs, equations, and
15 tables fails to convey a central themes that I know how to paraphrase. This is in part a severe
16 problem with organization. All is there.

17 The authors need to state that the paper is primarily about a key resource management issue
18 related to coastal issue considering MSFD. Then they need to relate the various sections of the
19 paper to this

20 problem thereby accounting for material in sections, sub-sections, and paragraphs. I cannot
21 recommend publication of this paper until I can state what the central themes and sub-themes
22 of the paper are.

23 Why the author's choose the two applied examples? Are they related? Is the MSFD related to
24 both of them and in which way?

25 *Author's response*

26 The manuscript has been revised according to this suggestion.

27 On page 4 in the lines interval 1-16, the central theme and the sub-themes are better
28 explained.

29 The role of MSP and MSFD in the management of coastal uses and in the conservation of
30 marine environment resources has been highlighted in "Introduction" from line 18 to 23.

31 A brief description of the physical and biological features of the north eastern Tyrrhenian sea
32 (Western Mediterranean region) has been integrated in "Study area" in the lines interval 19-27
33 of the page 4. The new references related to this argument are included in the:

- 1 • page 23 in the lines interval 14-15 (Hopkins, 1988);
- 2 • page 24 in the lines interval 29-30 (Pinaridi and Navarra, 1993);
- 3 • page 26 in the lines interval 4-6 (Vetrano et al. 2010);
- 4 • page 24 in the lines interval 27-28 (Pierini and Simioli, 1998).

5 The two applied examples have been chosen to show the C-CEMS capabilities in supporting
6 the management of conflicts between anthropic uses and sensitivity areas ("urban discharge -
7 bathing area" and "dredging - SCI" conflicts). Their relation with MSFD is reported on page
8 12 in the lines interval 5-10 and 25-27, on page 14 in the lines interval 11-13. The new
9 reference related to this argument is included in the page 20 in the lines interval 11-12
10 (Caruso, 2014).

11 In this revised version the key role of the numerical models within C-CEMS has been
12 emphasized since they enable the observational network to analyse and forecast the pollutants
13 dispersion at appropriate spatial and temporal resolutions. The conflicts are then evaluated
14 overlapping the model results with the thematic maps of the sensitivity areas. This
15 information is reported on page 6 in the lines interval 6-9 and 19-27.

16 As also suggested by the Referee#1, "Satellite Observation" has been rewritten highlighting
17 the data processing chain and the algorithms used to calculate TSM and Chlorophyll a
18 concentration. The change is reported on page 9 and on page 10 to the line 10. The new
19 references related to this argument are included in the:

- 20 • page 21 in the lines interval 20-22 (Cristina et al., 2015);
- 21 • page 24 in the lines interval 20-22 (Pichel et al., 2001);
- 22 • page 25 in the lines interval 7-9 (Santoleri et al., 2008);
- 23 • page 25 in the lines interval 1-3 (Qin et al., 2007);
- 24 • page 25 in the lines interval 4-6 (Ruddick et al., 2006);
- 25 • page 24 in the lines interval 17-19 (Ondrusek et al., 2012);
- 26 • page 21 in the lines interval 23-26 (Cui et al., 2014);
- 27 • page 22 in the lines interval 16-19 (Drusch et al., 2012).

28 The advantages of C-CEMS and the analysis of "urban discharge - bathing area" and
29 "dredging - SCI" conflicts are reported in the new section "Discussion" on pages 16-17.

30 The Figure 2 has been modified and better argued (caption at page 32) in order to highlight
31 the links between the C-CEMS components and their role in supporting the management of
32 marine environment resources.

1 According to the authors the large amount of work improves the structure and the
2 organization of the paper making it easier its reading and understanding.

3

4 Comments from Referee

5 1. The introduction must have way much more background on MSFD and very recent
6 scientific papers on the matter. No need to cover everything, but is good to increase the
7 litterature review especially in respect of MSFD. A cursory literature review turns up
8 numerous examples of similar technical applications on other coastlines with more scientific
9 questions related to MSFD, including:

10 - Cristina, Sónia, et al. "Using remote sensing as a support to the implementation of the
11 European Marine Strategy Framework Directive in SW Portugal." Continental Shelf Research
12 (2015). - Jayasinghe, RP Prabath K., Upali S. Amarasinghe, and Alice Newton. "Evaluation
13 of marine subareas of Europe using life history parameters and trophic levels of selected fish
14 populations." Marine Environmental Research (2015). - Pieralice, Francesca, et al. "An
15 innovative methodological approach in the frame of Marine Strategy Framework Directive: A
16 statistical model based on ship detection SAR data for monitoring programmes." Marine
17 environmental research 102 (2014): 18-35.

18 Author's response

19 In "Introduction", new references about the different approaches for the analysis of GES
20 descriptors, including those recommended by the referee, has been reported on page 2 (lines
21 interval 23-32) and 3 (lines interval 1-7). The new references related to this argument are
22 included in the:

- 23 • page 21 in the lines interval 20-22 (Cristina et al., 2015);
- 24 • page 24 in the lines interval 23-26 (Pieralice et al., 2014);
- 25 • page 23 in the lines interval 20-22 (Jayasinghe et al., 2015);
- 26 • page 25 in the lines interval 23-25 (Tornero and Ribera d'Alcalà, 2014).

27

28 Comments from Referee

29 2. The innovation missing from this paper is perhaps the great challenge of remote sensing
30 combined with the insitu analysis and the modelling: once you make the detection of different
31 variables, what do you really increase into the remote sensing community or in the coastal
32 managers community? What specific, physical or ecological insight do C-CEMS approach
33 allow? What exactly do we gain from combined temporal C-CEMS approach that we cannot

1 determine, for example, from a classical method? The technological advantage and whether or
2 not the analysis of that advantage is innovative depends on the research question. At this stage
3 the paper represent a series of analysis that is unclear how they set up the innovative method.

4 Author's response

5 The innovation of this paper concerns the development of the new observation network (C-
6 CEMS) to support the management of marine environment resources solving the coastal
7 conflicts between the anthropic uses and sensitivity areas at an appropriate spatial and
8 temporal scale. In this context the “Numerical models” component gives a fundamental
9 contribution within C-CEMS, as well as the fixed stations that ensure the availability of a
10 large amount of real-time data allowing the analysis of coastal conflicts by the detection of
11 pollution phenomena. Model results overlapped with the characteristics of the sensitivity
12 areas can be considered as the first step for the establishment of marine functional zoning
13 scheme made by different types of zones with varying levels of limited uses. This information
14 is mainly included in “Conclusions” (pages 17-18) that has been widely modified. The new
15 reference related to this argument is included in the page 25 in the lines interval 17-20
16 (Serafino et al., 2012).

17 The in-situ data collected by fixed stations and field survey are then combined with the
18 satellite observations to assign the initial and boundary conditions of the numerical models.

19 The links between C-CEMS components are reported in different parts of the paper:

- 20 • in “Fixed stations”, page 7, lines intervals 8-24;
- 21 • in “In-situ surveys”, page 8, lines intervals 23-32;
- 22 • in “Satellite observations”, page 9 (lines intervals 30-32) and 10 (lines intervals 1-
23 3);
- 24 • in “Numerical models”, page 11, line intervals 10-15.

25 The new references related to this argument are included in the:

- 26 • page 21 in the lines interval 23-26 (Cui et al., 2014);
- 27 • page 19 in the lines interval 12-14 (Beckers et al., 2006);
- 28 • page 26 in the lines interval 7-9 (Volpe et al., 2012).

29 In the paper we highlighted also how the in-situ and remote observations are used in C-CEMS
30 applications. This information is reported on page 13 in the lines intervals 18-21 and on page
31 15 in the lines intervals 9-11. The new reference related to this argument is included in the
32 page 25 in the lines interval 21-22 (Thoe et al., 2010).

33

1 Comments from Referee

2 3. The C-CEMS approach analysis is sound enough, but for a methodological paper, a more
3 robust testing or assessment is needed. There is a light comparison with field based data
4 especially within the EO part. There is a new bunch of literature more than the MODIS and
5 AVHRR processing chain considering MERIS and the new Sentinel-2 (Filipponi, F., et al.
6 "GENERATION OF GRIDDED OCEAN COLOR PRODUCTS FROM MERIS: AN
7 EFFICIENT PROCESSING CHAIN). Considering the new Copernicus world is the
8 speculation of EO within the paper sound enough? If I also consider what was developed
9 under FP7 EU Project COBIOS and what is under development with the BEAM project
10 (<http://www.brockmann-consult.de/cms/web/beam/>) I do highlight to the author that the message
11 that additional data processing and analysis can help define boundaries better is no doubt true,
12 but not very enlightening—the same would apply to additional effort paid to others analysis. I
13 do consider the authors expert in the area if they want to relate in management procedure (this
14 part is really confusioning to my knowledge).

15 Author's response

16 Since the pollutants dispersion represents the C-CEMS results, the capability of the
17 observation system in reproducing the output of coastal pressures has been evaluated
18 analyzing the accuracy of hydrodynamic field through the use of sea currents (WQB) and
19 wave data (WB2) acquired by fixed stations. This information is reported on the page 11 in
20 the lines intervals 16-18.

21 The algorithms used to analyse the Chlorophyll a concentration and TSM from MODIS data
22 have been validated with in-situ data measured by water quality station (WQB) and periodic
23 field surveys. In the manuscript the MODIS and AVHRR processing chain has been reported
24 too. This information is included in “Satellite observations”, on the page 9 (lines interval 10-
25 32) and 10 (lines interval 1-3). The new references related to this argument are included in
26 the:

- 27 • page 24 in the lines interval 20-22 (Pichel et al., 2001);
- 28 • page 25 in the lines interval 7-9 (Santoleri et al., 2008);
- 29 • page 25 in the lines interval 1-3 (Qin et al., 2007);
- 30 • page 25 in the lines interval 4-6 (Ruddick et al., 2006);
- 31 • page 24 in the lines interval 17-19 (Ondrusek et al., 2012);
- 32 • page 21 in the lines interval 23-26 (Cui et al., 2014).

1 Accordingly to the Copernicus program, C-CEMS provides a monitoring service for the
2 marine environment through multi-source data that include in-situ and remote sensing
3 observations. This information is reported on page 6 in the lines intervals 2-6.

4

5 Comments from Referee

6 4. Lastly, but importantly, the manuscript in its current form is crippled by disorganization.
7 The Introduction and Results & Discussion sections are sprawling and difficult to follow. I do
8 prefer to see in a scientific paper results and discussion well separated. The Data & physical
9 section is not reasonably clean and is lacking in information, but the Methods & Methodology
10 section is impenetrable with a lack of a simple workflow that could help the reader (Figure 2
11 is not helping the reader in that direction). Wherever it gets published, any subsequent version
12 of this work needs to clarify explicitly the authors' research question, motivation, hypothesis,
13 and outcomes. It is much too long & too detailed (I propose to reduce the length as well as the
14 # of tables and figures with at
15 least 20%). While reading I had the impression that it was rather a report of a technical project
16 than a paper; e.g. the different details used during the paper. You must focus much more on
17 the novelties and skip all superfluous background information & details.

18 Author's response

19 As reported on page 16 in the lines interval 6-8, the purpose of the authors is to write a
20 methodological manuscript that describes the C-CEMS observational network and how it
21 analyses the coastal conflicts.

22 The paper focused on: (1) the functioning of C-CEMS and its components (Section 3); (2) its
23 capabilities in reproducing the dispersion of fecal bacteria for bathing water quality
24 assessment and of dredged fine sediments to evaluate the effects on *Posidonia oceanica*
25 meadows present in the Sites of Community Importance (SCI) of the Civitavecchia coastal
26 area (Section 4); (3) the resulting analysis of "urban discharge - bathing area" and "dredging -
27 SCI" conflicts (Section 5). This information is reported on the page 4 in the lines interval 1-7.

28 To help the reader to understand the links between C-CEMS components and their role in
29 supporting the management of marine environment resources, the workflow of Figure 2 has
30 been improved.

31 In this regard "Data processing and standardization" has been reduced and integrated in
32 "Fixed station" (pages 7-8) and the Table 1 has also been removed (pages 27-28).

1 The authors consider that these changes can improve the structure and organization of the
2 manuscript.

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5 **The following additional changes, reported below, have also been considered by the**
6 **authors for the revised version.**

7

- 8 • In “Abstract”, MSP directive has been reported and the description of C-CEMS
9 components and applications has been improved.
- 10 • The need to study the marine environment resources by monitoring networks,
11 included C-CEMS, in the Mediterranean region has been clarified in
12 “Introduction”.
- 13 • In “Study area” the coastal zone between Marina di Tarquinia and Macchia Tonda
14 has been framed in the Mediterranean region.
- 15 • In “Components of the C-CEMS” we highlight that the analysis of economic
16 impact, reported also in the Figure 2, has not been evaluated in this work.
- 17 • In the other part of the manuscript, some technical corrections have been made to
18 improve the structure and organization of the paper.

The Civitavecchia Coastal Environment Monitoring System (C-CEMS): a new tool to analyse the conflicts between coastal pressures and sensitivity areas

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Abstract

The understanding of the coastal environment is fundamental for efficiently and effectively facing the pollution phenomena, as expected by Marine Strategy [Framework Directive](#), [and for limiting the conflicts between anthropic activities and sensitivity areas, as stated by Maritime Spatial Planning](#) ~~which is focused on the achievement of Good Environmental Status (GES) by all Member States by 2020~~. To address this, the Laboratory of Experimental Oceanology and Marine Ecology developed a multi-platform observing network that has been in operation since 2005 in the coastal marine area of Civitavecchia, where multiple uses and high ecological values closely coexist. The Civitavecchia Coastal Environment Monitoring System (C-CEMS), implemented in the current configuration, includes various [components allowing to analyse the coastal conflicts by an ecosystem based approach](#) ~~modules that provide integrated information to be used in different fields of the environmental research~~. The long-term observations acquired by the fixed stations are integrated ~~with~~ [by](#) in-situ [data collected for the analysis of surveys, periodically carried out for the monitoring of](#) the physical, chemical and biological ~~characteristics parameters~~ [of the water column, sea bottom and pollution sources detected along the coast and marine sediments, as well as of the benthic biota](#). The in-situ data, integrated with satellite observations (e.g. temperature, chlorophyll-a

1 and TSM), are used to feed and validate the numerical models, which allow the analysis and
2 forecasting of the dynamics of ~~conservative and non-conservative particles~~pollutants
3 dispersion under different conditions. ~~To test the capabilities of C-CEMSAs examples of C-~~
4 ~~CEMS applications~~, two case studies are reported in this work: 1) the analysis of fecal
5 bacteria dispersion for bathing water quality assessment and; 2) the evaluation of the effects
6 of the dredged activities on *Posidonia* meadows, which make up most of the two sites of
7 community importance located along the Civitavecchia coastal zone. The simulations results
8 are combined with the presence of bathing areas and *Posidonia oceanica* distribution ~~and~~
9 ~~bathing areas presence~~ in order to solve the conflicts between coastal uses (in terms of stress
10 produced by anthropic activities) and sensitivity areas ~~management~~.

11 **1 Introduction**

12 Coastal ecosystems are characterized by the spatial and temporal coexistence of multiple uses
13 connected to many human activities such as aquaculture, energy production, maritime
14 transport, tourism, and fishery. The overlap of such activities and their objectives has the
15 ability to create user-user and user-environment conflicts (Douvere, 2008) that result in
16 increasingly undesirable effects such as loss and destruction of habitat, pollution, climate
17 change, over-fishing, and cumulative threats to the oceans and human health as a whole.

18 The Integrated Marine Policy (IMP) has faced this issue by the adoption of the Maritime
19 Spatial Planning Directive (MSP, 2014/89/EU) whose main purpose is to promote the
20 sustainable management of uses and conflicts in coastal areas through an ecosystem-based
21 approach. MSP strategy allows to minimize the impacts on sensitivity areas, also enabling the
22 achievement of the Good Environmental Status (GES) by 2020, requested by Marine Strategy
23 Framework Directive (MSFD 2008/56/EC). In the last years a big effort was made by the
24 scientific community to provide new approaches for the analysis of GES descriptors like the
25 study of eutrophication (descriptor 5) through satellite ocean color data (Cristina et al., 2015)
26 and the assessment of sea-floor integrity (descriptor 6) by SAR imagery (Pieralice et al.,
27 2014). Important results were also obtained by the analysis of both commercial fishes and
28 foodweb (descriptors 3 and 4), to assess the environmental status of European seas
29 (Jayasinghe et al., 2015), and the levels of major contaminants (descriptors 8 and 9) and their
30 pollution effects on aquatic biota (Tornero and Ribera d'Alcalà, 2014).

31 ~~Within European environmental policy, the Water Frame Directive (WFD, 2000/60/EC) and~~
32 ~~the Marine Strategy Framework Directive (MSFD, 2008/56/EC) were recently approved to~~

1 ~~protect estuarine and coastal seas from increasing pressures and impacts and to move toward~~
2 ~~marine integrative management. Contrary to the WFD, which follows a 'deconstructing~~
3 ~~structural approach' to achieve a Good Ecological Status for all European water bodies by~~
4 ~~2015, the MSFD requires the achievement of a Good Environmental Status GES for all~~
5 ~~European seas by 2020 through a 'holistic functional approach'. A GES is based on the~~
6 ~~analysis of 11 descriptors that collectively represent the state and functioning of the whole~~
7 ~~system (Borja et al., 2008, 2010). In keeping with the holistic nature of the MSFD, the~~
8 ~~achievement and the maintenance of European marine ecological standards~~ need the support
9 of monitoring networks which use L-TER observations and integrate multi-disciplinary
10 datasets, fundamental to forecast specific events (Schofield et al., 2002). ~~requires detailed~~
11 ~~knowledge of the pressures exerted on marine environments, monitoring of physical,~~
12 ~~chemical, and biological components, and analysis of the services provided by ecosystems~~
13 ~~and the sustainable use of marine resources. However, A a~~ recent study by Crise et al. (2015)
14 revealed ~~a laekgaps~~ of data in the Mediterranean region (South European Seas) South
15 European Seas (SES), highlighting the scarcity, dispersion and heterogeneity of coastal waters
16 datasetsexistence of a clear North-South 'data and knowledge gradient' due to the chronic
17 scarcity of marine data. It is accordingly necessary to develop monitoring systems in the
18 southern European coastal areas capable of collecting both high-resolution and long-term data
19 and building multi-disciplinary datasets. ~~The correct management of coastal resources and~~
20 ~~environments requires climatologies deriving from physical and biological time series data as~~
21 ~~well as the capacity to forecast specific events (Schofield et al., 2002). Many efforts have~~
22 ~~been dedicated to the development of coastal ocean observatories, and r~~Recent advances in
23 communication and sensor technology have led to the development of worldwide multi-
24 platform networks that provide a significant amount of data on different spatial and temporal
25 scales for the study of oceanographic processes and marine ecosystem monitoring (Glasgow
26 et al., 2004; Hart and Martinez, 2006; Kroger et al., 2009). These monitoring tools are
27 especially suited for coastal systems (i.e., Chesapeake Bay Observing System, CBOS; Li,
28 2005; Long-term Ecosystem Observatory, LEO-15; Schofield et al., 2002) characterized by
29 high spatial and time variability and affected by strong conflicts between human uses and
30 ecosystem conservation. In this context, the Laboratory of Experimental Oceanology and
31 Marine Ecology developed a multi-platform observing network which operates since 2005 in
32 the coastal marine area of Civitavecchia (Italy, Tyrrhenian Sea, Western Mediterranean Sea),
33 critically interested by the presence of many conflicts.

1 This paper presents the C-CEMS as a tool to support the management of conflicts between
2 anthropic uses and sensitivity areas. We focused on: (1) the functioning of C-CEMS and its
3 components (Section 3); (2) its capabilities in reproducing the dispersion of fecal bacteria for
4 bathing water quality assessment and of dredged fine sediments to evaluate the effects on
5 *Posidonia oceanica* meadows present in the Sites of Community Importance (SCI) (Section
6 4); (3) the resulting analysis of "urban discharge - bathing area" and "dredging - SCI"
7 conflicts (Section 5).

8 ~~In this paper, we provide a thorough description of the Civitavecchia Coastal Environment~~
9 ~~Monitoring System C-CEMS observational network and its utilization for environmental~~
10 ~~research. Moreover, we present the main results of C-CEMS applications focusing on the~~
11 ~~analysis of fecal bacteria dispersion for bathing water quality assessment, and the evaluation~~
12 ~~of the effects of the dredged activities on *Posidonia oceanica* meadows in the Civitavecchia~~
13 ~~coastal area in the Italian western Mediterranean Sea. We used the integrated responses~~
14 ~~provided by C-CEMS to create an observatory and forecast system that can provide rapid and~~
15 ~~comprehensive information for the management of coastal conflicts and the potential effects~~
16 ~~of pollution.~~

18 **2 Study area**

19 The study area is located along the north-east Tyrrhenian coast (Western Mediterranean sea)
20 (Fig. 1A). The circulation of the Tyrrhenian basin is affected by mesoscale and seasonal
21 variability (Hopkins, 1988; Pinardi and Navarra, 1993; Vetrano et al. 2010). The presence of a
22 cyclonic gyre with a very pronounced barotropic component suggests that the wind play
23 likely a major role as a forcing agent (Pierini and Simioli, 1998). Like most of the Italian
24 coast, the north-east Tyrrhenian one counts many tourist and industrial areas primarily used
25 for maritime transport and energy production, involving an intense exploitation of marine
26 resources. Nevertheless, it houses several biodiversity hotspots and marine protected areas for
27 the conservation of priority habitats and species.

28 ~~In particular The this study area is focused on coastal zone between extends from Marina di~~
29 ~~Tarquinia to and Macchia Tonda in the northern Latium region of Italy, as shown in (Fig.~~
30 ~~1BA), and including Civitavecchia city, where all the above mentioned uses could produce~~
31 ~~potential conflicts which is a populated area characterized by the coexistence of industrial and~~
32 ~~human pressures with environmental resources and values. The Civitavecchia harbor is one of~~

1 the largest in Europe in terms of cruise and ferry traffic; it represents a fundamental point of
2 commercial exchange in Europe. Thanks to the new Port Regulating Plan, the Port of
3 Civitavecchia has increased its commercial traffic and cruise passenger flow. The
4 Interministerial Committee for Economic Planning (CIPE) approved the final project for the
5 'strengthening of Civitavecchia harbor hub – first parcel functional interventions: Cristoforo
6 Colombo embankment extension, ferries and services docks realization'. All of these
7 operations involve the handling of significant quantities of sediments; the impacts of dredging
8 on the adjacent natural ecosystems can be varied and difficult to predict (Nayar et al., 2007;
9 Windom, 1976; Cheung and Wong, 1993; Lohrer and Wetz, 2003; Zimmerman et al., 2003).

10 In conflict with the port activities, the study area hosts four ~~Sites of Community Importance~~
11 ~~(SCIs) included in the seventh updated list of the Natura 2000 database based on the Italian~~
12 ~~Environmental Minister decree as an enactment of the European Commission decision~~
13 ~~2013/739/EU. SCIs~~ They are characterized by the presence of habitats (*Posidonia oceanica*
14 meadows and reefs of rocky substrates and biogenic concretions) and species (*Pinna nobilis*
15 and *Corallium rubrum*) enclosed in the attachment 1 and 2 of the European Union (EU)
16 directive 92/43/CEE, ~~which can be affected by direct and indirect impacts of port activities.~~

17 Moreover, the promotion of underwater natural beauty, touristic exploitation connected to the
18 increased cruise traffic and the realization of suitable bathing facilities have led to a drastic
19 increase in the population density in Civitavecchia during the summer. Many services are now
20 available for recreation thanks to the several beach licenses granted for food, bathing,
21 mooring of private vessels, and sport activities. An updated list of the Latium Region Office
22 counts 72 beach licences released in 2014 to the municipal districts of Santa Marinella and
23 Civitavecchia. However, this urban development was not associated with an upgrade of the
24 wastewater treatment plant, which often caused the discharge of untreated water into the
25 bathing areas to be frequently discharged into bathing areas. This situation is in direct conflict
26 with the recreational use of the coastal zone. Along the coast, between Civitavecchia harbor
27 and the Punta del Pecoraro bathing areas, four discharge points have been identified as shown
28 in Fig. 1 CB in conflicts with the recreational use of the coastal zone. These discharge points
29 present high concentrations of pathogenic bacteria that have been potentially affected by fecal
30 contamination episodes.

31

3 Components of the C-CEMS

C-CEMS is a multi-platform observing system implemented in 2005 along the coastal area of Civitavecchia (Latium, Italy) to face the coastal conflicts by an ecosystem-based approach. Accordingly to the Copernicus program, C-CEMS provides a monitoring service for the marine environment through multi-source data including in-situ and remote sensing observations. In addition, C-CEMS integrates this information within mathematical models that allow to simulate specific events and forecast potential impacts with a high spatial and temporal resolution, necessary to analyse the conflicts in coastal areas (Bonamano et al., 2015b). It is analogous to a coupled system in which all of the data are assimilated by mathematical models to forecast specific events or impacts and to improve and optimize survey strategies. The C-CEMS includes different modules (fixed stations, in-situ measurements and samplings, satellite observations, and numerical models) that provide integrated information that can be used in different fields of environmental research (Bonamano et al., 2015b).

As shown in Fig. 2, C-CEMS outcomes can be used to assess the conflicts between the pressures on both marine coastal resources and the environment and human health. components interact between them to assess the coastal pressures analysing the dispersion of pollutant substances coming from the anthropic activities located along the Civitavecchia coastal area. Data provided by fixed stations, in-situ surveys, and remote sensing play a crucial role being used as input (I = input in Fig. 2) and for the validation (V = validation in Fig. 2) of the numerical models. They give a fundamental contribution in C-CEMS allowing to forecast the dispersion of pollutant substances within the sensitivity areas represented mainly by marine protected areas and zones designated for recreational uses (bathing, diving, watersports, fishing, etc.). To analyse the potential conflicts between the pressures on both marine coastal environment and human health, the results of the pollutants dispersion, obtained under different weather conditions, are overlapped with the thematic maps of the sensitivity areas.

Since marine coastal ecosystems have been acknowledged as providing the most benefits among all terrestrial and marine ecosystems (Costanza et al., 1997), the appointment of assigning an economic value to these natural resources is essential for correct planning of marine coastal areas. Nevertheless the economic impact on the natural capital in terms of losses of ecosystem goods and services has not been evaluated in this work.

1 The block diagram (Fig. 2) shows all of the components of the C-CEMS that are outlined in
2 the following paragraphs.

3 *Fixed stations:* The capacity of time series data collection is fundamental to improve the
4 ability to control and forecast spatial and temporal variations in a marine environment. To this
5 end, different fixed stations were installed along the Civitavecchia coast to acquire physical,
6 chemical, and biological data, as shown in Fig.1. In particular, a weather station (WS)
7 acquires every 10 min ~~makes it possible to acquire~~ wind speed, wind direction, air
8 temperature, air pressure, humidity and solar radiation. The wind speed and direction
9 represent the main forcing of the hydrodynamic model while the solar radiation data are used
10 as input in the water quality model. ~~¶~~Two buoys (WB1 offshore, WB2 nearshore) measure
11 every 30 min ~~make it possible to collect~~ wave statistical parameters (significant height, peak
12 period, and mean direction). The wave model is fed with WB1 data and then validated with
13 the wave height data collected by WB2. ~~¶~~An Acoustic Doppler Profiler, ADP (WCS),
14 deployed in a Barnacle seafloor platform, acquires both current velocity (with an acquisition
15 rate of 20 min) ~~-and-direction~~ and wave height and direction (at intervals of 3 h). The current
16 velocity components are employed for the validation of the hydrodynamic model. ~~¶~~Three
17 water quality fixed stations, one buoy (WQB) outside the Civitavecchia harbor and two
18 coastal stations (WQS1 and WQS2), make it possible to acquire every 20 min sub-superficial
19 sea temperature, conductivity (salinity, density), pH, dissolved oxygen, fluorescence of
20 chlorophyll-a, and turbidity. In order to validate the satellite ocean color data, chlorophyll-a
21 (Chla) and total suspended matter (TSM) data acquired by WQB were calibrated with the
22 concentrations obtained by the water samples analyses. The physical and biological
23 parameters of the WQS1 and WQS2, as well as those acquired by satellite observations, are
24 used as initial conditions of the water quality model. The details of the C-CEMS sensors and
25 platforms are listed in Table 1.

26 ~~All of the data deriving from the fixed stations are transmitted to a website to enable a first~~
27 ~~look at data trends. Furthermore, this arrangement makes it possible to quickly respond in~~
28 ~~case of a malfunction. The data are then processed and organized as follows:~~

29 WQB and WQS data are processed following the SeaDataNet parameter quality control
30 procedures: daily validated datasets are produced in order to monitor in near real time the
31 water quality, and Edios xml files are provided for monthly time series and stored following
32 ISO 19139 and ISO 19115 formats provided for metadata.

~~*Data processing and standardization:* Scientific research, particularly interdisciplinary research involving human impacts on the natural environment, depends on access to data provided by observatory networks. As highlighted in the EU INSPIRE directive (2007), the importance of the realization of network infrastructures for data sharing derives from the ability to provide useful information. Given the recent growth in large scale collaborative oceanographic research programs, data quality control is essential. If quality control is not ensured, data from different sources cannot be combined or re-used. For this reason, the SeaDataNet (SDN) Infrastructure was developed in the EU FP6 framework program in order to realize an efficient, distributed Pan-European marine data management infrastructure for managing large and diverse datasets (Schaap, 2010). Thanks to this initiative, datasets are converted into data and metadata standard format by SDN software and tools. The University of Tuscia (LOSEM) is part of the SDN (under the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, OGS, collating center). Part of the data collected in the C-CEMS are already processed following the SDN parameter quality control procedures: daily validated datasets are produced in order to monitor in near real-time the status of water quality, and Edios xml files are provided for monthly time-series and stored following ISO 19139 and ISO 19115 formats provided for metadata.~~

~~The next step is to apply the processing procedure to all of the data produced by the observing system.~~

In-situ surveys: A spatial extension of the observatory system is provided by in-situ collected data. The sampling strategy is conceived with the scope and context of the project objectives in order to select the most appropriate and efficient sampling approach. The field surveys typically include periodic and ad-hoc activities. The firsts concern the acquisition of the physical, chemical and biological variables of the water column performed by multiparameter probes and sea water samples. Data acquired during periodic surveys are used to validate and integrate the satellite observations in order to give the spatial distributions of the seawater parameters as the initial conditions of the water quality model. The ad-hoc samplings are carried out in order to define the nature and composition of the sea bottom and to analyse the indicators of pollution near the human activities outputs. These data feed the water quality model for the estimate of the bottom shear stress, as well as the dispersion and/or the decay of pollutants in the nearshore coastal waters data acquired by multiparameter probes, acoustic instruments, water, sediments, and biological samples.

1 *Satellite observations:* Remote sensing data are essential to provide synoptic and extensive
2 maps of biological and physical properties of the oceans (Schofield et al., 2002). Few studies,
3 among which Cristina et al. (2015), demonstrated the usefulness of remote sensing to support
4 the MSFD, using MEdium Resolution Imaging Spectrometer (MERIS) sensor products.
5 Similarly~~In this work~~, we exploited both ocean color from the Moderate Resolution Imaging
6 Spectroradiometer (MODIS) sensor and thermal infrared color from the Advanced Very High
7 Resolution Radiometer (AVHRR) to obtain daily chlorophyll-a Chla, total suspended matter
8 (TSM), and sea surface temperature (SST) data. Such sensors data were chosen for their
9 availability both in the region of interest and in the period of C-CEMS data acquisition.

10 Regarding the AVHRR data, they are~~The MODIS data were downloaded from the NASA~~
11 ~~website at level L1-A (which contains raw radiance counts, spacecraft and instrument~~
12 ~~telemetry, and calibration data) and processed by the SeaDAS image analysis package that is~~
13 ~~freely distributed to users by NASA. The AVHRR data were~~ downloaded from the NOAA
14 website as a Local Area Coverage (LAC) dataset, at a resolution of 1.1 km. These data
15 ~~are~~ ~~were~~ ~~then~~ processed using ENVI software, which computes SST images in degrees
16 Celsius, using AVHRR bands 3, 4, and 5 and applying the Multi-Channel Sea Surface
17 Temperature (MCSST) algorithms (Pichel et al., 2001).

18 Regarding the MODIS data, we download from the NASA website and process by the
19 SeaDAS image analysis package that is freely distributed to users by NASA. The processing
20 begins with a Level-1A file containing top of the atmosphere (TOA) radiance values recorded
21 by the satellite radiometer. The second step is the Level-2 processing which takes the TOA
22 radiance intensities in the Level-1A file and performs atmospheric corrections to derive a
23 Level-2 file of normalized water leaving radiances (nLw), Chla concentration, geophysical
24 parameters and quality control flags. A third step takes the geophysical data contained in the
25 Level-2 file and maps it from the raw satellite perspective to a cylindrical coordinate system.
26 To estimate Chla concentration, MedOC3 bio-optical algorithm is applied (Santoleri et al.,
27 2008, Qin et al., 2007), while TSM estimation is derived from the 645 normalized water-
28 leaving radiance (645 nLw) by applying the MUMM NIR atmospheric correction (Ruddick et
29 al., 2006; Ondrusek et al., 2012).

30 Finally Chla and TSM~~The results of the chlorophyll a and suspended matter concentration~~
31 ~~data collected by WQB and periodic in-situ surveys analyses of in-situ water samples were~~
32 are used to ~~compare and~~ validate the algorithms used for remote sensing data. We are working

1 on the implementation of a local algorithm specifically developed in the area of interest
2 (CASE II waters) in order to reach a better quantification of Chla and TSM concentrations
3 along the study area (Cui et al., 2014). Our aim was to create a local algorithm for quantifying
4 TSM and chlorophyll a concentrations in CASE II waters in detail to yield a better
5 understanding of seasonal variations along these areas. These data are essential for providing
6 synoptic maps of the spatial distribution of sea surface temperature, suspended materials, and
7 phytoplankton in coastal waters. Accordingly with the Copernicus vision, the future
8 development of this module considers to integrate EO data coming from the Optical High-
9 Resolution Sentinel sensors (Drusch et al., 2012), in order to increase the spatial resolution for
10 a more accurate analysis of coastal dynamic processes.

11 *Numerical models:* Mathematical models play a key role in the C-CEMS by making it
12 possible to analyse coastal processes at high spatial and temporal resolution. In this context,
13 the entire datasets collected by fixed stations, satellite observations, and in-situ samplings
14 were employed as input conditions and as a validation of the numerical simulations. The
15 mathematical models used in C-CEMS included the DELFT3D package, specifically
16 DELFT3D-FLOW (Lesser et al., 2004) to calculate marine currents velocity, SWAN (Booij et
17 al., 1999) to simulate the wave propagation toward the coast, and DELFT3D-WAQ (Van Gils
18 et al., 1993; Los et al., 2004) to reproduce the dispersion of conservative and non-
19 conservative substances. The governing equations of these models are described in detail in
20 Lesser et al. (2004) and Bonamano et al. (2015a).

21 The DELFT3D-FLOW model domain is rectangular and covers 70 km of coastal area with
22 the Civitavecchia port located at the center. We applied Neumann boundary conditions on the
23 cross-shore boundaries in combination with a water-level boundary on the seaward side,
24 which is necessary to ensure that the solution of the mathematical boundary value problem is
25 well-posed. Since small errors may occur near the boundaries, we positioned the study area
26 away from the side of the model domain. ~~We solved the~~The hydrodynamic equations are
27 solved on a finite difference curvilinear grid with approximately 39,000 elements. In order to
28 limit computational requirements, we applied a different resolution in the model domain
29 extending from 15×15 m in the Civitavecchia harbor area to 300×300 m near the seaward
30 boundary. We subdivided the water column in the vertical direction into 10 sigma layers with
31 a uniform thickness to ensure sufficient resolution in the near-coastal zone.

1 Since dynamical processes occurring in coastal areas are modulated by wind and wave
2 conditions (we neglect tidal forcing because it does not exceed 0.40 m over the simulation
3 periods), we obtained the hydrodynamic field by coupling the DELFT3D-FLOW with SWAN
4 that uses the same computational grid. Wind data collected by WS were used to feed
5 DELFT3D-FLOW, and the wave parameters acquired by WB1 (offshore wave buoy) were
6 employed to generate the JONSWAP wave spectra (Hasselmann et al., 1980) as boundary
7 conditions of the SWAN model.

8 To resolve the turbulent scale of motion, the values of horizontal background eddy viscosity
9 and diffusivity were both set equal to $1 \text{ m}^2\text{s}^{-1}$ (Briere et al., 2011), and the k- ϵ turbulence
10 closure model was taken into account (Launder and Spalding, 1974). To assign the spatial
11 patterns of physical and biological parameters as initial conditions of DELFT3D-WAQ, the
12 satellite observations in the offshore zone and the WQS measures in the nearshore one were
13 used respectively. These data are integrated in the water quality model applying the DINEOF
14 technique (Beckers et al., 2006; Volpe et al., 2012) that reconstructs the missing data along
15 the coast and in the areas affected by clouds.

16 Since the pollutants dispersion represents the C-CEMS results, the capability of the
17 observation system in reproducing the output of coastal pressures has been evaluated
18 comparing the model results with sea currents (WQB) and wave (WB2) data.

19 The performance of the hydrodynamic models (DELFT3D-FLOW and SWAN) was evaluated
20 using the Relative Mean Absolute Error (RMAE) and the associated qualitative ranking
21 (excellent, good, reasonable, and poor) (Van Rijn et al., 2003).

22 The marine currents resulting from the coupling between DELFT3D-FLOW and SWAN were
23 compared with in-situ measurements collected by WCS from 13–18 January 2015. The
24 velocity magnitude was reproduced with a 'good' accuracy since the RMAE value was less
25 than 0.2. The long-shore and cross-shore components of the marine currents exhibited a
26 higher RMAE: 0.28 and 0.3, respectively. The validation of current speed, cross-shore, and
27 along-shore components is shown in Fig. 3.

28 We evaluated the performance of the SWAN model using data acquired by the WB2. We
29 calculated the RMAE both for the entire dataset and for three wave direction intervals: 139–
30 198°N (1st interval), 198–257°N (2nd interval), and 257–316°N (3rd interval). Considering
31 the entire dataset, the wave height has been accurately simulated (RMAE<0.1), but the model
32 error changes significantly on the basis of the wave direction: the RMAE is higher between

1 139°N and 198°N (0.26; reasonable agreement) and lower ~~between- in the 2ndN and 3rdN~~
2 intervals (<0.01; excellent agreement), as reported in Fig. 4.

4 C-CEMS Applications

5 To test the capabilities of C-CEMS in defining the areas mainly affected by pollutants
6 dispersion, we considered two case studies which concern ~~In this study, C-CEMS has been~~
7 ~~used to support the assessment of~~ the potential effects produced by untreated wastewater
8 discharge and dredging activities (coastal pressures) on bathing areas and SCIs (sensitivity
9 areas), respectively. ~~To analyse the dispersion of polluted substances in the coastal marine~~
10 ~~environment, we considered in~~ For both cases two periods-scenarios with different weather
11 conditions are considered: one reproduces a low wind intensity and low wave height (low
12 condition, LC), and the other simulates a strong high wind speed and high wave height (high
13 condition, HC).

4.1 Bacterial dispersion in bathing areas

16 The presence of pathogenic bacteria in seawater may cause several illnesses including skin
17 infections and dangerous gastrointestinal diseases (Cabelli et al., 1982; Cheung et al., 1990;
18 Calderon et al., 1991; McBride et al., 1998; Haile et al., 1999; Colford et al., 2007).

19 The probability of human infection depends on the exposure time and the concentration of the
20 bacterial load in bathing areas. These parameters are linked to the presence of untreated
21 wastewater discharge in the study area and the local hydrodynamical (currents and waves) and
22 environmental (salinity, temperature, and solar radiation) conditions. Among the bacteria that
23 can damage the health of bathers, *Escherichia coli*, a Gram-negative enteric bacteria present
24 in the feces of humans and warm-blooded animals, is considered to be an indicator of water
25 quality. Although the pathogenic bacteria are neglected by MSFD, microbes are relevant to
26 several GES descriptors, notably Descriptor 1 (D1, Biological Diversity), Descriptor 4 (D4,
27 Foodwebs), Descriptors 5 (D5, Eutrophication), Descriptor 8 (Contaminants) (Caruso, 2014).
28 However, ~~C~~controlling water quality in bathing waters is required by national (d.lgs
29 116/2008) and community environmental directives (2006/7/CE).

1 Under the umbrella of C-CEMS to provide fecal pollution monitoring, in-situ water samplings
2 were performed weekly during the summer 2012 at the discharge points indicated in Fig. 1 ~~CB~~
3 to analyse the abundance of *E. coli* according to standard culture methods (APAT CNR,
4 2003).

5 To ~~define the zones mainly affected by provide a map of the potential effects for bathers, we~~
6 ~~analyzed~~ the dispersion of pathogenic bacteria in the Civitavecchia bathing area, ~~using we~~
7 ~~used~~ the Microbiological Potential Risk Area (MPRA), defined as the area over which the *E.*
8 *coli* concentration is greater or equal to 1% of the concentration measured at a discharge point
9 (Bonamano et al., 2015a). ~~Since this parameter does not depend on the input load~~
10 ~~concentration, it can be used for evaluating potential effects on human health.~~ The dispersion
11 of *E. coli* has been simulated by DELFT3D-WAQ using the mean bacterial concentration
12 measured during the summer at the discharge points. The model shows a good performance of
13 reproducing the bacterial load concentration near the discharge points (Zappalà et al., 2015).
14 The LC and HC simulations that last two days were set to occur on August weekends when
15 the beaches are characterized by a larger number of bathers. The distribution of bacterial
16 concentration calculated by DELFT3D-WAQ over the study area depends on the
17 hydrodynamic field obtained from coupling between DELFT3D-FLOW and SWAN and on
18 the decay rate ~~proposed by Thoe et al. (2010). It was calculated using the salinity acquired by~~
19 ~~WQS1, WQS2 and WQB, the surface solar radiation measured by WS, TSM and SST~~
20 ~~obtained by the integration between satellite observations and WQS stations data estimated~~
21 ~~with WQS1, WQS2, and WQB temperature and salinity and the WS solar radiation data.~~

22 The *E. coli* concentration calculated near the discharge points was high when low marine
23 currents (LC) were present, as reported in Fig. 5A. In particular, the area around the PI18
24 point exhibited maximum values of pathogenic bacteria because of the slow dilution of
25 contaminated waters in that area. During intense weather conditions (HC), the *E. coli*
26 concentration near the discharge points was lower than that calculated in the LC simulation.
27 However, the *E. coli* concentration was distributed over a more extended area, as reported in
28 Fig. 5B. In both simulations, the dispersion of *E. coli* did not affect the bathing area located to
29 the south of the study area.

30

4.2 Dredged sediments dispersion on *Posidonia oceanica* meadows

As previously reported, the port of Civitavecchia has been subjected to extensive dredging between 1 November 2012 and 31 January 2013. During the first phase of the project, the dredging of the channel to access the port of Civitavecchia was conducted by deepening the seabed to a depth of -17 m above mean sea level over an area of approximately 31,000 m². In the ferry dock area, the seabed reaches a depth of -10 m over an area of approximately 123,650 m² and -15 m over an area of approximately 51,900 m². The total dredging volume was approximately 918,000 m³.

Studying sediment resuspension caused by these dredging activities is critical because of its role in the dispersion of particulate matter in the adjacent marine environment in both the sediment and water (Van den Berg et al., 2001). Within MSFD, turbidity due to fine sediment dispersion is an indicator reported in Descriptor 1 (D1, Biological biodiversity), Descriptor 5 (D5, Eutrophication) and Descriptor 7 (Hydrographical condition). In this work, we considered two out of the four SCIs coded as IT60000005 (434.47 ha) and IT60000006 (745.86 ha) localized in the north and the south of the Civitavecchia harbor, as shown in Fig. 1BA. Since *Posidonia oceanica* makes up most of the SCIs, we focused on studying the effects of dredging activities on the status of the seagrass. Dredging-induced suspended sediment transport and deposition may have direct and indirect impacts on this seagrass such as reducing the underwater light penetration and producing the burial of the shoot apical meristems, respectively. The survival of the plant can be compromised if the light availability is less than 3–8% of SI (Erftemeijer and Lewis, 2006) or if low-light conditions persist for more than 24 months (Gordon et al., 1994). The survival rates of *Posidonia oceanica* can also be reduced if the sedimentation rate exceeds 5 cm per year (Manzanera et al., 1995).

~~For these reasons, the health status of *Posidonia oceanica* meadows located in the two SCIs has been evaluated by shoot density descriptor. This parameter was acquired by scuba-divers in the late Spring of 2013 in correspondence of 14 stations (3 in IT6000005 and 11 in IT6000006) following the method reported in Buia et al. (2003). The thematic map is obtained spatially interpolating the data collected in the two areas, closest to the harbor (IT 6000005 and IT 6000006) has been monitored by in-situ samplings. The sampling activity and the results of the analyses allowed us to create a thematic map of the shoot density of the marine phanerogam, which is essential for estimating the direct and indirect impacts of sediment dispersion.~~

1 The potential impacts due to dredging activities have been evaluated by DELFT3D-WAQ
2 simulations assuming a continuous release of fine sediments (< 0.063 mm) in the northern
3 zone of Civitavecchia harbor. The amount of material released during dredging was calculated
4 using a formula from Hayes and Wu (2001) using a resuspension factor of 0.77%, which is
5 typical of hydraulic dredges (Anchor Environmental, 2003). The percentage of fine sediment
6 fraction is 8.87% and its density is 2650 kg m^{-3} according to sedimentological data collected
7 in the area affected by the dredging works. Considering also that the time spent on dredging
8 operations was approximately 3 months (from November 2012 until January 2013), we
9 assumed a continuous release of 0.314 kg s^{-1} . TSM distribution, obtained by the integration
10 between satellite observations and WQB data, was used as a proxy of spatial variation of fine
11 sediment concentration in the study area to provide the initial conditions of DELFT3D-WAQ.
12 The transport, deposition, and resuspension processes associated with the fine particles was
13 reproduced taking into account a settling velocity of approximately 0.25 m day^{-1} , a critical
14 shear for sedimentation of 0.005 N m^{-2} , and a critical shear for resuspension of 0.6 N m^{-2}
15 (Alonso, 2010). The DELFT3D-WAQ simulations were run over the periods 26 November
16 2012 through 3 December 2012 (HC simulation) and 3–10 January 2013 (LC simulation).
17 These time intervals included the dredging period.

18 Analogous to the analysis of bacterial dispersion, the fate of dredged sediments within the
19 study area was evaluated over an area in which the suspended solid concentration was greater
20 or equal to 1% of the value estimated at the source point. This area is referred to as the
21 Dredging Potential Impact Area (DPIA). The results of the LC simulation, reported in Fig.
22 6A, revealed that the dredged suspended materials were transported into the southern zone of
23 the study area achieving a maximum distance of approximately 2 km from dredging point. In
24 the HC simulation reported in Fig. 6B, the dredged sediment dispersion moved is toward the
25 north with higher concentration in the nearshore zone. Although the sediment plume extends
26 20 km from the source, higher values of suspended solid concentration the DPIA only affects
27 the *Posidonia oceanica* meadow closer to the harbor (the southern part of SCI IT 6000005)
28 (Bonamano et al., 2015b). ~~The results of the LC simulation, reported in Fig. 6A, revealed that~~
29 ~~the dredged suspended materials were transported into the southern zone of the study area~~
30 ~~relatively close to the source (a maximum distance of approximately 2 km).~~

31

5 Conclusions Discussions

C-CEMS was implemented in 2005 along the coast of Civitavecchia (~~Latium, Italy~~), which is a highly populated area characterized by the coexistence of industrial and human pressures with environmental resources and values. It integrates fixed stations, in-situ survey and satellite observations which ensure the availability of a large amount of data allowing the analysis of coastal conflicts by the detection of pollution phenomena. Moreover C-CEMS provides an ecosystem-based monitoring tool for the analysis and forecasting of the coastal conflicts thanks to the use of mathematical models. The validation of hydrodynamic models with sea currents (WCS) and wave (WB2) data, shows how C-CEMS is able to reproduce accurately the output of coastal pressures in terms of pollutants dispersion. DELFT3D-FLOW reproduces with good accuracy the velocity components of marine currents, while SWAN calculates the wave height in the nearshore area with an higher skill when the interval direction is 198-316 °N. On the contrary, when the wave direction ranges between 139 °N and 198 °N, the capacity of the model is more affected by the increase of diffraction processes due to the Civitavecchia harbor breakwater.

The application of C-CEMS to the two case studies examples allowed to define the MPRAs in bathing zones and the DPIAs on SCIs under different weather conditions (HC and LC). The overlap of the model results with the thematic maps of the sensitivity areas enabled the detection of the coastal areas interested by conflicts.

~~We present the application of C-CEMS to two different case examples, which allow us to analyze the potential impacts on both the marine environment and human health.~~

In the first case, the overlap of MPRAs calculated in LC and HC scenarios shows that most of the bathing areas are affected by high level of bacterial contamination (Fig. 7A). Maximum values areas with high bacterial concentrations of *E.coli* abundance were found near the PI18 and PP24 discharges because the dilution of the contaminated waters was inhibited by the presence of artificial barriers. These unfavorable conditions may cause possible risks to human health ~~and are~~ related to the contamination of potentially infectious microorganisms ~~for bathers. in the nearshore waters.~~ As a result, the bathing facilities located within this zone are at risk of suffering significant economic losses. ~~On the contrary, as highlighted by the MPRA shown in Fig. 7A, However~~ the southern bathing area, where more bathers are found, is never affected by *E. coli* dispersion (Fig. 7A).

1 In the second case study, the simulation results differ among LC and HC scenarios (Fig. 7B) it
2 was possible to observe the potential impacts on *Posidonia oceanica* meadows due to
3 dredging activities, as reported in Fig. 7B. In the LC scenario, DPIA does not overlap the
4 southern SCI (IT 6000006), even though the seagrass meadows are characterized by poorer
5 health than in northern SCI. In the HC simulation, despite the suspended sediments being
6 transported up to 20 km away from the source point, the area with a higher dredged material
7 concentration (DPIA) includes a restricted zone of *Posidonia oceanica* meadow (98.84 ha) in
8 the northern SCI, closer to Civitavecchia harbor, characterized by high shoot density values
9 (between 400 and 550 shoots m²). The fine sediment dispersion reproduced in the LC
10 simulation does not reach the southern SCI (IT 6000006) where the seagrass meadows are
11 characterized by poorer health than northern SCIs. A previous study (Bonamano et al. 2015b)
12 shows that after the dredging activities the shoot density values were slightly higher than
13 before, highlighting how this conflicts does not produce a loss of environmental resources.

14 The results of the two application cases show that C-CEMS is suitable for analyzing 'urban
15 discharge bathing area' and 'dredging SCI' conflicts, as well as many other conflicts. C-CEMS
16 is therefore a new useful tool for coastal zone management. The results of the C-CEMS
17 observational network are a first step toward environmental and economical sustainable
18 management of conflicts along the Civitavecchia coastal area.

19

20 **6 Conclusions**

21 The main objective of C-CEMS is to provide an observation system for a rapid environmental
22 assessment and to forecast the coastal dynamic processes at appropriate temporal and spatial
23 resolutions. It can also contribute to the availability of marine observations and coastal data,
24 increasing the knowledge about the environmental status of marine ecosystems. To make C-
25 CEMS more effective, a flexible X-Band Radar System to continuously measure the sea-state
26 (surface currents and wave field) in the near-shore zone (Serafino et al., 2012) has been
27 recently integrated. Moreover, to improve the resolution of multi-spectral imagery in the
28 study area, C-CEMS will be soon available to get data also from Sentinel-2 mission.

29 The final goal of this system study was to use this tool C-CEMS to address potential conflicts
30 among the different human activities that persist on the coast using an ecosystem-based
31 approach as requested by IMP for the EU. ~~In fact, the demand for resources, services, and~~

1 ~~space can exceed the capacity of marine areas to meet all of the demands simultaneously~~
2 ~~(Ehler, 2009).~~

3 C-CEMS- ~~allowed to define the output of human activities by the use of 'potentially-polluting~~
4 ~~zoning indicators' as MPRA and DPIA giving the potential impacts produced by pathogenic~~
5 ~~bacteria and dredged fine sediment on sensitivity areas. Such information overlapped with the~~
6 ~~characteristics of recreational coastal uses and marine ecosystems can be considered as the~~
7 ~~first step for the establishment of marine functional zoning scheme made by different types of~~
8 ~~zones with varying levels of limited uses (Douvere-,2008). The last step toward an adequate~~
9 ~~management and conservation of marine environment resources concerns the quantification of~~
10 ~~economic impacts related to the losses of ecosystem services and goods through the analysis~~
11 ~~of the present and future conflicts.can contribute to the achieving GES as requested in the~~
12 ~~context of the MSFD. C-CEMS can also contribute to the availability of marine observations~~
13 ~~and coastal data, which increases our knowledge of spatial and temporal variations in~~
14 ~~environmental status. In this way, public administrators and decision makers can acquire a~~
15 ~~clear view of the ecological and economic potential of a study area to ensure that the spatial~~
16 ~~planning process, as established by the Marine Spatial Planning Directive (2014/89/EU), can~~
17 ~~take into account easily accessible information about the importance of ecosystem benefits.~~

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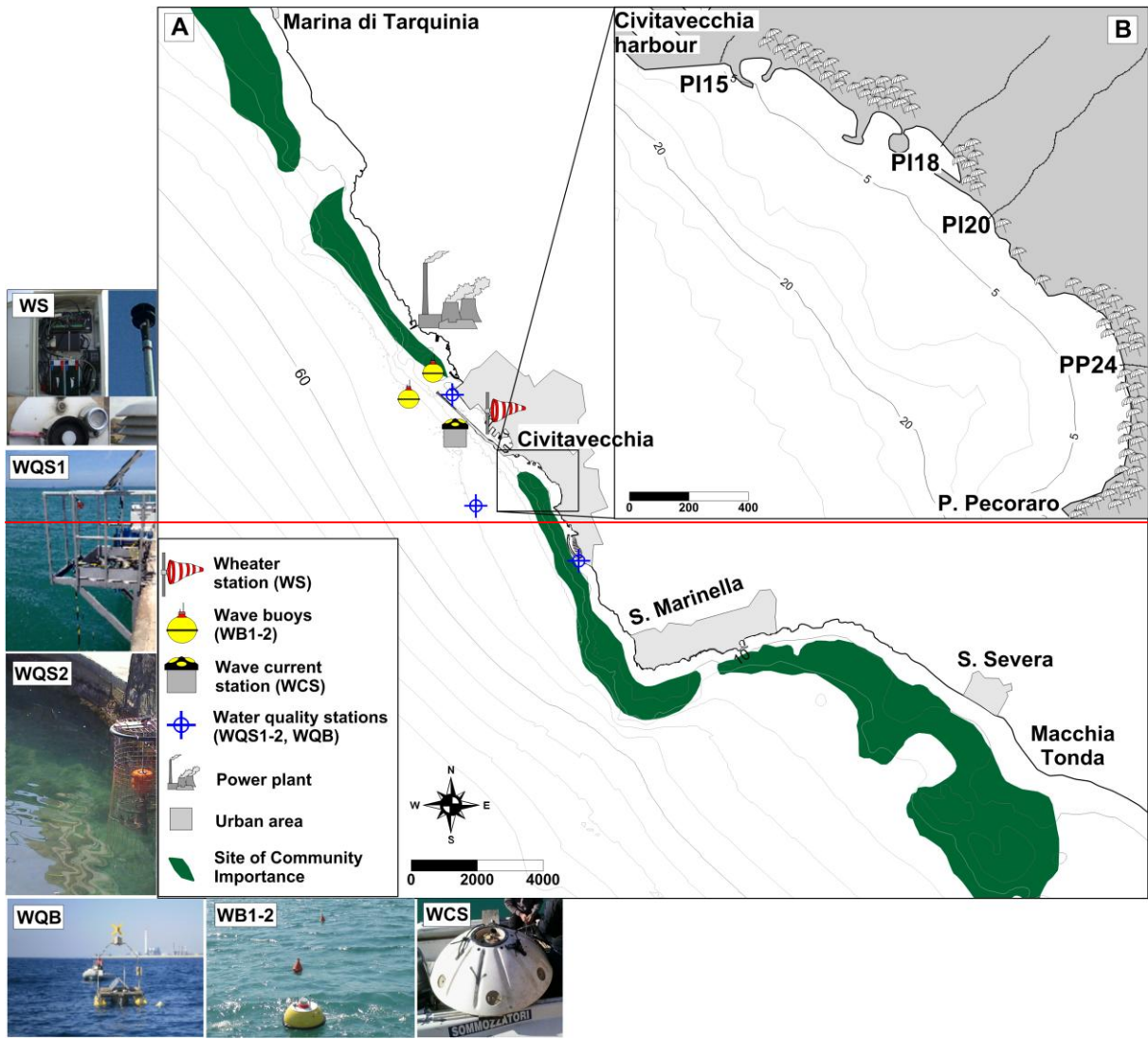
Table 1. Specifications of C-CEMS sensors and platforms.

<i>(WS) WEATHER STATION SPECIFICATIONS</i>			
	Range	Accuracy	Resolution
Wind Speed	0...60 m s ⁻¹	±2%	0.01 m s ⁻¹
Wind Direction	0...360°	±3	1°
Air Temperature	-40...+60°C	±0.3 K	
Relative Humidity	0...100 %	±5.0%	0.50%
Air Pressure	600...1060 mbar	±0.5 mbar	±0.05 mbar
Total solar radiation	400...1100 nm	±3%	±0.05
Precipitation		0.1 mm	±1% till 10 mm h ⁻¹
<i>(WCS) WAVE CURRENT STATION SPECIFICATIONS</i>			
	Range	Accuracy	Resolution
Current Velocity	±10 m s ⁻¹	±1% meas. Vel.	0.1 cm s ⁻¹
Compass/tilt sensor		±1° (Heading) ±1° (Pitch, Roll)	0.1°
Wave Height (strain-gage pressure sensor)		0.10%	
Wave Direction	0..360°		±1°
<i>(WBI-2) WAVE BUOYS SPECIFICATIONS</i>			
	Range	Accuracy	Resolution
Wave Height	±20 m	better than 1%	0.01 m
Period	1.5..33 sec	better than 1%	0.1 sec
<i>(WQB) BUOY SPECIFICATIONS</i>			
	Range	Accuracy	Resolution

Pressure	0-100dbar	0.10%	0.03%
Temperature	-3...+50°C	0.003°C	0.0005°C
Conductivity	0...6.4 S m ⁻¹	0.0003 S ⁻¹	0.0001 S ⁻¹
pH	0...14	0.01	0.001
Dissolved oxygen	0...50 ppm	0.1 ppm	0.1 ppm
Chlorophyll a Fluorescence	0...5 µg L ⁻¹	0.025 µg L ⁻¹	
Turbidity	0...100 NTU	0.05 NTU	
<i>(WQSI-2) COASTAL STATIONS SPECIFICATIONS</i>			
	Range	Accuracy	Resolution
Pressure	0-100dbar	0.10%	0.03%
Temperature	-3...+50°C	0.003°C	0.0005°C
Conductivity	0...6.4 S m ⁻¹	0.0003 S ⁻¹	0.0001 S ⁻¹
pH	0...14	0.01	0.001
Dissolved oxygen	0...50 ppm	0.1 ppm	0.1 ppm
Chlorophyll a Fluorescence	0...5 µg L ⁻¹	0.025 µg L ⁻¹	
Turbidity	0...100 NTU	0.05 NTU	

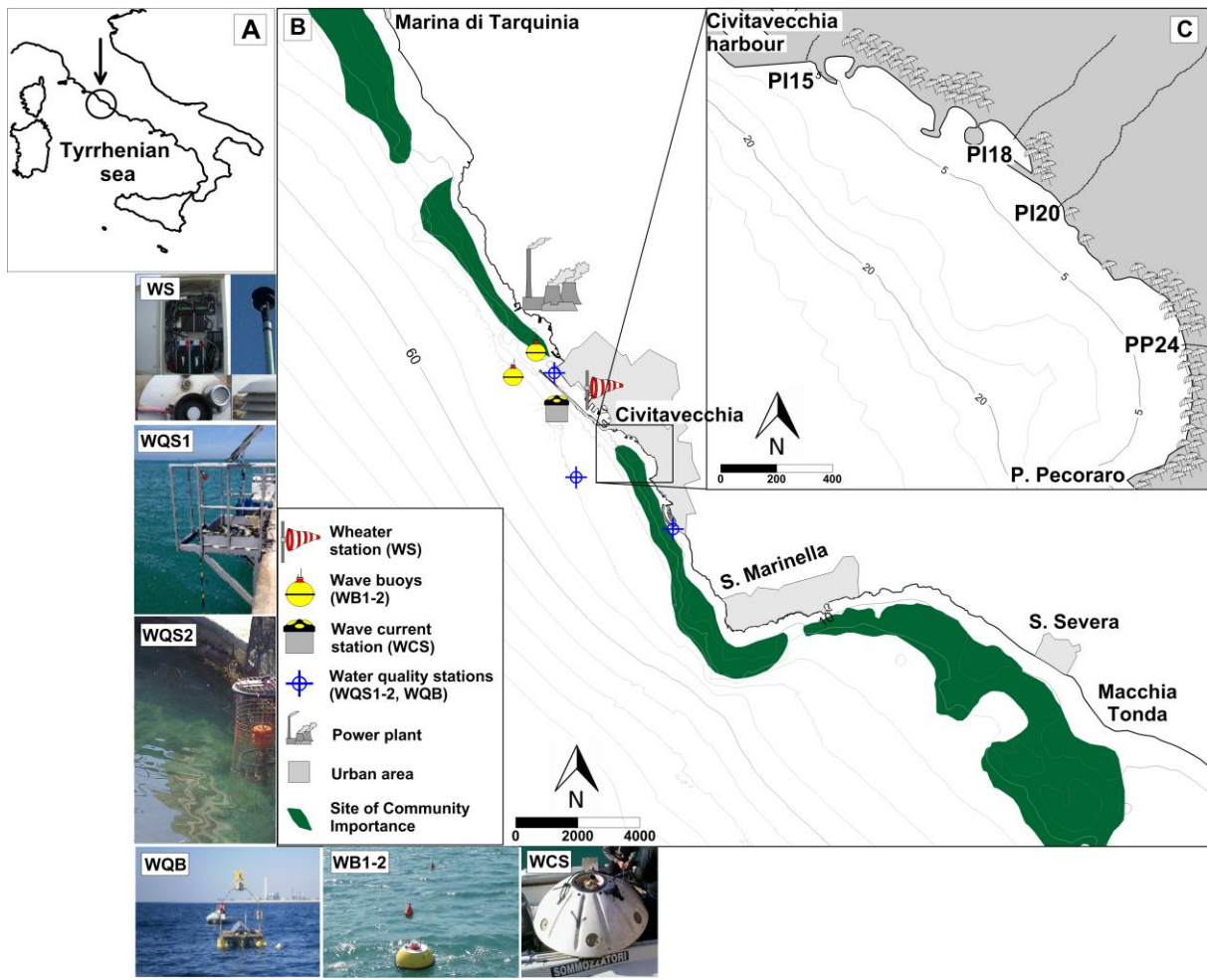
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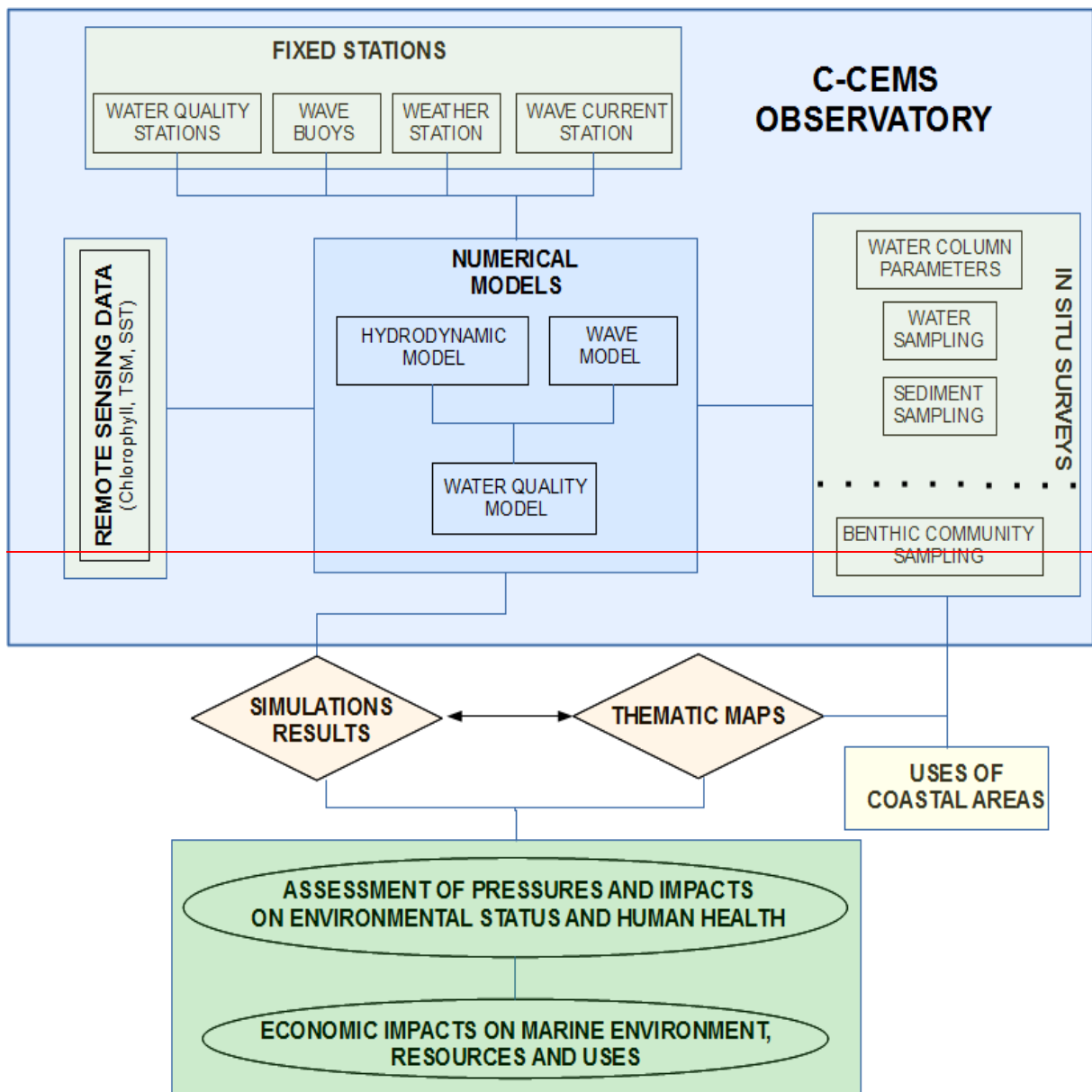
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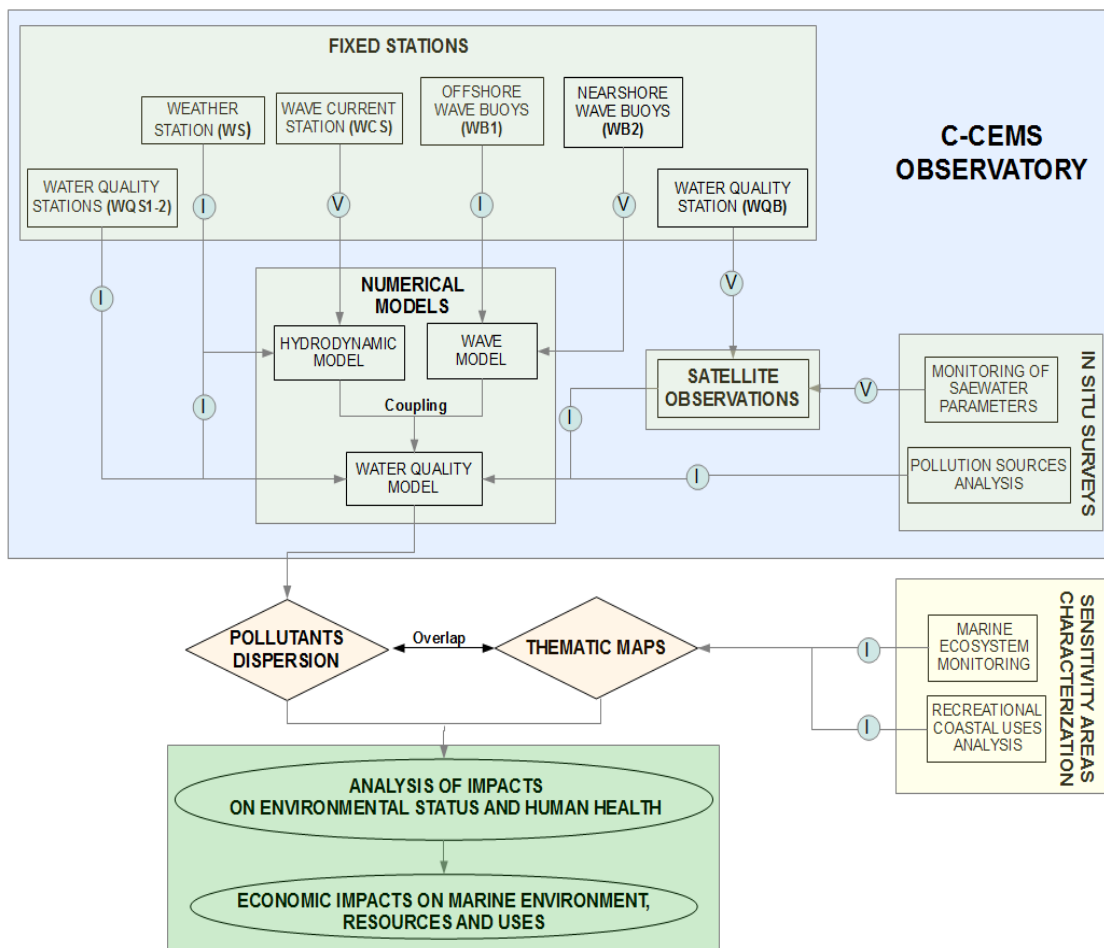


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Figure 1. Location of the study area along the north-east Tyrrhenian coast of Italy (Western Mediterranean sea)~~Study area with the location of coastal uses, SCIs, and measurement stations indicated~~ (A), and zoom-in on the area of C-CEMS applications: the location of coastal uses, SCIs, and measurement stations indicated (B) and the Civitavecchia bathing areas with discharge points and bather density indicated (1 umbrella corresponds to 5 bathers) (BC). The fixed station pictures are reported in the bottom-left corner of the figure.



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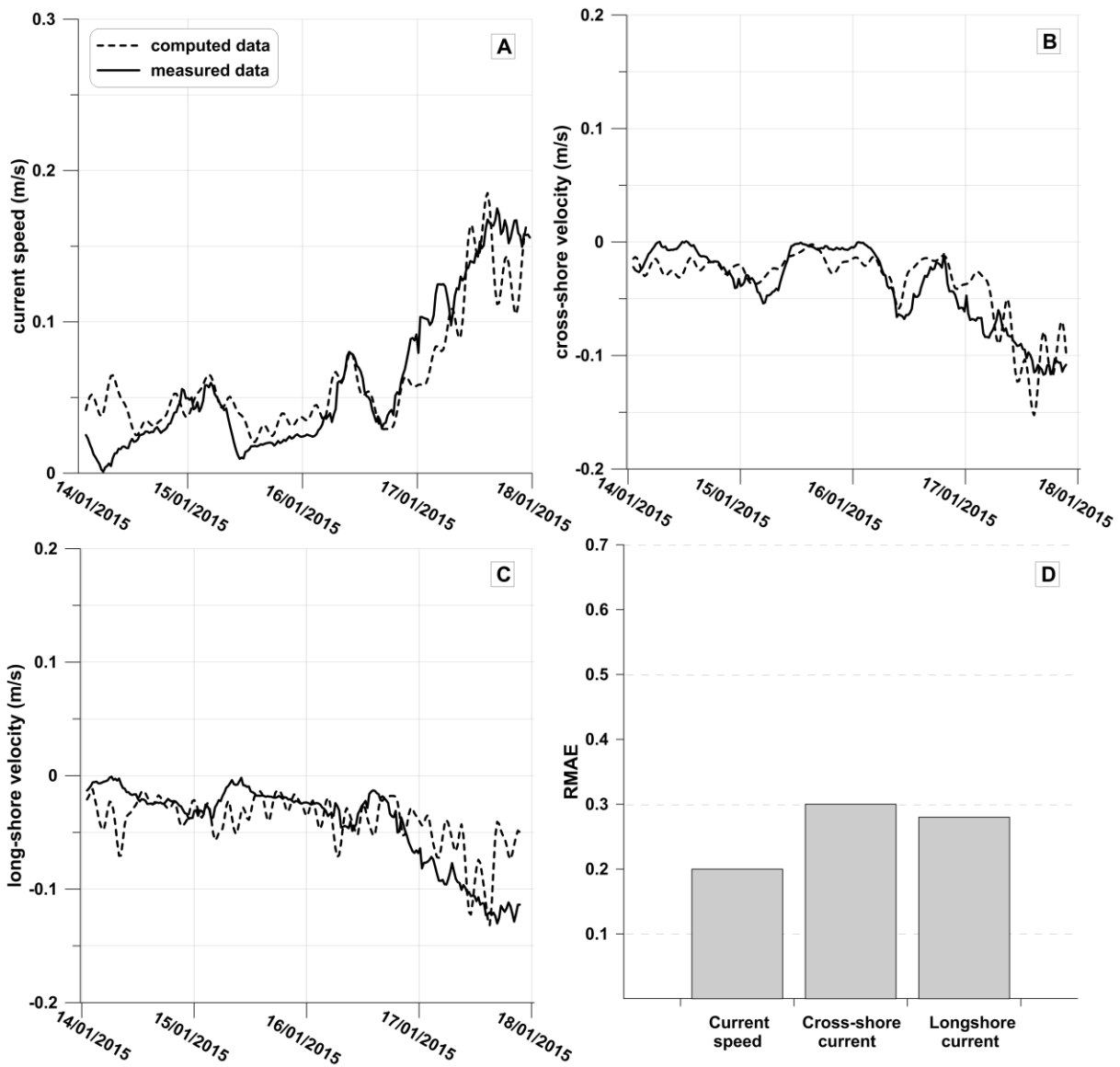
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2 **Figure 2. The functioning of C-CEMS for the analysis of the conflicts between coastal**
 3 **pressures and sensitivity areas. The C-CEMS components interact between them to transfer**
 4 **data (by input (I) and validation (V)) from the in-situ and satellite observations to numerical**
 5 **models in order to reach a temporal and spatial resolution enough to analyse the pollutants**
 6 **dispersion in coastal waters. The conflicts are evaluated overlapping the model results with**
 7 **the thematic maps of the sensitivity areas. The economic impact of the conflicts on the marine**
 8 **environment and human health is reported, even though it is not analysed in this work**
 9 **Block diagram of C-CEMS.**

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4 Figure 3. Validation of current speed (A), cross-shore (B), and along-shore (C) components.

5 The solid and dotted lines represent the measured and computed time series, respectively.

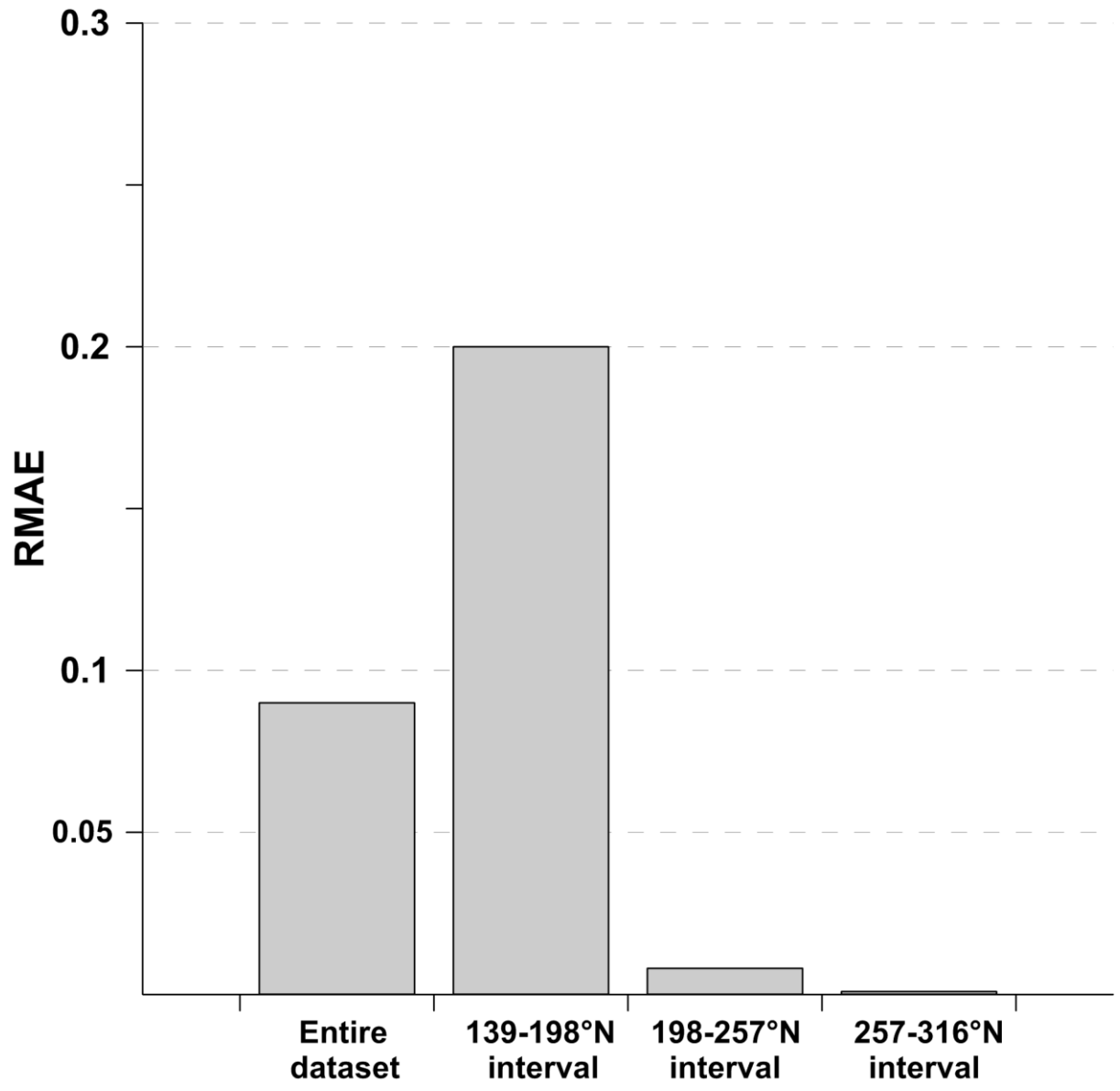
6 Statistics (RMAE) for current speed, cross-shore, and along-shore components are reported in

7 panel D.

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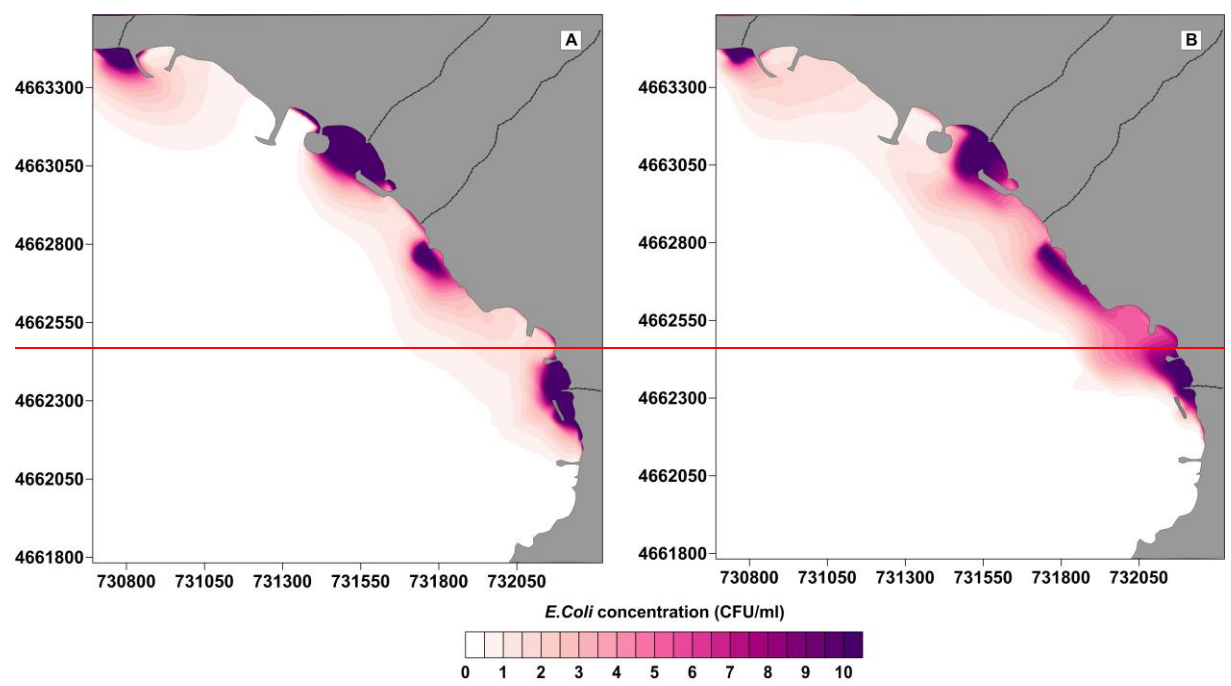
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4 Figure 4. Validation of the SWAN model using RMAE values calculated both for the entire
5 dataset and for three wave direction intervals.

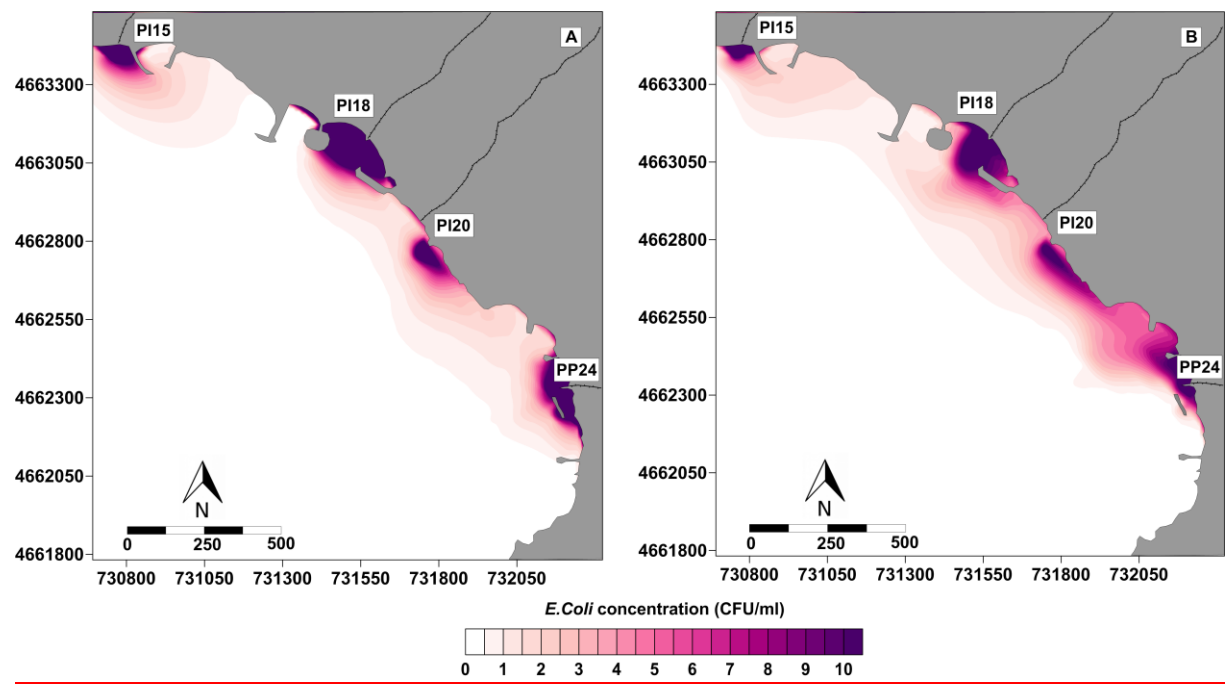
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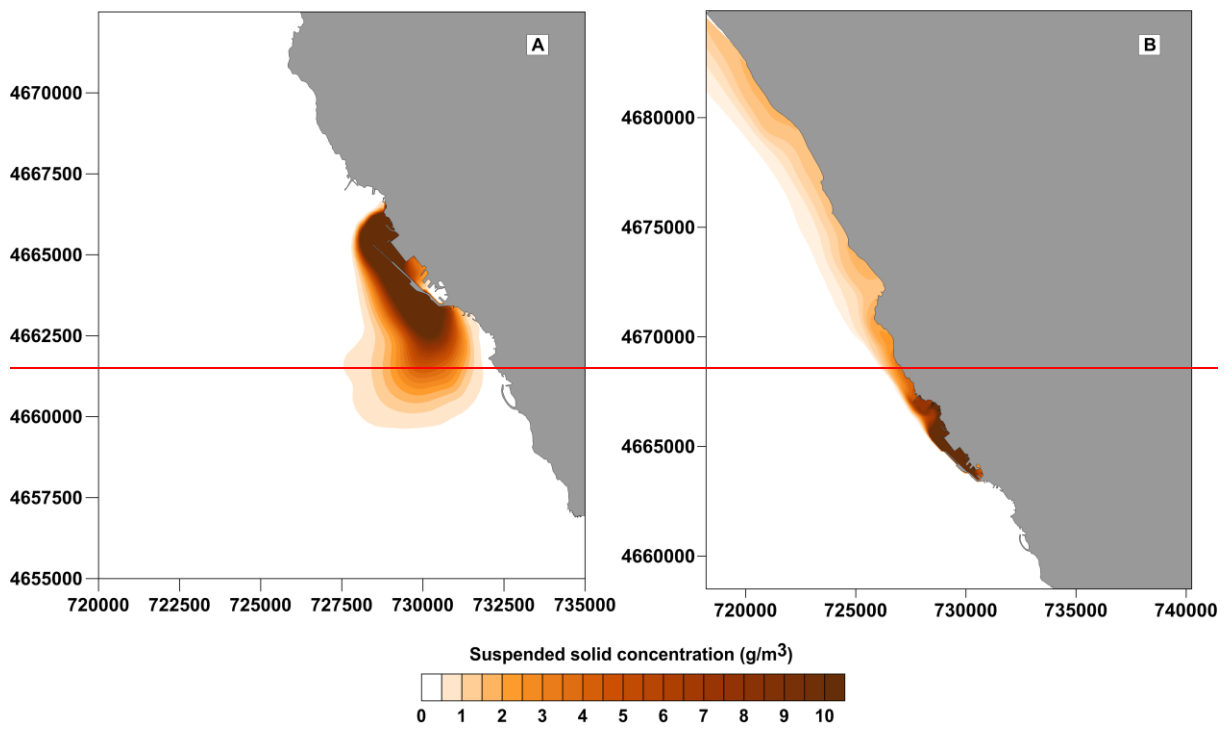
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5 Figure 5. LC (A) and HC (B) simulations results of the bacterial dispersion in the
6 Civitavecchia bathing areas. The distribution of *E. coli* concentration refers to the end of the
7 simulation period.

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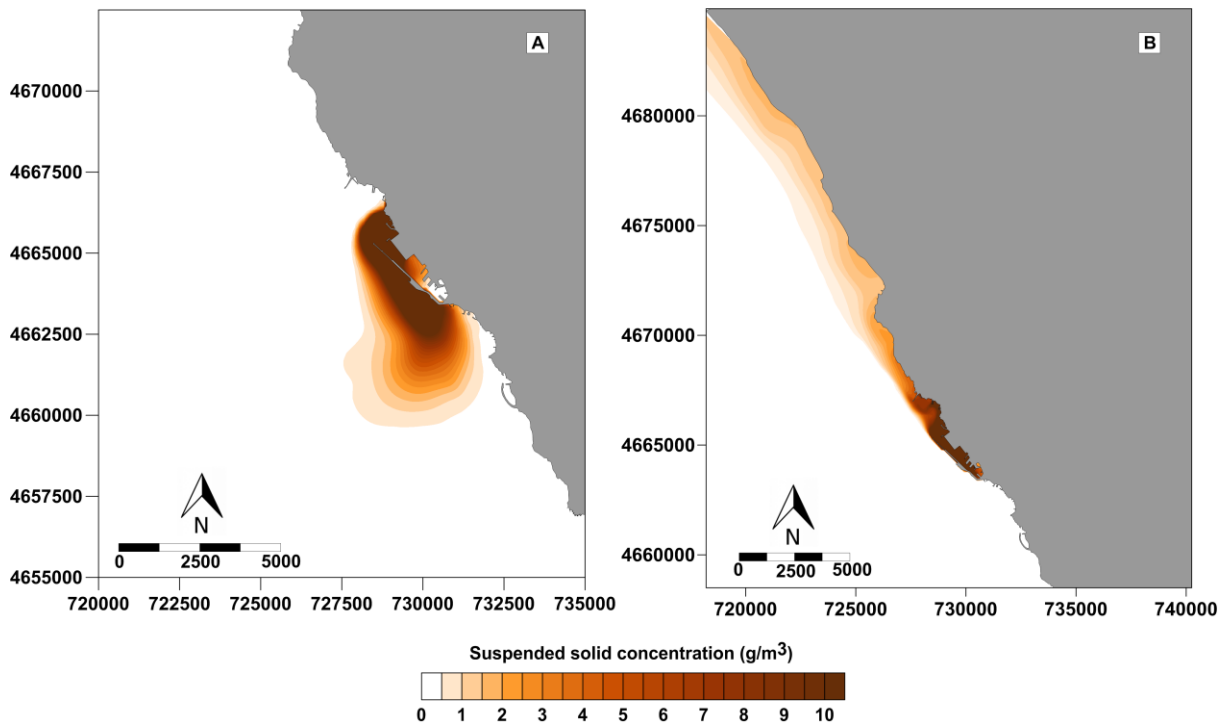
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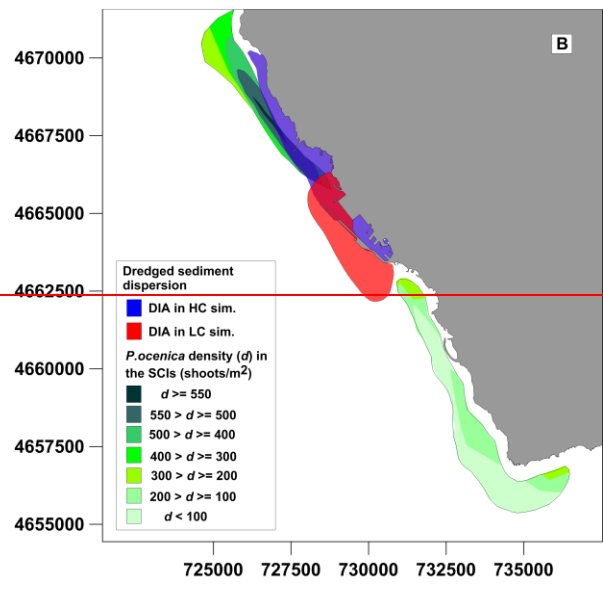
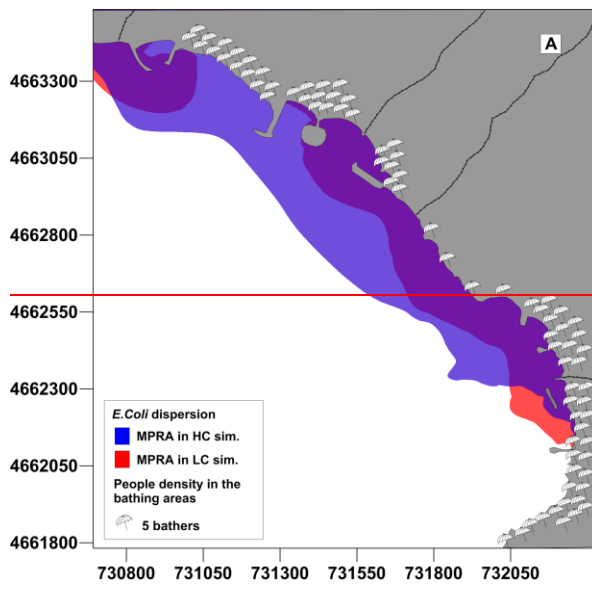
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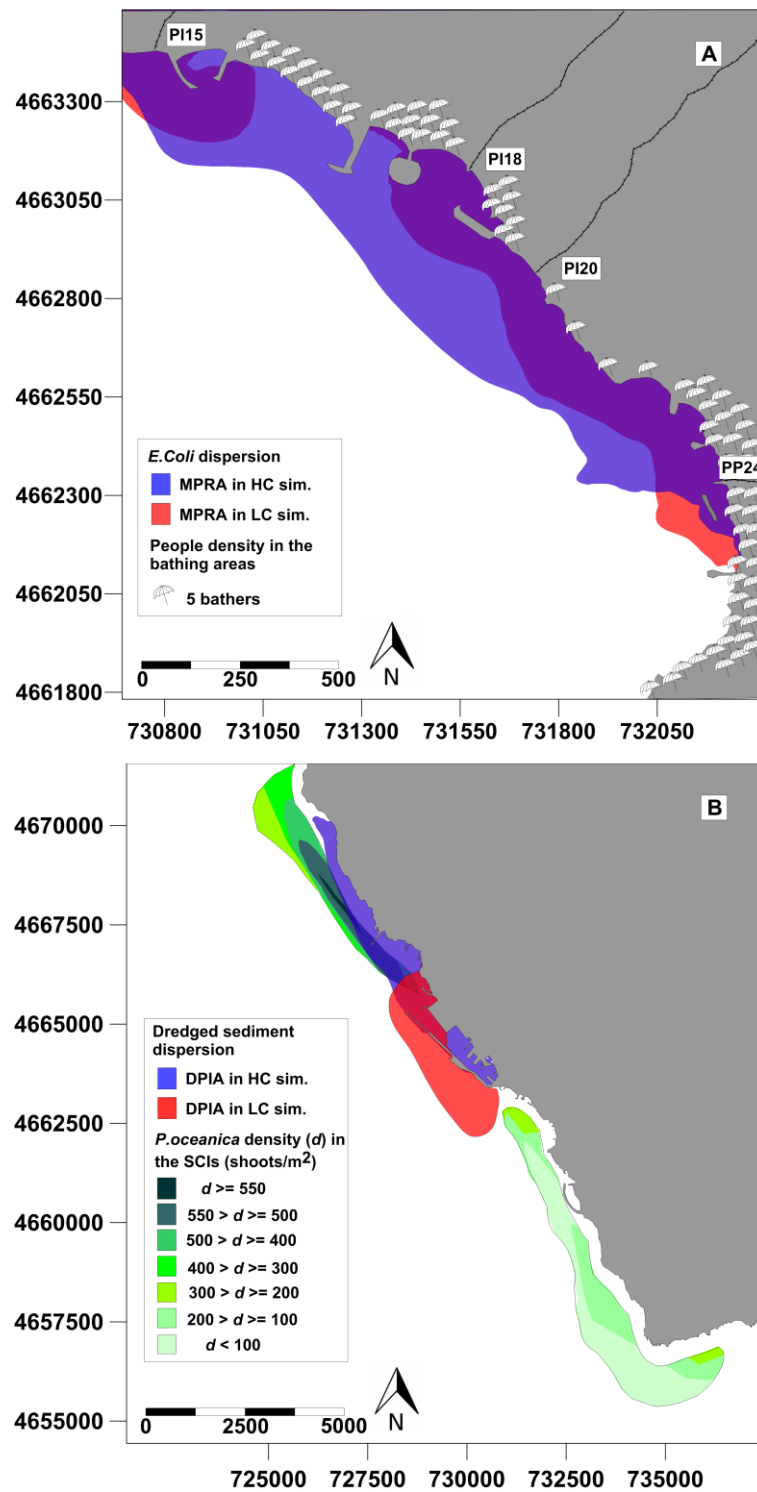
5 Figure 6. LC (A) and HC (B) simulations results of the dispersion of dredged materials in the
6 study area. The distribution of fine sediment concentration refers to the end of the simulation
7 period.

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 2 Figure 7. Overlap between anthropic pressures indicated by the 'potentially-polluting zoning
 3 indicators' (MPRA and DPIA) simulation results and sensitivity areas represented as thematic
 4 maps to analyze 'urban discharge bathing area' (A) and 'dredging SCI' (B) conflicts.