LETTER

Connecting research infrastructures, scientific and sectorial networks to support integrated management of Mediterranean coastal and rural areas

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Abstract

Many Mediterranean coastal areas encounter similar problems and gaps between science, governance, and implementation of sustainable management at local-regional scales. There is often a lack of coordination between management of inland and coastal areas, and a lack of integrated land-sea data and knowledge exchange to support transitions towards sustainable development and synergies between rural and coastal areas. In this paper, we illustrate the main challenges to reach a sustainable development of coastal-rural areas followed by a review of major existing RIs, scientific knowledge and collaboration networks that can help support integrated management of Mediterranean coastal zones. Based on this, we developed recommendations for a better integration of RIs and collaboration networks in the management of coastal-rural areas, including (1) the creation of local networks to facilitate periodical meetings between all sectors involved and to connect science and policy actors and (2) setting up local RIs that support the data processing and the use of regional and international RIs by scientists and policy stakeholders.

1. Introduction

Coastal areas are very useful laboratories to study global change for several reasons. Among others, they are interfaces between terrestrial and aquatic systems, and between different sectors (agriculture, tourism, fisheries, etc); they host protected areas of great ecological value; they are places with great economic and ecosystem productivity (Selig et al 2018); they are usually densely populated; they are highly influenced by biophysical processes occurring at watershed scale and they present great vulnerability to global change (Aerts and Botzen 2014).

Multiple environmental, social-cultural and economic values are found in coastal areas, often with competing interests and depending on scarce resources, being water and soil usually the most important. Moreover, coastal ecosystems are often directly affected by inland watersheds. Due to these multiple interacting agents and processes, coastal management is often considered a typical wicked problem (Parker and Crona 2012, Strijker-van Asperen and van Tulder 2016, Ramm et al 2018, Dhiman et al 2019). Wicked problems are defined as 'problems that are complex, involving multiple possible causes and internal dynamics that cannot assumed to be linear, and
have very negative consequences for society if not addressed properly' (Rittel and Webber 1973).

Coastal areas are also characterized by the interaction between economic activities, such as offshore energy production, inland agriculture and fisheries, affecting natural ecological values of marine and terrestrial ecosystems with strong implications for environmental and socioeconomic sustainability. Besides, the strong seasonality of tourism and related economic activities can be considered a distinctive feature of Mediterranean coastal areas. The design of management interventions to promote sustainable development of these areas must be based on the current scientific knowledge about land-sea interactions, as well as on a holistic and long-term perspective of these socio-ecosystems considering multiple potential transition pathways (EEA 2015). The Barcelona Convention (Pavasovic 1996) pointed out the need to move towards sustainable modes of agriculture, tourism and fisheries in many Mediterranean coastal areas in order to avoid negative consequences, such as a drop in fish catches, landscape and marine recreation attractiveness (Westerberg et al 2013, García-Ayllón 2017).

Effective policy development to deal with multiple interests in the planning of coastal areas requires a continuous stakeholder engagement in which all stakeholders have access to high quality information regarding status and impacts of different spatial planning, land use and management alternatives on environmental, socioeconomic and cultural factors (Martínez-López et al 2019). Other recommendations for effective stakeholder engagement in the management of social-ecological systems include, but are not limited to, careful selection of participants, attractive forms of participation, use of structured methods of information aggregation, and promotion of long-term commitment (de Vente et al 2016, Reed et al 2018). Each situation may, however, require a different type of stakeholder participation, depending on the theoretical understanding of the context, process design, management of power dynamics and scalar fit of the process (Reed et al 2018).

In recent years, there have been many efforts to collect information that allows us to better understand how coastal systems work, like monitoring observatories, process simulation models, integration of different data sources, participatory processes, etc (Piromdi et al 2015, Patricio et al 2016). All these efforts have some traits of the concept of research infrastructures (RIs), which refers to facilities that help leverage the creation of scientific knowledge. In this manuscript we follow the definition used by the European Commission (European Commission 2010): 'RIs are facilities, resources and related services that are used by the scientific community to conduct top-level research in their respective fields and cover major scientific equipment or sets of instruments; knowledge-based resources such as collections, archives or structures for scientific information; enabling information and communication technology-based infrastructures such as grid, computing, software and communication, or any other entity of a unique nature essential to achieve excellence in research. Such infrastructures may be ‘single-sited’ or ‘distributed’ as an organized network of resources’.

RIs have been probably one of the main contributions to the generation of knowledge in the past few years (Tsivaras 2016). They generally provide data and other services at several spatial scales. Although the focus of the definition of RIs is on research, environmental RIs have the mission of providing services to decision makers and other stakeholders in order to support sustainable management of natural resources (Dubois et al 2013, Dubois et al 2015, 2016, Martínez-López et al 2016), insinuating that RIs may be central to facilitate science-policy interaction Some of the most advanced European RIs dealing with coastal issues are: Danubius (Bradley et al 2018), the Joint European Research Infrastructure for Coastal Observatories (Jerico-Next; Puillat et al 2016), Baltic Earth (Meier et al 2014), previously known as BALTEX (Reckermann et al 2011) and the Copernicus Marine Environment Monitoring Service (CMEMS; Le Traon et al 2016), HELCOM (Backer et al 2010) and OSPAR (Tromp and Wieriks 1994).

Despite the existence of these RIs, there are still important gaps between the knowledge and data that are generated by science and the knowledge and data that are put into practice when managing coastal systems and their interactions with rural islands. This means that many managerial decisions are not taken using the most advanced scientific knowledge currently available and RIs may not always be collecting the most policy relevant information. Some illustrative examples of these gaps in European coastal areas can be found in the Belgian coastal zone (Douvere et al 2007), the Aveiro coastal lagoon in Portugal (Lillebø et al 2019, Martínez-López et al 2019), the Norrström coastal basin in Sweden (Darraçq et al 2008, Meacham et al 2016), the Charente River Basin in France (Martins et al 2013), the Danube basin and estuary (Stanica et al 2007, Domisch et al 2019, Funk et al 2019), the Mar Menor Coastal Lagoon (Martínez-Fernández et al 2014) and the Guadalete basin-coastal system (Bergillos and Ortega-Sánchez 2017), among others.

Management strategies in inland basins and coastal areas are often developed independently and in isolation. As illustrative examples, river basin authorities often do not take into account the possible consequences of river regulation on sediment transport, which is a natural source for beach nourishment in the coast. Public local administrations often lack open data services that can be used by scientists or available data are not updated and thus not representative of the current conditions. The availability of water for irrigation and drinking water for tourism is also a key issue.
in many Mediterranean coastal areas and might be reduced under future climate conditions. However, accounting for climate change at local scale by public administrations is also difficult without the proper know-how and data availability.

The overall objective of this work is to evaluate how more collaboration between RIs, scientific knowledge and stakeholder networks could contribute to a more integrated, informed and effective management of Mediterranean coastal-rural areas. The methodology followed consists of: (i) the identification of the main management challenges in coastal areas based on a literature review, (ii) an inventory of the main existing RIs, scientific knowledge and collaboration networks related to Mediterranean coastal environments to explore their potential as facilitators of the knowledge exchange between scientists and policy stakeholders, and (iii) the development of recommendations for the implementation of more effective coupling between scientific knowledge and decision making in coastal areas linking international and regional RIs with local networks and management initiatives.

2. Land-sea challenges in Mediterranean coastal areas

This section provides a concise overview of the major challenges facing society to reach sustainable development of Mediterranean coastal areas based on a narrative literature review. Following the Drivers, Pressures, State, Impact and Response (DPSIR) framework to assess socio-ecological systems (OECD 1993), we can distinguish different drivers and pressures that affect the state and impacts of coastal systems resulting in a range of potential mitigation, prevention and adaptation responses from policy, Civil Society Organizations (CSOs), and the private sector (figure 1). In relation to drivers, climate change is expected to cause increased coastal erosion (Toimil et al 2017, Mills et al 2018) and decrease the availability of freshwater, with increased risk for saltwater intrusion into coastal wetlands and aquifers (Antonellini et al 2008, Mollema et al 2012). Especially in semiarid areas, watercourses suffer from periodic droughts, making water supply for human consumption and economic activities either from surface or groundwater sources a major challenge.

Mass tourism is an important economic sector that often forms a pressure leading to coastal environmental degradation if not properly regulated, especially seasonal tourism that is concentrated during the summer months (Gössling et al 2012). Another pressure is provided by intensive irrigated agriculture that is often widespread in watersheds directly draining to coastal areas. If not properly managed by conservation agriculture and other sustainable land management practices, intensive agriculture usually implies the excessive use of fertilizers and other agrochemicals in frequently ploughed large mono-cropping systems, leading to land degradation, overexploitation of aquifers, soil erosion and transport of sediments and contaminants to coastal areas (Reganold et al 1987, Pimentel et al 1995). Water quality and ecological
status of nearshore coastal ecosystems, such as wetland and marine benthic communities, are often affected by nutrient loads and pesticides transported to the coast, fish farming wastes, and poorly treated urban and industrial effluents leading to eutrophication and increase of water turbidity. This situation is especially critical in semi-enclosed coastal lagoons (Smith 2003).

Many Mediterranean rivers provide large volumes of sediment to the coast, which is of crucial importance for delta ecosystems and to prevent coastal erosion. While unsustainable land use practices can result in excessive sediment and nutrient fluxes, frequently, inland and coastal human infrastructures disturb natural sediment fluxes in rivers and across the coasts. These disturbances can lead to severe coastal erosion, shoreline retreat and flooding (Bergillos et al 2016, Bergillos and Ortega-Sánchez 2017), damaging the infrastructures located around the coast (e.g. residential properties, roads, farming settlements, golf fields, restaurants and hotels, among others). In addition, effective management to prevent reservoir sedimentation is often lacking (Millares and Moñino 2018), leading to loss of reservoir storage capacity affecting irrigation and drinking water, electricity supply and flood control (de Vente et al 2005). The present-day sediment delivery to the Ebro River delta (Spain), for example, is only 1% of the value before dam construction (Guillen and Palanques 1992). Obviously, this affects delta development and coastal erosion along the Spanish Mediterranean coast and threatens environmental services like rice production, fisheries, tourism and coastal protection (Woodward 1995). Coastal infrastructures, like harbours and breakwaters, alter nearshore currents, sediment transport and natural coastal morphodynamic processes. Industrialization, including oil and gas exploration activities and cargo ports, are common in many coastal areas around Europe and in the Mediterranean, and form an important additional pressure with negative consequences in areas with rich biodiversity (Coll et al 2010). Likewise, sand dredging to refill beaches is a common practice in many European coastal areas that can lead to habitat degradation and biodiversity loss. These perturbations prevent achieving the Good Environmental Status required by the Water Framework Directive (Commission E 2000 Common Implementation Strategy for the Water Framework Directive (2000/60/EC) Romania) and the Marine Strategy Framework Directive (EU-MSFD; European Commission 2008). Moreover, the degradation of those aquatic ecosystems, including the presence of alien species, negatively affects the development of important economic activities, such as tourism, fishing and mariculture, also leading to a decrease in recreational opportunities for local populations (Katsanevakis et al 2016).

In an unsustainably managed system, the interactions between drivers-pressure-state often impact negatively human well-being in rural and coastal areas. Bonet-Garcia et al (2015) showed that several municipalities in Andalusia (Southern Spain) suffering a reduction in well-being between 1989 and 2009 were located in coastal areas. This situation could be explained by the overexploitation of coastal natural resources caused by the migration of population from islands to coastal areas and uncontrolled coastal development. The low profitability of agriculture, the lack of economic development, and the absence of public services in many Mediterranean rural areas have resulted in migration of people from the islands to the coasts, resulting in densely populated Mediterranean coastal areas (Arnaez et al 2011, Lasanta et al 2017). The population increase in coastal areas is an important driver that puts pressure on available water resources, housing, and sanitation infrastructures (Díaz et al 2002).

Typical challenges for well-informed response actions, management and policy development are related to the lack of data and monitoring of environmental parameters, ecosystem functioning and the value of ecosystem services for society. For instance, public administrations often lack of information and capacity to effectively monitor and control the use and fate of fertilizers used in agriculture. There is also a general lack of coordination regarding data and knowledge exchange among different areas (i.e. ministries) and levels (local, regional, national) of public administrations that impede effective long term planning and implementation. Other typical management challenges are related to difficulties in controlling the use of illegal fishing and recreational motor boats, illegal groundwater extractions, control of fertilizer use, and maintenance of infrastructures for highly seasonal tourism. The lack of urban planning policies that consider the seasonality of tourism in order to minimize the area occupied by urban areas also causes important soil sealing processes.

Dealing with the above described challenges related to DPSIRs for sustainable development of coastal areas requires:

- Relevant, reliable and interoperable information regarding the functioning of coastal socio-ecosystems, including biophysical, socio-economic and cultural aspects. This information is paramount to quantify drivers, pressures, status and impacts.
- Knowledge sharing platforms where scientists, managers, policy makers and other stakeholders can work together to address the above-mentioned challenges.
- Coordination of research, policy and management activities through communities of practices to facilitate co-creation of durable solutions.

The following sections first review existing RIs, scientific knowledge and collaboration networks and then provide recommendations on how to use them to
Table 1. Main research infrastructures related to monitoring, assessment and management of Mediterranean coastal areas.

| RI                                      | Main topic                                                                 | URL                                                                 |
|-----------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------|
| Jerico-Next (EMODnet)                   | Interaction between physics, biogeochemistry and biology                  | http://jerico-ri.eu/                                                 |
|                                         |                                                                           | http://emodnet.eu/                                                  |
|                                         |                                                                           | http://emodnet-chemistry.eu/                                        |
|                                         |                                                                           | http://emodnet-mediterranean.eu/                                    |
| Copernicus Marine Environment Monitoring System | European coastal and marine environments                                | http://marine.copernicus.eu/                                        |
| SeaDataNet                               | Pan-european infrastructure for ocean and marine data management           | https://seadatnet.org/                                              |
| SOCIB                                    | Coastal Ocean Observing and Forecasting system located in the Balearic Islands | http://socib.es/                                                 |
| LABEX OT-MED                             | Global change and natural hazards in the Mediterranean basin              | http://otmed.fr/                                                  |
| European Environmental Marine Information System | Marine Geoportal providing biological and physical variables             | http://mcc.jrc.ec.europa.eu/emit/                                    |
| Sea level station monitoring facility    | IOC-UNESCO real time sea level measurements                                | http://ioc-sealevelmonitoring.org/                                  |
| European Alien Species Information Network (EASIN) | Access to data on Alien Species reported in Europe                        | https://easin.jrc.europa.eu/easin                                    |
| POSEIDON OSM                             | Oil spill Model                                                            | http://poseidon.hcmr.gr/listview.php?id=134                        |
| Global Lake Watch                       | Lake water quality monitoring tool                                         | http://globallakewatch.org/                                         |
| FerryBox                                 | Network of automated monitoring instruments on ships                      | https://ferrybox.com/routes_data/routes/mediterranean_sea/index.php.en |
| Coastal Coriolis                         | Real-time data from eulerian platforms                                     | http://coriolis-cotier.org/                                        |
| MONGOOS                                  | Mediterranean Operational Network for the Global Ocean Observing System    | http://mongoos.eu                                                   |
| Euro-Argo RI                             | Network of autonomous monitoring instruments                               | https://euro-argo.eu/                                              |
| ECMWF                                    | European Centre for Medium-Range Weather Forecasts.                       | https://ecmwf.int/                                                 |
| Global Surface Water Explorer            | High-resolution mapping of global surface water and its long-term changes | https://global-surface-water.appspot.com/                           |
| Portail des données marines             | Mediterranean marine Data Portal supported by IFREMER                     | http://data.ifremer.fr/pdm/portalsearch/main                        |
| Israel Oceanographic and Limnological Research (IOLR) | Mediterranean marine Data Portal supported by IOLR                | https://isramar.ocean.org.il/isramar2009/                           |
| Mediterranean Ocean Observing System for the Environment (MOOSE) | Mediterranean marine Data Portal                                         | http://mio.pytheas.univ-amu.fr/moose/                               |
| Mediterranean JellyWatch monitoring program (CIESM) | Monitoring data on jellyfish blooms along Mediterranean coasts and in the open sea. | http://ciesm.org/marine/programs/jellywatch.htm                     |
| General Fisheries Commission for the Mediterranean (GFCM) | Data on fisheries and aquaculture                                       | http://fao.org/gfcm/data/en/                                        |
| Dynamic Ecological Information Management System | Information management system about long-term ecosystem research sites | https://deims.org/search/all                                        |
| European Maritime Safety Agency (EMSA)   | Data from Earth Observation satellites, vessel tracking, oil or chemical marine pollution | http://emsa.europa.eu/                                             |
| Integrated Climate Data Center —ICDC     | Access to climate relevant data from in situ measurements and satellite remote sensing | http://icdc.cen.uni-hamburg.de/1.html                              |
| Large Scale Integrated Sea-level and Coastal Assessment Tool—LISCOAST | Data on coastal hazards and vulnerability in coastal areas               | http://data.jrc.ec.europa.eu/collection/LISCOAST                    |
| WITOIL                                   | Web service for predicting the fate and transport oil spills in the Mediterranean Sea | http://witoil.com/en/join                                          |
| AQUA-USERS                               | Data for the aquaculture industry                                         | https://portal.aqua-users.eu/                                      |
| METEOSURF                                | Provision of wind and wave conditions of the Mediterranean Sea            | http://marzocca.net/linux/meteosurf_en.html                         |
| Planet OS                                | Datahub for multi-sector environmental data distribution                 | http://data.planetos.com/datasets/cnms_medsea_wave_analysis_forecast_0042 |
| SHOM                                     | Coastal ocean models                                                      | http://data.shom.fr/                                               |
| Rheticus Marine                          | High-performance geo-information service for monitoring coastal water quality | https://rheticus.eu/                                              |
connect science and policy for better design, implementation and evaluation of integrated, adaptive coastal management.

3. Current RIs, scientific and stakeholder collaboration networks in Mediterranean coastal areas

International cooperation among scientists and stakeholders is crucial to address the above mentioned challenges in a coordinated way, since many coastal areas are directly affected by management in different regions or countries. This cooperation should take into account the interactions between local scale (where the majority of the managerial activities occur) and larger scale initiatives (where legislation and policy is developed). The cooperation should facilitate two directional data and knowledge exchange between scientists and decision makers, and form the basis of integrated management plans. Collaborations between scientists, CSOs, and administrations to set relevant research agendas and increase the dissemination and implementation of research results are fundamental to improve the effectiveness of governance and sustainable development (de Vente et al 2016, Reed et al 2018). This section provides an inventory of existing initiatives aiming at coupling research and knowledge creation with decision-making in Mediterranean coastal areas. This mapping activity groups the collected initiatives according to the three requirements outlined at the end of the previous section.

The monitoring of environmental parameters and ecosystems, which are relevant for management of coastal areas across realms and at different scales, could greatly benefit from the current European RIs (Hering et al 2010, Langhans et al 2019). Table 1 shows an inventory of relevant monitoring RIs that provide useful data and/or models in relation to the management of Mediterranean coastal systems. This table illustrates the huge number of existing RIs providing data and tools related to a wide range of topics. Existing RIs provide data that can support monitoring of environmental conditions, such as sea salinity, currents, chlorophyll, turbidity and temperature, but also enable the evaluation of the ecological status; the monitoring of potential oil spills, the recreational beach sanitary risk, harmful algae blooms for aquaculture farms; the assessment of wave energy resources, etc.

Satellite data can also be used, for example, for territorial planning by mapping cropland and urban areas at watershed scale and by providing early warning indicators of drought, crop stress or water use efficiency (García-León et al 2019). The ecological status of marine and brackish water bodies and wetlands can be inferred by direct remotely sensed observations and models of nutrients, salinity, turbidity and plant communities (Ferreira et al 2011, Martínez-López et al 2014c, 2015), or indirect measures of the extent of irrigated land areas upstream (Martínez-López et al 2014a, 2014b). Remotely sensed data can be also used for precision farming in order to minimize the impact of agricultural activities by reducing the water and nutrients input, as well as for the management of Mediterranean forests by providing biophysical data to existing decision support tools (Costa Freitas et al 2019). Regarding freshwater bodies, water quality and occurrence can be also monitored by remote sensing derived information, such as the Global lake watch tool (Zlinszky et al 2017) and the Global Surface Water Explorer (Pekel et al 2016, Bastin et al 2019).

Coastal water quality, marine litter and the ecological status of coastal water ecosystems can be assessed using several RIs, such as EMODnet Chemistry, Coastal Coriolis, CMEMS, MONGOOS or Euro-Argo RI (Romero-Ramirez et al 2013, Pastor et al 2017, Liubartseva et al 2018, Borja et al 2019). Assessment of

| RI | Main topic | URL |
|----|------------|-----|
| Quonops | Underwater sound mapping service | https://qos.quiet-oceans.com/ |
| ODYSSEA | Network of observing and forecasting systems across the Mediterranean basin | http://odyssseaplatform.eu/ |
| CHLO4MSFD | Chlorophyll-a data from satellites | http://chlo4msfd.aizi.es/ |
| Satellite Winds | Synthetic Aperture Radar wind maps | https://satwinds.windenergy.dtu.dk/ |
| CEAMed | Mediterranean sea surface temperature portal | http://ceam.es/ceamet/SST/ |
| WISE-Marine | GIS map viewer about protected areas and marine regions | https://maps.eea.europa.eu/wab/wise-marine-map |
| MAMIAS | Marine Mediterranean Invasive Alien Species | http://mamias.org/ |
| Mediterranean Platform on Biodiversity | Data on marine and coastal biodiversity | http://data.medchm.net/en/home |
| HyMeX | Observational and modelling systems of the hydrological cycle in the Mediterranean | https://hymex.org/ |
| Med-CORDEX | Atmospheric, land, surface, river and oceanic models | https://medcordex.eu/ |
pressures, such as noise mapping and forecasting activities, can be supported by the Quonops platform and oil spills can be monitored using the MONGOOS and POSEIDON OSM platforms. Monitoring illegal fishing and motorboats can be done also from the space using Copernicus and multisatellite data (Wahl et al. 2005, Corbane et al. 2010, Fukun Bi et al. 2012, Yang et al. 2014, Shengxiang Qi et al. 2015).

Coastal flooding and wave energy resources can be assessed using EMODnet wave and bathymetric data, tide regional models (e.g. Egbert and Erofeeva 2002) and hydrodynamic and wave propagation models (Lesser et al. 2004, López-Ruiz et al. 2016, 2018). Storm-impact models (Roelvink et al. 2009) fed by topography, bathymetry, wave and tide conditions, and sediment properties have been used for studying coastal flooding (Bergillos et al. 2019). Coastal erosion has been studied by means of one-line type models or morphodynamic models fed by topography, bathymetry, wave and tide conditions, and sediment properties (Bergillos et al. 2017a, 2017b). Sea level rise can be monitored by means of LISCOAST and ICDC (Brown et al. 2019).

The monitoring and management of alien species in coastal areas can be supported by EASIN and Copernicus data (Deriu et al. 2017, Coro et al. 2018). Algae blooms can be monitored using FerryBox data. Alterations to river morphology can be assessed through high resolution topographic (LiDAR) data and models (Milne and Sear 1997, Rumsby et al. 2008).

Soil erosion processes at continental or watershed scale and the effect of climate change, extreme events and sustainable land management can be assessed by means of hydrological and erosion models fed by topography, meteorological data (high intensity precipitation events), land cover, agricultural practices and soil data (Borrelli et al. 2018, Eekhout et al. 2018, Eekhout and de Vente 2019). Extreme weather events, such as rainfall estimates, can be monitored using Satellite and Radar data from Copernicus or NASA (Cánovas-Garcia et al. 2018) and HyMex models (Drobinski et al. 2014). Illegal groundwater extraction can be identified using LTER (Long-Term Ecological Research) monitoring data and assessing the origin of groundwater samples through machine learning (Baudron et al. 2013).

The design and implementation of renewable energy sources in coastal areas could also be supported by data from some European RIs, such as offshore wind and wave energy resources, which can be evaluated by means of the EMODnet wind farm siting service, and bathymetric, wave and wind data (Astariz et al. 2015, Astariz and Iglesias 2016, Gomariz-Castillo et al. 2017).

RIs focusing on monitoring and assessment alone, often run the risk of not being applicable to actual policy or decision making. In order to bridge the gap between science, policy and management, scientific results need to be integrated into applicable methodologies and shared through platforms for knowledge exchange that consider economic, social and ecological relationships between ecosystems and human activities. Free access to knowledge and information is crucial to share ideas and facilitate research cooperation and RIs should be able to help answering practical questions from planners and policy makers. Scientific knowledge exchange platforms can support the management of coastal and rural areas by sharing solutions and experiences from other regions facing similar problems and by connecting researchers, stakeholders, and institutes with complementary expertise. Many of these knowledge exchange platforms combine data with methodological frameworks and models for studying land-sea synergies, including synergistic business road maps and policy guidelines for land-sea collaborations, platforms for exchange of expertise and experiences between stakeholders and researchers facing similar issues, as well as a set of performance indicators to measure coastal and rural development and synergies in different contexts. Scientific knowledge exchange platforms often provide services and guidance, such as training, assessing the functioning of

| RI                                      | Main topic                                                                 | URL                              |
|-----------------------------------------|---------------------------------------------------------------------------|----------------------------------|
| OceanGov COST action                    | Ocean Governance for Sustainability—Challenges, Options and the Role of Science | https://oceangov.eu/             |
| International Blue Carbon Initiative    | Mitigation of climate change                                              | http://thebluecarboninitiative.org |
| The European Maritime Spatial Planning Platform | A service for Member States to share relevant knowledge and experiences on Maritime Spatial Planning | https://msp-platform.eu/         |
| MedECC                                  | A network of Mediterranean Experts on Climate and environmental Change     | http://medecc.org/               |
| COASTAL Knowledge exchange platform      | Platform giving access to knowledge, solutions, and experiences in relation to land-sea interactions | https://coastal-xchange.eu/       |
| FISHREG                                 | Scientific and Technical Support on fisheries and aquaculture by the Joint Research Centre | https://fishreg.jrc.ec.europa.eu/projects |
| Mediterranean biodiversity knowledge platform | Provides scientific evidence for supporting best practice on protected area management | http://panaceaweb.adabyron.uma.es/ |
coastal areas, gathering knowledge to promote restoration of coastal areas, scientific and technical support for fishing activities, etc. Table 2 shows an inventory of ongoing scientific knowledge exchange platforms relevant for the integrated management of Mediterranean coastal areas at local scale.

Knowledge exchange platforms form an important step towards co-creation of coastal management. However, effective design and implementation of policy and management decisions for sustainable coastal development require further collaboration between all stakeholders involved in coupled rural-coastal socio-ecosystems. Coordination and collaboration across management scales and involving a wide range of stakeholders from all sectors in planning and management is fundamental to identify synergies, create acceptance and ownership over decisions amongst all stakeholders involved. There are normative, pragmatic, and instrumental reasons (Chambers 2003, Reed 2008) to develop stakeholder participation platforms to exchange local and scientific knowledge and skills on the different types of management solutions, and innovative ideas for sustainable development. Facilitation of collaborations between sectors and stakeholders helps arriving at better informed and feasible decisions, that are often more durable, flexible and lead to higher level of acceptance by stakeholders and decision makers. Moreover, well designed forms of participation can enable groups to collectively develop innovative solutions through deliberation and reflection in an inspiring group atmosphere representing the multiplicity of perspectives involved (Pahl-Wostl and Hare 2004, Siebenhüner and Suplie 2005, de Vente et al 2016). Table 3 shows an inventory of (multi-)sectorial stakeholder collaboration networks that promote collaboration for sustainable development in Mediterranean coastal areas. Some of these networks aim to foster regional cooperation and dialogue (e.g. Union for the Mediterranean) or an integrated coastal zone management (e.g. ICZM platform), while others are focused on specific aspects such as development of ecotourism (e.g. MEET) or collaboration between marine protected areas (e.g. MedPAN).

4. Recommendations for coupling Mediterranean RIs, knowledge exchange and collaboration networks to improve integrated management of coastal and rural areas

Mediterranean coastal areas host not only high species and habitat biodiversity, but also a complex net of human settlements with a long history of land use change and ecosystem services appropriation. Multiple pressures from different sectors in Mediterranean coastal areas lead to cumulative impacts, being together with climate change the main threats to biodiversity and human well-being. Thus, it is paramount to define a comprehensive management strategy in which it is crucial to have access to data, monitoring programmes and scientific research outputs. Besides, coastal areas cannot be managed in isolation without taking into account the rural areas in the upstream catchments draining towards the coasts. Therefore, it is also important to empower rural and coastal stakeholders to be part of the solutions through participatory approaches and try to find management strategies that have positive impacts on both coastal and rural areas. In other words, the interdependence found in the different aspects of the coastal socio-ecosystem, must be mimicked by the relationships among stakeholders through stronger cooperation threads.

In previous sections we provided a concise review of the main existing RIs, knowledge exchange platforms, and collaboration networks available. Our diagnostic illustrates that we already have many of the needed ingredients to create an integrated management approach in coastal areas. However, we believe that further integration between existing RIs, knowledge exchange platforms and collaboration networks is needed to make such an integrated management of coastal areas more effective. Based on this fact, in this section we propose several networking and collaborative guidelines that could improve the capability of Mediterranean coastal areas to address the socio-ecological challenges described in the above sections. Our proposal takes into account two spatial scales (local and watershed) as well as the three types of initiatives considered in this manuscript (RIs, knowledge exchange platforms and multi-sectorial collaboration networks).

4.1. Coastal local scale

Many of the main RIs, scientific knowledge exchange platforms and multi-sectorial collaboration networks identified in this manuscript operate at a regional scale. This means that we are missing local initiatives that put the focus on specific coastal areas. We believe that the plethora of existing coastal initiatives must adopt a spatially hierarchical structure. This means that it would be useful to create a set of site-based RIs that monitor data on specific sites and on specific socio-ecological problems. Other successful monitoring infrastructures such as LTER, NEON (National Ecological Observation Network), HELCOM (Baltic Marine Environment Protection Commission—Helsinki Commission) and OSPAR (Protecting and conserving the North-East Atlantic and its resources) are functioning on a site-based basis.

But monitoring is not the only topic to be addressed by local initiatives. Some of the functionalities that we have identified within existing knowledge exchange platforms and multi-sectorial collaboration networks should also be considered in the creation of
Table 3. Main (multi-)sectorial collaboration networks related to Mediterranean coastal areas.

| RI | Main topic | URL |
|----|------------|-----|
| MEDITERRANEAN WETLANDS INITIATIVE | Supporting the effective conservation of Mediterranean wetlands | medwet.org |
| MEDPAN | Mediterranean Marine Protected Areas | http://medpan.org |
| MEDENER | Mediterranean Association of National Agencies for Energy Management | https://medener.org/en/ |
| CPMR INTERMEDITERRANEAN COMMISSION (IMC) | Mediterranean territorial cooperation | https://cpmr-intermed.org/ |
| General Fisheries Commission for the Mediterranean (GFCM) | Sustainable development of fisheries and aquaculture | http://fao.org/gfcm/en/ |
| UNION FOR THE MEDITERRANEAN (UFM) | Enhancement of regional cooperation | https://ufmssecretariat.org/ |
| ICZM PLATFORM | Integrated Coastal Zone Management in the Mediterranean | http://iczmplatform.org/ |
| MEDITERREAN INFORMATION OFFICE FOR ENVIRONMENT, CULTURE AND SUSTAINABLE DEVELOPMENT (MIO-ECSD) | Federation of 127 Mediterranean Non-Governmental Organizations (NGOs) | http://mio-ecsde.org/ |
| MEDIES | Environmental Education and Education for Sustainable Development | http://medies.net/main1.asp |
| Coordinating Unit for the Mediterranean Action Plan | Marine environmental degradation | http://web.unep.org/unepmap/ |
| SWITCHMED | Promoting social and eco innovations in the Mediterranean | https://switchmed.eu/en |
| Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC) | Promoting sustainable consumption and production models | http://cprac.org/ |
| IUCN CENTRE FOR MEDITERRANEAN COOPERATION | Promoting sustainable livelihoods and biodiversity conservation | https://iucn.org/regions/mediterranean |
| MEDITERRANEAN WETLANDS INITIATIVE | Supporting the effective conservation of Mediterranean wetlands | https://medwet.org/ |
| GWPMED | Knowledge exchange on Integrated Water Resources Management (IWRM) | https://gwp.org/en/GWP-Mediterranean/ |
| EURO-MEDITERRANEAN FORUM OF INSTITUTES OF ECONOMIC SCIENCES (FEMISE) | Promoting economic relations between Europe and its Mediterranean partners | http://femise.org/en/ |
| MEDITERRANEAN WORLD ECONOMIC FORESIGHT INSTITUTE (IPEMED) | Promoting economic cooperation among Mediterranean countries | http://ipemed.coop/en/ |
| PLAN BLEU | Mediterranean Observatory on environment and sustainable development | http://planbleu.org/en |
| (RAC/SPA) | Mediterranean Activity Centre for Specially Protected Areas | http://rac-spa.org |

local coastal infrastructures. Local-based initiatives must also take into account the linkages between coastal science, policy and management. These ideas can be solidified through the creation of methodological frameworks and modelling approaches to study land-sea-human relationships. Moreover, observations and modelling must go together to arrive at useful decision support systems for local decision makers.

Furthermore, we strongly advocate for the integration of multi-sectorial activities within local-based infrastructures. Most of the already existing initiatives are missing this functionality, which is paramount to address multifaceted environmental challenges. All the multi-sectorial collaboration networks identified in this manuscript (see table 3 for details) are focused on supra-local scales. We believe that this set of functions are more properly aligned with the requirements of local environmental problems. This proposal could take the shape of Communities Of Practices (Pyro et al. 2017): a group of people with diverse professional profiles who genuinely care about the same real-life problems or hot topics. The implementation of this idea would imply that scientists, public administrations, non-governmental organizations and stakeholders of several socio-economic sectors (fishing, agriculture, tourism, local populations, etc) work together in the pursuit of a common objective.

Finally, we think that site-based management initiatives (public or private) must be properly linked with other scales, since they are the ones most strongly connected with local problems. These site-based initiatives are key to iteratively walk the path between the local and the national/regional scales. They would deliver the results generated at local scale to the national/regional initiatives in order to increase their awareness of the local scale. They would also collect ideas, procedures and policy directives from the national/regional scale in order to be implemented in the local scale.

The implementation of these ideas at a local scale requires, among other things, the development of sustainable business cases based on public-private collaborations in Mediterranean coastal areas. Those cannot be reached without bringing together stakeholders from different sectors, nor without having enough data and knowledge of the interactions and
causal relationships among different activities and socio-ecosystems. The creation of public entities that manage the coastal-watershed unit as a whole is also fundamental for a comprehensive assessment of best management solutions in coastal areas. We argue that coupling local and regional RIs, knowledge exchange platforms and stakeholder collaboration networks through the development of interconnected communities of practice is fundamental to support the design and implementation of effective integrated and adaptive management of coastal socio-ecosystems.

We also believe that the promotion of startups capable to process raw data and offer environmental consultancy services is key for making data produced by RIs available at the local level. There are ongoing initiatives, such as the Copernicus Start-up Programme, supporting small companies in order to create continuous information services related to biodiversity monitoring, pollution control, etc, which could be coupled with local environmental information systems and used for management by different authorities (Buchanan et al. 2018). The lack of computing capacity for processing high resolution data by public administrations and research institutions can be overcome by means of new public cloud platforms, such as EGI (https://egi.eu/).

4.2. Watershed scale
Sustainable development of coastal and hinterland areas requires an integrated response from policy, management, CSO’s and private sectors that strengthen governance at multiple scales (local to European) and facilitate the flow of knowledge and information between interconnected sectors and regions. This includes crucial aspects, such as the efficient use of water, implementation of innovative farming practices, a transition to sustainable models of ecotourism and agrotourism in hinterland areas, less sensitive to seasonality, the promotion of offshore renewable energy facilities, the promotion of education regarding environmental issues and policies, including capacity building of farmers on the use of fertilizers, and the improvement of the sewerage systems in coastal areas.

The need for coordination among peers with potentially different interests arises mostly at watershed scale, i.e. different initiatives located at different areas that pursue objectives that do not need to be totally compatible among them. For example, coastal initiatives could be interested in maintaining the sediment flux from rivers, while hinterlands initiatives are retaining those sediments in dams. However, in spite of this potential lack of alignment of objectives, coastal and hinterland local-based infrastructures exhibit a high degree of interdependence: they need each other to address fuzzy and wicked problems that put in risk the system’s capability of providing services to the socio-economic system.

We think that, in order to succeed with the cooperation at this scale, training in soft skills is also needed that enable participatory management (Parker and Crona 2012), such as: social sensitivity, emotional engagement, governance, communication patterns, empathy, etc. These skills are needed to distillate common values and objectives from the different site-based initiatives (coastal and hinterland) that constitute a single watershed (Cairney and Kwiatkowski 2017).

At the watershed scale it is paramount to create spatially explicit models able to forecast (in the short and medium scale) the functioning of coastal-inland systems using different socio-economic scenarios. These models should also be able to translate their outcomes from the scientific jargon to a language easily understandable by other actors, such as policy stakeholders, farmers, fishermen, etc (Schwirth et al. 2019).

The integration of local-based initiatives to create the above mentioned models reveals a common problem: the need to harmonize data collected in different local-based infrastructures using different methods and for different objectives. Thus, data and methods harmonization is one of the most important factors that limit interoperability among site-based infrastructures. We suggest that, besides technical solutions that help to integrate datasets from different sources, it is paramount to create conceptual frameworks that would act as crosswalks among the particular ‘mind-sets’ of every local-based initiative. For example, a given local-based initiative can be focused on land use changes, while another one could be more concerned with hydrological issues. Each of them are referring to a similar reality, although their structure and functioning could have been designed according to the local scientific and social traditions. This ‘local personality’ could make integration at higher spatial scales difficult. The concept of ‘essential variable’ (Pereira et al. 2013, Bojinski et al. 2014) aims to address this mismatch acting as a sort of crosswalk or common ground framework useful to put together concepts and datasets coming from disparate local-based initiatives in order to easy the data transfer to the broader scales of the hierarchy. Essential variables are a minimum set of variables to capture major dimensions of environmental change. They provide an intermediate abstraction layer between data collected in local-based initiatives and indicators calculated at regional/global scales. Regarding the above mentioned example, a set of ‘coastal essential variables’ would help to put together data coming from each site-based initiative, irrespective of their thematic focus. Each local-based initiative should create a procedure to translate its local monitoring variables to the set of essential variables.

Finally, a cluster of coastal and hinterland site-based initiatives located in a single watershed should also pay attention to its integration with national and
international governance initiatives. They are very valuable at an international scale because they can provide case studies of integration that could be ‘exported’ to other areas making use of international knowledge exchange platforms and stakeholder collaboration platforms effectively linking science with policy.

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Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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