



Opening Marine Long-Term Ecological Science: Lesson Learned From the LTER-Italy Site Northern Adriatic Sea

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This work presents a practical case study of the Open Science principles applied to the valorization of a long-term marine dataset collected in the Northern Adriatic Sea, one of the Long-Term Ecological Research (LTER) sites of the LTER-Italy network. The dataset covers a temporal range of 50 years (1965–2015), and it is composed of abiotic, and phyto- and zooplankton data, for a total of 21 parameters. The case study involved many actions, which will be described here, distinguishing between the ones affecting the whole research project workflow and those acting more specifically on the dataset. We evaluate strengths, weaknesses, and possible improvements for each action. The present study pointed out that, despite the initial and still some remaining mistrust, opening research projects is more than a best practice. It is (i) important because it improves research transparency (increasing researchers' credibility, replicability of science, and products reuse), (ii) required by many international initiatives and regulations, and (iii) enriching because it encourages cooperation between scientists across different fields and laboratories.

Keywords: LTER-Italy, EcoNAOS, Northern Adriatic Sea, Open Science, open data

INTRODUCTION

Open Science embraces transparency at all stages of the research process, implying free and open access to research ideas, data, metadata, tools, code, and papers. It is increasingly recognized that moving toward the Open Science approach leads to higher impacts and better quality of research (Eysenbach, 2006; Hajjem et al., 2006; Bernius and Hanauske, 2009; Gargouri et al., 2010; Swan, 2010; Hampton et al., 2015; McKiernan et al., 2016; Tennant et al., 2019). The FAIR guiding principles proposed by Wilkinson et al. (2016), described how research data should be managed for optimal reuse beyond the data publication process and consist of the following:

1. Findable: data must have a Persistent Object Identifier associated and they must be indexed by the major research engines;
2. Accessible: there should not be barriers between data and user (e.g., email site registration or other limitations) and they must have a liberal license associated;
3. Interoperable: data should be available for exploitation and optimized with interoperability with multiple tools and operating systems. This implies using standard data formats;
4. Reusable: they must be widely documented through metadata and the license associated must allow the reuse of the dataset.

These four principles enable data to be qualified as being open or not and they represent a turning point for the application of Open Science principles to data. Moreover, Wilkinson et al. (2016) incorporated the concept of “data stewardship,” which is meant to involve a holistic approach beyond simply maintaining the data (“data management”). Data stewardship actions may include, but is not limited to: anticipate researchers’ data needs, manage concurrent projects in which data could be involved, and create plans for data collection, maintenance, publishing, and curation.

Jacobsen et al. (2020) conceptualized a workflow for the FAIRification of data, identifying three different stages under the guidance of the data steward professional:

1. Pre-FAIRification phase: identify data, analyze data and metadata.
2. FAIRification: create semantic models and make data and metadata linkable.
3. Post-FAIRification phase: assessment of FAIRness of the system.

Compared with the fields of Physics and Chemistry (e.g., arXiv¹ established in the early 1990s), Open Science has only recently attracted interest and debate in the fields of Environmental Science and Ecology (Reichman et al., 2011; Hampton et al., 2015; Stall et al., 2019). Ecology, being intrinsically a multidisciplinary research domain, might surely benefit from the Open Science approach, which enables to enlarge the vital cooperation required for properly addressing the current complex socio-ecological issues, challenges, and opportunities (Powers and Hampton, 2019).

Both technological and cultural barriers persist for practicing ecology as Open Science and for generating the shift of the scientists’ mindset from data ownership to data stewardship, which was promoted some years ago by Hampton et al. (2015). In order to foster the adoption of the Open Science principles, it is necessary to let them settle in the ecologist scientific community, by respecting and taking care of the cultural resistances and uncertainties, which should not be considered only as negative aspects but, instead, appreciated as vital parts to be included and dealt with along the path toward Open Science. Crucial to this respect, is the development of practical case studies,

where researchers, both in ecology and in data management, could cooperate within a framework of shared understanding of the present constraints and possibilities of implementation of Open Science principles in the field of ecology. The participatory process is crucial if obstacles to Open Science (cultural differences, barriers, and fragmentation) are to be overcome (Björk, 2004; Janssen et al., 2012; Barry and Bannister, 2014).

Open Science principles are a matter of interest, discussion, and application in different fields of science, with levels of awareness and fulfillment that have been rising in the last 20 years, in different ways across the countries. In Europe, Open Science has been fostered by keystone initiatives, such as the Berlin Declaration on Open Access (Various Authors, 2003), the INSPIRE directive (European Commission, 2007) which set up mechanisms to harmonize and share relevant geospatial data, the Moedas’ speech at the European Parliament (Moedas, 2015) and the Open Science and Open Innovation connection established by the European Commission (2016). Only recently some initiatives like the establishment of the European Open Science Cloud (EOSC)^{2,3} or the work pursued during the last years by the Research Data Alliance⁴ helped researchers giving practical application to these principles. The scientific community seems now ready to implement Open Science in its routine work. However, despite its significance to research, in Europe, the adoption rate of open data technology remains low across all disciplines (Stieglitz et al., 2020). By contrast, some United States (US) governmental institutions (e.g., NASA, NOAA, and USGS), took effort to the application of Open Science principles in the past decades especially on the open data front (e.g., data releases by the ASTER NASA program since 2000⁵, including oceanography data by the NOAA Sentinel Site program⁶), allowing the use of open data to become common practice at government level, long before similar applications occurred in Europe. In legislation, Open Science practice has been sealed in the US by the Federal Crowdsourcing and Citizen Science Act, signed into law in January 2017⁷.

The Open Science approach is strongly supported in the data management plans of the LTER networks (Kunkel et al., 2019), at the national, European (LTER-Europe⁸), and global level (ILTER⁹). The publication of ecological observational datasets and data papers is encouraged to improve data reuse and knowledge sharing in the field of ecology (Shin et al., 2019). LTER-Europe, the formal European regional group of the global ILTER network, is a distributed network of research sites for multiple purposes in the fields of ecosystem and socio-ecological research. LTER-Europe currently comprises 26 national site networks, more than 400 LTER sites, and 35 Long-Term Socio-Ecological Research (LTSER) platforms, which are

²https://eosc-portal.eu/sites/default/files/eosc_declaration.pdf

³<https://www.eosc-portal.eu/>

⁴<https://www.rd-alliance.org/>

⁵<https://asterweb.jpl.nasa.gov/>

⁶<https://oceanservice.noaa.gov/sentinelsites/>

⁷<https://uscode.house.gov/statviewer.htm?volume=130&page=3019>

⁸<http://www.lter-europe.net/>

⁹<https://www.ilter.network>

¹<https://arxiv.org/>

large areas facilitating socio-ecological research (Dick et al., 2018; Haase et al., 2018; Mirtl et al., 2018). LTER-Italy is an official member of theILTER and LTER-Europe networks since 2006. It consists of 79 research sites, organized in 25 parent sites (i.e., made by multiple research sites), including terrestrial, freshwater, transitional, and coastal marine ecosystems, managed and coordinated by public research institutions, universities, and environmental agencies.

The LTER marine component, which represents around 10% of the LTER-Europe sites, is predominantly comprised of transitional and coastal ecosystems, where the research activities focus mainly on the changes in ecosystem structure and function in response to a wide range of environmental pressures. The exceptional rate and intensity of anthropic pressures in the transitional and coastal environments make the scientific and social value of LTER observations more critical than ever for the effective assessment of the state of these ecosystems and for a suitable management of human impacts. In this context, data and metadata curation are key processes, which facilitates access to the necessary ecological information required for supporting research activities and governance initiatives. Indeed, for the LTER European data policy, one of the guiding principles is to “focus on Open Source products as well as to foster an Open Access policy wherever possible and useful” (Kunkel et al., 2019, p. 5).

The adoption of the Open Science principles is also at the foundation of the establishment of marine ecological observatories at the European level, for sustaining European marine policies and biodiversity conservation (Heip and McDonough, 2012; Benedetti-Cecchi et al., 2018; European Marine Board, 2019), and for contributing to the harmonization and implementation of global frameworks, such as the Ecosystem Integrity, the Essential Biodiversity Variables (EBV; Haase et al., 2018) and the Essential Ocean Variables (EOV; Zilioli et al., 2019a,b).

Within this wider European context, the Northern Adriatic Sea (NAS) is a significant geographical zone for establishing a marine ecological observatory, due to the presence of sensitive habitats and ecosystems, heavy and diversified human pressures and economic interests, numerous ongoing monitoring and research activities (above all the LTER ones), existing facilities and infrastructures. The Italian national flagship project RITMARE (“Italian research for the sea”¹⁰, Fugazza et al., 2014), funded by the Italian Ministry of University and Research, supported, during the years 2017–2018, the creation of a marine ecological observatory in the NAS, with a dedicated research line, while the Interreg Italy–Croatia project “ECOSS” (Ecological observing system in the Adriatic Sea: oceanographic observations for biodiversity¹¹) has been further developed between 2019 and 2021.

In this paper, we present such a case study, where the principles of Open Science have been applied to long-term marine ecological data, focusing on one of the eight marine research “parent sites” of the Italian Long-Term Ecological

Research (LTER) network (LTER-Italy)¹²: the NAS, where efforts to establish a marine ecological observatory are ongoing. Our starting point was the willingness to openly release 50 years of water quality and plankton data (Minelli et al., 2018b; Acri et al., 2019, 2020). Since the beginning of this work, we decided to achieve this goal by embracing an open vision of the whole research lifecycle, ranging from the research idea to results and data, from metadata to methods and software. A multi-disciplinary working group, comprising ecologists and information scientists, collaborated throughout the process, with the aim of sharing and harmonizing the different experiences, needs, and points of view.

In this paper, we report and critically discuss all the necessary steps and actions that we have undertaken for opening the whole research lifecycle, in the process that brought us to giving open access to marine LTER data in the NAS, detailing the lessons learned, the strength and the weaknesses encountered. The whole process of applying the Open Science principles to the NAS ecological observatory is referred to as the project “EcoNAOS” (Ecological Northern Adriatic Open Science Observatory System) in the text. The case study involved many actions, including those affecting the whole research project workflow, in contrast to those acting more specifically on the dataset. Our final goal was to demonstrate that a change of vision from “publishing as soon as possible” to “sharing and collaborating” (Moedas, 2015), was indeed possible.

MATERIALS AND METHODS

Setting the Workflow

Open Science is not about one single element or step of the research. Instead, it involves a broad and comprehensive approach toward making research steps accessible, reusable, and understandable.

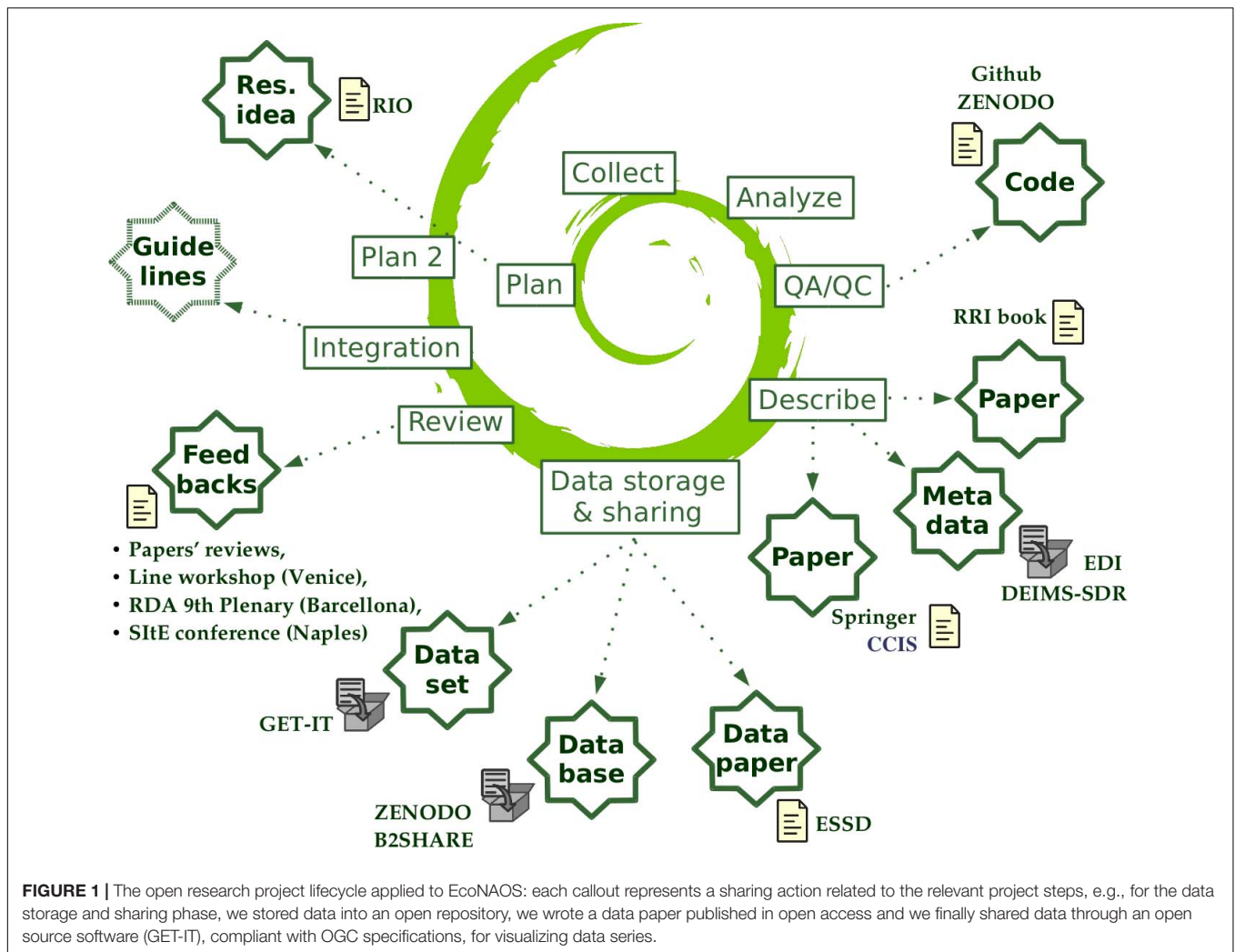
For this reason, we decided to define a research workflow to include all the elements relevant to be tackled, together with the actions and tools supporting the opening of all the steps.

Different authors (Humphrey, 2006; University of Central Florida Libraries Research Lifecycle Committee, 2012; Grigorov et al., 2014; Cox and Tam, 2018) described typical research lifecycles. Among them, Rüegg et al. (2014) suggested a lifecycle related to research data, where some traditional steps (planning, collection, quality assurance/control, analysis) are improved by additional activities aiming at describing/documenting and then preserving/publishing data. Inspired by that, we outlined an open research life cycle that can be represented as a spiral model (**Figure 1**), where the more traditional phases of a research process (i.e., plan, collect, analyze, quality assessment/quality control, describe, data storage and sharing, review, integration, and the start of a new plan) are enriched with actions aimed at openly sharing outputs or relevant knowledge produced at each step. Each action is supported by specific tools, such as data repositories, publishing platforms, free open source software (FOSS) and code repositories, which can increase the visibility,

¹⁰<http://www.ritmare.it/>

¹¹<https://www.italy-croatia.eu/web/ecoss>

¹²<https://deims.org/network/7fef6b73-e5cb-4cd2-b438-ed32eb1504b3>



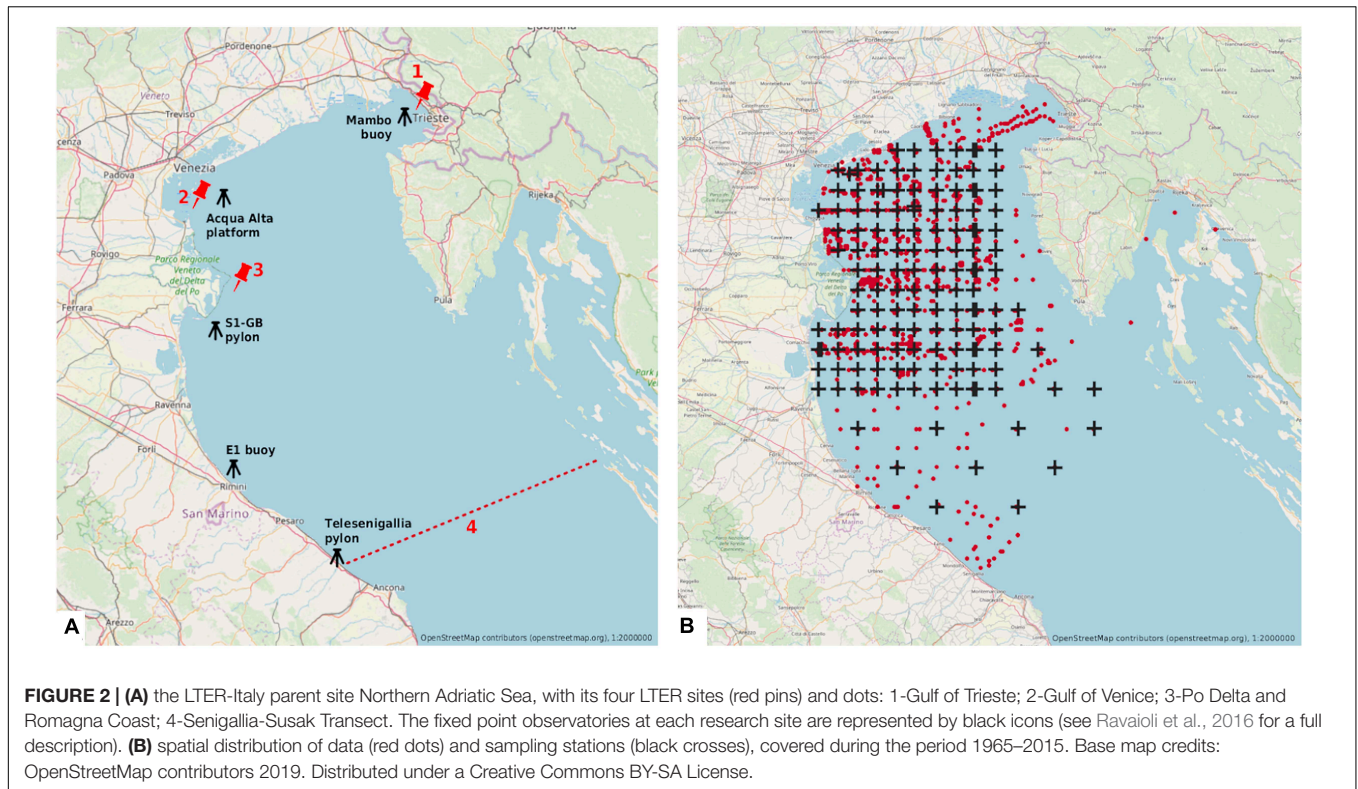
availability, dissemination, and reuse of the outputs. We chose a spiral, instead of a circle, since it graphically provides the message of consecutive and connected levels of improvement, which forms the core of an effective Open Science vision.

In the following sections, the application of the workflow to LTER data coming from the NAS is detailed. We analyzed the different steps by dividing the main actions into two groups: (i) those aimed at data valorization and open access, making data findable, accessible, interoperable, and reusable, following the FAIR principles (Wilkinson et al., 2016; Boeckhout et al., 2018), and (ii) those focused on the opening of other research products, through sharing and dissemination actions.

The Study Area and the Dataset

The NAS (Figure 2) is the northernmost basin of the Mediterranean Sea and one of its most productive areas. It is characterized by a shallow depth and by a dominant cyclonic circulation. The oceanographic and meteorological parameters show a marked seasonal and interannual variability. The major forcings of the system are represented by the remarkable river inputs along the Italian coast, by the Eastern-Adriatic-Current

(EAC), which brings high salinity and oligotrophic waters from the southern basin, and by the notable sea-level range, relative to the Mediterranean area. The NAS is subject to multiple anthropogenic impacts, e.g., nutrient inputs, coastal urbanization, professional fishing activity, tourism, and maritime trade. The NAS has undergone overfishing (Fortibuoni et al., 2010), it has been subjected to frequent development of mucilage aggregates until the first decade of the 2000s (Giani et al., 2005; De Lazzari et al., 2008), it has been characterized by marked eutrophication (Lotze et al., 2011), followed by a phase of oligotrophication (Mozetić et al., 2010) and subsequently, increasing nutrient loading (Totti et al., 2019; Grilli et al., 2020). The LTER-Italy parent site NAS currently includes four research sites: The Gulf of Trieste, The Gulf of Venice, The Po Delta and Romagna Coast, and The Senigallia–Susak Transect (Figure 2A). At each site, meteo-oceanographic and biological data, mainly on plankton, are gathered both during oceanographic cruises and at fixed point observatories (Figure 2B). Each site is supervised by a research institution that also manages the system of fixed sensors, which record data in near real-time (Ravaioli et al., 2016). Detailed information on the NAS and on the single research sites



can be found on the ILTER Dynamic Ecological Information Management System Site and Dataset Registry, DEIMS-SDR¹³ (Wohner et al., 2019). The area of NAS, of interest for this paper, spans about 40,000 km², ranging between 43.7° and 45.8° north and 12.2° and 14.3° east (Coordinate Reference System WGS84).

The NAS dataset (Acri et al., 2019) is composed of observations on abiotic parameters (physical and chemical) and on phyto- and zooplankton abundances, collected over 50 years (1965–2015) at various stations sampled during multiple oceanographic cruises, principally in the Gulf of Venice (Figure 2). The NAS dataset varied in sampling frequency, methodologies, units of measure, data treatment, and format (Acri et al., 2020). Results coming from the analysis of this long-term activity can be found in Bernardi Aubry et al. (2006, 2012), Pugnetti et al. (2008, 2011), and Socal et al. (2011). The dataset is organized in a tabular format (see Table 1 for summary), containing observations on 21 parameters and their metadata (Acri et al., 2019).

RESULTS

Actions on the Dataset

The present section details steps taken (“actions,” see Figure 1) to make the dataset compliant with the FAIR principles (Wilkinson et al., 2016). They were:

- **Findability**—We assigned a unique and persistent identifier (a Digital Object Identifier: DOI) to the NAS dataset.
- **Accessibility**—We deposited the dataset in a public repository assigning a liberal license, and we wrote machine-actionable metadata.
- **Interoperability**—We deployed some interoperable tools in order to exploit NAS data.
- **Reusability**—We distributed code with the dataset, added some brief data description (providing a “README”), and published an open-access data paper (Acri et al., 2020).

Reference will be made to these tenets throughout the next sections to give more details about individual activities with a particular focus on where and how they increased the “FAIRness” of the dataset.

We wish to emphasize that, since the observations in the dataset were collected starting from the 1960s, planning and data gathering were obviously completed before the introduction of the Open Science concept, and, therefore, the Open Science principles were at that time not considered at all. This is the main reason why for EcoNAOS it was not possible to establish a data management plan (DMP). Besides, the oldest research practices to collect data, which were mainly reported by retired researchers, sounded like informal “best practices,” making it impossible to answer many of the points which have to be addressed into a DMP. Conversely, the elaboration of a DMP is under consideration for the most recent data, since also within the frame of the European LTER networks, the Open Science approach has been addressed more systematically (Kunkel et al., 2019)

¹³<https://deims.org/92fd6fad-99cd-4972-93bd-c491f0be1301>

and shared guidelines for long-term DMP are currently under elaboration. For what regard specifically LTER-Italy, some best practices for sharing data and metadata were defined and suggested to the network in Bergami and Oggioni (2020), in line with the tools that are available within eLTER-RI.

Making Long-Term Data Findable, Reusable, and Accessible

Data harmonization and metadata collection

Due to the high heterogeneity of the original dataset (Acri et al., 2020), the first crucial actions for allowing the reuse of data were data harmonization and metadata collection. The heterogeneity is intrinsic to the long-term nature of the dataset: for 50 years, different researchers have collected and managed data with diverse protocols, which in some cases were poorly or not at all described. There were instances for example, where names of sampling stations were changed through time, or where precise locations were poorly documented without the convenient use of modern day GPS technologies. Furthermore, some instruments, as well as sampling and analytical methods, changed significantly. The reconstruction of these variations and their description in the metadata was a time-consuming step, which required the following actions:

- harmonization of the name of the sampling stations, starting from the oldest accounts (Franco, 1970, 1972, 1982), using a scripting approach (i.e., identifying points belonging to the same sampling station in a point cloud around the expected latitude–longitude coordinates), while keeping track of the changes of the name for the same station;

- homogenization of coordinates format to decimal degrees (coordinates for the oldest data were in degree–minute–second format) and correction of geographically misplaced sampling points based on the sampling station name;
- metadata collection about instruments, sampling, and analytical methods for each parameter, through both bibliographic references and interviews with active and retired researchers. When this reconstruction was not possible, we clearly indicated this in the data paper (Acri et al., 2020), in order to allow for an appropriate assessment of the reliability of the data for their proper use.

For the first two actions, the accuracy of geographical information, especially for observations before GPS advent, was highly variable since it basically depended on how the operator selected the sampling point locations. We did not investigate further the positional accuracy, but we kept the points scattering around each conventionally adopted location, which for the old stations were reported in specific grids, not to alter the original information (Acri et al., 2020). More details about how we dealt with uncertainty during the processing is also reported in the code and the pseudocode available in Minelli (2020).

File naming conventions, machine-actionable metadata

In order to be published, data has to be properly named and described, by adding also ancillary information:

- As suggested by Santaguida (2010), we followed best practices on files and folder naming convention. For example, it is recommended to use “_” and not other symbols (“\$”, “;”, “%” and so on) in file naming since, if the

TABLE 1 | Parameters in the North Adriatic Sea (NAS) dataset with their main descriptive information.

Parameter	Number of observations	Temporal coverage	Sensor	Unit of measure
Transparency	2,322	1965–2015	Secchi Disk	m
Temperature	107,648	1965–2015	CTD	C
Salinity	107,655	1965–2015	CTD	dimensionless
Density	99,961	1965–2015	Derived from temperature and salinity	kg m ⁻³
pH	70,376	1965–2011	CTD	–
Alkalinity	492	1965–2002	Titrimetric titration	meq l ⁻¹
Oxygen	12,791	1965–2012	CTD	cc l ⁻¹
N-NH ₃	11,154	1965–2015	Automated nutrient analysis	μM
N-NO ₂	11,232	1965–2015	Automated nutrient analysis	μM
N-NO ₃	11,299	1965–2015	Automated nutrient analysis	μM
P-PO ₄	11,191	1965–2015	Automated nutrient analysis	μM
Si-SiO ₄	11,420	1965–2015	Automated nutrient analysis	μM
Chlorophyll-a	11,541	1965–2015	Spectrofluorimeter	μg l ⁻¹
Pheopigments	6,352	1979–2015	Spectrofluorimeter	μg l ⁻¹
Total Phytoplankton	3,463	1977–2015	Inverted microscope	Cells l ⁻¹
Diatoms	3,070	1977–2015	Inverted microscope	Cells l ⁻¹
Dinoflagellates	3,070	1977–2015	Inverted microscope	Cells l ⁻¹
Coccolithophores	3,070	1977–2015	Inverted microscope	Cells l ⁻¹
Others	3,070	1977–2015	Inverted microscope	Cells l ⁻¹
Zooplankton	372	1987–2015	Stereo microscope	n. ind. m ⁻³

For details see Acri et al. (2020).

file is automatically processed, some of these symbols could generate syntax or interpretation errors;

- as stated by Force11 (2018), a data object is “an Identifiable Data Item with Data elements + Metadata + an Identifier” and a fundamental property is that it must contain at least some basic machine-actionable metadata that allows it to be automatically distinguished from other data objects. In order to supply this basic information, we prepared a readme file reporting descriptive metadata (4TU.Centre for Research Data, 2016). Submitted together with the dataset, this file reports the creator of the database, the list of contributors, the publisher, the publication year, the creation time range, a brief description, the subject of the research data by keywords, the spatial and temporal coverage of observations, the language, the license, and the link to the related data paper (Acri et al., 2020).

Data publishing

The basic requirements for a repository responding to Open Science principle should be (a) assignment of a Persistent Identifier (PID); (b) open access; (c) liberal copyright; (d) long term availability.

Several repositories meet these criteria: from the more generalist ones (e.g., Zenodo¹⁴, B2SHARE¹⁵, 4TU.Centre for research data¹⁶), to those more focused on environmental sciences (e.g., Pangaea¹⁷), and those specifically dedicated to oceanography (e.g., British Oceanographic Data Centre¹⁸, SEANOE¹⁹), also considering LTER related catalog (DEIMS-SDR²⁰).

Our selection of the suitable repository has been driven by two types of considerations:

1. Target user group: Who are we trying to reach? Access could be kept restrictive and narrow or broad and suitable also for non-specialist scientist users.
2. Technical aspects: Which are the functions made available within the repository? How fast is the publishing process? Is there a review process (formal and/or scientific) of data available with the publishing service?

DEIMS-SDR potentially would have been the most suitable solution, since all the LTER sites are registered in this repository and it is possible to associate the datasets to each site. However, at the time we uploaded data, DEIMS-SDR was not able to issue DOIs. As alternatives Pangaea and Zenodo have been taken into account. Pangaea allows scientific review of data, filter data by year, geographical zone, theme, and research project, but the time between data submission and publication can take up to 2 months, which was considered a too long period. As internal data review was applied and data should be published without

delay, we selected Zenodo (DOI: 10.5281/zenodo.4756741), a platform that takes a generalist approach to the hosting of data, with no preference given over discipline, country of origin, research funders, and so on. We assume our data to be of interest to a wide range of potential users, which along with the fact that DOIs are assigned immediately, meant Zenodo was likely to be a good match for our data. Moreover, despite Zenodo not performing a specific review of the dataset, it is indexed by Data Citation Index of Web of Science. The fact that the NAS LTER dataset has received, since its publication, more than 590 views on the Zenodo repository and 313 downloads, makes us assume its usefulness for a wide community.

Making Data Interoperable: Use of Targeted Instruments

The creation of interoperable tools and services allows broader data exploitation thanks to the use of common uniform standards. Since our main objective was to enhance the visibility of the dataset, we used an interoperable tool for preservation, sharing, publishing, and discovery of geospatial data, modeled on standard Open Geospatial Consortium (OGC) web services. The open source software suite GET-IT (Geoinformation Enabling ToolKIT starterkit²¹, Oggioni et al., 2017) and the customizable, template-driven metadata editor EDI²² (Tagliolato et al., 2016) have been used for this scope.

We uploaded on the GET-IT platform²³ more than 15,000 observations, which represent a consistent subset of the entire dataset (fully published separately) selecting, for all the parameters, only the observations gathered at the near-surface layer. This choice was made basing on the GET-IT inability to graphically represent observations along the water column at the same location and date (vertical profile) resulting in a corruption of the data model. By visiting the sensors' page, the data belonging to each sensor can be freely downloaded. Data coming from a query can be downloaded creating a new view by selecting a specific data source, and a sampling station to query and visualize results. Then we created a Sensor Observation System (SOS²⁴): an OGC standard, relying on the 52° North service²⁵, for data and metadata related to sensors and observations: in this way we allow publishing in real-time data coming from different sources. Finally, we described the sensors (each instrument/method capable to return a value for the observed parameter) by EDI interface (Pavesi et al., 2016), which is a metadata editor compliant with the most diffuse standard for metadata like INSPIRE, RNDT, and SensorML. In GET-IT, it would be also possible to specify the DEIMS.ID²⁶ of a related LTER site in the section “Feature of Interest.” For this work, this information has not been added since many of the sensors were described before the adoption of the DEIMS.ID within the LTER community.

¹⁴<https://zenodo.org/>

¹⁵<https://b2share.eudat.eu/>

¹⁶<https://researchdata.4tu.nl/>

¹⁷<https://www.pangaea.de/>

¹⁸<https://www.bodc.ac.uk/>

¹⁹<https://www.seanoe.org/>

²⁰<https://deims.org>

²¹<http://www.get-it.it/>

²²<http://edidemo.get-it.it/>

²³<http://vesk.ve.ismar.cnr.it/>

²⁴<http://www.opengeospatial.org/standards/sos>

²⁵<https://52north.org/>

²⁶<https://deims.org/docs/deimsid.html>

The same software has been used for data and sensor metadata visualization thanks to its graphic representation and elaboration capabilities. The data policy used in GET-IT follows the specifications defined by the Italian LTER community (Bergami and Oggioni, 2020).

Even if data collection has continued in time, for the moment the “historical dataset” (shared via Zenodo) is not planned to be updated; therefore, it must be considered a “stand alone” dataset. It is however an important aspect (still to be afforded) to establish how and when these updates could occur, in order to make the dataset factually dynamic.

At the present time, it is fair to say that no versioning is possible for GET-IT platform, and there is no synchronicity between GET-IT and Zenodo, as this last platform does not manage external datasets or datasets shared through web services. However, we strengthened the link between Zenodo dataset and GET-IT platform by indicating in the Zenodo dataset the URLs of sensors created in GET-IT and used to collect data, where applicable. Moreover, even if there is not a common discovery record, and data represented in the two datasets are partially different, we tried to manage this discrepancy by clearly stating into the “alternate identifier” field of Zenodo that GET-IT dataset is part of Zenodos’ one. In the same way, if new updates will be available in the future for the Zenodo dataset, we plan to indicate that the new data is a continuation of the previous dataset.

Beyond the Data: Opening Other Research Products

According to the EcoNAOS workflow (Figure 1), FAIR concepts can be applied also to other research products. For example, it is in line with Open Science principles to make a research project findable or sharing the source code in order to make a model reusable and the research reproducible. In our case study, we contributed to this issue by trying to open each step of the research cycle.

Opening the Research Ideas and Outcomes

During the EcoNAOS project, we opened our research by publishing four open access papers:

- A research idea paper, reporting the outline of EcoNAOS project, on Research Ideas and Outcomes journal (RIO, Minelli et al., 2018b);
- A report of our experience on the application of the Open Science principles to the NAS dataset (Minelli et al., 2018a);
- A paper published in Communication in Computer Science (Minelli et al., 2019), presenting the EcoNAOS workflow and making a first assessment of the whole process;
- A data paper on Earth System Science Data (Acri et al., 2020), describing the dataset published in Zenodo (Acri et al., 2019).

Considering the cultural and technological implications, we hereby describe in detail the experience of two of the abovementioned activities: the publication of the research ideas and the data paper.

A research ideas paper should be written at the very beginning of a research project as a way to share with the scientific

community a position paper on what will be the outline and main expected outcomes of the research. Other interesting functions of a research ideas paper are to find funds for the development of the research ideas and create connections among researchers for possible cooperation in the project itself. Even if it is possible to share research ideas in different journals (e.g., as short or position papers), the RIO journal²⁷ has a specific format for this kind of paper. The format allows distinguishing between previous information (background and state of the art in a specific field) and new information (the contribution the research project aims to supply to the current knowledge level on that field), and it leads the author in the project presentation, with appropriate required steps. RIO is a gold open access journal, and it implements an open peer review process. Moreover, each review is citable (a DOI is assigned to it), and anyone from “outside” can comment on any specific part of the paper, ask for explanations, and give feedback. While some scientists could look at this practice with a certain caution for the integrity and originality of their research, we are convinced that sharing research at its very early stage could lead to the improvement of research itself, by adding new ideas and suggestions. In particular, the comments we received from our reviewers (Marchesini, 2020; Peterseil, 2020) helped us in the development of EcoNAOS plans, by improving some aspects related to its framing into the LTER networks, enhancing some Open Science issues and better finalizing the expected outcomes. Moreover, it is worth pointing out that, for most of the researchers involved in EcoNAOS, the possibility to publish research ideas as well as the whole process of “opening” the paper, including the review and the comments, was unknown, and this kind of publication represented an innovation. Therefore, this publication helped to foster a cultural opening, enlarging the view about the possibility to share the research activities since their beginning.

For what concerns the choice of the most suitable journal for the data paper (Acri et al., 2020), in full compliance with Open Science principles, we selected Earth System Science Data (ESSD²⁸), which is a diamond open access journal (not requiring article processing charges); it applies a CC-BY license to the paper, and it has an interactive and public peer review. The discussion paper (basically a data paper preprint) is published in the ESSD forum, which is freely accessible, the authors obtain both comments from reviewers and short comments from the whole scientific community to be included and answered for submitting the revised paper. Another interesting aspect of ESSD is the support of Alternative Metrics (No authors listed, 2012). As repeatedly pointed out by many researchers (e.g., Amin and Mabe, 2000; Jacsó, 2001; Coelho et al., 2003; Giglia, 2016; Shanahan, 2016; Larivière and Sugimoto, 2018; Hickman et al., 2019; Saenen and Borrell-Damian, 2019), the current metric system for research evaluation has some issues, being, in short, unable to correctly represent the real impact of research and being susceptible to manipulation, due to economic interests of commercial publishers potentially being at stake. In addition to citation-based impact, alternative metrics take into

²⁷<https://riojournal.com>

²⁸<https://www.earth-system-science-data.net/>

account peer reviews, citations on Wikipedia and in public policy documents, discussions on research blogs, mainstream media coverage, bookmarks on reference managers like Mendeley²⁹, and mentions on social networks such as Twitter³⁰. So it represents a record of wider attention to the specific research, tracking each time a research is cited or seen on the web and a measure of dissemination in both the scholar and public field. Last, ESSD supports the “living data” mode, which is extremely interesting when considering dynamic databases: it implies that, if the dataset changes, the data paper must change accordingly. Authors are, thus, encouraged to submit revised versions of the same data paper in order to follow dataset version changes.

Besides publications, we undertook several dissemination actions: we organized workshops and meetings with LTER researchers involved in other LTER-Italy marine sites, as well as participating in national and international meetings and conferences.

We also created a blog³¹, which contained a collection of our experiences and reporting of interesting news with respect to Open Science applications to marine and LTER data. Information about our work was regularly shared on both scientific and generalist social media: ResearchGate³², Figshare³³, and Zenodo for linking papers, posters, and presentations, Twitter for conferences and meetings updates, and a Facebook account dedicated to the RITMARE project³⁴.

Open Source Code Release

In order to harmonize sampling station names and their geographical position, the code used was openly released and published on the CNR-ISMAR GitHub repository³⁵ and a DOI assigned via Zenodo³⁶ (Minelli, 2020). Together with the code, we posted a readme file containing important information about code execution, the pseudocode, and a short sample of data in order to test the code functionality. The code is released under GNU GPL 3 license. While on the GitHub repository we did not notice any particular activity on the code (fork, pull, and push requests), through Zenodo, we noted 48 unique visitors and six code downloads since its publication. These results are not surprising since the code is very specific for our dataset and it deals with quite specific problems, like the harmonization of station names.

Sharing code is a good practice for the applications of Open Science principles since it increases the transparency and the visibility of the work. It also helps in finding possible bugs (as reported by Linus law: “given enough eyeballs, all bugs are shallow,” Raymond, 1999), and it definitely allows the research to be reproducible.

Opening to Scientists Across Time and Space

Cooperation in research often means productiveness and it has been evidenced that, in ecology, cooperation of researchers from different research fields produces the best results (Goring et al., 2014). Moreover, especially for long term data, cooperation with retired researchers could represent an important source of experience and information, in order to increase and refine metadata. The EcoNAOS working group was made by both information scientists and field ecologists, directly responsible for the dataset coming from different research institutes: OGS (National Institute of Oceanography and Applied Geophysics, Trieste), CNR-ISMAR (National Research Council-Institute for Marine Sciences, Venezia and Bologna sites), CNR-IRBIM (National Research Council-Institute for Biological Resources and Marine Biotechnologies, Ancona), and SZN (Stazione Zoologica Anton Dohrn, Napoli). It involved retired researchers and researchers from different research groups, sharing activities and expertise on LTER ecological marine data. The scientists involved in EcoNAOS were all willing to improve their understanding of Open Science and how it could be implemented into their own research routines. In general, there was a universal agreement with Open Science or, at the least, with its principles. At the time, only a few were involved with projects where opening the data was under consideration. As evidenced also by other authors (Mann et al., 2008; Andreoli-Versbach and Mueller-Langer, 2014; Stieglitz et al., 2020), a certain resistance to openly share the data was present, at least at the beginning. These resistances were mainly due to the concern about the proper acknowledgment to the data producers and the extra time needed to follow and accomplish the whole process (Digital Science et al., 2020). This latter, was often seen as a further workload added to the ongoing research activity and the perceived disadvantages outweighing the advantages. Besides, the different opportunities of publishing in open journals, with all their pros and cons, were also poorly known and considered with skepticism: some researchers are actually concerned about how publishing in these journals could impact the evaluation of their professional careers, due to the hard-to-eradicate idea that “Open Access” still means “Low Impact Factor” journal. Furthermore, researchers were quite critical about the relevance that the career evaluation process still gives to published datasets. This concern is basically real since indexing published datasets on Web of Science and the practice of data papers in journals with an impact factor, is actually quite a new practice, which needs still to enter the common publication practices (see e.g., Amin and Mabe, 2000; Coelho et al., 2003; Hickman et al., 2019; Shin et al., 2019).

Working in a group where both information and ecology scientists cooperated side by side allowed for the identification and frank discussion of all the difficulties, as well as created an environment conducive for collaborative problem solving and therewith fostering a bilateral cultural change. Besides, it required sharing, in a concrete and pragmatic way, visions, tools, and languages. One of the unexpected products was, for instance, a glossary³⁷ (Scovacricchi, 2020), initially started in jest

²⁹<https://www.mendeley.com/>

³⁰<https://twitter.com>

³¹<https://cnr-ismar.github.io/econaos/>

³²<https://www.researchgate.net/>

³³<https://figshare.com/>

³⁴<https://www.facebook.com/ProgettoRitmare/>

³⁵<https://github.com/CNR-ISMAR/econaos/tree/master>

³⁶<http://doi.org/10.5281/zenodo.3600991>

³⁷<https://doi.org/10.5281/zenodo.4302115>

after each meeting. The glossary now contains all the terms and acronyms that were used and were not understandable, in particular in the informatics field. This glossary has been then organized and fruitfully used as a tool to learn and share a terminology that often could hamper the integration between different expertises.

Finally, the contribution from the retired researchers has been invaluable, not only for the knowledge they have about the oldest data, being frequently among those who gathered them but also because they allowed faces and persons to appear from the past. This brought to light the awareness of all the human efforts behind the dataset and of the crucial importance of Open Science as a heritage that we receive from the past and that we have the duty to leave for future generations.

DISCUSSION: LESSONS LEARNED, STRENGTHS, AND WEAKNESSES

In **Table 2**, we summarize strengths and pitfalls of our approach and we also suggest possible solutions to deal with the main weaknesses.

Among these actions, we wish to stress the need of a unique framework, providing a step-by-step roadmap for open access publication of different products (e.g., research ideas, raw and elaborated datasets, data paper, code, notebooks, and presentations), which could guide the researchers to openly publish the outcomes of different stages of their research during the entire duration of a project. In the European context, EOSC could represent a possibility in this sense. In fact, it has been conceived not only as a portal

but also as a “meeting point” for the whole European open research. As stated in the EOSC declaration² (signed during the EOSC Summit of June 12, 2017), EOSC aims to become a unique catalog for the open research community across Europe, connecting them with stakeholders and service providers. Through the EOSC portal³, resources for networking, computation, storage, sharing/discovering of research products, data management, and applications are made available. These are all key aspects to perform Open Science, in particular when EOSC will reach its full operationality.

The need for clear policies for open access in scientific publishing is rather striking. A rapid assessment of publication policies in existing major editorial groups is made. Some subscription-based journals implemented the open access principles in an “hybrid” approach, by requesting the payment of article processing charges (Björk, 2012; Mittermaier, 2015), generating the malpractice of double-dipping by journals (authors pay to be published and their institutions pay for them to access their work) and thereby creating a degree of confusion among researchers with respect to what open access is. This is the precise reason why we need:

(i) clear open access practices statement at higher institutional level. Some attempts have been made in this sense by the European Union with the Plan S initiative (Schlitz, 2018), an agreement between public administration and research institutions, involving public and private stakeholders, with the following aim: “With effect from 2021, all scholarly publications on the results from research funded by public or private grants provided by national, regional and international research councils and funding bodies, must be published in Open Access

TABLE 2 | Critical overview of the different actions undertaken: strengths, issues encountered, possible improvements, and optimal solutions are shortly addressed.

Action	Strengths	Issues or improvements	Optimal solution
Data harmonization/metadata collection	Sharing code used for harmonization; meticulous bibliographic research and metadata reconstruction	Need for a better refinement of data harmonization code; lack of reliable information for some old data	Adoption of a Data Management Plan. Implementation of a real quality assessment/control routine; clear indication of lack of information in the metadata
Data preparation for publishing	Robust file naming; addition of descriptive metadata	–	–
Creation of interoperable instruments	Precise standard compliance for data and metadata; high graph representation effectiveness	Temporary impossibility to release data by the platform	Adoption of a data policy
Data publishing	Open Science compliance; sector-specific repository	Dynamic data citation processes and tools not yet mature/established	–
Publications in open access journals using open peer review processes	Availability for the wide scientific community; sharing of research ideas; extensive metadatation of data (data paper)	–	Adoption of a unique institutional protocol/service (i.e., at European level) that would follow the production/publication of the whole written research outcomes of a research project
Open source code release	Procedure completely reproducible; clear instructions for usage	–	–
Involvement of scientists from different research fields and labs	Multi-disciplinarity; cooperation between different groups	Scraps of mistrust especially on Open Data theme (e.g., for what concerns work acknowledgment)	Better information about open policy and licenses; continuous update on Open Science themes evolution

Journals, on Open Access Platforms, or made immediately available through Open Access Repositories without embargo³⁸.

(ii) the creation of a unique common front at academic level against classic editorial models by the introduction of more equitable contracts, the so-called transformative agreements. These agreements must be concluded between research institutions (usually research libraries) and editorial groups in order to obtain more equitable fees for journal subscription, with the twofold aim to provide a wider access to scientific knowledge, and trying to mitigate the effect of double-dipping practices. Due to a progressive awakening of consciousness and the always rising journals subscription fees, in these last years some efforts have been made in this direction. A transformative agreement can be done by an individual library, a library system, and a library consortium (Hinchliffe, 2019) and a very complete review of all transformative agreements currently taking place is reported by the ESAC (Efficiency and Standards for Article Charges) initiative³⁹. Some pure open access publishers (Open Access publishers, 2020) also evidenced that transformative agreements, as they have been conceived until now, have not the temporary nature required by a full open access transition, since they also account for subscription journals which can also give the opportunity to authors to publish restricted access research. So they proposed new agreements in order to deliver full, immediate, and transparent (FIT) open access, offering a high-quality, cost-effective alternative to hybrid models.

We wish then to emphasize how crucial it was, for proceeding on the road of Open Science, the setting up of a participatory process, involving field researchers and data scientists, and being open to receiving and accepting feedback, suggestions, and evaluations. It is actually a crucial part of the Open Science process to understand researchers' perceptions and barriers (technical or cultural) in order to find the right way to apply Open Science, evaluating and overcoming in a joint community the existing obstacles.

Some other critical issues concerned the implementation of a functional dynamic data citation system that would increase accessibility and reusability of the dataset itself (Groth et al., 2020). Actually, the nature of a long-term dataset is intrinsically dynamic: it implies that observations are collected with a pluriannual perspective and substantial changes in format, methods, instruments, precision, and so on are likely to occur. So far, the issue of the citation of a dynamic object is still a matter of debate also within the LTER community at the global level, since it entails relevant and still open questions about, e.g., how to cite only portions of data or of aggregated data, how to identify a threshold where changes are so significant in the whole dataset that a new version of the dataset is required.

To properly address these aspects, the definition and the adoption of protocols on data maintenance and of long-term ecological DMP is strongly recommended. Especially in the case of a dynamic dataset, it is of primary importance to

ensure data consistency through time, by planning recurrent and extraordinary reconnaissance of data, also for checking the maintenance of the interoperability of data and compatibility with new instruments of analysis. Despite the use of DMPs being in practice for a long time in the United States, by comparison, in Europe, the practice became formally implemented only recently, also thanks to the extension of the Open Research Data European Pilot initiative to H2020 projects (European Research Council (ERC), 2017). This must be considered in a wider perspective to appreciate that, in the United States–Europe context, the open access transition is in fact progressing at unequal velocities.

Moreover, a proper quality assessment/quality control routine should be implemented: dealing with near real-time data (e.g., from sensors) and very old data at the same time does not represent an obstacle if data is well documented also in terms of reliability.

The possibility to adopt DMPs and specific data policies in the framework of the eLTER-RI has been analyzed in Kunkel et al. (2019) within the eLTER H2020-funded project (Grant Agreement 654359). DMP should consider, from one side, the measures to be taken on managing past data, which very likely were gathered without the frame of a real management plan; from the other, it should set the guidelines for making the LTER data FAIR, clarifying as well rights and available processes and practices on each specific dataset.

CONCLUSION

This work represents a practical case study on the application of the Open Science principles to the valorization of a long-term (50 years) ecological marine dataset (plankton and abiotic data) collected in the NAS, one of the sites of the LTER-Italy network. We developed two different types of actions: one strictly related to the data, and one to the whole lifecycle of the project. We applied the FAIR data management practices on the dataset and we extended the Open Science principles to the project lifecycle, in accordance with the "Rainbow of Open Science practices" presented by Kramer and Bosman (2018). The following practices were implemented: publishing the research ideas in open access, making the source code available through GitHub, sharing code and data with a DOI through Zenodo, describing the dataset in an open-access data paper on the Earth System Science Data journal. All the steps were shared and discussed through a participatory process, which involved ecology field researchers and data scientists.

With respect to open access publication, we want to emphasize that comprehensive information and guidelines are available to researchers at the SHERPA/RoMEO portal⁴⁰. This resource provides journal-specific instructions, with respect to pre-prints, accepted versions, post-prints, and editor's PDF versions and whether these are openly shareable, or restricted for self-archiving only.

From our case study, we can highlight that the process of opening science is constructive and collaborative. In fact,

³⁸<https://www.coalition-s.org/>

³⁹<https://esac-initiative.org/about/transformative-agreements/agreement-registry/>

⁴⁰<http://www.sherpa.ac.uk/romeo/index.php>

the process fosters the cooperation and the involvement of scientists from different research fields, who share different views or address the same practice with different means. Also, the contribution of retired researchers was fundamental in this work, and it is almost mandatory when dealing with long term data.

Our case study indicates that it still remains necessary to increase researchers' awareness on the materials and methods available for properly opening their research so as to really facilitate and encourage the adoption of open practices. It is primarily important to pursue dissemination actions on open licenses and data policy, which still remain an obscure matter, even to the most informed researchers.

The acknowledgment of Open Data publication in the research products evaluation process is fundamental in order to motivate researchers in adopting open practices. We are actually just at the beginning of this process, since databases only recently started being indexed with the Web of Science, which in part led to the opening of data being more steadily recognized, as a valuable research product (Torres-Salinas and Martín-Martín, 2013; Force and Robinson, 2014; Robinson-García et al., 2016).

Open Science represents the main road of scientific research in the next future (Mirowski, 2018; Rabesandratana, 2018; Klenk et al., 2019). Training the young generation of scientists to the Open Science principles is highly recommended, since it will prove invaluable to create a mind shift, making open science a common practice, really embedded into the research practices, providing a great opportunity of development for the future of the whole research community (Powers and Hampton,

2019). Moving Open Science from “best practices” to “common practices” still requires efforts and cultural changes, on the side of both researchers' training and research evaluation process, which needs to promote, with appropriate rewards, the Open Science activities.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: <https://doi.org/10.5281/zenodo.3266245>, Zenodo.

AUTHOR CONTRIBUTIONS

AM, AS, AO, and AP contributed to conception and design of the study. MB, FB, EC, and AM organized the database. AM wrote the first draft of the manuscript. CB, AP, AO, and AS wrote sections of the manuscript. All the authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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