Volume 10
Issue 3
September 2022

ISSN 2325-6192 (print)
ISSN 2325-6206 (online)

Journal of Environmental Accounting and Management

L&H

Journal of Environmental Accounting and Management

Continued on back materials

Journal of Environmental Accounting and Management

Volume 10, Issue 3, September 2022

Editors
Antonio M Lopes
Jiazhong Zhang

L&H

L&H Scientific Publishing, LLC, USA

Publication Information

Journal of Environmental Accounting and Management (ISSN 2325-6192 (print), eISSN 2325-6206 (online)) is published quarterly (March, June, September, and December) by L & H Scientific Publishing, LLC, 25 Glen Ed Professional Park, Glen Carbon, IL62034, USA. Subscription prices are available upon request from the publisher or from this journal website. Subscriptions are accepted on a prepaid basis only and entered on a calendar year basis. Issues are sent by standard mail (Surface in North America, air delivery outside North America). Priority rates are available upon request. Claims for missing issues should be made within six months of the date of dispatch.

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Printed in USA on acid-free paper.

Journal of Environmental Accounting and Management 10(3) (2022) 215-217

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Natural Capital, Ecosystem Services, and Environmental Accounting

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Submission Info

Communicated by Pier Paolo Franzese
Received 14 February 2022
Accepted 20 February 2022
Available online 1 October 2022

Keywords

Natural capital
Ecosystem services
Environmental accounting
Nature conservation

Abstract

Natural capital stocks generate ecosystem services flows that are directly used or enjoyed by people, providing benefits to human well-being. Anthropogenic pressures on natural ecosystems cause biodiversity loss and, in turn, affect the capability of natural ecosystems to provide flows of good and services to humans. Environmental accounting represents a useful tool to assess the value of ecosystem goods and services, also providing useful information to local managers and policy makers in charge of implementing management and policy strategies oriented to the sustainable use of natural resources. Given this premise, this special issue includes theoretical, methodological, and applied papers focusing on natural capital, ecosystem services, and environmental accounting.

1 Introduction

"Natural capital" can be defined as abiotic and biotic stocks of natural resources (Buonocore et al., 2018; Costanza and Daly, 1992). Natural capital stocks provide "ecosystem services" flows that are directly used or enjoyed by people, providing benefits to human well-being (Barbier, 2017; MEA, 2005). They include provisioning services (i.e., food, building materials), regulation and maintenance services (i.e., carbon sequestration, water purification), and cultural services (i.e., tourism, recreational benefits) (Haines-Young and Potschin, 2018).

The availability of natural resources ensures a life support system vital for human well-being while setting the ecological limits for the development of human economy. Still, multiple human pressures on natural ecosystems cause biodiversity loss and, as a consequence, seriously affect the capability of natural ecosystems to provide flows of goods and services (Cardinale et al., 2012; Pauna et al., 2018; Vihervaara et al., 2019; Sebastiani et al., 2021).

Valuing nature is crucial to raise awareness on its importance, support conservation strategies, and boost the sustainable management of natural resources (TEEB, 2010). Integrated approaches capable of combining

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DOI:10.5890/JEAM.2022.09.001

ecological and socio-economic aspects are much needed to protect natural capital and ensure the delivery of ecosystem services (Buonocore et al., 2020; 2021; Rawluk et al., 2019).

Environmental accounting represents a useful tool to assess the biophysical and economic value of ecosystem goods and services (Franzese et al., 2019, 2020). Environmental accounting systems allow exploring the relationships between natural ecosystems and human economy and are capable of providing useful information to managers, policy makers, and other stakeholders in charge of implementing management schemes and policies oriented to the sustainable use of natural resources (Mattei et al., 2021; Nikodinoska et al., 2018; Häyhä and Franzese, 2015).

Given this premise, this special issue gathers theoretical, methodological, and applied papers focusing on natural capital and ecosystem services with a special focus on the use of environmental accounting as a tool for their assessment.

2 Objectives and contributions

The main goal of this special issue is to present a set of articles exploring different aspects related to the topic of natural capital, ecosystem services, and environmental accounting. In particular, this volume includes theoretical, methodological, and applied papers exploring the following research areas: a) natural capital and ecosystem services assessment in marine protected areas, b) recreational ecosystem services in forest ecosystems, c) impacts of human activities on ecosystems and generated services, d) socio-ecological benefits generated by lagoon ecosystems. Papers presented in the special issue are as follows:

- Appolloni et al. (2022) assess local *métiers*, accounting for actual fish catches of Small-Scale Fishery (SSF), and explore what is exploited by local SSF in Marine Protected Areas in order to obtain information useful to improve their management.
- Allocca et al. (2022) evaluate the impact of cattle grazing on groundwater-related ecosystem services in a karst environment located within the Monti Picentini Regional Park, in Campania region (southern Italy).
- Paletto et al. (2022) assess the socio-economic importance of forest-based recreational activities in a black pine forest in Italy (Pratomagno forest) using the travel cost demand analysis.
- Pauna et al. (2022) present the results of a literature review which focuses on particularly impactful marine microplastic methodological and analytical articles from 2004 to 2017 to identify possible gaps or inconsistencies in the reported data.
- Renzi et al. (2022) report results on bio-oil extraction efficiency in two different species of macrophytes in a Mediterranean lagoon (Lesina lagoon, south-eastern Italy), by testing effects of different factors on oil production and oil quality.
- Visintin et al. (2022) focuses on an integrated environmental accounting model developed for protected areas and applied in the research programme coordinated by the Italian Ministry of Environment aiming to implement an environmental accounting system for the Italian Marine Protected Areas.

3 Concluding remarks

The Guest Editors hope that this volume will boost the interdisciplinary knowledge on natural capital, ecosystem services, and environmental accounting.

Acknowledgement

A special thank is due to all the Reviewers who contributed their time and valuable effort. Without their work and scientific support this special issue would not have been possible.

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Journal of Environmental Accounting and Management 10(3) (2022) 219-236

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Demand Analysis on Forest-based Recreational Activities

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 30 June 2021
Available online 1 October 2022

Keywords

Forest recreation
Ecosystem services
Questionnaire survey
Travel costs method
Pratomagno forest (Italy)

Abstract

The nature-based recreational activities can be considered one of the most important cultural ecosystem services provided by forests. They provide benefits to local economy, human health and well-being reducing depression and mental illnesses risk and increasing social interactions. The aim of the present study is to assess the socio-economic importance of forest-based recreational activities using the travel cost demand analysis. The study was implemented in a black pine forest in Italy (Pratomagno forest) characterized by a multifunctional forest role and a diversified recreational attendance. The study on forest-based recreational activities was organized in four steps: development and pre-testing of a questionnaire; identification of the sample of visitors; administration of the questionnaire to the visitors; data processing. The results show that the most important forest-based recreational activity carried out by visitors is relaxing in the nature, followed by hiking and picnicking. The occasional visitors prefer more passive recreational activities (relaxing in the nature and picnicking), while regular and loyal visitors prefer more active recreational activities (hiking, mountain biking, picking non-wood forest products). A consumer surplus in the range between 39 and 44 € per visit was estimated based on the model (Poisson and Negative binomial model), corresponding to 60.5-68.3 € per hectare. The results show that nature-based recreational activities can generate positive direct and indirect benefits for forest managers and local people. The local decision makers should act on forest stand characteristics with the aim of increasing the recreational attractiveness and the consequent economic benefits.

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials
DOI:10.5890/JEAM.2022.09.002

1 Introduction

In 2005, the publication of the Millennium Ecosystem Assessment (MEA) Report focused the global attention on the importance of natural capital and ecosystem services – defined as the benefits humans gain from healthy and functional ecosystems – for society (MEA, 2005). At first, the scientific community has defined, classified, assessed, evaluated, and mapped the ecosystem services provided by several natural resources (Burkhard et al., 2012; Stürck et al., 2014; Häyhä et al., 2015; Langat et al. 2018). Afterwards, the policy makers have started to define and implement policies and actions to maintain natural capital and to improve related ecosystem services at international, national, and local level (Larigauderie and Mooney, 2010; La Notte et al., 2012). In Europe, the Biodiversity Strategy to 2020 (COM/2011/0244) and the European Union (EU) Strategy on Green Infrastructure (COM/2013/249) emphasized that the ecosystem services concept helps to understand and define more clearly the relationship between human well-being and the state of ecosystems (Schleyer et al., 2015). In the United States, several federal agencies have begun incorporating the ecosystem services concept into land use planning and water resources management to increase the environmental and social benefits without compromising the economic growth (Schaefer et al., 2015). In China, the provision of ecosystem services has been improved through the implementation of the Natural Forest Conservation Program (NFCP) aimed to protect and restore natural forests (Liu et al., 2008).

In the international scientific literature, ecosystem services have been classified in many ways as emphasized by Häyhä and Franzese (2014). The most common classification is the one provided by the Millennium Ecosystem Assessment that classified the ecosystem services in four main categories (MEA, 2005): provisioning (products directly obtained from ecosystems such as food, fiber, timber, fuelwood), regulating (benefits obtained from the regulation of ecosystem processes such as water and carbon cycle regulation), supporting (indirect services such as soil formation, nutrient cycling, photosynthesis), and cultural (nonmaterial benefits people obtain from ecosystems such as aesthetic values, recreation and ecotourism) services. Subsequently, The Economics of Ecosystems and Biodiversity (TEEB) classification substituted supporting services with habitat services, which include lifecycle maintenance and gene pool protection (TEEB, 2010). More recently, other ecosystem services classification systems known at international level are: the Common International Classification of Ecosystem Services-CICES (Haines-Yong and Potschin, 2012), the U.K. National Ecosystem Assessment (UK NEA, 2011), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019).

Across all categories and classifications of ecosystem services, the cultural services play a key role for the physical and psychological well-being of people by providing recreational opportunities, spiritual enrichment, cognitive development, relaxation and reflection (De Meo et al., 2015; Yoshimura and Hiura, 2017). The cultural ecosystem services include some measurable direct economic benefits, while other cultural services are more intangible such as spiritual experiences, education, and aesthetics (Nesbitt et al., 2017). From an economic and social perspective, the nature-based recreation (or nature-based recreational activities) have a particular importance among all the cultural ecosystems services due to their capacity to facilitate social interactions, foster empowerment, and promote social cohesion (Cortinovis et al., 2018). Besides, the nature-based recreation can generate positive direct and indirect effects on local and national economy (Gray et al., 2003; Fredman et al., 2012). According to Cordell (2008) nature-based recreation can be defined as outdoor activities in natural settings or otherwise involving in some direct way elements of nature (e.g., soil, vegetation, wildlife, water bodies).

Forests play a pivotal role in the natural-based recreation providing attractive scenery for consumptive and non-consumptive activities such as walking, hiking, mountain biking, fishing, hunting, bird watching, camping, mushroom and berry collection (Gössling and Hickler, 2017). The term forest-based recreation refers to the use of forest resource in producing nature-based tourism experiences (Marcouiller, 1998). In this context, forest management practices – e.g., thinning, regeneration cutting, selective cutting, clearcutting – can directly influence the forest-based recreation by intervening on stand characteristics such as (Hynynen et al., 2005; Ruddel et al., 2007; Marchi et al., 2018): forest system (coppice vs. high forest), horizontal and vertical stand structure (even-aged vs. uneven-aged stand), tree species composition (pure vs. mixed forest stand), and stand density (open vs. closed forest). Forests managed in different ways can have different levels of recreational attractiveness – defined as the perceived ability of the destination to deliver individual benefits (Mayo and Jarvis, 1981) for the forest-based recreational activities. According to Dorwart et al. (2010) exploring the factors that influence visitors' experiences is an important prerequisite to fully understand forest-based recreation. To understand most attractive recreational forest types for visitors, it is necessary to collect and analyze visitors' behaviors, opinions and preferences related to the forest-based recreational activities. In this way, recreational demand and underlying economic values of forest resource can be estimated with a travel cost analysis (Ward and Beal, 2000). The Travel Cost Method (TCM) estimates the economic value of forest-based recreation considering the visitors' recreation behavior and preferences in terms of their visits, travel cost, time, and forest resource settings (Shrestha et al., 2007).

Starting from these considerations, the main aims of the present study are: (1) to assess the socio-economic importance of forest-based recreational activities; and (2) to investigate the influence of visitors' experiences on forest-based recreational activities. The study was conducted within the framework of SelPiBio LIFE project aimed to develop and test innovative silvicultural interventions in planted black pine stands with the goal of increasing the provision of ecosystem services. The study was implemented in a case study in Central Italy (Pratomagno forest) characterized by a multifunctional forest role and a diversified recreational attendance.

2 Materials and methods

2.1 Study area

The study area is the Pratomagno (43°39′N 11°39′E) located in the northwestern part of the Arezzo province (Tuscany region, Central Italy) in the municipality of Loro Ciuffenna (AR) (Figure 1). The nearest urban area – 50 km away – is the Arezzo town with approximately 99000 inhabitants. Pratomagno covers a total area of about 3300 ha, with an average elevation of 1150 m a.s.l., a south-west exposure and an average slope of 40%. Approximately 95% of the area is covered by public forests belonging to Tuscany Region and managed by the Unione dei Comuni del Pratomagno, a local authority formed by the union of some municipalities. The other main land cover classes are shrub lands, shrubby grasslands, and grasslands (Viciani et al., 2018). The current forest area is the result of a gradual increase in forest area since 1936 estimated in (Cantiani et al., 2017): 1429 ha of forests in 1936, 2396 ha in 1978, and 3152 ha in 2015. Pratomagno was affected by reforestation activities started in 1954 and ended in the 1980s with the aim to increase water and soil erosion protection, and to avoid landslides and other natural hazards. Since 1980, three forest management unit plans (FMUPs) have been implemented, the last FMPU will run until 2021 (Cantiani et al., 2017). Currently, the Pratomagno forest is an important recreational destination with an average number of visitors per year of 5140. Pratomagno is free access forest (without entrance fees) characterized by many panoramic paths, and restaurants (named trattorias and osterias) offering typical Tuscan cuisine for experiencing local food.

From the historical and cultural point of view, on the top of Pratomagno mountain (1591 m a.s.l.) a holy cross, dedicated to St. Francis, was made in 1928. Currently, the holy cross is an important destination for pilgrims who go to the Verna sanctuary.

The main tree species used in the reforestation activities were: Calabrian pine (*Pinus brutia* Ten. subsp. *brutia*), Austrian black pine (*Pinus nigra* J.F.Arnold), and some broadleaved species such as Turkey oak (*Quercus cerris* L.), European beech (*Fagus sylvatica* L.), Downey oak (*Quercus pubescens* L.) and flowering ash (*Fraxinus ornus* L.). The shrub layer is made up of several fruit species such as hazel (*Corilus avellana* L.), junipers (*Juniperus communis* L.), European raspberry (*Rubus ideaus* L.), and blackberry (*Rubus* spp.). Besides, the Pratomagno forest is characterized by the presence of many species of edible mushrooms belonging to the *Boletus*, *Cantharellus*, *Lactarius* and *Russula* genera.

In the Pratomagno forest, the average growing stock is 632 m^3 ha^{-1} with 1077 trees ha^{-1}, a basal area of 69

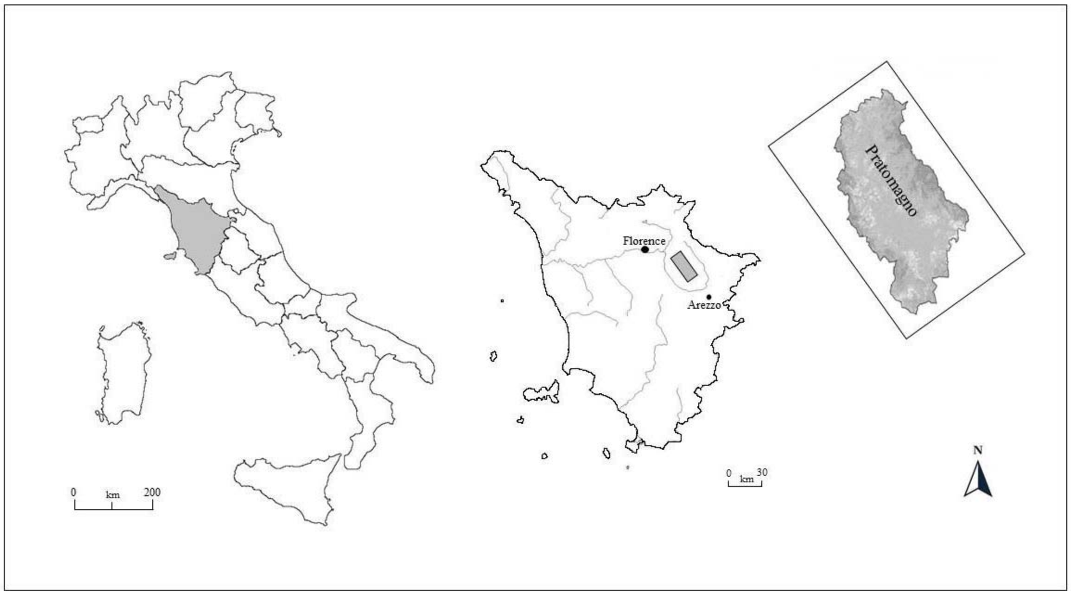

Fig. 1 Location of the study area (Pratomagno forest, Tuscany region in Italy).

m^2 ha^{-1}, a mean diameter of 28.7 cm and a mean height of 18.8 m (Cantiani and Marchi, 2017). The Shannon index for tree species is in a range between 0.40 and 0.91, while the floristic Shannon index is 2.1 with a low species richness (Marchi et al., 2018).

From the lithological point of view, Pratomagno is characterized by quartz-feldspar sandstones alternated by siltstones and argillites. The argillites and siltstones provide a very thin layer whose thickness ranges from a few up to 15 cm, while thickness of the sandstone layers is more considerable, exceeding half meter; this implies the emersion of large banks of thick sandstone whose heads are well visible.

With respect to climate, the average annual temperature is 10.5°C (maximum 19°C in July and minimum of 1.5°C in January), while the average rainfall is 997 mm with a maximum peak in autumn and a minimum precipitation in June.

2.2 Research framework

The survey aimed to assess the socio-economic importance of forest-based recreational activities was organized in four steps that can be summarized as follows: (1) Development and pre-testing of a questionnaire; (2) Identification of the sample of visitors of Pratomagno forest (sampling); (4) Face-to-face administration of the questionnaire to the visitors; (4) Processing of the collected data and interpretation of the results.

In the first step of the study, a preliminary version of the questionnaire was developed by researchers and local experts involved in the SelPiBio LIFE project. In May 2017, the preliminary version of the questionnaire was pre-tested with five randomly chosen visitors of Pratomagno forest. The pre-test stage of the questionnaire was performed to identify critical issues on some questions, check wording and to estimate time for completing the questionnaire. After the pre-test stage, two questions have been simplified and one question has been deleted in accordance with visitors' comments and suggestions.

The final version of the questionnaire consists in 31 closed-ended and open-ended questions divided in three thematic sections. The questionnaire was divided into thematic sections for two reasons: each section contains questions about different topics and the section division psychologically facilitates the questionnaire compilation.

The first thematic section focuses on the information related to the TCM such as: number of visits to Pratomagno forest in the last 12 months; preferred visiting days (weekend or both weekend and working days); number of persons and time of current visit (all day, a few hours, less than an hour); vehicle used and kilo-

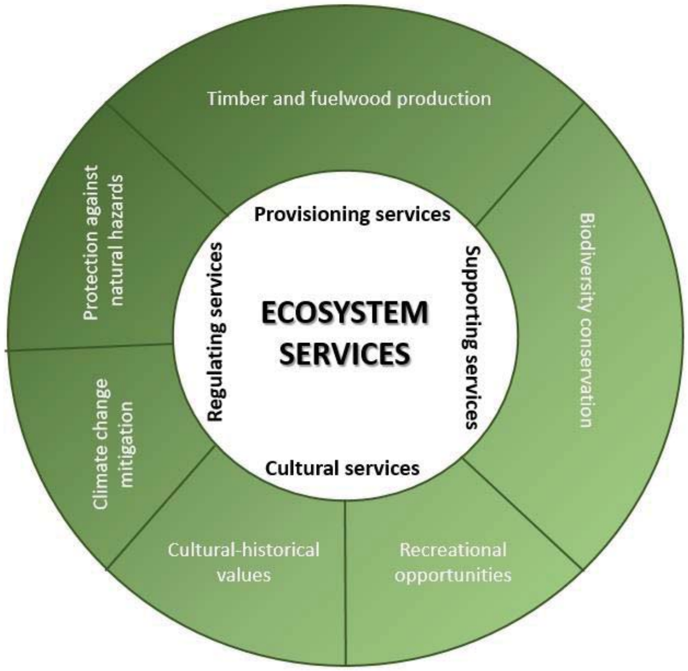

Fig. 2 Ecosystem services by Millennium Ecosystem Assessment (MEA) category considered in the survey.

meters traveled in current visit; costs incurred for the visit of Pratomagno forest (meals, accommodation, other expenses); visiting group (alone, with family members, with friends, in organized group); and the reasons for visiting (hiking, mountain biking, picking non-wood forest products-NWPF, relaxing in the nature, picnicking, experiencing food). Regarding this latter aspect, the respondents assessed each reason for visiting using a 5-point Likert scale (from 1=very low importance to 5=very high importance).

The second thematic section investigates the visitors' preferences and perception of the main ecosystem services provided by Pratomagno forest. The ecosystem services considered in the questionnaire are the following (Figure 2): timber and fuelwood production; climate change mitigation through temporary carbon stocking; protection against natural hazards (e.g., landslides, rockfalls); biodiversity conservation; outdoor recreational opportunities; and protection of cultural and historical values. The respondents assigned the level of importance to each ecosystem service provided by Pratomagno forest using a 5-point Likert scale (from 1=very low importance to 5=very high importance).

The last thematic section of questionnaire considers socio-demographic characteristics of respondents such as: gender; age (distinguishing among four classes: less than 25 years old; 25-34 years old, 35-44 years old, 45-54 years old, 55-64 years old, and more than 64 years old); level of education (elementary school degree; high school degree; university degree and post-university degree); occupation (employed in the public sector; employed in the private sector; housewife; student; pensioner; and unemployed); and place of origin (distinguishing between Arezzo province; other provinces of Tuscany region; other Italian region or foreign countries).

In the second step, the visitors of Pratomagno forest have been systematically selected in two sampling points – called "Pian dei Lavacchi" and "Abetina" – identified in collaboration with the local forest managers. The criteria used to select the sampling points were accessibility to the area and the presence of landscape observation points. The visitors to be interviewed were selected one for every two that arrived in the two sampling points. "Pian dei Lavacchi" is a rest area located close to the most popular path of the forest, while "Abetina" is the starting point of a scenic landscape path of the study area.

During the third step, the final version of the questionnaire was face-to-face administered to a sample of visitors in the summer period (from June to September 2017). The questionnaire was administered to the visitors by a lead interviewer and an assistant, both in working days and weekend to include in the sample the different types of visitors (single person, couples, families, groups of friends). The total number of survey days was 25 days so distributed: 17 in weekends and 8 in workdays.

In the fourth step, the collected data were processed to produce the main descriptive statistics: mean, median and standard deviation for the data collected using the Likert-scale format, percentage of frequency distribution (%) for other questions. For the data concerning the reasons for visiting the Pratomagno forest and the importance of ecosystem services the non-parametric Kruskal-Wallis and Mann-Whitney U tests were performed using the XLStat 2017 software. The non-parametric tests were applied rather than parametric tests for the following reasons: the sample size is not large enough, the assumption of normality is violated.

The Kruskal-Wallis test ($\alpha = 0.01$) – a non-parametric statistical test to assess the differences among three or more independently sampled groups on a single, non-normally distributed continuous variable – was used to highlight differences between categories of visitors (frequency, visit group, and time).

The Mann-Whitney U test ($\alpha = 0.01$) – a non-parametric statistical test to assess the differences between two independently samples groups – was used to point out differences between weekend visitors and daily visitors (persons who come to the Pratomagno forest on weekends and on weekdays).

Finally, the data of the first thematic section of the questionnaire was used for estimating user benefits from visits to the Pratomagno forest (see paragraph 2.3).

2.3 Travel cost method

The Travel Cost Method is a non-market technique that estimates a demand curve for use values with no market price, including nature-based recreational activities (Hanley and Barbier, 2009). This technique assumes that people are travel cost sensitive, meaning that the expected number of trips to a certain site is lower at higher costs sustained to reach the destination (Garrod and Willis, 1999). In other words, as the travel cost increases, the number of trips decreases. The demand function is usually integrated with socio-demographic characteristics (gender, age, level of education, occupation) and other variables to assess a profile of visitors. Formally, the number of trips Yi taken by individual I can be expressed by the following function (Champ et al., 2003):

$$Yi = f[(TCi, Li, hi(Di, Vi, Si)]$$

Where: TC_i is the cost of the visitor i for the round-trip, I_i is the income of the visitor i, while, h_i is a vector of visitor-specific characteristics. The travel cost variable was created multiplying the distance covered to reach the Pratomagno forest by the unit cost per km (0.26-0.39 € per km), depending on the means of transport and fuel type[a].

h_i may include information about alternative sites (S_i), study site (V_i) and socio-demographic characteristics (D_i). The dependent variable takes only non-negative integer values and therefore count regression models are suitable for the analysis, in particular Poisson and Negative binomial (NB) models. The Poisson regression has the following probability density function:

$$Pr[Y = y] = \frac{e^{-\mu} \cdot \mu^{y}}{y!}, \quad Y = 1, 2, ..., n.$$

Where μ is the mean of the distribution, which is usually parameterized as $\mu_i = \exp(x'\beta)$, where x is the set of regressors and β the vector of parameters to be estimated. The econometric model should also consider sampling distortions caused by on-site interviews, namely truncation at zero and endogenous stratification. Truncation refers to the fact that individuals with zero visits are not included in the sample because everyone took at least one visit, i.e. the visit at the time of the interview. If the regression model is not corrected for truncation, the predicted number of visits and the related welfare analysis are inflated. Endogenous stratification occurs because very frequent visitors are more likely to be interviewed compared to occasional visitors, thus making the sample

[a] The cost per km as available from the Italian automobile club was used (ACI: http://www.aci.it/) considering car and motorbike as individual travel modes and distinguished between diesel, petrol and methane fuels.

not completely random (Martínez-Espiñeira and Hilbe, 2008). Similarly, to truncation, endogenous stratification inflates the estimates of visits. A Poisson model can be simultaneously corrected for truncation and endogenous stratification simply replacing the number of trips Y_i with $Y_i^* = Y_i$–1 (Englin and Shonkwiler, 1995). However, the Poisson model has the limitation to assume equi-dispersion – the mean of the distribution of visits to be equal to the variance – which is not likely to hold in practice as most distributions are over-dispersed (Cameron and Trivedi, 2005). To address over-dispersion a common solution is to use a NB model, which includes a parameter α that models over-dispersion (Hilbe and Martínez-Espiñeira, 2005). A NB model corrected for truncation and endogenous stratification has the following log-likelihood function:

$$Pr[Y = y \mid Y > 0] = y_i \frac{\Gamma(\alpha^{-1} + y)}{\Gamma(\alpha^{-1})\Gamma(y+1)} \alpha_i^{y_i} \mu_i^{y_i - 1} (1 + \alpha_i \mu_i)^{-(y_i + \alpha_i^{-1})}.$$

Where Γ is the gamma function. A Poisson and a NB model were estimated using the Stata command "poisson" for the Poisson model and the user-written command "nbstrat" for the NB model corrected for truncation and endogenous stratification (Hilbe and Martínez-Espiñeira, 2005). After the estimation of the demand model the consumer surplus (CS) was estimated as a measure of the benefit derived from the visit of Pratomagno forest as follows:

$$CS = \frac{-1}{\beta_{tc}}.$$

Where β_{tc} is the coefficient associated with the cost of travel, estimated from the count models. Another useful metrics that we consider is the elasticity of the demand to the cost, which indicates how sensitive is the variation of the demanded quantity to variation of the travel cost:

$$e_p = \frac{\partial E(\mu)}{\partial X_{tc}} \frac{X_{tc}}{\mu} = \beta_{tc} X_{tc}.$$

Where X_{tc} is the average cost sustained by visitors. An elasticity coefficient comprised in the [0,-1] interval indicates that the demand is inelastic, therefore the number of trips should not vary significantly when the cost to reach Pratomagno changes. An elasticity coefficient lower than -1 indicates an elastic demand function, which suggests that visitors would reduce the number of visits at increasing cost levels and vice versa.

3 Results

3.1 Socio-demographic characteristics of the visitors

At the end of data collection period, 200 visitors participated in the survey, while 690 visitors were not willing to participate in the survey (response rate of 22.2%). The sample size was determined considering the total annual number of visitors of Pratomagno forest (5140 visitors). Therefore, the sample of 200 visitors corresponds approximately to 4% of the total visitors. The sample of visitors consisted of 155 visitors interviewed on weekends and 45 visitors interviewed on workdays.

The non-response rate obtained varies widely from a maximum of 85% on holidays and Sunday to a minimum of 70% on Saturday and working days. The response rate of the present study is much lower than the response rates found in other in-situ studies carried out in Italy that show a response rate between 70% and 90% (Notaro and Dallapiccola, 2000; Gios and Notaro, 2001; Paletto et al., 2017). The reasons for the low response rate in the present study may be the gender and age of the interviewer (25-year-old male) and the location of two sampling points (away from refreshment areas or parking). Other studies have shown that females and mature people have higher propensities to convince respondents to be involved in the survey compared to male and young people (Singer et al., 1983; Jäckle et al., 2011). In addition, some authors emphasized that visitors to forests are more likely to participate in surveys near stopping points such as refreshment and parking areas (Pastorella et al., 2016).

Most respondents in our sample were males (62.0%), while the remaining 38.0% were females. The visitors of Pratomagno forest mainly came from the same province – Arezzo province – where the forest is located (88.5%), while 10.5% of visitors were from the Firenze province and 1.0% from other Italian regions (Emilia-Romagna and Piedmont regions). No visitor came from foreign countries. In general, most respondents were recreational visitors (hikers, pickers), while the number of overnight tourists was low.

The distribution of respondents by age can be summarized as follows: 20.9% of respondents were less than 25 years old, 16.6% were between 26 and 34 years old and between 35 and 44 years old respectively, 23.1% were between 45 and 54 years old, 10.1% were between 55 and 64 years old, while the remaining 13.1% of respondents had more 65 years old.

The distribution of respondents by occupation shows that 52.0% of respondents was employed in public or private sector, 4.5% were housewife, 19.0% were students, 14.0% retired, while the remaining 10.5% were unemployed people.

Regarding the level of education, most respondents had a high school degree (44.2% of total respondents), followed by peoples with a university degree (36.7% of total respondents thus divided 26.1% master degree and 10.6% bachelor's degree) and people with an elementary and technical school degree (19.1%).

The respondents had an annual income distributed in the following way: 41.2% of respondents have an income less than 20,000 € ; 26.6% of respondents have an income between 20,000 and 35,000 € and between 35,001 and 50,000 € respectively; and the remaining 5.6% of respondents have an income more than 50,000 €.

3.2 Behavioral characteristics of the visitors

The results show that 39.5% of total respondents visited less than 5 times in the last 12 months to the Pratomagno (occasional visitors), 40.5% of respondents between 5 and 15 times (regular visitors), and the remaining 20.0% more than 15 times (loyal visitors). Observing the three visitor categories by gender, the results show that occasional visitors were mainly females (53.2% of occasional visitors), while regular and loyal visitors were mainly males (64.2% and 87.5% respectively). The majority of occasional visitors were young people (30.4% with less than 25 years old and 16.5% with 25-34 years old), while the regular and loyal visitors are composed of more adult people (40.7% of regular visitors and 62.5% of loyal visitors has more than 45 years old). The distribution by occupation shows that the majority of visitors were employed people: 40.5% of occasional visitors; 60.5% of regular visitors; and 57.5% of loyal visitors. In addition, it is interesting to emphasize that there is a high percentage of retired people in the loyal visitors (20.0% of loyal visitors), while the students were only occasional or regular visitors.

The results show that almost half of the visitors come to Pratomagno forest with friends (48.0% of total respondents), followed by 27.0% visitors with family members, 12.5% both alone visitors and visitors in organized groups respectively. Alone visitors were almost exclusively males (96.0%) over 44 years old (68.0%) employed or retired (48.0% and 8.0% respectively). Conversely, visitors with family members and in organized groups were mainly females (55.6% and 56.0% respectively). Generally, visitors with friends were young people with less than 34 years old (54.2%), while visitors in organized groups mainly elderly over 64 years old (32.0%) and retired (36.0%). Regarding the level of education, it is interesting to highlight that visitors with friends had a higher level of education (60.4% of respondents have a high school degree and 32.3% a university degree) compared to the other three categories of visitors.

The majority of respondents visited Pratomagno over the weekend and holidays (68.8%), while the remaining 31.2% of respondents were daily visitors. Observing the distribution of respondents by socio-demographic characteristics, the results show that among weekend visitors 57.2% were males and 42.8% were females, while the most part of daily visitors were males (72.6%). The daily visitors were mainly people with more 45 years old (59.7%), while the weekend visitors were on average younger than daily visitors (60.1% of respondents have less than 45 years old). Besides, a higher percentage of daily visitors were retired and unemployed persons compared to the weekend visitors: 22.6% vs. 10.1% for retired persons, 16.1% vs. 8.0% for unemployed persons.

Frequency of visits		**Time of visit**	
Occasional visitors	(39.5%)	All day visitors	(46.0%)
Regular visitors	(40.5%)	Few hours visitors	(41.5%)
Loyal visitors	(20.0%)	Less than one hour visitors	(12.5%)
Day of visit		**Visiting group**	
Weekend visitors	(69.0%)	Alone visitors	(12.5%)
Daily visitors	(31.0%)	Visitors with family members	(27.0%)
		Visitors with friends	(48.0%)
		Visitors in organized groups	(12.5%)

Fig. 3 Distribution of respondents by category of visitors.

Finally, the results showed that 46.2% of respondents spend the whole day in the Pratomagno, 41.2% of respondents spend 2-3 hours, while the remaining 12.6% spend less than one hour. All day visitors were mainly males (67.4% of all day visitors) with an age between 35 and 54 years (48.9%) employed in private or public sector (60.9%). A high share of visitors that spent less than one hour was retired persons (48.0%), while a high percentage of persons with an annual income above 35,000 € were all day visitors (43.8%). Besides, it is interesting that less than one hour visitors were young persons under 25 years old (36.0%) or older persons over 64 years old (52.0%).

The distribution of respondents by category of visitors is shown in Figure 3.

3.3 The results on forest-based recreational activities

The results show that the most important forest-based recreational activities carried out by visitors is relaxing in the nature (mean value of 3.93), followed by hiking (3.13) and picnicking (3.00). Conversely, the two least important activities were picking non-wood forest products (NWFP) (mean value of 1.99) and mountain biking (2.18). The levels of importance of forest-based recreational activities are shown in Table 1.

Observing the data by frequency of visit, the results show that occasional visitors consider relaxing in the nature (mean value of 3.95) and picnicking (3.37) as priorities, while for regular visitors the most important activities were relaxing in the nature (4.09), followed by hiking (3.54). Likewise, for loyal visitors the most important activity is hiking (mean value of 3.93), followed by relaxing in the nature (3.55). It is interesting to highlight that loyal visitors assign a high value to mountain biking and picking NWFP, while occasional visitors emphasize the importance of picnicking and experiencing food. These results point out that loyal visitors prefer moving activities (i.e. hiking, mountain biking, picking NWFP), while occasional visitors prefer sedentary activities (i.e. picnicking and experiencing food). The Kruskal-Wallis non-parametric test shows statistically significant differences among the three groups of visitors for the following reasons: hiking ($p < 0.0001$); mountain biking ($p < 0.0001$); and picking NWFP ($p < 0.0001$). For all these three reasons the loyal visitors assigned a higher value compared to the other two groups.

The results show that visitors who spent less time in Pratomagno forest (few hours or less than one hour) assign a higher importance to picnicking and experiencing food, while visitors who spend more in time in the Pratomagno (all day visitors) emphasize the importance of hiking and mountain biking. The Kruskal-Wallis non-parametric test shows statistically significant differences among the three categories of visitors for the following reasons: hiking ($p < 0.0001$); mountain biking ($p < 0.0001$); and picking NWFP ($p = 0.002$).

The results show that for alone visitors the most important reason to visit the Pratomagno is hiking (mean value of 3.76), followed by relaxing into the nature, mountain biking and picking NWFP. For visitors with family

Table 1 Levels of importance of reasons for visiting the Pratomagno forest (mean values with standard deviation in brackets).

Target of visitors	Hiking	Mountain biking	Picking NWFP	Relaxing in the nature	Picnicking	Experiencing food
Frequency of visits						
Occasional visitors ($n = 79$)	2.32 (*1.54*)	1.42 (*0.91*)	1.42 (*0.98*)	**3.95** (*1.33*)	**3.37** (*1.55*)	2.54 (*1.63*)
Regular visitors ($n = 81$)	**3.54** (*1.45*)	2.33 (*1.58*)	1.90 (*1.18*)	**4.09** (*1.24*)	2.83 (*1.54*)	2.20 (*1.43*)
Loyal visitors ($n = 40$)	**3.93** (*1.44*)	3.35 (*1.75*)	3.28 (*1.62*)	**3.55** (*1.50*)	2.63 (*1.64*)	1.70 (*1.16*)
Time of visit						
All day ($n = 92$)	**3.67** (*1.49*)	2.65 (*1.63*)	2.32 (*1.48*)	**4.18** (*1.20*)	2.99 (*1.59*)	2.05 (*1.42*)
Few hours ($n = 83$)	2.83 (*1.66*)	1.95 (*1.52*)	1.59 (*1.07*)	**3.73** (*1.41*)	**2.98** (*1.62*)	2.34 (*1.47*)
Less than one hour ($n = 25$)	2.16 (*1.28*)	1.16 (*0.37*)	2.08 (*1.63*)	**3.60** (*1.44*)	**3.12** (*1.56*)	2.56 (*1.78*)
Day of visit						
Weekend visitors ($n = 138$)	**3.07** (*1.66*)	2.12 (*1.54*)	1.75 (*1.17*)	**3.97** (*1.31*)	**3.07** (*1.54*)	2.37 (*1.57*)
Daily visitors ($n = 62$)	**3.27** (*1.54*)	2.29 (*1.62*)	2.52 (*1.67*)	**3.82** (*1.41*)	2.84 (*1.69*)	1.94 (*1.27*)
Visiting group						
Alone ($n = 25$)	**3.76** (*1.64*)	2.68 (*1.95*)	2.64 (*1.68*)	**3.64** (*1.50*)	1.68 (*1.25*)	1.56 (1.16)
With family members ($n = 54$)	2.76 (*1.55*)	1.89 (*1.31*)	1.76 (*1.20*)	**3.85** (*1.42*)	**2.83** (*1.58*)	2.44 (*1.54*)
With friends ($n = 96$)	3.16 (*1.62*)	2.23 (*1.61*)	1.95 (*1.37*)	**4.02** (*1.29*)	**3.35** (*1.54*)	2.11 (*1.41*)
In organized groups ($n = 25$)	3.24 (*1.64*)	2.08 (*1.38*)	1.96 (*1.37*)	**4.00** (*1.19*)	**3.32** (*1.41*)	2.92 (*1.68*)

In bold the two most important activities by target of visitors

members, friends, and organized groups the preferred recreational activity was relaxing in the nature (mean values of 3.85, 4.02 and 4.00 respectively), followed by picnicking (2.83, 3.35 and 3.32 respectively). Besides, also experiencing food is an important reason to come in Pratomagno for these three groups of respondents. However, the Kruskal-Wallis non-parametric test shows statistically significant differences among the four categories of visitors only for picnicking ($p < 0.0001$) and experiencing food ($p = 0.005$).

Regarding the differences between weekend and daily visitors, the results show that for weekend visitors the three most important reasons for spending time in Pratomagno forest were relaxing into the nature (mean value of 3.97), hiking (3.07), and picnicking (3.07). Conversely, daily visitors consider more important mountain biking and picking NWFP. The Mann-Whitney U non-parametric test shows statistically significant differences among the two categories of visitors only for picking NWFP ($p = 0.003$).

3.4 The results on ecosystem services

The results showed that for respondents most important ecosystem services provided by the Pratomagno forest were protection against natural hazards (mean score of 3.79), followed by climate change mitigation (3.65) and biodiversity conservation (3.26). Conversely, in accordance with visitors' opinions the less important ecosystem services were timber and fuelwood production with a mean value of 2.67, cultural and historical values with a mean value of 2.85, and outdoor recreational opportunities with a mean value of 2.74. It is important to highlight that the low values assigned to the timber and fuelwood production is due to the low quality of potential wood products obtainable from Calabrian and Austrian black pine and current low harvesting rates.

The levels of importance of ecosystem services provided by the Pratomagno forest assigned by different target of visitors are shown in Table 2. The results show only small differences on the importance of single ecosystem services. For all categories of visitors, the first three ecosystem services provided by the Pratomagno forest were: protection against natural hazards, climate change mitigation, and biodiversity conservation. The occasional visitors emphasized more the importance of timber and fuelwood production (mean score of 2.89) and outdoor recreational opportunities (2.94) compared to the other two categories. However, the non-parametric Kruskal–Wallis test showed no significant differences among the three categories of visitors (occasional, regular,

Table 2 Levels of importance of ecosystem services provided by the Pratomagno forest (mean values with standard deviation in brackets).

Target of visitors	**Outdoor recreational opportunities**	**Biodiversity conservation**	**Climate change mitigation**	**Protection against natural hazards**	**Cultural and historical values**	**Timber and fuelwood production**
Frequency of visits						
Occasional visitors ($n = 79$)	2.94 (*1.44*)	3.47 (*1.33*)	**3.58** (*1.38*)	**3.54** (*1.34*)	2.89 (*1.51*)	2.89 (*1.48*)
Regular visitors ($n = 81$)	2.72 (*1.31*)	3.14 (*1.36*)	**3.75** (*1.26*)	**3.93** (*1.30*)	2.75 (*1.36*)	2.64 (*1.43*)
Loyal visitors ($n = 40$)	2.40 (*1.37*)	3.10 (*1.22*)	**3.58** (*1.13*)	**4.00** (*1.26*)	2.95 (*1.34*)	2.28 (*1.32*)
Time of visit						
All day visitors ($n = 92$)	2.66 (*1.40*)	3.20 (*1.29*)	**3.73** (*1.24*)	**3.84** (*1.37*)	2.88 (*1.41*)	2.49 (*1.40*)
Few hours visitors ($n = 83$)	2.78 (*1.46*)	3.30 (*1.30*)	**3.66** (*1.30*)	**3.80** (*1.25*)	2.76 (*1.38*)	2.88 (*1.44*)
Less than one hour visitors ($n = 25$)	2.88 (*1.42*)	**3.36** (*1.52*)	3.32 (*1.38*)	**3.60** (*1.38*)	3.00 (*1.55*)	2.60 (*1.53*)
Day of visit						
Weekend visitors ($n = 138$)	2.60 (*1.44*)	3.24 (*1.37*)	**3.56** (*1.36*)	**3.67** (*1.38*)	2.81 (*1.42*)	2.67 (*1.40*)
Daily visitors ($n = 62$)	3.05 (*1.35*)	3.31 (*1.22*)	**3.85** (*1.08*)	**4.06** (*1.11*)	2.92 (*1.39*)	2.66 (*1.54*)
Visiting group						
Alone ($n = 25$)	2.56 (*1.33*)	3.16 (*1.11*)	**3.68** (*1.18*)	**4.28** (*1.10*)	2.48 (*1.39*)	2.04 (*1.31*)
With family members ($n = 54$)	2.89 (*1.51*)	3.37 (*1.40*)	**3.48** (*1.53*)	**3.69** (*1.40*)	3.06 (*1.51*)	2.85 (*1.53*)
With friends ($n = 96$)	2.65 (*1.44*)	3.21 (*1.35*)	**3.81** (*1.14*)	**3.79** (*1.31*)	2.76 (*1.31*)	2.75 (*1.45*)
In organized groups ($n = 25$)	2.96 (*1.24*)	3.32 (*1.28*)	**3.36** (*1.32*)	**3.52** (*1.33*)	3.08 (*1.55*)	2.56 (*1.19*)

In bold the two most important ecosystem services by target of visitors

and loyal) for all ecosystem services.

The time of visits cannot be considered an important variable to analyze the visitors' preferences towards ecosystem services. The visitors who spend the whole day in Pratomagno forest assigned higher value to two ecosystem services compared to the other visitors: climate change mitigation and protection against natural hazards. The non-parametric Kruskal–Wallis test showed no significant differences among the three categories of visitors for all ecosystem services.

The people who attended Pratomagno forest both on weekend and on working days assigned a higher value to almost all ecosystem services except for timber production. In particular, the differences were more pronounced for two ecosystem services: protection against natural hazards (mean values of 4.06 and 3.67 respectively) and outdoor recreational opportunities (mean values of 3.05 and 2.60 respectively). The Mann-Whitney U non-parametric test shows no statistically significant differences among the two categories of visitors.

Observing data by visiting group, the results show that alone visitors emphasized more natural hazards protection compared to the other visitors, while the visitors with friends emphasize more climate change mitigation. The visitors in organized groups underlined the importance of the two cultural ecosystem services: outdoor recreational opportunities (2.96) and historical and cultural values (3.08). The non-parametric Kruskal–Wallis test showed no significant differences among the four categories of visitors.

3.5 The results of econometric models

The results of the TCM analysis were reported in Table 3. The models were consistent as there were no changes in the sign of the coefficients, only their magnitude and significance level vary. Akaike Information Criteria

(AIC) and Bayesian Information Criterion (BIC) statistics were lower for the NB model, however the Alpha parameter that models over-dispersion is not significant, which indicates that the Poisson model is also suitable for the data.

As expected from the economic theory, the travel cost coefficient is negative and statistically significant in both model, which indicates that the number of trips decreases as the cost increase. The variables related to the trip motivations were all statistically significant; coefficients associated with “active” motivations such as mountain biking, picking NWFP and hiking were positive, while relaxing in the nature was negative. This result suggests that individuals were more likely to visit Pratomagno for activities that involve physical activity rather than relaxing in the nature. Age is positively associated with the number of trips, which indicates that the reference level of people below the age of 25 years were less likely to visit compared to older visitors. Males were more likely to visit than females and individuals were more likely to visit alone than with family members, with friends or in organized groups. Graduated people were more likely to visit than non-graduated people.

With respect to employment status, members of the reference level of employed in public sector were more likely to visit compared to people in any other occupational status (i.e. employed in private sector, housewife, student, retired, unemployed). With regard to place of origin of visitors, inhabitants of other provinces of the Tuscany region were more likely to visit than respondents living in the Arezzo province or elsewhere.

CS is estimated in the range between 39 and 44 € , depending on the model. The estimate obtained from the negative binomial model has a larger confidence interval, which indicates less accuracy in the assessment. The demand was found to be inelastic from both models, which indicates that visitors were not expected to change their visits aftershocks in the unit price sustained to reach the destination. The total travel cost of the Pratomagno forest is between 200,460 € and 226,160 € based on the average number of visitors per year corresponding to 60.5-68.3 € per hectare.

4 Discussion

The results of our study show that forest-based recreational activities have an important economic and social impact at local level. Each year, on average 5140 visitors attend Pratomagno forest mainly in the spring-summer season. Pratomagno forest is frequented by local people (coming from Arezzo province) for three main reasons: relaxing in the nature, hiking, and picnicking. Summarizing the results of this study, visitors can be divided in two groups based on visitor-resource relationship. The visitors who spend more time in close contact with forest resource (i.e. loyal and regular visitors, all day visitors) prefer active forest-based recreational activities – hiking, mountain biking, picking NWFP –, while visitors who spend less time in contact with forest resource (i.e. occasional visitors, few hours visitors and less than one hour visitors) prefer passive forest-based recreational activities (picnicking and experiencing food). For the first group of visitors, the focal point is the nature experience itself, while for the second group of visitors the forest resource was the natural setting for a recreational activity, but the focal point of the nature experience was social relationship. These visitors visited the forest with friends or family members and travelled short distances both to reach the forest and within the forest. According to Louv (1996) and Dorwart et al. (2010) nature experiences were created and affected by some “social” factors such as family, community, and individual attitudes. Therefore, forest-based recreational activities were influenced by the visitor’s perceptual. In other words, the visitors interpret their environment in terms of their needs and prefer natural settings in which they were likely to function more effectively (Kaplan and Kaplan, 1989). Generally, the planted conifer forests – such as Pratomagno forest – were characterized by medium-low recreational attractiveness compared to the natural forests with special regard to the mixed forests (Gundersen and Frivold, 2008; Filyushkina et al., 2017; Pelyukh et al. 2019). The main recreational limits of the planted conifer forests can be summarized as follows: low species richness, homogenous stand structure, and high canopy density. The Pratomagno forest is characterized by these recreational limits: Calabrian and Austrian black pine species cover more than 80% of tree species composition, slightly differentiated vertical and horizontal stand structure, and high canopy cover. Another study in a similar area (planted Calabrian and black

Table 3 Econometric models for TCM analysis (coefficients with standard errors).

Model	Poisson Model	NB model
Travel cost	-0.0256***	-0.0225**
	0	-0.01
Reason for visiting		
Hiking	0.0502**	0.102*
	-0.02	-0.05
Mountain biking	0.0661***	0.0975*
	-0.02	-0.05
Picking NWFP	0.195***	0.234***
	-0.02	-0.05
Relaxing in the nature	-0.0884***	-0.0836
	-0.02	-0.05
Age classes (ref. level: less than 25 years old)		
25-34 years old	0.376***	0.489*
	-0.1	-0.23
35-44 years old	0.361***	0.851**
	-0.11	-0.26
45-54 years old	0.314**	0.453
	-0.11	-0.26
55-64 years old	0.352**	0.42
	-0.12	-0.33
More than 64 years old	0.159	0.129
	-0.2	-0.58
Gender (ref. level: female)		
Male	0.213**	0.191
	-0.07	-0.15
Travel with (ref. level: Alone)		
With family members	-0.608***	-0.580**
	-0.08	-0.22
With friends	-0.431***	-0.533**
	-0.06	-0.19
In organized groups	-1.135***	-1.152***
	-0.11	-0.26
Has a university degree	0.261***	0.256
	-0.06	-0.14
Occupation (ref. level: Employed in public sector)		
Employed in private sector	-0.356***	-0.560**
	-0.08	-0.21
Housewife	-0.387*	-0.564
	-0.17	-0.38
Student	-0.564***	-0.539
	-0.11	-0.28
Retired	-0.123	-0.236
	-0.17	-0.51

Table 3. Continued.

Model	Poisson Model	NB model
Unemployed	-0.371***	-0.572*
	-0.09	-0.27
Place of origin (ref. level: Arezzo province)		
Other provinces of Tuscany region	0.292**	0.46
	-0.1	-0.25
Other Italian regions	-1.086*	-0.871
	-0.46	-0.71
Constant	2.505***	1.439**
	-0.18	-0.48
Alpha		-0.0219
		-0.29
AIC	1627.3	1255.4
BIC	1703.1	1334.6
ll	-790.6	-603.7
Observations	200	200
Welfare measures:		
CS	39.01	44.41
	-4.58	-13.55
Elasticity	-0.471	-0.413
	-0.06	-0.12
* $p < 0.05$	** $p < 0.01$	*** $p < 0.001$

pine forests in Tuscany region) showed that recreational attractiveness is affected by forest stand characteristics (Paletto et al., 2017). To increase the recreational attractiveness, silvicultural interventions – i.e. selective thinning or thinning from below – should encourage natural regeneration of broadleaved species and reduce canopy density removing dominated and unstable trees. In addition, standing dead trees and lying deadwood should also be removed to facilitate the accessibility of the forest to visitors and to reduce safety risks (Ebenberger and Arnberger, 2019; Simkin et al., 2020).

In the international literature, some studies highlighted that forest stand characteristics have a direct influence on visitors' recreational activities such as walking, alpine skiing, going on outings, enjoying nature, exercising, picking berries or mushrooms, biking (Goossen and Langers, 2000; Eriksson et al., 2012). In this sense, Atauri et al. (2000) emphasized that visitors' landscape perception is influenced by the recreational activities in which they participated. The results of the present study show that Pratomagno forest – a Calabrian and Austrian black pine (*Pinus brutia* Ten. subsp. *brutia* and *Pinus nigra* J.F.Arnold) forest – can be considered a suitable forest stand for hiking and picnicking. Similarly, Smailes and Smith (2001) highlighted that in a Monterey pine (*Pinus radiata* D.Don) plantation in Australia the preferred recreational activities were picnicking, followed by walking and cycling. Similarly, Raish et al. (1997) highlighted the recreational role of ponderosa pine (*Pinus ponderosa* Douglas) forests in New Mexico and Arizona (United States) emphasizing the importance of the following forest-based recreational activities: camping, picnicking and scenery viewing. Therefore, planted pine forests can be considered a favorable environment for some recreational activities notwithstanding the above-mentioned recreational limits.

The results of present study show that forest-based recreational activities were an important cultural ecosystem services with high social and economic impacts. The economic value of Pratomagno forest was estimated in a consumer surplus between 39 and 44 € corresponding to 60.5-68.3 € per hectare. However, the visitors assessed recreational opportunities among the less important ecosystem services provided by Pratomagno forest.

This inconsistency in visitor responses is probably since recreational opportunities are a foregone conclusion for many respondents. Supposedly, some visitors consider recreational opportunities equal to those of other forests surrounding the Arezzo town, while other ecosystem services are specific for the Pratomagno mountain (e.g., protection against natural hazards). For the majority of visitors, the Pratomagno forest is an important resource to provide protection against natural hazards (i.e. landslides and rockfalls) and to mitigate climate change. The importance of these two ecosystem services is confirmed by a recent study focused on biophysical assessment of ecosystem services provided by the Pratomagno forest (Marchi et al., 2018).

In the international literature, some studies estimated the economic value of nature-based recreational activities using the travel cost demand analysis. Zandersen and Tol (2009) performed a meta-analysis of forest recreation in Europe based on studies that have applied the TCM covering twenty-five studies in nine European countries. Those authors showed a consumer surplus between 0.72 $ (0.66 €) and 122 $ (112 €) with a median of 4.90 $ (4.5 €).

Then, in a meta-analysis of nineteen TCM studies, Grilli et al. (2014) estimated an average consumer surplus of 14.13 € (median 5.72 € per visit) for forest-based recreational activities in Alpine forests. Those authors highlighted that Alpine conifer forests – mainly Norway spruce (*Picea abies* (L.) H.Karst.) dominated forests, Scots pine and black pine dominated, European larch (*Larix decidua* Mill.) and Swiss pine (*Pinus cembra* L.) dominated forests – have an average value (7.79 € per visit) lower than Alpine mixed forests.

Ezebilo (2016) quantified the economic value of nature-based recreational activities in Sweden through an application of the travel cost method. That author pointed out that participation in recreation activities is influenced by accessibility and the costs associated with travelling to recreation areas. The travel cost plus opportunity cost of travel time (total travel cost) was estimated in 16 $ (14.7 €) for a trip to a nature area in Sweden. Besides, Ezebilo (2016) showed that trips to mountain-dominated areas had the highest total travel cost followed by areas dominated by water, and forest-dominated areas (mainly conifer forests) had the least.

Mayor et al. (2007) estimated for Irish forests – mainly Sitka spruce (*Picea sitchensis* Bongard, Carrière) and Scots pine (*Pinus sylvestris* L.) plantations – a mean consumer surplus per adult equivalent per trip equal to approximately 8 € . Those authors corrected the mean consumer surplus to 3 € – instead of 8 € – eliminating the outliers (individuals who are “extreme consumers” of forest recreation).

The results of the above-mentioned studies show a wide range of values due to forest stand characteristics and location of site. Generally, the pure conifer forests have recreational values lower than natural and semi-natural forests. Within the pure conifer forests, forest stands composed of two or more tree species and characterized by a low stand density are those with highest recreational attractiveness (i.e. European larch and Swiss pine dominated forests). Conversely, dense and planted forest stands are those with lowest recreational attractiveness (i.e. Calabrian and black pine dominated forests). However, the results of this study underline that even these forest stands can show a very high economic value of nature-based recreational activities probably due to a mix of reasons and characteristics of the forest. We can assume that a main reason could be the distance from Arezzo town to the Pratomagno forest (approximately 50 km outward journey), combined with the fact that most of visitors reach the Pratomagno forest alone using their car. Furthermore, the high consumer surplus is influenced by the fact that most of visitors stay all day long in the Pratomagno, probably having lunch at restaurant.

5 Conclusions

This study investigated the benefits of recreational activities in forest in a case study in Italy, i.e. the forest of Pratomagno. An on-site questionnaire survey has been carried out to understand recreational behaviors and preferences of visitors. Data on recreational activities were collected using Likert scales, while a demand model for the site has been estimated using the travel cost method. The results suggested that forest-based recreational activities can generate positive direct and indirect benefits for local economy of rural and mountain areas with low environmental impact, thus representing a sustainable way to preserve natural resources. The direct local monetary benefits were mainly related to the costs incurred on-site such as parking fee, entrance fee for the paid forest areas, meals, and housing. The indirect benefits refer to purchases of outdoor equipment (e.g., tents, hiking gear, climbing equipment, and boating mechanisms) and travel costs (e.g., fuel and toll costs). It is important to highlight that the direct benefits can be managed by the public forest managers to improve the structural and functional characteristics of the forest stand, while the indirect benefits can contribute to increase the income of the local people. To increase recreational attractiveness of an area, forest managers and planners can improve forest stand characteristics in accordance with visitors' preferences and the main recreational activities performed in the area. In this way, also forest stands with a medium-low recreational attractiveness – such as pure conifer forests – can be enhanced and improved from the recreational point of view.

From the methodological point of view, the main weakness of the proposed method is related to the small sample of visitors corresponding to 3.9% of the total annual visitors of Pratomagno forest. However, we believe that the random sampling method used may have intercepted all potential categories of visitors. For this reason, we collected the data on both workdays and weekends, at different times of the day, and in two sampling points with different characteristics.

The future steps of the study will be the biophysical assessment and economic evaluation of other ecosystem services (timber and bioenergy production, climate change mitigation, protection against natural hazards) provided by Pratomagno forest with the aim to compare the economic value of forest-based recreational activities with those of other ecosystem services.

Acknowledgments

This study was carried out and funded by the SelPiBio LIFE project (Innovative silvicultural treatments to enhance soil biodiversity in artificial black pine stands, i.e., LIFE13 BIO/IT/000282) for demonstration of innovative silvicultural treatments in artificial black pine stands.

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Journal of Environmental Accounting and Management 10(3) (2022) 237-252

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Different *Métiers* Affect Fish Catches Accounting in Marine Protected Areas: A Pilot Investigation Method

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 2 July 2021
Available online 1 October 2022

Keywords

Métiers
Marine Protected Areas
Small-Scale Fishery
Fish assemblages accounting
Ecosystem based management

Abstract

The present investigation is a pilot study, carried out in a single season, aiming to account for the effects of local Small-Scale Fishery (SSF) métiers on actual catches, as recommended by the Ecosystem Based Management. According to local métiers, 3 trammel nets (GTR) and 3 longlines (LLS) were hauled for 8 hours in 4 Marine Protected Areas (MPAs) of Campania Region (central Tyrrhenian Sea): Regno di Nettuno (RN) and Punta Campanella (PC), in the northernmost Gulf of Naples, Santa Maria di Castellabate (SMC) and Costa degli Infreschi e della Masseta (CI), along the southernmost coasts of Cilento National Park. PERMANOVA analyses were performed to assess differences in GTR and LLS catches among MPAs; CAP analyses were used to assess similarities among MPAs catches; PERMDISP analyses were performed to verify small scale data homogeneity and comparability; ABCurves were used to assess MPAs fish assemblages quality status. Results show that GTR catches are higher than those of LLS in terms of fish diversity, abundance and biomass. Instead, LLS catches are more selective for a few target species and for larger specimens. PERMANOVA results highlight significant differences of both GTR and LLS data among MPAs, but pair-wise test indicates that LLS catches are more affected by local métiers linked to MPAs environmental characteristics. CAP analyses show that GTR species are coherently correlated with northernmost and southernmost MPAs while, species from LLS are correlated with the morphological characteristics (steep or flat bottoms) of the MPAs. PERMDISP reveals homogeneity among GTR data but not among LLS ones. ABCurves evidence that GTR, due to its low selectivity, is a suitable gear to monitoring MPAs fish assemblage. On the contrary, the high selective of LLS makes it an effective gear to provide data about the main target species of local métiers useful to define more effective MPA management measures.

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials © 2022 L&H Scientific Publishing, LLC. All rights reserved.
DOI:10.5890/JEAM.2022.09.003

1 Introduction

Small-Scale Fishery (SSF) contributes about half to the amount of the world fishery (Kolding et al., 2014). This activity is highly heterogeneous in terms of fishing gears and strategies (Schuhbauer and Sumaila, 2016).“Métiers” (i.e., the combination at local scale of a particular fishing gear, fishing ground, season, target species and operational process linked to the cultural heritage) are the most important drivers determining catches and yields of SSF (Samy-Kamal et al., 2014; Roditi and Vafidis, 2019).

Because of the amount of differences among local “métiers”, information on SSF is scarce and fragmented when compared to industrial fishery (Quetglas et al., 2016; Saldaña et al., 2017) and data on catches very often come from standardized experimental hauls, without taking into account for actual local “métiers”. Thus, the need to improve the knowledge on the ecological and economic role of SSF, as recommended by the Ecosystem-Based Management (EBM), is of primary importance especially to manage Marine Protected Areas (MPAs) (Chollett et al., 2016; Prato et al., 2016). Indeed, the EBM approach (Katsanevakis et al., 2011) considers species, habitats and stakeholders, with their cultural heritage, as elements of the same integrated system to be managed through an holistic approach. Appropriate management and protection tools allow an efficient conservation of many ecological components (Donnarumma et al., 2018a, 2018b; Ferrigno et al., 2018; Appolloni et al., 2020; Buonocore et al., 2020a) with positive effects both on habitats and marine resources (Appolloni et al., 2017). The increase of SSF target species produces economic benefits to local fisherman due to the higher value of their catches and the opportunity to enhance touristic activities such as fishing tourisms and local food services (Badalamenti et al., 2000; McCook et al., 2010; Appolloni et al., 2018a; Rendina et al., 2019).

Moreover, management and protection policies, such as MPAs, are recognized worldwide as important tools for mitigating human impacts on marine ecosystems, conserving natural capital stocks and ensuring the delivery of ecosystem services needed for human well-being (Pauna et al., 2018; Buonocore et al., 2019).

However, one of the main problems affecting MPAs is the low integration between conservation goals and stakeholders needs, that often give rise to a marked uncertainty of management strategies (Margules and Pressey, 2000; Appolloni et al., 2018b). MPAs efficiency is strongly related to the time laps from establishment and their enforcement depends by the time since protection tools effectively take place. Indeed, often protection is only in theory (“paper parks”) and the restrictions are not respected for many years after MPAs establishment (Guidetti et al., 2008). Enforcement occurs in the time when conservation strategies and stakeholders needs match, ensuring the compliance with restrictions.

The assessment of opportunity and environmental costs (Naidoo et al., 2006; Franzese et al., 2015), related to human activities such as the SSF, is of primary importance to convey the value of natural capital stocks to managers and policy makers (Franzese et al., 2017; Vassallo et al., 2017; Buonocore et al., 2020b). Together with the estimations of what nature makes available (natural capital and ecosystem services), Appolloni et al. (2018a) pointed out the need of an accurate monitoring of what is actually exploited by local populations. The integration of stakeholders needs with the assessments of the ecosystem services is the main future challenge for a sustainable development which could avoid the overexploitation of natural resources.

Fishermen are the main resource exploiters from MPAs and they are also the main keepers of maritime culture and heritage. For this reason, in Italy their involvement in the MPAs planning process is essential for the success of this important management tool (Di Nora et al., 2015).

The present study is based on information from fishermen operating by local “métiers” in four MPAs of Campania Region (central Tyrrhenian Sea). It is a pilot study aiming to assess: i) the effects of local métiers, to account for “actual” fish catches of Small-Scale Fishery (SSF) instead of ad hoc standardized experimental hauls, and ii) what is really exploited by local SSF in already established MPAs, in order to obtain information useful to improve their management.

2 Materials and methods

2.1 Study areas

Four MPAs were chosen along the coasts of the Campania Region (Fig.1): Regno di Nettuno (RN, established in 2008) and Punta Campanella (PC, established in 1998) are the northernmost MPAs located in the Gulf of Naples (GoN) (Appolloni et al., 2018c); Santa Maria di Castellabate (SMC, established in 2010) and Costa degli Infreschi e della Masseta (CI, established in 2010) are the southernmost MPAs located along the Cilento National Park coast. Coherently with the inshore physical characteristics (de Ruggiero, 2013; de Ruggiero et al., 2016), all the investigated MPAs are basically featured by four main macro-habitats (Buonocore et al., 2020b): *a)* photophilic hard bottoms, dominated by green and brown algae; *b)* sciaphilic hard bottoms (coralligenous), dominated by red algae; *c) Posidonia oceanica* seagrass beds, which is considered a key habitat for many fish species; *d)* soft bottoms, mainly hosting burrowing organisms (Donnarumma et al., 2018b). As concern the morphology of the sea ground, PC and CI are characterized by cliff and steep bottoms while RN and SMC include wide flat bottoms.

The zoning scheme of the Italian MPAs is based on three main levels of protection: the “A” Zone is a “no entry-no take” area and all human activities are forbidden; inside the “B” Zone, human activities are strictly regulated (swimming, sailing, recreational diving) and SSF is authorised to resident professional fishermen; inside the “C” Zone more human activities are permitted under authorization, as SSF and recreational fishing, also by non resident people.

2.2 Sampling activities and data collection

In this study, data were collected directly from fishermen activities, in order to take a snapshot of the actual catches according to the different “métiers” typical of each MPA (Pennino et al., 2020).

The European Data Collection Framework (DCF, Reg 199/2008 and 665/2008) defines a “métier” as a group of fishing operations (i.e., targeting similar species, using similar gears, fishing in similar periods of the year, within similar areas), characterized by similar exploitation patterns that indirectly describe fishing activities. For our study, the two fishing gears chosen were trammels (GTR) and longlines (LLS) (International Standard Statistical Classification of Fishing Gear, ISSCFG (Nédélec and Prado, 1990)), commonly used in all the four MPAs.

In October 2018, in the C zone of each MPA, catches from three fishing hauls (8 hours at about 30 meters depth) of GTR (2000 m of length, inner mesh size 70 mm, outer mesh size 350 mm) and from three LLS (500 Mustad fishhooks, size 8) were collected by researchers boarded on fishing boats.

2.3 Data analyses

Data from a total number of 24 catches, (3 GTR + 3 LLS) x 4 MPAs, were used to calculate the following indexes: Species Richness (SR), Abundance (A), diversity (H’, Shannon-Wiener index) and evenness (J’, Pielou index). Size ranks of individuals (S = Small, M = Medium and L = Large) were recorded for population’s structure analyses (f) and for the biomass (B) estimations using the weight-length relationship (Froese and Pauly, 2012).

To investigate what is actually exploited by SSF in the MPAs and to collect information useful for management, catches of each gear were separately analysed. The experimental design took into account the MPAs as the only factor (fixed, four levels, n=3). We did not consider other ecological factors since gears are located almost randomly in the MPA C zones, often crossing macro-habitats.

A permutational univariate analysis of variance, based on Euclidean distances (Terlizzi et al., 2007), was performed on species richness, total abundance, total biomass, diversity and evenness indices. A permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001a), based on Bray-Curtis similarities, was also used on catches abundances and biomasses. Both analyses aim to detect for differences in fish catches within

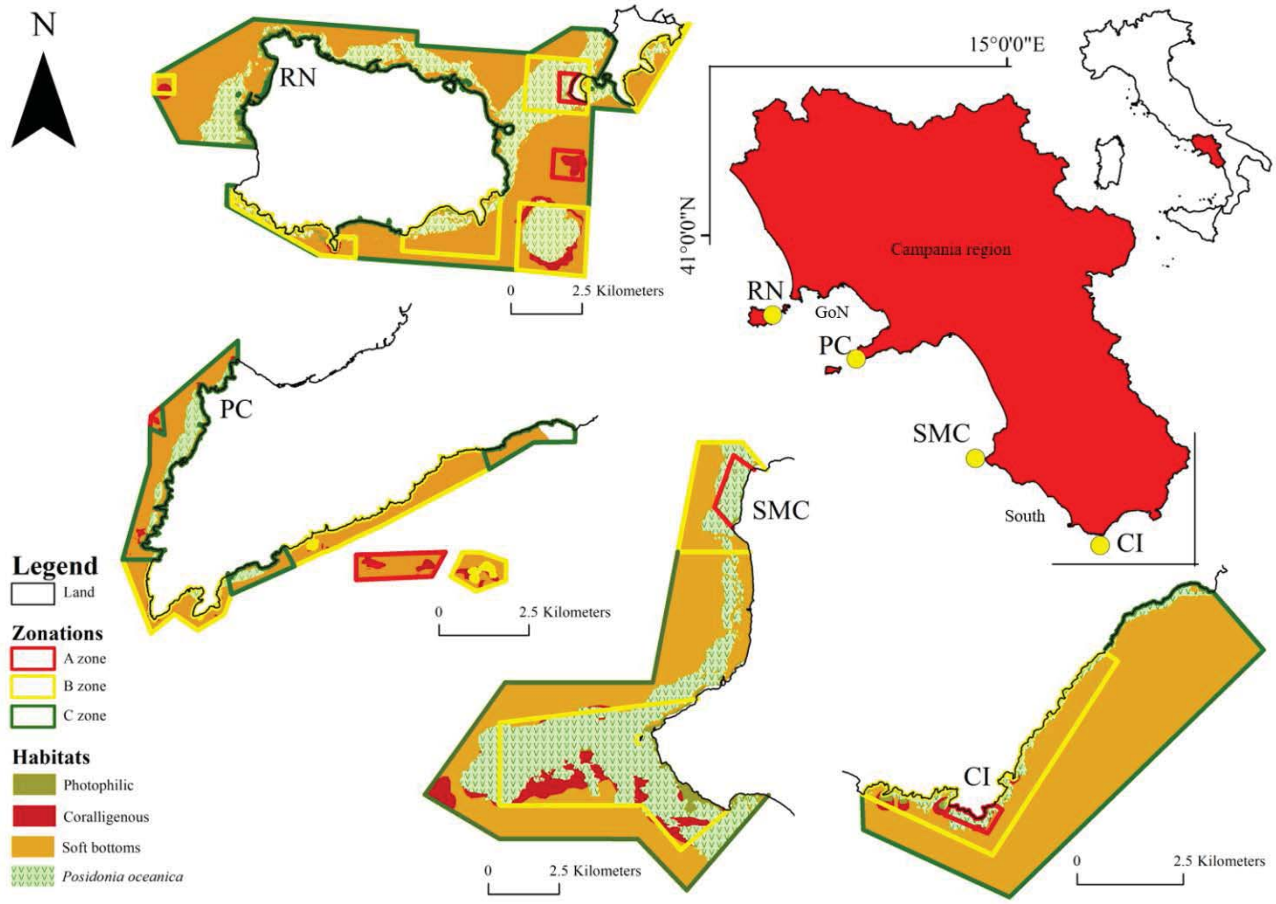

Fig. 1 Map showing, the three zones with different protection levels and the four macro-habitats of the studied MPAs along the Campania Region coasts: RN (Regno di Nettuno), PC (Punta Campanella), SMC (Santa Maria di Castellabate) and CI (Costa degli Infreschi e della Masseta).

each MPA by the two fishing gears.

Fish abundance and biomass data were square root transformed (Guidetti et al., 2014) prior to all statistical analyses to reduce the weight of very abundant species. A total of 4999 random permutations (Anderson, 2001b; Anderson and Braak, 2003) were performed for the analyses and a post-hoc pair-wise comparison test was conducted when significant differences were found.

MPAs multivariate patterns were explored through Canonical Analysis of Principal coordinates – CAP (Anderson and Willis, 2003) and species were considered correlated if Pearson coefficient (ρ) was higher than 0.6.

Permutation tests of multivariate dispersion (PERMDISP) on abundances and biomasses were employed as a measure of small-scale heterogeneity (Anderson et al., 2006). They were also used to test the homogeneity of variance to verify the comparability of data among MPAs (Newman et al., 2012).

Finally, ABCurves (Clarke et al., 2014) were employed to compare abundance/biomass relationship of fishing gears among MPAs. Cumulative biomass curve is higher than cumulative abundance curve in low impacted areas where fish assemblages are dominated by few individuals of large size. The more the difference between biomass and abundance curve (W-statistics value), the more the MPA is in good quality status.

Table 1 Results from pair-wise test performed on longlines catches. Values in bold indicate significant differences with p<0.05. A= Abundances; f = frequency ranks; B = Biomasses; RN = Regno di Nettuno MPA, PC = Punta Campanella MPA, SMC = Santa Maria di Castellabate MPA, CI = Costa degli Infreschi e della Masseta MPA.

	A data		f data		B data	
Pairs of MPAs	t	*p*	T	*p*	t	*p*
RN, PC	4.4064	**0.0032**	2.4572	**0.0002**	4.5737	**0.002**
RN, SMC	1.6974	0.0944	1.4136	0.091	1.4124	0.1836
RN, CI	3.4018	**0.007**	1.9184	**0.002**	3.1159	**0.0074**
PC, SMC	2.5414	**0.0146**	1.7261	**0.0062**	2.715	**0.0126**
PC, CI	2.8913	**0.01**	1.7983	**0.0012**	2.9256	**0.0098**
SMC, CI	2.4233	**0.0146**	1.4469	**0.0164**	1.948	**0.0426**

3 Results

3.1 Descriptive and univariate analysis

The average abundances and biomasses in kg of species caught by GTR and LLS in each MPA are shown in Appendix A and B.

As for GTR (length 2000m): in RN were caught 11 $\pm$ 3 species, mainly *Oblada melanura* and *Scopaena notata*; in PC were caught 13 $\pm$ 3 species, mainly *Mullus surmuletus* and *Sarpa salpa;* in SMC were caught 10 $\pm$ 5 species, mainly *Mullus surmuletus, Mullus barbatus* and *Pagellus erythrinus;* in CI were caught 11 $\pm$ 2 species, mainly *Scorpaena porcus*, *Lithognathus mormyrus* and *Dentex dentex.*

As for LLS (500 fishhooks): in RN were caught 5 $\pm$ 1 species, mainly *Diplodus sargus*; in PC were caught 5 $\pm$ 0 species, mainly *Pagellus acarne;* in SMC were caught 4 $\pm$ 1 species, mainly *Serranus cabrilla*, *Spondyliosoma cantharus* and *Diplodus vulgaris*; in CI were caught 3 $\pm$ 1 species, mainly *Sparus aurata* and *Dentex dentex.*

Figure 2 shows the results of synecological indices as well as size frequency ranks, and total biomasses from GTR and LLS catches.

Among GTR catches (Figure 2, left), significant differences were not detected except for Abundances, greater in SMC respect to the other MPAs ($p < 0.01$). As concerns the other synecological descriptors (SR, H', J' and B) no significant variability was detected. As regards Abundances, the higher value was detected in SMC (89.67$\pm$16.03 individuals), the lower in RN (26.67$\pm$13.77 individuals). Also size frequency ranks did not show significant differences, even if at SMC no fishes of large size were detected.

Among LLS catches (Figure 2, right) significant differences were detected. Species Richness at PC was significantly ($p < 0.01$) lower (3$\pm$0 species) respect to the other MPAs. The Abundance in PC and CI showed significantly ($p < 0.01$) lower values than in RN and SMC. The differences of H', J' and B indexes between RN and SMC were not significant while significant differences ($p < 0.01$) were detected between PC and CI. Size frequency ranks showed significant differences between PC – SMC, where Small and Medium sizes are dominant, and between RN – CI, where Large and Small sizes are dominant, respectively.

3.2 Multivariate analysis

As for GTR, differences detected by the PERMANOVA on abundance, size frequency ranks and biomass of catches in each MPA were significant (respectively: $p_A = 0.0346$, $p_f = 0.0146$, $p_B = 0.0112$) but were not significant by the pair-wise tests.

As for LLS differences detected by PERMANOVA on abundance, size frequency ranks and biomass of catches in each MPA were significant (respectively: $p_A < 0.001$, $p_f < 0.01$, $p_B < 0.001$) as the results of the pair-wise tests (Table 1).

CAP analyses (Figure 3), based on the abundance of GTR catches, display 4 clusters corresponding to the

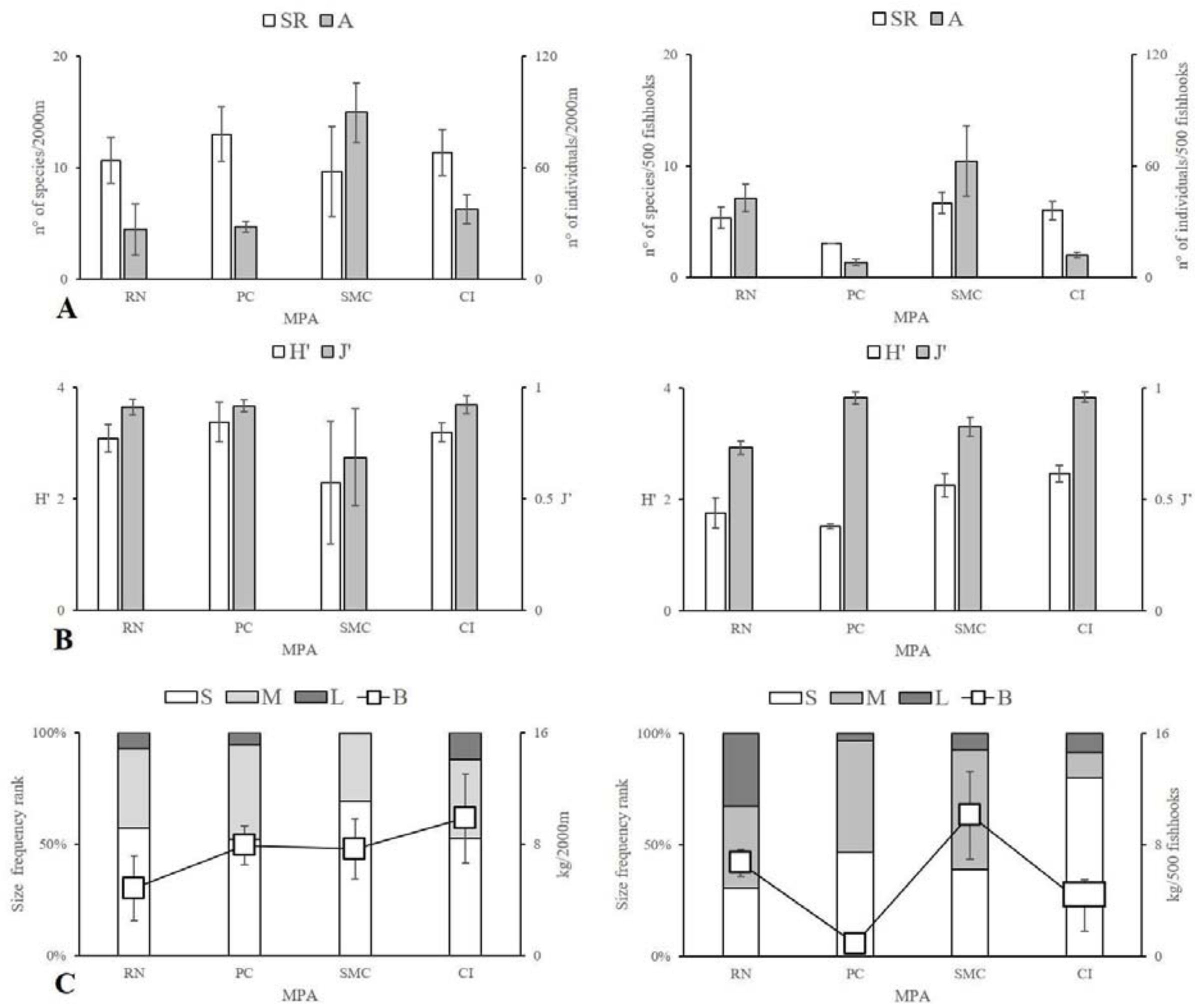

Fig. 2 Comparison between fishing gears (GTR on the left, LLS on the right). A) Specie Richness (SR) and Abundance (A); B) Species Diversity (H') and Evenness (J'); C) size frequency ranks (S=Small, M=Medium, L=Large) and total Biomass (B). RN = Regno di Nettuno MPA, PC = Punta Campanella MPA, SMC = Santa Maria di Castellabate MPA, CI = Costa degli Infreschi e della Masseta MPA.

four MPAs. However, when CAP uses the biomass data, two groups of MPAs are shown, according to the northernmost and southernmost position of the MPAs in the Campania Region. Abundance is more correlated to MPAs than biomass and some species are well related to local *métiers*. Only one species (*Mugil cephalus*) characterizes RN while *Scophthalmus rhombus* and *Spondyliosoma cantharus* are the fish which mainly identify PC. Three fish species (*Pagellus erythrinus*, *Pagellus acarne*, and *Mullus barbatus*) characterize SMC while *Sciaena umbra* and *Scorpaena scrofa* are mostly representative of CI.

CAP analyses (Figure 4), based on both abundance and biomass of LLS catches, highlight three clusters: the first group (RN – SMC) includes the MPAs characterized by flat bottoms, the other two clusters include the steep bottom MPAs (PC and CI). The flat bottom MPAs (RN and SMC) are characterized by *Oblada melanura*, *Diplodus sargus* and *Diplodus vulgaris,* while *Sparus aurata*, *Pagellus erythrinus*, *P. acarne* and *Serranus cabrilla* are the species mostly representative of PC and *Dentex dentex, Serranus cabrilla* and *Scorpaena scrofa* are the fish species which mainly characterize CI.

When considering small-scale heterogeneities, PERMDISP performed on GTR abundance and biomass did not show any significant differences among MPAs (Figure 5a). Significant differences for the abundance and biomass ($p < 0.05$) among MPAs were instead found for LLS (Figure 5b); catches from RN are much less

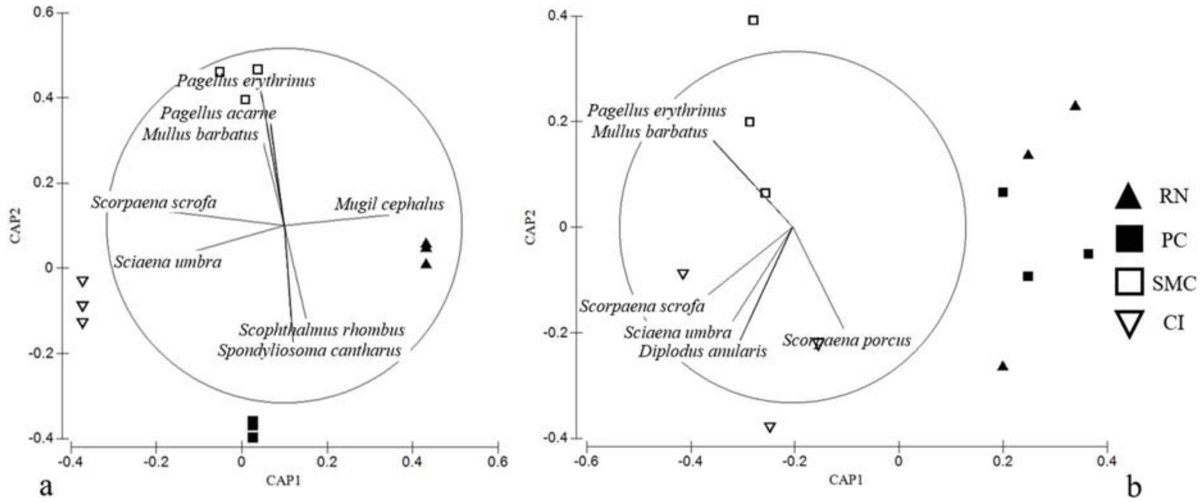

Fig. 3 Canonical Analysis of Principal coordinators (CAP) on (a) Abundances and (b) Biomasses of fish caught by GTR. All fish datasets and MPAs are correlated with Pearson coefficient ($\rho > 0.6$). Straight lines are vectors of fish species whose orientation and length are proportional to the most correlated MPAs. Circle represents 95% confidence interval. RN = Regno di Nettuno MPA, PC = Punta Campanella MPA, SMC = Santa Maria di Castellabate MPA, CI = Costa degli Infreschi e della Masseta MPA.

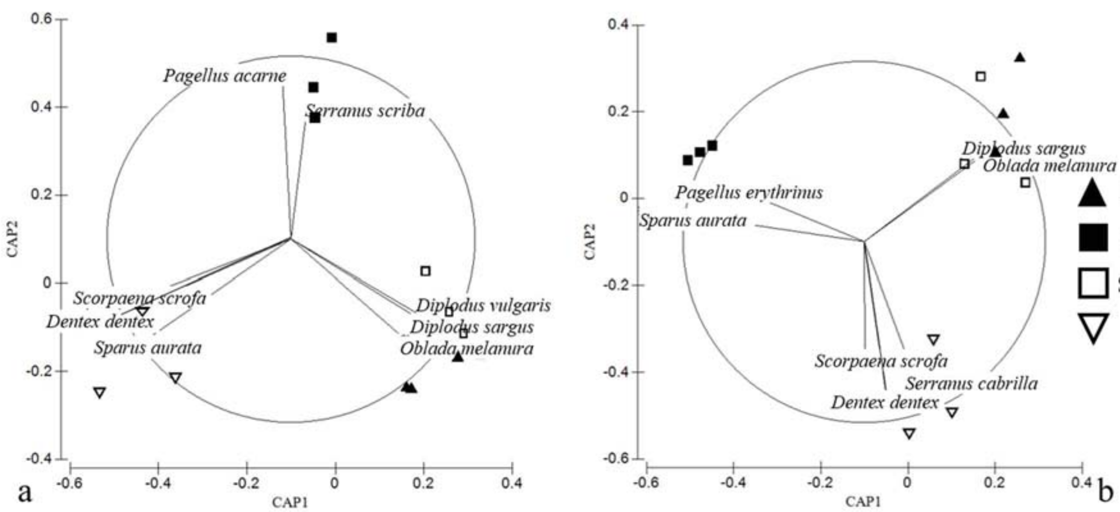

Fig. 4 Canonical Analysis of Principal coordinators (CAP) on (a) Abundances and (b) Biomasses of fish caught by LLS. All fish datasets and MPAs are correlated with Pearson coefficient ($\rho > 0.6$). Straight lines are vectors of fish species whose orientation and length are proportional to the most correlated MPAs. Circle represents 95% confidence interval. RN = Regno di Nettuno MPA, PC = Punta Campanella MPA, SMC = Santa Maria di Castellabate MPA, CI = Costa degli Infreschi e della Masseta MPA.

heterogeneous than those from all the other MPAs.

In Figure 6, results of ABCurves by GTR catches are shown. Graphs reveal unstressed fishing grounds for three MPAs (the abundance curves are below the biomass curves); only SMC (Figure 6c) shows a negative W-statistic value.

In Figure 7, results of ABCurves by LLS catches are shown. Graphs suggest that all fishing grounds are stressed (the abundance curves are above the biomass curves) except for RN (Figure 7a), where a positive W-statistic value is shown.

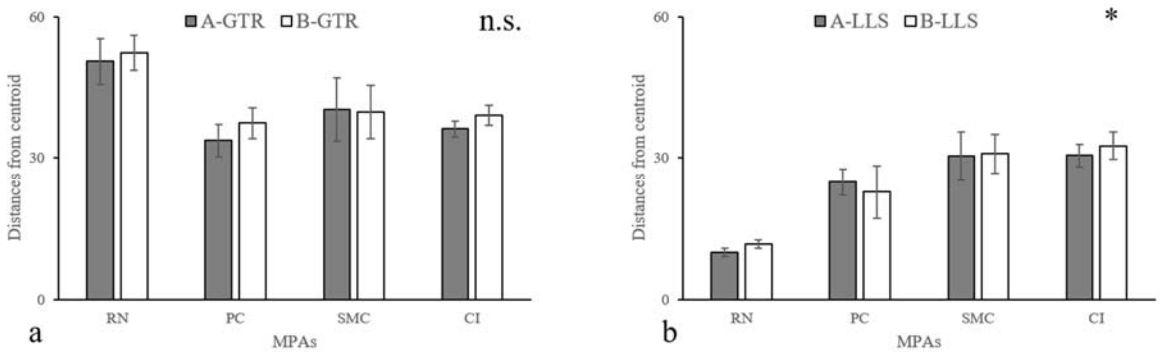

Fig. 5 Mean (±SE, n = 3) multivariate dispersion of replicates around MPA centroids calculated on abundances (A) and biomasses (B) data from (a) GTR and (b) LLS catches. * = significant difference: $p < 0.05$; n.s. = not significant: $p > 0.05$. RN = Regno di Nettuno MPA, PC = Punta Campanella MPA, SMC = Santa Maria di Castellabate MPA, CI = Costa degli Infreschi e della Masseta MPA.

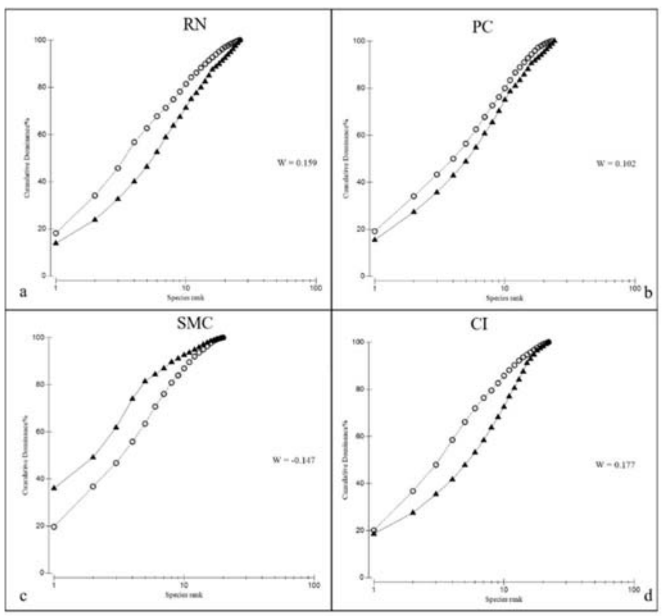

Fig. 6 Abundance (black triangles)-Biomass (white circles) Curves coming from data collected by GTR in the four MPAs. W = W-statistic value; a) RN = Regno di Nettuno MPA, b) PC = Punta Campanella MPA, c) SMC = Santa Maria di Castellabate MPA, d) CI = Costa degli Infreschi e della Masseta MPA.

4 Discussion

Although twenty years of research on fishing gears and catches have led to substantial data improvements, they mainly refer to industrial activity (Sinopoli et al., 2012). As concern SSF, only few studies attempted its characterization (Schuhbauer and Sumaila, 2016) and mostly focused on just few target species (e.g. Albouy et al., 2010; Sala and Lucchetti, 2010; Marengo et al., 2014). Furthermore, SSF studies are mainly based on standardized experimental gears and hauls, that often are not representative of the real exploitation of the natural capital, since they do not consider local *métiers* related to cultural heritage (Ulrich et al., 2012; Oliveira et al., 2014).

The present investigation is a first attempt to account for SSF catches in different MPAs, comparing fish resources and focusing on the local *métiers* as source of variability.

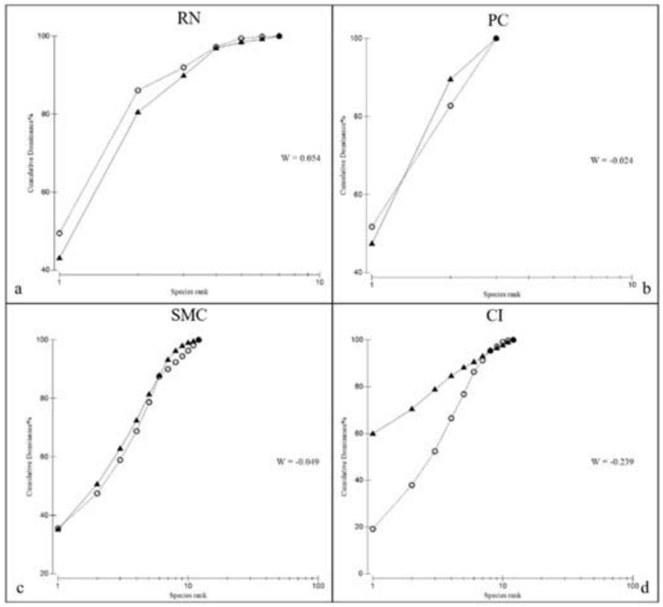

Fig. 7 Abundance (black triangles)-Biomass (white circles) Curves coming from data collected by LLS in the four MPAs. W = W-statistic value; a) RN = Regno di Nettuno MPA, b) PC = Punta Campanella MPA, c) SMC = Santa Maria di Castellabate MPA, d) CI = Costa degli Infreschi e della Masseta MPA.

As concerns the comparison of fish catches from GTR and LLS gears, PERMDISP analysis on GTR catches did not show significant differences in heterogeneity both within and among MPAs. Indeed, the low data dispersion accounts for their homogeneity allows their comparability despite the different local *métiers* (Newman et al., 2012; Saldaña et al., 2017). GTR, hauled close to the seafloor, is able to intercept the necto-benthic component of the fish assemblages (Erzini et al., 1997; Matić-Skoko et al., 2011; Lloret and Font, 2013). Trammel net is characterized by a low selectivity (Batista et al., 2009; Olguner and Deval, 2013) as confirmed by high species diversity (H') and evenness (J'). As a consequence, they are strongly subjected to stochastic factors due to the patterns of habitat patches. This is coherent with the significant differences in species and biomass among MPAs, as highlighted by the lack of consistent results in pair-wise test. Conversely, LLS showed a significant heterogeneity among highly selective catches, that results in low species diversity (H') and high evenness (J'). The high selectivity of Longlines is also confirmed by significant differences in biomass. As hooks (of medium size) and baits (mainly fragments of *Sardina pilchardus* and *Loligo vulgaris*) are the same for the MPAs, the differences among catches of necto-benthic species are due to a different habitat distribution and patchiness inside them (Roditi et al., 2018, 2020).

Results from CAP analysis on the two investigated gears are consistent with the previous considerations. Catch-points of GTR biomasses are grouped in three clusters, a first composed by the northernmost MPAs (RN - PC) and the other two composed by the southernmost MPAs (SMC and CI). This result emphasizes the different *métiers* for GTR, due to different historical traditions between the North and the South of Campania Region. Catch-points of LLS are also grouped in three clusters: the first composed by flat bottoms MPAs (RN - SMC) while the other two by steep bottoms MPAs (PC and CI). This result can be explained as an adaptive consequence of LLS *métiers* to local sea-bottom morphology. Indeed, in RN and SMC, mainly characterized by flat bottoms, longlines are completely displaced close to the seafloor, while in PC and CI, characterized by steep bottoms, longlines could be displaced both on the seafloor and in the water column.

Such findings clearly show that *métiers* strongly affect catch differences among MPAs. Leleu et al. (2014) pointed out that *métiers* are adapted to local environmental features to increase fishing efficiency. PC and CI are mainly characterized by steep calcareous rocky bottoms that provide catches of high commercial value especially by LLS. Conversely, RN and SMC are characterized by more flat bottoms with a greater habitat patchiness, including wide seagrass beds, that provide catches with a high variety of species, mainly caught by GTR (Battaglia et al., 2017; Falautano et al., 2018). The rather low biomass values obtained in this study can be explained by the difficulty of local fishermen in adopting the proposed management measures and the need for real implementation of these actions. MPAs enforcement, as effective implementation of protection actions, is still undergoing and an unexpected effect is the gradual loss of *métiers*. Older fishermen hardly change their fishing tradition to match the rules needed for conservation. Thus, they were often forced either to change their traditional gears or to find new fishing grounds outside the MPA (Mallol and Goñi, 2019). In any case, changes in fishing gears or grounds lead to a better exploitation of natural capital both inside and outside MPAs, contributing to the maintenance of SSF (Chollett et al., 2016).

As for fish community quality status, ABCurves have been successfully applied in many studies (Kaiser et al., 2000; Bobori and Salvarina, 2010; Matic-Skoko et al 2011; Padilla-Serrato et al 2017) also within the MPAs (Yemane et al., 2005; Appolloni et al., 2017). In this study, ABCurves reveal that SMC is the most impacted area, showing a negative W-statistic value for both the analysed fishing gears. The less impacted area is RN, showing a positive W-statistic value for both GTR and LLS. Of particular interest are the results for PC and CI, showing positive W-statistic values for GTR, and negative for LLS. On the basis of PERMDISP, these latter findings are explained by the more heterogeneous GTR catches respect to LLS ones. Indeed, being GTR less selective (Grekov and Pavlenko, 2011), it is more effective to assess fish community quality status than the more selective LLS (Swimmer et al., 2011).

5 Conclusions

This pilot study on *métiers* of SSF in the MPAs of Campania Region, although limited to a single season, allows some important considerations. First of all, actual catches recommended by Ecosystem Based Management provide useful information on the selectivity of fishing gears and on the quality status of fish assemblages. In fact, GTR catches are less selective but more effective to assess the quality status of fish assemblages, and therefore more useful for monitoring programs of fish stocks. Conversely, LLS are more selective and more suitable to recognize the main target species of local *métiers*, for which management plans of the MPAs are needed.

However, further studies on SSF have to be carried out to cover the annual cycle of the different artisanal fishing activities and in more MPAs, to evaluate the real enforcement of management measures. This is because data collected seem to show that restrictions are not always respected by fishermen, even though MPAs were established many years ago. The match between conservation policies and their enforcement by the *métiers* is, therefore, of primary importance to avoid “paper parks”.

Aknowledgements

Thanks are due to the anonymous reviewers for the valuable suggestions and comments. This work was supported by the EU-FEAMP funds.

Appendix

Table A1 Average abundances and biomasses caught by GTR in the four MPAs.

	Average Abundances				Average Biomasses			
	RN	PC	SMC	CI	RN	PC	SMC	CI
Auxis thazard thazard (Lacepède, 1800)	0.00	0.00	0.00	1.33	0.00	0.00	0.00	1.44
Boops boops (Linnaeus, 1758)	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.07
Chelidonichthys lucerna (Linnaeus, 1758)	0.67	0.67	0.67	0.00	0.15	0.09	0.04	0.00
Chelon auratus (Risso, 1810)	0.00	2.00	0.00	0.00	0.00	0.69	0.00	0.00
Citharus linguatula (Linnaeus, 1758)	1.67	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Dentex dentex (Linnaeus, 1758)	0.00	1.33	2.33	2.33	0.00	0.34	0.69	1.08
Diplodus annularis (Linnaeus, 1758)	1.00	0.67	1.33	2.00	0.03	0.05	0.04	0.31
Diplodus puntazzo (Walbaum, 1792)	0.33	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	2.00	1.67	1.33	1.67	0.08	0.34	0.06	0.06
Diplodus sargus (Linnaeus, 1758)	0.00	1.00	0.00	0.00	0.00	0.15	0.00	0.00
Epinephelus marginatus (Lowe, 1834)	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.23
Euthynnus alletteratus (Rafinesque, 1810)	0.67	0.67	0.00	0.00	0.75	1.79	0.00	0.00
Labrus viridis Linnaeus, 1758	0.00	0.33	0.00	0.00	0.00	0.02	0.00	0.00
Lithognathus mormyrus (Linnaeus, 1758)	0.00	0.00	0.00	2.33	0.00	0.00	0.00	0.76
Merluccius merluccius (Linnaeus, 1758)	0.67	0.00	0.33	0.00	0.48	0.00	0.24	0.00
Mugil cephalus Linnaeus, 1758	1.33	0.00	0.67	0.00	0.92	0.00	0.46	0.00
Mullus barbatus Linnaeus, 1758	0.67	0.00	32.33	3.00	0.06	0.00	1.77	0.46
Mullus surmuletus Linnaeus, 1758	1.67	3.33	11.67	1.67	0.15	0.22	1.55	0.65
Muraena helena Linnaeus, 1758	0.33	0.33	0.00	0.00	0.21	0.21	0.00	0.00
Oblada melanura (Linnaeus, 1758)	3.67	0.00	0.00	1.33	0.66	0.00	0.00	0.27
Pagellus acarne (Risso, 1827)	1.00	0.33	6.67	0.67	0.09	0.01	0.24	0.02
Pagellus bogaraveo (Brünnich, 1768)	0.00	0.33	0.00	0.00	0.00	0.09	0.00	0.00
Pagellus erythrinus (Linnaeus, 1758)	0.33	0.00	11.33	0.00	0.02	0.00	1.00	0.00
Pagrus pagrus (Linnaeus, 1758)	0.00	1.33	1.00	0.00	0.00	0.22	0.45	0.00
Phycis blennoides (Brünnich, 1768)	0.33	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Phycis phycis (Linnaeus, 1766)	0.00	0.00	1.00	0.33	0.00	0.00	0.14	0.04
Raja brachyura Lafont, 1871	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.22
Sarda sarda (Bloch, 1793)	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.80
Sarpa salpa (Linnaeus, 1758)	1.67	4.33	2.67	1.67	0.25	1.28	0.27	0.15
Sciaena umbra Linnaeus, 1758	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.09
Scophthalmus rhombus (Linnaeus, 1758)	0.00	0.67	0.00	0.00	0.00	0.63	0.00	0.00
Scorpaena notata Rafinesque, 1810	2.67	0.00	0.00	2.00	0.05	0.00	0.00	0.08
Scorpaena porcus Linnaeus, 1758	2.33	1.67	0.00	3.33	0.27	0.49	0.00	0.45
Scorpaena scrofa Linnaeus, 1758	0.00	0.33	2.33	7.00	0.00	0.15	0.41	1.26
Seriola dumerili (Risso, 1810)	0.00	0.67	0.00	1.33	0.00	0.30	0.00	1.20
Serranus cabrilla (Linnaeus, 1758)	0.00	0.33	11.00	0.00	0.00	0.03	0.43	0.00
Solea solea (Linnaeus, 1758)	0.33	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Sparisoma cretense (Linnaeus, 1758)	0.00	0.33	0.00	0.00	0.00	0.11	0.00	0.00
Sparus aurata Linnaeus, 1758	0.33	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Sphyraena sphyraena (Linnaeus, 1758)	0.00	0.00	0.67	0.00	0.00	0.00	0.11	0.00

Table A1 Continued.

	Average Abundances				Average Biomasses			
	RN	PC	SMC	CI	RN	PC	SMC	CI
Spicara maena (Linnaeus, 1758)	0.00	0.00	1.00	0.00	0.00	0.00	0.03	0.00
Spondyliosoma cantharus (Linnaeus, 1758)	0.33	2.33	0.00	0.00	0.01	0.18	0.00	0.00
Symphodus roissali (Risso, 1810)	0.33	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Symphodus tinca (Linnaeus, 1758)	0.33	1.33	1.00	2.00	0.07	0.08	0.06	0.17
Trachurus trachurus (Linnaeus, 1758)	0.33	0.00	0.33	0.00	0.02	0.00	0.06	0.00
Umbrina cirrosa (Linnaeus, 1758)	1.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00
Uranoscopus scaber Linnaeus, 1758	0.67	1.67	0.33	0.33	0.13	0.56	0.01	0.07
Zeus faber Linnaeus, 1758	0.00	0.33	0.33	0.00	0.00	0.07	0.07	0.00

Table A2 Average abundances and biomasses caught by LLS in the four MPAs.

	Average Abundances				Average Biomasses			
	RN	PC	SMC	CI	RN	PC	SMC	CI
Boops boops (Linnaeus, 1758)	3.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Conger conger (Linnaeus, 1758)	0.00	0.00	0.33	0.00	0.00	0.00	0.21	0.00
Dentex dentex (Linnaeus, 1758)	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.43
Diplodus annularis (Linnaeus, 1758)	0.33	0.00	3.33	0.67	0.03	0.00	0.22	0.18
Diplodus puntazzo (Walbaum, 1792)	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.66
Diplodus sargus (Linnaeus, 1758)	18.33	1.00	22.00	0.67	2.46	0.00	4.05	0.08
Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	4.00	0.67	5.67	0.67	0.40	0.25	1.01	0.09
Epinephelus marginatus (Lowe, 1834)	0.00	0.00	0.33	0.00	0.00	0.00	0.23	0.00
Lithognathus mormyrus (Linnaeus, 1758)	0.33	0.00	0.00	0.33	0.01	0.00	0.00	0.01
Oblada melanura (Linnaeus, 1758)	16.00	0.00	6.00	0.00	3.31	0.00	1.31	0.00
Pagellus acarne (Risso, 1827)	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00
Pagellus erythrinus (Linnaeus, 1758)	0.00	0.00	1.00	0.00	0.00	0.37	0.21	0.00
Pagrus pagrus (Linnaeus, 1758)	0.00	0.00	4.00	0.67	0.00	0.00	1.35	0.00
Scorpaena scrofa (Linnaeus, 1758	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.22
Serranus cabrilla (Linnaeus, 1758)	0.00	0.67	9.67	0.00	0.00	0.00	0.28	0.46
Serranus scriba (Linnaeus, 1758)	0.00	3.00	2.00	0.33	0.00	0.14	0.09	0.00
Sparus aurata (Linnaeus, 1758)	0.67	0.00	0.00	2.33	0.00	0.15	0.00	0.01
Spondyliosoma cantharus (Linnaeus, 1758)	0.00	0.00	7.67	0.33	0.35	0.00	1.13	0.86
Trachurus trachurus (Linnaeus, 1758)	0.00	0.00	0.67	0.00	0.00	0.00	0.08	0.01

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Journal of Environmental Accounting and Management 10(3) (2022) 253-267

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Integrated Environmental Accounting for Assessing the Value for Money in Marine Protected Areas: the Case of Tremiti Islands (Italy)

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 2 July 2021
Available online 1 October 2022

Keywords

Marine protected area
Environmental accounting
Ecosystem service
Life cycle assessment
Cost-benefit analysis

Abstract

The paper focuses on the integrated environmental accounting model called "eValue" developed for protected areas and applied in the research programme coordinated by the Italian Ministry of Environment aiming to implement an environmental accounting system for the Italian Marine Protected Areas (MPAs). eValue aimed to calculate the economic value of Protected Areas adopting a Cost-Benefit Analysis approach. Financial accounting based on costs and revenues was integrated with environmental accounting, which reflected not only environmental costs but also environmental revenues, *i.e.* environmental benefits. Environmental costs assessed the impacts related to human activities in the MPA and environmental benefits assessed ecosystem services. The overall annual flow account accounted for costs and benefits, both economic and environmental, and the difference represented the value produced (or consumed) by the MPA. The eValue model was applied in the Tremiti Islands MPA. eValue demonstrated that the annual benefits-costs ratio reaches 2.1. In addition, the ratio between the net benefit and the public funding is 5.0 completely covering the amount of public transfers and thus summarizing the overall value for money of the MPA. Finally, the outcomes of the project are functional to the Mapping and Assessment of Ecosystem Services initiative carried out by the European Union.

1 Introduction

Protected areas (PAs) provide a series of fundamental services for the constituents of human well-being the so called Ecosystem Services (ES), which are defined as "the benefits people obtain from ecosystems" (Costanza et al. 1997; MA, 2005; TEEB, 2010). These include provisioning services such as food and water; regulating

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials © 2022 L&H Scientific Publishing, LLC. All rights reserved.
DOI:10.5890/JEAM.2022.09.004

services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits" (MA, 2003, p.3). More recently, ES were defined as "the contributions of ecosystem structure and function (in combination with other inputs) to human well-being" (Burkhard et al., 2012, p.26). This implies that humankind is strongly dependent on well-functioning ecosystems and on natural capital that are the basis for a constant flow of ES from nature to society (Burkhard and Maes, 2017).

Expressing the value of ES in monetary units is a crucial point for policy-makers helping them assess the financial value for money of policies, make effective decisions on resource allocation between competing uses (de Groot et al., 2012), and drawing the attention to the economic benefits of biodiversity including the growing cost of biodiversity loss and ecosystem degradation (TEEB, 2010).

In the early 1990s, the United Nations Statistics Division undertook a review of the System of National Accounts (SNA) and proposed a System for Integrated Environmental and Economic Accounting (SEEA) in order to integrate environmental accounting into economic accounting (UN et al., 2003). As reported in the introduction of the handbook, integrating economic and environmental information in a common framework permits a consistent analysis of the contribution of the environment to the economy and of the impact of the economy on the environment. This is intended to meet policy-makers' needs by providing metrics and descriptive statistics to monitor the interaction between the economy and the environment, as well as serving as a tool for strategic planning and policy analysis to identify more sustainable development paths.

At EU level, the EU Biodiversity Strategy to 2020 (EC, 2011) adopted the TEEB recommendation which suggested that the economic value of biodiversity be factored into decision making and reflected in accounting and reporting systems. The Biodiversity Strategy stated that Member States map and assess the state of ecosystems and related ES, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level. This activity is implemented thanks to the SEEA Central Framework (SEEA CF) which is the international statistical standard (UN et al., 2014a), besides the Experimental Ecosystem Accounts (SEEA EEA) (UN et al., 2014b; UN, 2017) and the SEEA Application and Extensions (UN et al., 2017) which are receiving growing attention (La Notte and Rhodes, 2020). To support the implementation of the EU Biodiversity Strategy target, the Mapping and Assessment of Ecosystems and their Services (MAES) initiative was set up and the MAES working group established in order to draw the methodological approach (Maes et al. 2014). Then, the Knowledge Innovation Project-Integrated system of Natural Capital and ecosystem services Accounting in the EU (KIP-INCA) was developed in order to integrate the MAES activity with an EU environmental accounting framework within 2020 (EEA, 2019). The most recent contribute to the accounting system is provided by the project "LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging" (LISBETH) (La Notte et al., 2020). The project is based on the KIP-INCA and aims to facilitate the use of INCA accounts in traditional economic analysis tools. Thanks to the application of these approaches, the recent EC Communication on "EU Biodiversity Strategy for 2030 – Bringing nature back into our lives" makes a step forward. The EC Communication gives evidenced, on one side, to the fact that the targets defined under the Convention on Biological Diversity are insufficient to adequately protect and restore nature and, to the other side, that enlarging protected areas is also an economic imperative (EC, 2020, p.4). Studies on marine systems estimated that every euro invested in marine protected areas would generate a return of at least €3 (Brander et al., 2015).

In 2013, the Italian Ministry of the Environment financed the development and implementation of the integrated environmental accounting system in the Italian Marine Protected Areas (MPAs). The project aimed to assess the MPA's ecological and economic value, with particular reference to the ES generated in each protected area (Buonocore et al., 2018; Franzese et al., 2015). In this frame, the integrated environmental accounting model eValue (Visintin et al., 2016) applied to the MPAs contributes to the debate at the local scale and aims to be a tool to support communication, policy and social acceptability goals. In terms of communication tool, it aims to show that the wealth produced within the MPA is greater than the public investment and that the establishment of a protected area should not be understood as a limiting factor in the economic development of the territory as much as an opportunity to create economic, social and environmental wealth. In terms of policy tool, results should demonstrate to the decision-makers, stakeholders and funding bodies that, besides having an invaluable value in general terms, the protected areas have a value at least equal to that estimated by the application of the integrated environmental accounting. In terms of social acceptability tool, the integrated environmental accounting should highlight the reserve effect, which is an effect correlated to the MPA establishment enhancing fish abundance, thanks to management effectiveness of the protected area, as well as increasing tourist attraction, thanks to the presence of environmental values.

Section 2 of the paper illustrates the integrated environmental accounting model eValue developed for assessing the MPA's value from the socio-economic point of view, and then Section 3 describes the results obtained applying the model to the Tremiti Island Marine Protected Area (TI-MPA) investigating what and how much value the MPA was able to create from the money allocated by government and funding bodies in nature conservation. The last section provides an analysis of the results and draws the conclusions.

2 Material and method

The integrated environmental accounting model eValue was built with the aim to integrate the institution's financial accounting with the environmental costs and benefits, which reflect the value of the impacts on the environment and the benefits deriving from ES delivered by the MPA. Therefore, the Cost-Benefit Analysis conceptual approach was adopted (Marangon et al., 2006; Marangon et al., 2008; Visintin et al., 2016). The model is based on two main annual accounts (Table 1): the stock account and the flow account. In the financial accounting system, stock refers to the value of an asset at a balance date, while flow refers to the total value of transactions (sales or purchases, incomes or expenditures) during an accounting period. Stocks and flows are related because the available stock of resources is usually increased by the flow of new investment and depleted by the flow of depreciation. In the eValue model the stock account refers to the capacity of the natural resources to provide the ES flow. For example, in case of the "Wild animals and their outputs" ES, the capacity indicator accounts for the fish stock which generates the flow indicator "Harvested fish and shellfish". In case of the "Global climate regulation" ES, the capacity indicator accounts for the "Seagrass extension" and related "Carbon sequestration potential" while the flow indicator accounts for the "Annual Carbon fixation". However, the notion of capacity is still under debate (La Notte et al., 2019). Following the SEEA-EEA (United Nations, 2017), capacity should be calculated as the Net Present Value (NPV) of the annual potential flow of the ES over a period of time. Adopting this approach, the stock is called "virtual stock" because it deals with the capacity to keep on generating an ecological process and can not be accumulated (La Notte et al., 2019). In the eValue model we assumed that the stock could be accumulated, as happens for organisations, if the potential flow (or sustainable flow) is higher than the actual flow (the use). For the purposes of this research the capacity is calculated in biophysical terms, and is intended as the stock of good and services which guarantees the provisioning of the ES flow and related benefit. On this base, the ES capacity indicators construct the stock account. The flow account was built with the aim to supplement financial accounting (based on institution's expenses and revenues) with environmental accounting, which reflects not only environmental costs but also environmental revenues, *i.e.* environmental benefits. These indicators are used to report the flows of goods and services produced by the ES of the MPA. The benefit indicators translate the flow indicator into monetary equivalent. The flow and benefit indicators build the flows account. In line with the Cost-Benefit Analysis approach, the difference between economic and environmental benefits and costs represents the net benefit and the value produced or consumed by the MPA.

Environmental costs refer to what the economy defines negative externalities, and occur when the production or consumption influences in negatively way the well-being of a third party, without the latter receiving compensation equal to the cost. For example, tourism produces as negative externality the pollution due to vehicular traffic and the greenhouse gas emissions; boating activity is responsible for the eradication of seagrass due to anchoring with indirect impact on coastal erosion and habitat loss for many animal species. The environmental

Table 1 MPA integrated environmental accounting model - eValue.

Stock account	**Flow account**	
	Costs	**Benefits**
- ES capacity indicators (biophysical and quantitative metric)	**(C1) Expenses**	**(B1) Revenues**
	- Income statement expenses (monetary metric)	- Income statement revenues (monetary metric)
	(C2) Environmental costs	**(B2) Environmental benefits**
	- Impact indicator (biophysical and quantitative metric)	- ES flow indicator (biophysical and quantitative metric)
	- Environmental cost indicator (monetary metric)	- ES benefit indicator (monetary metric)
	(C) Total costs = (C1) + (C2)	**(B) Total benefits = (B1) + (B2)**
	(NB) Net benefit = (B) – (C)	

costs assessment provides a value to the negative externalities. In order to assess environmental costs, the model calculates the impacts on the environment by estimating the carbon footprint of the activities authorised and carried out in the MPA.

Environmental benefits estimate the value of positive externalities, which occur when the production or consumption influences positively the well-being of a third party, without the latter paying a price equal to the value of the benefit received. For example, the protection of species and habitats within the MPA maintains a high level of biodiversity, which contributes in increasing the attractiveness for birdwatching or diving experience. The environmental benefits assess the externality by assigning a value to the service that tourist benefits from. To reach this aim, the model selected the ES by adopting the methodology proposed by the MAES and the Common International Classification of Ecosystem Services (CICES) indicators (Haines-Young and Potschin, 2013).

Finally, the accounting figures allow calculating a number of main economic and environmental indicators: the relationship between the net benefits produced by the MPA and the public funding; the return on investment, which corresponds to the economic, environmental and social benefit provided by the MPA for 1 euro of public investment; the ratio between carbon emission and carbon sequestration. For the purposes of the research, we focused on the annual flow account of the eValue algorithm developed by eFrame ltd.

3 Results

The TI-MPA was established in 1989 by decree of the Ministry of Environment and its management is entrusted to the Gargano National Park Authority. The TI-MPA lies 12 miles North of the Gargano promontory in the centre part of the Adriatic Sea (Italy). It is made up of three big islands and encompasses a surface of 1,466 hectares and a coastline of 20,410 meters. The archipelago is an example of outstanding natural heritage, both for the wild nature of its depths, for the landscape and for the historical-architectural elements, and represents a very important geological and geomorphological laboratory. The TI-MPA is characterised by different areas of environmental protection regime: zone A – integral reserve with an area of 180 hectares, zone B – general reserve with an area of 268 hectares, zone C – partial reserve with an area of 1,018 hectares as shown in Figure 1.

The MPA integrated environmental accounting model was applied to the TI-MPA with respect to the annual flow account. The reference period was the average of tree-year period 2014-2016 in order to smooth out year-on-year fluctuations. In order to assess the figures, which build the flow account, the following activities were carried out: selecting ES, accounting of income statement revenues and assessment of environmental benefits, accounting of income statement expenses and assessment of environmental costs, and finally building the flow account.

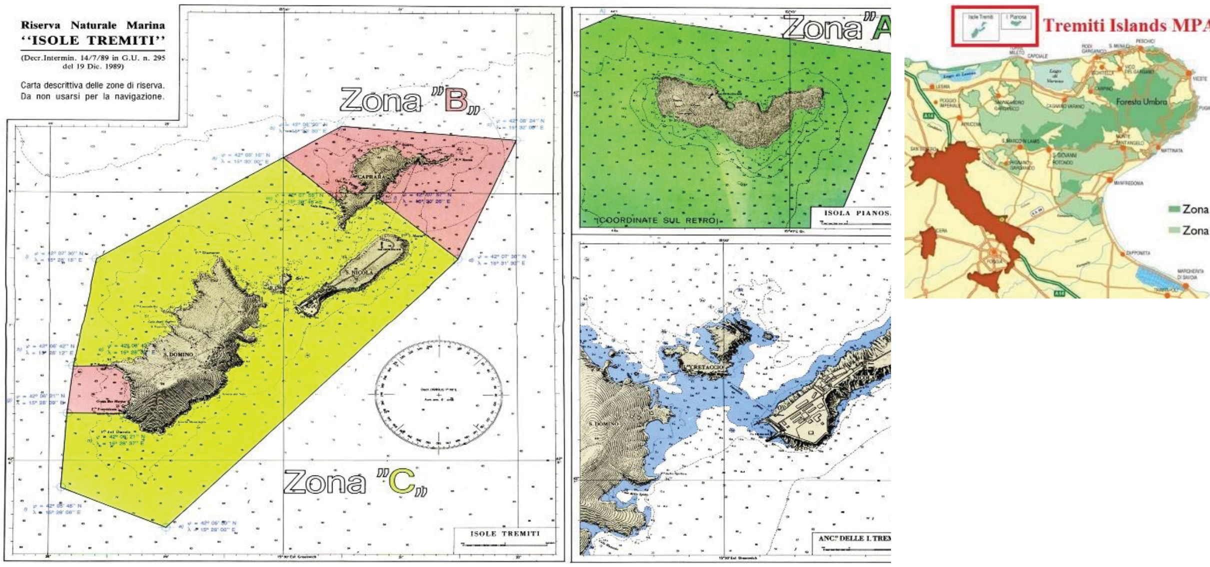

Fig. 1 TI-MPA zoning and TI-MPA within the Gargano National Park.

3.1 Selecting ES

Several ES classification are available: the Millennium Ecosystem Assessment (MA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010), the Common International Classification of Ecosystem Services (CICES) (Haynes-Young and Potschin, 2013; Maes et al., 2013). For the purposes of this research, we adopted the CICES because it was developed with the aim to support the environmental accounting framework and to comply with the SEEA. The CICES provides a comprehensive list of ES related to the Marine coastal water ecosystem (Haynes-Young and Potschin, 2013), but being a still experimental project, seven among the thirty-six ES was selected, which, albeit in a limited number, are representative of the MPA, and with respect to which the MPA already had data useful for the following evaluation phase. In accordance with the MPA manager, the restricted core of ES was selected as follows: Wild animals and their outputs; Mass stabilization and control of erosion rates; Global climate regulation by reduction of greenhouse gas concentrations; Experiential use of plants, animals and land/sea-scapes in different environmental settings; Physical use of land/sea-scapes in different environmental settings; Scientific; and Educational.

3.2 Accounting of income statement revenues and assessment of environmental benefits

Revenues are derived from the MPA income statement. Due to the anomalous trend of the revenues of the TI-MPA statement, in order to provide a figure which represents more faithfully the trend, the average of the three-year period was assessed (Table 2).

The ES assessment was based on the annual flow and benefit indicators suggested by the literature (Maes et al., 2014; Haynes-Young and Potschin, 2013) and adapted to the local scale and to the characteristics of the TI-MPA marine ecosystem (Visintin et al., 2016).

In order to assess the ES flow, benefit and cost indicators, data were collected though surveys carried out during the 2016 bathing season. Thanks to the collaboration with the University of Bari (Mastrototaro et al., 2018) questionnaires were administered face-to-face and submitted to a sample of 1,216 tourists of which 600 sunbathers (500 public beach users and 100 bathhouse users), 396 divers, 136 boaters, 12 boat renters and 72 recreational fishermen. Interviews were submitted to a sample of 17 economic operators of which 3 professional fishermen, 4 diving centers and 10 boat rentals. TI-MPA economic and management data were provided by the Gargano National Park Authority.

The "Wild animals and their outputs" ES's annual flow and benefit indicators accounted respectively for

Table 2 TI-MPA income statement revenues.

Revenues	2014 (€)	2015 (€)	2016 (€)	Average (€)
Current transfers	179,939.06	310,898.03	110,156.16	200,331.08
Capital transfers	95,488.76	149,282.00	114,633.95	119,801.57
Total	275,427.82	460,180.03	224,790.11	320,132.65

Table 3 Fishermen, fish catches and annual benefit.

	2014	2015	2016	2017
Fishermen authorized by the MPA (n.)	4	8	3	3
Catches (kg/a)	3,500	10,500	8,950	9,703
Catches within the MPA (kg/a)				6,982
Benefit – Market value (€/a)				147,375.48

commercial and artisanal fish and shellfish landed (t/a), and for the fish and shellfish sales (€/a) (Haynes-Young and Potschin, 2013). During the three-years period the fleet authorized for fishing within the MPA was stabilized to three operators. Interviews were administered to fishermen in order to collect data about catch and market price per species. As a result, Mastrototaro et al. (2017) assessed that fishermen caught about 7 t/a within the MPA. Considering the extent of the harvested fish, the landed is totally sold to the local market represented by restaurants, which are willing to pay the catch within the MPA at twice the price of the catch outside. It highlighted the so called "effect of reserve protection", which means the recognition of an effective protective effect on coastal fish stocks both in terms of size and quality, thanks to the MPA conservation policy and management. The annual benefit related to the ES was assessed applying the catches and market price per species as recorded from fishermen interviews and was estimated at 147,375.48 €/a (Table 3).

The "Mass stabilization and control of erosion rates" ES was assessed based on capacity indicators such as indices related to the extent of selected emerged, submerged and intertidal habitats (seagrass/seaweed cover, vegetation cover and properties such as density, stiffness, height), coastal geomorphology and measures adopted to preserve that habitat (Haynes-Young and Potschin, 2013). Due to lack of data about replacement cost for damaged infrastructures and avoided cost for shoreline protection in the TI-MPA, the benefit indicator was not assessed. The emerged, submerged and intertidal habitats were 312.4 ha, 1.6 ha and 1,465.0 ha, respectively (Chimienti et al., 2017). For preventing erosion rate, marine habitats seagrass meadows such as *P. ocenica* and *Cymodocea nodosa*, as well as coralligenous bioconstructions, play a major role. The attenuation effect of *P. oceanica* on the hydrodynamics is related to the wave height attenuation, wave energy decay and reduction of the sediment transport in wave-current. In order to preserve the *P. oceanica* meadows the TI-MPA built some mooring fields with the result of hinder coastal erosion.

The seagrass meadows extension was used to assess the "Global climate regulation by reduction of greenhouse gas concentrations" ES. The annual flow indicator is the potential carbon fixation (Haynes-Young and Potschin, 2013). Assuming an annual average carbon fixation of 90.5 gC/m^2/a (Diaz Almela, 2014; Mateo e Serrano, 2011; Pergent et al., 2012), the avoided carbon emission was assessed to the 16 ha extension (Fig. 2), and an average carbon sink value of 51.9 tCO_2/a was calculated. In order to give a monetary value to the benefit, the Social Cost of Carbon (SCC) was adopted (Brander et al., 2020; Tol, 2013). The SCC is the marginal damage cost of carbon emission or the marginal benefit of reducing greenhouse gas emission (Pearce, 1993). In our analysis the SCC was assumed to be 36.92 €/tCO_2 (EPA, 2016). The applied SCC is aligned with the unit cost of CO_2eq suggested by the EC (2015) that ranges between 25 euro/tCO_2eq in 2010 and 45 euro/tCO_2eq assuming a gradual increase until 2030. Applying the SCC, the total annual benefit related to the global climate regulation was estimated at 1,916.15 € (Table 4).

The "Experiential use of plants, animals and land/sea-scapes in different environmental settings" ES referred

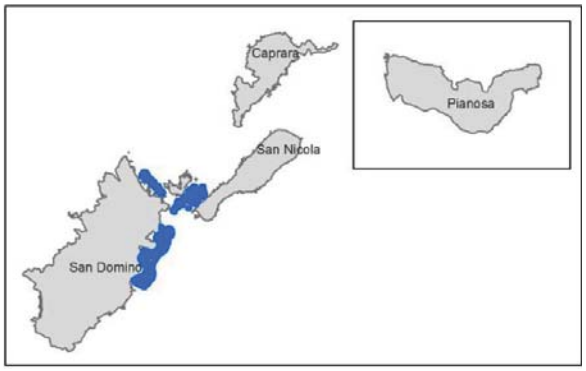

Fig. 2 *Posidonia oceanica* distribution within the TI-MPA.

Table 4 Carbon fixation and annual benefit.

	Carbon fixation (tC/a)	**CO_2 (tCO_2/a)**	**Benefit – SCC (€/a)**
Primary production	14.1	51.9	1,916.15

to the sunbathing, diving, boat renting, boating and recreational fishing activities. The analyses focused on the assessment of annual flow and benefit indicators expressed in terms of visitor flows in 2015 and willingness to pay (WTP) (Haynes-Young and Potschin, 2013), respectively (Table 5). According to official statistics, the flow was assessed. Based on ferry transfer provided by the Harbour Masters Corp located in Termoli, the excursionist reached 149 thousand units per year and, based on overnight stays in registered accommodation, the overnight stays reached 90 thousand units per year (Agenzia Regionale del Turismo, 2016). Summing up the data, the annual visitor flow amounted to about 240 thousand tourists, which spent the time in several recreational activities. In order to elicit the value tourists attach to the experience enjoyed in the TI-MPA, the WTP was assessed and a survey was carried out. To obtain these value estimates we adapted a stated preference technique called "Contingent Valuation Method" (CV) (Mitchell and Carson, 1989). This method creates a simulated market to elicit intended behavior contingent upon the change posed by the survey and assess how respondents would react to this change. A portion of the survey carried out was devoted to the description of the ES of interest to be able to elicit the monetary (Hicksian) measure of welfare (*i.e.* the maximum WTP). Although one primary concern with any stated preference method is hypothetical bias, Louviere et al. (2000) cited several studies suggesting that intended behavior can be considered a reasonable indicator of actual behavior. Our CV surveys were organized in a manner, which reflected current practice: firstly, the presentation of the CV scenario including what the intervention was designed to accomplish, how it would be implemented and paid for. We hypothesized a ban of all tourism activities and asked citizens if they were willing to pay more in they trip costs. Secondly, what will happen under the current *status quo* situation if the intervention were not implemented. Moreover, a question asking for the respondent's WTP for the ES. In detail, respondents were asked whether they would pay a predetermined increase in trip cost to continue to visit the MPA. Hanemann (1984) views the respondent as evaluating the difference in utility associated with access at an increased amount to full income but no access to MPA. If the difference in utility is positive for access, the individual would respond "Yes" and point out the amount she/he is willing to pay according to an "open-ended" format of CV (Nikodinoska et al., 2015). The questionnaire included a number of debriefing questions to help ascertain how well interviewees understood the scenario. As result, the recreational demand function was estimated from which the so-called consumer surplus was derived, *i.e.* the value that the consumer assigns to the services delivered by the MPA in excess of the fee. The survey investigated the TI-MPA value for each tourism activity. The questionnaires were submitted to 1,216 tourists randomly selected on site and invited to take part to the survey without particular sampling scheme (Grilli et al., 2016). A cheap talk was included asking respondents to reply to questions about

Table 5 Annual visitor flows and annual benefit in 2015.

Activity	Tourists by activity (n)	Sample (n)	Percentage of those who declared their maximum willingness to pay (%)	WTP (€/a)	Benefit – WTP and market value (€/a)
Sunbathing – public beach – tourists	22,424	500	32	6.83	48,973.71
Sunbathing – public beach – excursionist	148,706		6	6.87	61,266.93
Sunbathing – bathhouse	16,240	100	40	8.75	28,420.00
Diving	8,974	396	20	33.55	13,771.94
Renting boat	17,581	12		n.a.	n.a.
Boating	3,245	136		n.a.	n.a.
Recreational fishing	434	72		5.50*	n.a.
Recreational fishing – fish catches					453,712.51
Total annual arrivals	22,424				
Total annual overnight stays	90,259				
Total annual excursionists	148,706				
Total annual visitor flow	238,965				
Total		1,216			606,145.09

n.a. = not available; * = not statistically significant

WTP considering their budget constraints as they should pay in that moment.

The annual benefit was assessed by summing the WTP estimated per each tourist category (the WTP was assessed taking into account only those who declared their maximum willingness to pay) and the market value of the fish catches by recreational fishermen, reaching a value of about 606 thousand euro.

The "Scientific" ES valorized the characteristics of living systems enabling scientific investigation both on location and via other media. Annual flow and benefit indicators were assessed: the former was achieved by accounting the number of research publications and projects; the latter by accounting the budget of the research projects and the number of researchers and employees expressed in terms of full-time equivalents (fte) (Haynes-Young and Potschin, 2013). During the three-year period, the TI-MPA was involved in two projects reaching a budget of 55 thousand euro. The human resources were part-time employers counting for 6 units which summed up to 1,9 fte.

The "Educational" ES valorized the characteristics of living systems enabling education and training both on location and via other media. Based on literature (Haynes-Young and Potschin, 2013), flow indicators accounted for the number of educational projects, publications and didactic tools, visitor flows and exhibitions. Benefit indicator assessed the related revenues. The MPA managed seven educational projects during the three-year period, which involved more than 14 thousand children. Based on accounting data provided by the managing authority, the educational activities produced revenues for 79 thousand euro.

The last ES we assessed was called "Physical use of land/sea-scapes in different environmental settings". In the frame of the integrated environmental accounting model, the "Physical use" ES aimed to demonstrate that protecting nature does not contrast with the economic development and on the contrary generates wealth and job opportunities in the area. Annual flow indicator assessed marine recreation activities in regards to economic operators and employment supported; benefit indicator calculated the total annual tourism expenditures generated (Haynes-Young and Potschin, 2013). These values served to highlight how nature conservation and management policies can contribute to the local economic development. Values assessed the local socio-economic impact and have been listed separately in the TI-MPA Cost-Benefit Analysis. The economic impact of tourism can be disaggregated into direct, indirect and induced effect. Direct effect derives from tourists' spending (added value),

Table 6 Average economic operators in the three-year period (2014-2016) and average annual employment impact.

Activity	**Operator (n)**	**Employee (n)**	**Fte (n)**
Diving centers	4	13	9.3
Boat rentals	12	19	4.1
Total – direct effect	16	32	13.4
Total employment impact – direct, indirect and induced effects			22.9

Table 7 Annual tourism expenditure in 2016, indirect and induced effect.

Expenditure category	**Tourism expenditure (€)**
Main expenditure (accommodation, food, transport, parking)	11,298,460.46
Bathhouse	201,084.10
Diving guide and equipment	837,214.24
Mooring and general boat maintenance	217,271.71
Boat renting	558,580.00
Fishing license and general boat maintenance	175,112.20
Total tourism expenditure – direct effect	13,287,723.72
Total tourism impact – direct, indirect and induced effect	25,113,795.94

whereas indirect and induced effects are the contribution of tourism to income generation. They are estimated by multiplying the added value by the tourism multiplier (Fletcher, 1989). It is therefore necessary to estimate daily tourist expenditure according to spending categories. Tourism expenditure refers to the amount paid for the acquisition of consumption goods and services, as well as valuables, for own use or to give away, for and during tourism trips. As for the expenses, the employment impact was assessed. The tourism multiplier can be used to calculate indirect and induced employment created thanks to income paid to tourism workers. The income and the employment activation multipliers are yearly assessed at national level. For the purpose of this research, we referred to the 2014 and we assumed to be 1.89 and 1.71 respectively (Becheri and Maggiore, 2016).

In order to assess the flow indicator, data were collected by interviewing 14 economic operators (4 diving centers and 10 boat rentals); while for benefit indicator assessment the yearly total expenditures generated by tourists were gathered through questionnaires submitted to a sample composed by 1,204 tourists.

As regard economic operators, only diving centers and boat rentals provided official data. As shown in Table 6, 16 operators were authorized in the three-year period (2014-2016) on average. During the reference period, the economic operators hired on average 32 part-time employees of which: 13 by diving centers (8 for 1,720 hours/a, 2 for 720 hours/a 1 hired for 640 hours/a, and 2 hired for 240 hours/a) and 19 by boat rentals (1 for 490 hours/a, 10 hired for 480 hours/a, 1 for 450 hours/a, 1 for 300, 1 for 250, 2 for 240, 2 for 200, and 1 for 100). Considering that, the fte is equivalent to one person working full-time (1,760 hours annually) the employees corresponded to 13.4 fte as direct effect (9.3 by the diving centers and 4.1 by the boat rentals) and 22.9 considering the indirect and induced effect.

As regard tourists' expenditure, tourists sample was asked to provide information on some main expenses categories: accommodation, food, transport, parking and fees charged for tourism activities (bathhouse, diving guide, mooring and general boat maintenance, boat renting, fishing license and general boat maintenance). The average tourism expenditure was assessed per each category. In order to estimate a precautionary value, the averages were multiplied by the tourist flows considering only the percentage of respondents (**Table 5**). The elaboration of the data assessed the direct tourism effect that amounted to 13 million euro and, by applying the income activation multiplier of 1.89, the overall annual tourism impact within the TI-MPA raised to 25 million euro (Table 7).

Table 8 TI-MPA income statement expenditures.

Expenditures	2014 (€)	2015 (€)	2016 (€)	Average (€)
Current expenditures	228,089.09	448,848.05	238,739.39	305,225.51
Capital expenditures	114,926.82	195,940.00	123,133.95	144,666.92
Total	343,015.91	644,788.05	361,873.34	449,892.43

3.3 Accounting of income statement expenditures and assessment of environmental costs

As for revenues, expenditures were derived from the MPA income statement. For the three-year period they vary a lot with an extraordinary peak in 2015, therefore the average figure was adopted (Table 8).

Environmental costs were evaluated by assessing the impact produced by anthropogenic activities carried out within the protected area, with particular reference to the impact on global warming potential. Besides institutional activity, professional fishing and tourism were analyzed having care to focus on bathing, diving, boat renting, boating and recreational fishing. These activities represent a common subset representative of the activities usually authorized in the MPAs. Tourism generates several externalities, among which the use of motor vehicles to reach the area, and the use of complementary and accessory materials for carrying out outdoor and recreational activities. Factors related to anthropic presence (transport, consumer durables, consumer non-durables, food, etc.) contribute to the production of carbon dioxide. The valuation was based on the impact indicator and the environmental cost indicator. The first one was linked to the ES use and was represented by the 100-years global warming potential (GWP100) associated to the carried out activities. The indicator measured the overall annual CO_{2eq} tons generated by the activities. In other words, it calculated the carbon footprint along the entire life cycle of the services provided adopting the Life Cycle Assessment approach, which is based on the UNI EN ISO 14064 standard and was assessed by the OpenLCA software (version 1.7 beta) with Ecoinvent 3.3 database. Complying with the standard, the boundary was set. For the institutional activity the organizational boundary overlapped with the TI-MPA activity; for the activities authorized within the TI-MPA (professional fishing, bathing, diving, boat renting, boating and recreational fishing) the boundary included activities and related inputs of both economic operators (professional fishermen, bathhouses, diving centers, boat rentals) and users (sunbathers, divers, boat rentals, recreational fishermen). Input included in the reporting boundary were: equipment (*i.e.* boats), consumable products, energy (electricity and fuel) and water in case of managing authority and economic operators; transport fuels in case of users. End-of-waste management was not included. Data were gathered through the economic operators' interviews and the average of a range of three-year period (2014-2016) was calculated. In addition, the allocation was estimated by partitioning the input flows on the base of the ratio between the activities carried out within the TI-MPA compared to the total activity. Then, the life cycle inventory was quantified in order to assess the impact. Finally, the environmental cost indicator transformed the impact into economic value (€/a) multiplying the CO_2eq by the SCC (36.92 €/tCO_2). Table 9 shows the environmental costs linked to each activities, and the overall amount of €/a 69,765.36 environmental costs.

3.4 Building the annual flow account

The annual flow account summarised environmental costs and benefits together with MPA expenditures and revenues. Table 10 shows a total benefit produced by the TI-MPA of about 1 million euro. The accounting figures allowed calculating some main indicators, which highlighted the economic, social and environmental impact. The net benefit produced by TI-MPA and as perceived by the community amounted to about 555 thousand euro. The annual benefits-costs ratio reaches 2.1, which is a relevant result if we consider that in case of values lower than 1 we can assume that costs are too high to maintain the system. In addition, the ratio between the net benefit and the public funding is 5.0 and 1.8 considering funding for current transfer and funding for both current and capital transfer respectively. The two figures summarizes the overall value for money of

Table 9 TI-MPA annual environmental costs.

Activities	CO_2 emission ($kgCO_2eq/a$)	Environmental cost (€/a)
MPA institutional activity	8,071	297.98
Professional fishing	29,476	1,088.25
Bathing	308,383	11,385.50
Diving	65,804	2,429.48
Boat renting	637,679	23,543.11
Boating	96,501	3,562.82
Recreational fishing	743,722	27,458.22
Total	1,889,636	69,765.36

Table 10 TI-MPA annual flow account.

Costs	(€)	Benefits	(€)
Expenditures	**449,892.43**	**Revenues**	**320,132.65**
Current expenditures	305,225.51	Current transfers	200,331.08
Capital expenditures	144,666.92	Capital transfers	119,801.57
Environmental costs	**69,765.36**	**Environmental benefits**	**755,437.10**
MPA institutional activity	297.98	Wild animals and their outputs	147,375.48
Professional fishing	1,088.25	Mass stabilization	n.a.
Bathing	11,385.50	Global climate regulation	1,916.15
Diving	2,429.48	Experiential use	606,145.09
Boat renting	23,543.11	Scientific	*55,000.00*
Boating	3,562.82	Educational	*26,333.33*
Recreational fishing	27,458.22		
Total costs	**519,657.79**	**Total benefits**	**1,075,569.75**
		Net benefit	**555,911.96**
		Tourism impact	**25,113,795.94**
		Employment impact (fte)	**21.9**

TI-MPA. The annual carbon fixation respect to the carbon emission is 0.03. The low level of the ratio is related on one side to the poor extension of seagrass meadows, and on the other to the high carbon footprint of tourism activities with special regard to recreational fishing and boat renting. Finally, the tourism and employment impact, which assessed annual flow and benefit indicators of the "Physical use" ES, amounted to 25 million euro and 21.9 fte respectively.

4 Discussion and conclusion

Measuring the ES provided by the MPA is essential for nature to be taken into account in the decision-making processes. The integrated environmental accounting system can play a key role in systematically collecting information on the links between the ecosystems and the socio-economic system. The eValue model is particularly relevant when compared with similar approaches. We refer for example to voluntary environmental management instrument, such as the sustainability report published by organization about the economic, environmental and social impacts related to the everyday activities; the environmental management and audit schemes (Reg. (EC) 196/2006 amending the Reg. (EC) 761/2001) and the environmental management system (ISO 14001: 2015) designed to help any organization to assess, manage and continuously improve their environmental performance.

The first one describes positive and negative impacts of the organization, but only in qualitative and quantitative terms. The second one provides a comprehensive analysis of the organization's activities, products and services and their environmental impact and commit the organization to improve its environmental performance. The impacts are described only in qualitative and quantitative terms. eValue did a step forward. Starting from sustainability report and environmental management assessment, benefit and cost were compared, not only in qualitative and quantitative terms but also in monetary units. In addition, considering the scale level the voluntary instruments refer to the organization while eValue focuses on the area. Then, considering the approach, the voluntary instruments analyse the environmental management while eValue by aligning with the ecosystem services approach (Beaumont et al., 2018) assessed both anthropic impacts and services provided by the ecosystems. Referring to MPAs, the eValue model represents the socio-economic approach to the natural capital accounting which integrates the ecological approach or eMergy assessment (Buonocore et al., 2018; Franzese et al., 2015), by highlighting the flows of ES provided by the MPA and by assessing their value in monetary terms. Respect to the aims of the project, a number of results were reached. In terms of communication, the integrated environmental accounting model eValue demonstrated that the TI-MPA is not a limiting factor in terms of local economic development, as the benefit produced within the MPA amounts to about 1 million euro, the most part of which are economic activities related to professional fishing and tourism activities. Financial data showed that the expenditures exceed the revenues highlighting a deficit in the annual income statement. In terms of environmental policy, the financial deficit calls for public funding in terms of both current and capital transfer in order to sustain nature conservation, from which the humankind benefits in terms of valuable ES. The environmental accounting model supports public investment as against 1 euro of public funding the wealth produced by the TI-MPA is 1.8 euro.

Finally, it is useful to underline some additional elements that could contribute to improve the environmental accounting approach described here, especially if integrated environmental accounting would aim to support nature conservation management and strategy. Concerning nature conservation, Grizzetti et al. (2019) emphasised that ecosystem capacity to provide the services is always positively correlated to the ecological status. The accounting model should therefore include in the analysis adequate metrics of ES, and besides capacity, flow and benefit, the sustainability and efficiency metrics should be taken into account. In fact, sustainability and efficiency indicators are relevant to understand how the protection and restoration of the marine ecosystems support human well-being and how the exploitation of ecosystems can affect the conditions of the ecosystem. In this regard, Maes et al. (2018) and La Notte et al. (2019) suggest to use the Extent and condition accounts, *i.e.* accounts that provide information about the ecological status of the ecosystem, relevant for influencing nature conservation policy. The idea is that the Extent and condition accounts determine the ecosystem capacity to deliver service to the community (the so-called potential flow or sustainable flow) while identifying the point of no return, *i.e.* the point beyond which the use (*i.e.* the actual flow) is no longer sustainable because, by exceeding the capacity of the ecosystems, it causes its degradation.

By this approach, the environmental accounting model would be then enriched by the analysis of the ES potential flow defining the supply side, and the ES actual flow defines the demand side, in order to address the management policy resulting from nature conservation and sustainable exploitation. In this way, the supply-and-use table approach would be included in the model with the aim to identify the cause-effect relationship and ultimately the beneficiary stakeholder of the ES which, in case of actual use greater than potential use, impacts on the ecosystem. Such topics are going to be explored in next application of the eValue model.

Acknowledgments

This study was funded by Ente Parco Nazionale del Gargano-Gargano National Park Authority (Research agreement with CoNISMa 19/05/2016). GC was supported by the Italian Ministry of Education, University and Research (PON 2014–2020, AIM 1807508- 1, Linea 1).

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Journal of Environmental Accounting and Management 10(3) (2022) 269-278

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

The Impact of Cattle Grazing on Recreational Ecosystem Services in a Park Area: a Gray Water Footprint Assessment

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 3 July 2021
Available online 1 October 2022

Keywords

Gray water footprint
Cattle grazing
Nitrogen contaminants
Karst aquifer
Ecosystem services

Abstract

In park areas (PAs), restrictions on anthropogenic activities are often established to achieve the long-term conservation of nature and its associated ecosystem services and cultural values. The economic literature on freshwater ecosystem services has identified the depletion of aquatic ecosystem quality as a crucial issue, suggesting appropriate methods to evaluate this degradation in monetary terms. An alternative approach is water footprint accounting, which is employed in this study to evaluate scarcity and quality issues originating from groundwater depletion in a dynamic setting. In this study, we evaluate the impact of cattle grazing on groundwater-related ecosystem services in a karst environment located within the Monti Picentini Regional Park, located in the Campania region in southern Italy. In so doing, we guide policy makers to achieve sustainable environmental and socioeconomic management decisions for the target ecosystem to balance the competitive uses of freshwater ecosystem services in the Monti Picentini Park Area.

1 Introduction

Ecosystem services (ESs) are defined as the benefits people obtain from ecosystems and consist of the flow of material, energy and information from natural capital stocks, which enhances human welfare. ESs include provisioning services (such as water, food, fuel and fiber), regulating services (such as the regulation of floods, drought, land degradation and disease control), supporting services (such as soil formation and nutrient cycling) and cultural services (such as recreation, scenic values, spiritual values, or values that are important for cultural heritage or identity) (Millennium Ecosystem Assessment, MEA, 2005).

Mountain areas are a source of important ecosystem services. In southern Italy, karstic Apennines reliefs provide a variety of ecosystem services, and several regional parks have been established there to preserve the natural capital stocks and related services. The implementation of protected areas (PAs) mandates that restrictions to anthropogenic and productive activities are set, in accordance with the specific territory's characteristics,

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials © 2022 L&H Scientific Publishing, LLC. All rights reserved.
DOI:10.5890/JEAM.2022.09.005

and is enforced by the authority in charge of the park management. PAs, like those presented in our research, are clearly defined geographical spaces that are recognized, dedicated and managed through legal or other effective means to achieve the long-term conservation of nature and its associated ecosystem services and cultural significance (Dudley, 2008). They have an important role in conserving geobiodiversity, which provides important recreational and cultural services, by enhancing the resilience of vulnerable human communities to cope with natural disasters and promoting human health and well-being (Stolton and Dudley, 2010). They are found in all countries, but some countries and regions (e.g., Africa, South America, Australia, Greenland and Russia) contain a few very large reserves, whereas other regions (e.g., Europe) tend to have a higher number of smaller protected areas. Most areas are on land and collectively protect a surface area equivalent to 14.9% of the world's terrestrial space. Marine protected areas, despite being fewer in number, represent 7.3% of the world's oceans (UNEP-WCMC & IUCN, 2018).

Information about ESs provided by PAs can be useful to drive decision making and support the protection and management of natural ecosystems to ensure the ongoing sustainable and fair flow of services to current and future generations. In recent years, the growing interest in understanding the ESs associated with PAs has resulted in the development of an array of ES assessment tools. Each tool is different, based on diverse approaches (qualitative, quantitative, monetary, nonmonetary) and selected for specific purposes. They all provide an opportunity to shed light on ecosystem service issues and support management and policy decisions.

Regarding freshwater ecosystem services, such as those that are the focus in the present study, PAs, if well managed, can show improvements in the water quality and, in some situations, the quantity of available water. Indeed, the economic literature has identified the degradation of water ecosystem quality as a crucial issue (Koundouri et al., 2016). In such circumstances, water quality depletion results in the deterioration of the total economic value of the resource, the intensity of which has typically been evaluated in monetary terms by means of appropriate evaluation techniques (for instance Koundouri and Davila, 2015).

An alternative approach to monetary quantification methods is water footprint accounting, which allows to evaluate the quantity and quality issues originating from groundwater depletion in a dynamic setting. The use of water footprint accounting methods is largely employed in studies dealing with sustainable water uses at the river basin level (Pellicer-Martínez and Martinez-Paz, 2016; Taffarello et al., 2020). The use of the gray water footprint (GWF, hereinafter), in particular, is well suited for evaluating the impact of anthropogenic activities on groundwater-related ecosystem services, as defined recently by Tuinstra and van Wensem (2014).

In this article, by using the concept of the environment-related gray water footprint as introduced by Allocca et al. (2018), we examine the effect of cattle grazing on ambient water quality in a karstic environment located within the Monti Picentini Regional Park in the Campania region, southern Italy. Water uses documented in the area of study refer to in-stream uses, namely, cattle grazing and recreational activities, such as picnicking, by the stream. As the analysis of the data available in the study area will show, cattle grazing has a remarkable polluting impact on the natural capital and the ecosystem services provided by the examined karstic environments, which we quantify in terms of the GWF. Livestock grazing may reduce the quality of ecosystem services associated with habitat provision, biodiversity and soil and water functions. Management of livestock grazing will be critical if we are to retain functional levels of ecosystem services into the next century (Eldridge et al., 2017) and, as a result, we should consider all the factors impacting the effects of grazing, such as the type of herbivore, intensity of grazing pressure, level of plant productivity and the site-level productivity (Eldridge et al., 2016). Provided that traditional cattle grazing is listed among the permitted productive activities by the authority of the Monti Picentini Regional Park, our results indicate that the approach of preserving ecosystem services through means of simple regulation might not be enough to guarantee their full preservation.

The remaining part of the article is organized as follows: Section 2 describes the study area, and the water footprint computations are detailed. Section 3 provides and discusses the main results of the research, while Section 4 concludes the article.

2 Materials and methods

2.1 The study area

The Monti Picentini Regional Park area hosts a valuable natural resource, a karstic environment, providing a series of ecosystem services ranging from provisioning services, such as drinkable water supply, to cultural services, such as spiritual, recreational, cultural and heritage related benefits. The rich variety of habitats in the park – Mediterranean forests and grasslands, groundwater bodies, karst lakes and springs and rocks – contributes to its variegated hydrogeo- and biodiversity. The Monti Picentini Regional Park is a nature reserve protected under the Natura 2000 program, which consists of a network of sites selected under the Habitat Directive (the Council Directive 92/43/EEC of 21 May 1992) to ensure the long-term survival of Europe's most valuable and threatened species and habitats.

The study area for this article is the Acqua della Madonna experimental site, located in the southern sector of the Mount Terminio karstic aquifer within the Monti Picentini Regional Park at an altitude of approximately 1200 m.a.s.l. (Allocca et al., 2008; Allocca et al., 2015; De Vita et al., 2018). Within the study area, the existence of highly permeable rocks and groundwater circulation through the karstified aquifer media implies a high vulnerability to groundwater pollution (Tufano et al., 2020) and that significant quantities of contaminants can be rapidly transported in the subsurface, albeit with a discontinuous time distribution, affected by the precipitation regime (Allocca et al., 2008). Among the activities generally allowed within the limestone aquifers in the southern Apennines, cattle grazing can act as a source of chemical (and bacterial) contamination in the groundwater and perennial springs, despite the existence of a soil pyroclastic that overlies the calcareous material (Celico et al., 2010; Naclerio et al., 2009; Bucci et al., 2015a; Bucci et al., 2015b; Allocca et al., 2018). The Acqua della Madonna experimental site is a valuable test site used to investigate and quantify the effects of anthropogenic activities on vulnerable natural resources. The site holds a compartmentalized perched karst groundwater body that feeds several high-altitude springs (Allocca et al., 2008; Allocca et al., 2015). The subbasin of spring S2 (Fig. 1) is of prime interest in this study as it contains a small endorheic karstic plain where grazing occurs (Podolica breed, approximately 300 heads, Fig. 1). Grassland is the predominant land cover in the karst plains, whereas deciduous forest (Fagus sylvatica L.) is the main land cover along the hillslopes. Boreholes collected in the plain (Fig. 1b) show that the water table is on average less than 10 m deep (Fig. 1). This causes a rapid response time of perched karst aquifer and spring S2 to rainfall, with a time lag of a few days (Allocca et al., 2008; 2015). Groundwater recharge of the perched karst aquifer mostly occurs from September to May by diffuse-direct net infiltration (autogenic recharge) of precipitation and percolation through the vadose zone and epikarst and concentrated-secondary infiltration (allogenic recharge) of local runoff formed within the endorheic area.

The climate of the Acqua della Madonna test site is of a Mediterranean mild (CSb) type (Geiger, 1954). The mean annual air temperature is 8.4 °C, and the mean annual rainfall is approximately 1730 mm, whereas the average annual groundwater recharge is 1280 mm, which is approximately 74% of the mean annual precipitation (Allocca et al., 2014). From December to March, there is intermittent and uneven snow cover within the pasture areas and on the carbonate slopes since snowfall alternates with rain.

Grazing is an anthropogenic source of groundwater chemical and microbial contamination transported into the groundwater body by infiltration; the flat morphology of the pasture area and the absence of outwards runoff processes imply that all the contaminants are transported into the groundwater body by infiltration and then flow into spring S2. Therefore, measuring the groundwater quality at spring S2 provides a complete and reliable depiction of the degree of pollutant loading due to grazing. However, this contamination can be detected only through expensive daily/weekly water analysis using reliable indicators.

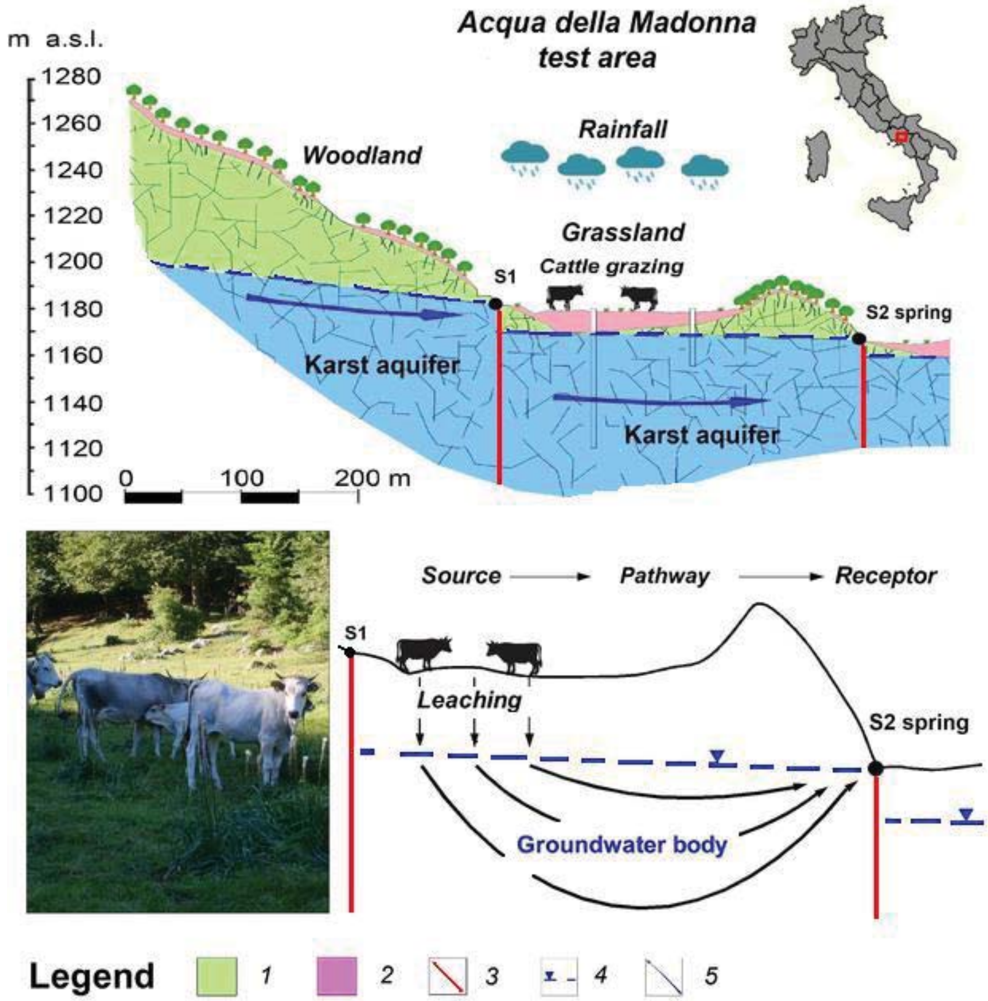

Fig. 1 Hydrogeological section of Acqua della Madonna experimental site and source-pathway-receptor conceptual model for the mechanism of chemical contamination (NO_2) of the groundwater body and S2 spring (Allocca et al., 2018, modified). Key to symbols: 1) Limestone karst aquifer; 2) Pyroclastic-fall deposits; 3) Faults; 4) Water table level; 5) Groundwater flow direction.

2.2 Data monitoring

Daily precipitation was recorded by a meteorological station for the hydrological year corresponding to September 2001-October 2002. For the same period, the discharge of the S2 spring was measured weekly or daily with a flow meter (SIAP-MICROS Inc., Italy). All discharge measurements were taken at the outlet of the Acqua della Madonna spring. Water samples for chemical analyses were collected weekly at the S2 spring to measure the concentrations of nitrate and nitrite (mg/L). Daily monitoring of groundwater quality was undertaken for a period of approximately two weeks in November 2001 and April 2002 to better investigate how pollution has been affected by hydrogeological dynamic processes.

2.3 A biophysical approach to environmental accounting: the gray water footprint

The water footprint (WF) is a measure of the human appropriation of global freshwater resources (Hoekstra et al., 2002). Built on the concept of "embedded water" or "virtual water" developed by Allan (1998), it is a multidimensional indicator of the total use of freshwater resources, looking at both the direct and indirect water use of a consumer or producer, and is specified at different levels of spatiotemporal detail. In this respect, it differs from traditional water consumption statistics, mainly focused on measuring “water withdrawals” and “direct water use”, since it considers water consumption as opposed to withdrawal.

According to Hoekstra et al. (2011), three subcategories of the water footprint can calculated. The blue WF component refers to the use of ground and surface water, whereas the green WF takes into account the amount of rainwater stored in soil as soil moisture used by plants. Finally, the third component, the gray water footprint (GWF), considers polluted water, i.e., the volume of freshwater necessary to allow receiving water bodies to assimilate pollution loading resulting from anthropic activities so that acceptable water quality standards are met. Therefore, the GWF is not the real water volume used during production but rather an estimated measure of the potential water needed to restore water quality impaired by production processes.

Some researchers have questioned the need to include the gray component in the measure of water use, since it is a fictional measure of water pollution that does not reflect a consumptive use of water or pollution treatment costs and is difficult to determine as the actual extent is largely dependent upon hydrology and water quality standards (Chenoweth et al., 2014). In this article, by using the concept of the environment-related gray water footprint as it was introduced by Allocca et al. (2018), we circumvent these concerns, since we provide a direct measure of the amount of polluted freshwater, in terms of chemical/nitrogen contamination, associated with cattle grazing in the karst environment of the southern Apennines (Italy).

It is widely acknowledged that livestock farming is among the major anthropogenic sources of inorganic nitrogen in aquatic ecosystems (Camargo and Alonso, 2006) along with the use of animal manure as fertilizer. Regarding the latter, Seeling and Nowatzki (2001) recommend the use of dry manure in sandy or gravelly soils that overlay shallow groundwater as a good management practice because NO_3 dissolved in water can be readily leached through the soil profile into groundwater[a]. However, a less debated topic is the effect of nitrogen leaching originating from cattle grazing. In the WF literature, grazing systems, when compared to conventional farming, have a lower impact in terms of the direct water footprint related to their service water consumption (Mekonnen and Hoekstra, 2012).

The existing WF accounts for livestock have determined that the main contributions originate from the green WF component (Mekonnen and Hoekstra, 2012; Gerbens-Leenes et al., 2014), with a negligible impact from the gray component. When considering studies that focus on dairy production systems, the gray component becomes important, especially due to its possible impacts in terms of eutrophication (Palhares and Mezzopane, 2015). In contrast to previous studies that has investigated the WF of livestock, which have suggested that cattle grazing has a limited impact on the gray water footprint (REF), Allocca et al. (2018) found that there is a nonnegligible effect from microbial contamination, precisely for fecal coliforms.

In the studies that have examined the WF resulting from the production of animal products, the focus has generally been on the green component, which originates from the feed necessary for animal farming. In this sense, existing studies emphasize that animal products from grazing systems have a smaller water footprint, mostly related to the blue component (Mekonnen and Hoekstra, 2012). Regarding the gray component, grazing production systems are generally identified as having no gray water footprint. The gray water footprint represents the virtual water needed to absorb the contamination loading. In general, the GWF is calculated through an indirect approach, namely, by using an estimated leaching coefficient, consistent with the tier 1 method (Franke et al., 2013):

$$\mathrm{GWF} = \frac{L}{C_{\max} - C_{\mathrm{nat}}} \tag{1}$$

where L is the pollutant load and C_{nat} and $C_{\max}$ are the natural and maximum acceptable concentrations of the considered pollutant, respectively. The latter can vary according to the use of the water resource. To calculate the gray WF, it is necessary to establish which pollutant is under consideration and what the use of the water resource is. In this study, we consider NO_2 (nitrite), and we restrict our attention to recreational water uses to determine the acceptable concentration of nitrite.

Following the approach recommended by Allocca et al. (2018), the employed WF metric used in this study

[a] Seeling and Nowatzki (2017) provide a very effective representation of the nitrogen cycle.

is the environment-related grey water footprint, $GWF_{env.}$ This is used as a direct measure of the pollutant load, which is obtained jointly by examining the following:

1) the duration of chemical contamination, i.e., the number of weeks during which nitrite contamination is detected in the water samples;

2) the amount of water that flows out of the groundwater body during the period of active contamination, as measured through the monitoring of spring discharge.

Hence, the direct approach of measuring GWF_{env} neutralizes one of the main criticisms levelled at the GWF, namely, the difficulty in determining how much freshwater will be contaminated by polluted water (Nazer et al., 2008).

The formula employed for $GWF_{env(l/s)}$ quantification is as follows:

$$GWF_{env(l/s)} = Q^*_{(l/s)} \frac{\left(\sum_{j=t}^{T} N_{j(mg/l)}\right)}{(T-t)} \frac{1}{(N_{\max} - N_{\text{nat}})mg/l} \tag{2}$$

where t denotes the first week of contamination, or the first week during which the concentration of nitrite N_j exceeds the threshold $N_{\max}$, T denotes the last week of observed contamination, and Q^* is the average spring discharge during the interval of contamination, $[T-t]$. Therefore, the numerator of Equation (2) is a direct measure of the pollutant load originating from cattle grazing. The interval of contamination is composed of several subperiods of contamination, each of which includes only the weeks with a level of contamination above the chosen water quality standard. In this study, we adopt as the maximum acceptable concentration the standard provided by the gray water footprint accounting (Franke et al., 2013) referring to ambient water quality standards for a receiving freshwater body. The recommended threshold for nitrite is 0.06 (mg/L), which is based on the guidelines established for the protection of aquatic life as proposed by the Canadian Council of Ministers of the Environment. This is a suitable measure for preserving the recreational value of the study area, where the spring feeds a stream and a small karst lake.

3 Results and discussion

3.1 Nitrite contamination and hydrological processes

To determine the drivers of chemical contamination triggered by cattle grazing in the study area, we first inspected the pollution dynamics in two different periods for which we had daily monitoring data: late November 2001 and April 2002. In both periods, no cattle grazing occurred; however, in November 2001, a herd of cattle had just left the small plain between springs S1 and S2 (Fig. 1), whereas in April 2002, the arrival of cattle in the area had not yet occurred.

In Fig. 2, we compare the patterns of NO_2 concentration detected in the groundwater with those of the effective rainfall and regime discharge of the S2 spring. As shown in Fig. 2, the two periods differed according to the pluviometric and discharge regimes. In November 2001, we observed a recession phase in the discharge, with no effective infiltration and transport of new contaminants (Fig. 2a). In the Fig. 2a graph, either the discharge and chemical concentration curves are flat, in proximity to zero. In contrast, in April 2002 (Fig. 2b), a recharge phase in the spring discharge, with episodes of effective infiltration, implies that NO_2 contamination is quite high and above the 0.6 mg/L concentration (the ambient water quality standard recommended by Franke et al., 2013). For the same level of pollutant loading in the study area, daily monitoring confirms that contamination is determined by recharge processes within the groundwater body related to the pluviometric regime.

In the next section, we will show how these patterns shape the assessment of the GWF.

Fig. 2 Nitrites contamination at spring S2, precipitation and S2 spring discharge. Interval of monitoring: a) November 2001; b) April 2002.

3.2 Assessment of the livestock GWF

In the September 2001-October 2002 hydrological year, a total of 5 episodes of NO_2 contamination were recorded, as listed in Table 1. For each of these episodes, we extract the necessary data required to calculate the impact of cattle grazing in terms of GWF, consistent with Equation (2).

As is clear from the data shown in Table 1, the contamination largely varies over the hydrogeological year. As expected, the largest GWF_{env} is associated with episodes of contamination related to high discharge regimes. The first three episodes of contamination recorded during the period of September-November 2001 all showed minor intensity compared to those recorded in spring of the hydrogeological year of 2001-2002. The GWF_{env} results in a range of 0 to less than 3 m^3 per cattle unit. In contrast, in the spring of 2002, episodes 4 and 5 were shown to be of considerable intensity in terms of the GWF_{env}. Episode 4, in particular, is characterized by a level of NO_2 contamination steadily above the ambient water quality standard of 0.06 mg/l for 8 consecutive

Table 1 Gray water footprint accounting.

	Episode 1 12-19 Sept. 2001	Episode 2 15-22 Oct. 2001	Episode 3 22-29 Nov. 2001	Episode 4 18 Mar. -13 May 2002	Episode 5 24 Jun. -2 Jul. 2002	Total
Spring discharge (L/s)	0.321	0	0.752	25.6	14.0	
Nitrite (mg/L)	0.22	0.17	0.06	0.20	0.61	
Duration (weeks)	01	01	01	08	01	
GWF_{env} (m^3/cattle)	2.85	0	1.82	1683	342.4	2030

weeks. The observed concentration of NO_2 ranged between a low value of 0.07 mg/L at the beginning of the episode (March 2002) and a high value of 0.37 mg/L recorded at the end of April 2002, with an average recorded contamination of 0.2 mg/L.

Therefore, the gray water footprint of the cattle is quite high since the average estimated GWF_{env} is 2,030 m^3 per cattle unit, a higher value than that estimated by Allocca et al. (2018) with regard to microbial contamination.

In the absence of monetary metrics for evaluating the ecosystem services of park areas, their total economic value is difficult to quantify. In such circumstances, the use of a physical metric, such as application of water footprint accounting, can assist in the choice of appropriate resource management strategies that aim to protect natural capital and its ecosystem services. The specific valuable contribution provided by the gray water footprint lies in the fact that it is not only quantitative deterioration that is a threat to the sustainable management of resources but also its qualitative deterioration. This is consistent with the approach advocated by the Water Framework Directive aiming to achieve a good water status (in terms of both quantity and quality) and suggesting conducting analysis in accordance with the polluter pays principle (Koundori and Davila, 2015).

The results of our quantification of the gray water footprint for grazing activities indicate that maintenance below a qualitative threshold, consistent with the recreational use of groundwater in karst areas, can be threatened by the grazing activity of podolic cows, as previously documented in the Apennines shallow water ecosystems (Solomini et al, 2000; Ruggiero et al, 2004).

4 Conclusion and policy implication

The management of protected areas needs to balance socioeconomic values, such as the needs of local communities, with environmental and social values. In the contemporary perception, protected areas are viewed as providers of ecosystem services, among which recreational areas play an increasingly important role.

In many cases, the conservation of biodiversity values of these sites will contribute to enhancing the provision of ES; however, it is important to recognize that the overexploitation of certain ESs (e.g., unsustainable grazing) might conflict with the conservation objectives at these sites.

The local authority of the Monti Picentini Regional Park, one of the largest regional parks in Italy, once made aware of the water footprint accounted for in this study, would be faced with the need to intervene to control the negative effects that cattle grazing, a productive activity for the local community, emplaces on water quality.

Our evidence suggests that the current approach of preserving ecosystem services by the local authority of the Monti Picentini Regional Park might not be enough to guarantee full preservation. Two possible (and alternative) policies that could be adopted to preserve water quality are i) introducing restrictions to cattle grazing and creating an appropriate drinking water system elsewhere in the endorheic karst plain and ii) imposing periodic cleaning events in the endorheic karst plain. As is often the case in public regulation, the optimal response strategy is a matter of balancing competitive uses of public goods, represented here by water quality.

Acknowledgements

The Authors are grateful to two anonymous Reviewers for helpful comments and suggestions. Vincenzo Allocca acknowledges financial support from Department of Earth, Environmental and Resources Sciences, University of Naples Federico II (Departmental Research, 2018). Elisabetta Marzano acknowledges financial support from University of Naples "Parthenope" (Research Programme, 2016-2018). Usual disclaimers apply.

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Journal of Environmental Accounting and Management 10(3) (2022) 279-297

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Reporting Marine Microplastics Data: the Need for a Standardized Protocol

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 4 July 2021
Available online 1 October 2022

Keywords

Plastic pollution
Marine ecosystems
General reporting protocol
Microplastics
Marine litter

Abstract

Marine microplastics have become an issue of great concern at the global level. The attention towards the issue of marine microplastics, highly recognized by international policy and scientific research, has increased considerably over the last decades. At the European level, several initiatives have been promoted addressing the reduction of plastic pollution as a high priority target, among which the *Marine Strategy Framework Objective (D10)* and the *European Strategy for Plastics in a Circular Economy.* In addition, researchers have explored many strategies to optimize the detection and monitoring of microplastics in sediments, seawater, and organisms and to effectively demonstrate their potential ecological harm. However, since pollution dynamics, the functioning of natural ecosystems, and their relationships are very complex, there still lacks a comprehensive understanding of the impacts of microplastics on marine ecosystems. This lack of knowledge may impact the effectiveness of decision-making processes in terms of plastic reduction and waste management. In this study, we present the results of a literature review which focuses on particularly impactful marine microplastic methodological and analytical articles from 2004 to 2017 to identify possible gaps or inconsistencies in the reported data. Based on this review, a framework for a general reporting protocol (GRP) is outlined to encourage increased collaborative research efforts to harmonize the reporting of microplastics data in scientific studies. The proposed GRP outline could be useful in addressing data needs for effective ecological risk assessment.

1 Introduction

Marine microplastics (MPs) have become a global environmental issue, posing serious threats on ecological and human health (Sharma and Chatterjee, 2017). The Mediterranean Sea is considered one of the greatest plastic

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials
DOI:10.5890/JEAM.2022.09.006

accumulation zones in the world along with the 5 gyres (Suaria et al., 2018). There are roughly 320 million inhabitants along the coast of the Mediterranean Sea and their activities lead to tons of plastic polluting the sea each year. While several initiatives have been promoted to address the reduction of plastic pollution, such as the *Marine Strategy Framework Objective (D10), European Strategy for Plastics in a Circular Economy,* and banning of single use plastic in Europe, plastic continues to accumulate in marine ecosystems.

The attention towards this environmental issue is clearly increased in the scientific research (Pauna et al., 2019). In recent years, researchers have explored many ways to optimize the detection and monitoring of microplastics in sediments, seawater, and organisms to effectively demonstrate their potential ecological harm. However, there still lacks a comprehensive understanding of how microplastics are transferred towards marine trophic webs, affecting natural capital stocks and their capacity to provide ecosystem services on which human well-being relies (Buonocore et al., 2018, 2019; Pauna et al., 2018; Renzi et al., 2018).

Pollution, the functioning of natural ecosystems, and their relationships are very complex issues. Nonetheless, several tools exist to support scientists and decision makers in identifying and predicting the potential future impacts of plastics on marine ecosystems.

1.1 Research efforts for quantifying anthropogenic pressure on marine ecosystems

The Intergovernmental Panel on Climate Change (IPCC) provides decision makers with prediction models to show the potential impacts of greenhouse gas (GHG) emissions. These prediction models are based on high-quality data collected at the global scale. However, gathering this data requires strong collaboration among numerous scientists involved in diverse fields of study. This type of global and interdisciplinary collaboration can be complicated, especially if there is a lack of clear guidelines for the contributing scientists.

Meanwhile, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), established in 1969, provides the United Nations (UN) with scientific information on marine environmental protection. GESAMP WG40 consists of a group of experts who come from a wide range of relevant disciplines and continue to contribute to the scientific research on marine litter and microplastics.

The International Union for Conservation of Nature (IUCN), a membership Union composed by both government and civil society organizations, works to provide information about the status of the natural world and measures for its protection. The IUCN has contributed extremely valuable reports to the scientific community and decision-makers including a review of plastic footprint methodologies “Laying the foundation for the development of a standardized plastic footprint measurement tool”. The IUCN recognizes that without a comprehensive understanding of the impacts of an anthropogenic pressure, we cannot know what to expect, given the current state of the marine environment. Also, it is not possible to predict how the state of the marine environment will change if we continue business as usual. This lack of knowledge may impact the effectiveness of decision-making processes in terms of plastic reduction and waste management. Meanwhile, as plastic production continues to grow, the Mediterranean Sea is filled with more and more plastic every day. In other words, the problem is growing at a concerning rate while scientists are forced to wait for more and better data.

While the IPCC has been able to quantify the impacts of GHG emissions, experts in the microplastic field have not yet been able to offer this kind of broad information. One of the main reasons could be that microplastic research is still relatively young as was demonstrated in a bibliometric analysis conducted by Pauna et al. (2019) which showed that significant research interest regarding MPs did not occur until 2013. In addition, there appears to be a problem related to the availability of the “right” data needed to understand the impacts of MPs on marine ecosystems. In particular, data which contains an adequate level of detail such that it can be compatible with other relevant analyses (Cowger et al., 2020). In this regard, future research efforts should be devoted to providing MPs data of a standardized level of detail.

According to the literature investigated in this review, most methodologies, standard operating procedures (SOPs), and experimentation in general have been focused on optimizing extraction of the MP particles from samples and assessing different aspects such as the overall % recovery and overall % digestion of organic matter. Meanwhile, recent studies already show that there is a potential for MPs to cause ecological harm and highlight the key data needs for understanding potential consequences of MPs at the ecosystem scale (Galloway et al., 2017). The mentality that there could be a one-size-fits-all procedure for microplastic sampling and analysis does not appear to be effective in terms of understanding and addressing the impacts of MPs generated at the ecosystem level. This could be due to the complexity of MPs pollution, arguably on the same scale of complexity as GHG emissions (Borrelle et al., 2017). Similar to how the IPCC was aware that as emissions continued to increase, so would the potential for irreversible damage, MP researchers are becoming more aware that as populations grow and plastic waste continues to be mismanaged, marine ecosystems are expected to be exceedingly pressured.

Miller et al. (2017) conducted a review on methodologies for microplastic assessment with the aim of providing recommendations to establish reproducible microplastic methodologies. Lusher et al. (2017) reviewed existing methodologies to find the pros and cons of each methodology in terms of their potential to damage microplastics in the samples. Finally, Burns and Boxall (2018) conducted a literature review to highlight the urgent need for performing high quality and more holistic monitoring studies along with environmentally realistic effects studies.

In this study, based on these three reviews, a literature review of 48 recent methodological and analytical articles was conducted to determine possible gaps or inconsistencies in the reported information. Based on the findings of the literature review in this study, an outline for a general reporting protocol (GRP) was developed to encourage future research efforts to focus on the standardization or harmonization of the reporting of microplastics data. In addition, examples of methods used by the co-authors for currently unpublished microplastic sampling and analysis of Mediterranean organisms, sediment, and seawater are listed. The proposed outline is intended to support the development of effective models capable of predicting the impacts of microplastics on marine ecosystems.

2 A review of methodologies for microplastics assessment

The articles in the literature review were chosen based on a thorough review article published by Miller et al. (2017) which focused on best practices of microplastic extraction and assessment. Among the articles reviewed in Miller et al. (2017), only those related to field samples were considered for this study. These selected articles were then re-reviewed to explore how the researchers defined the term “microplastics”, what reporting units were used, and how or if shape, color, polymer type and size were specified. Finally, a lack of standardization in data reporting is demonstrated via statistical graphs which represent the diverse reporting units and various MP particle details found within the reviewed articles. The purpose of this approach was to ensure that the articles reviewed in this study are those which have contributed valuable information to microplastic extraction protocols and are already considered among the most used and accepted methods for extracting and analyzing microplastics in the marine environment.

Based on this literature review, it was found that existing publications on MPs show great variability in the information that is reported as well as the reporting units. This variability is not only the result of studies being focused on different samples (i.e., sediment vs. seawater vs. biota), but is also likely due to the lack of a standardization for the reporting units, which was clearly variable even within the sole investigation of marine individuals, sediment, and seawater (Figure 1).

The reporting units for the marine organisms ranged from being reported as the number of MP particles per individual, to the percent of individual that ingested at least one MP particle, or the number of particles per wet weight of individual. In the case of sediment, the number of particles per dry weight of sediment or per wet weight of sediment is reported, and in some studies the number of particles per volume of sediment and the number of particles per area of sediment is reported. Seawater studies also show variability in reporting units. Given the various reporting units found among the reviewed articles, it appears that there is lack of consistency in the reporting of microplastics data. Furthermore, given that some MP research studies did not specify units when reporting observed MP particles, it could be possible that it has not yet been made clear to the scientific

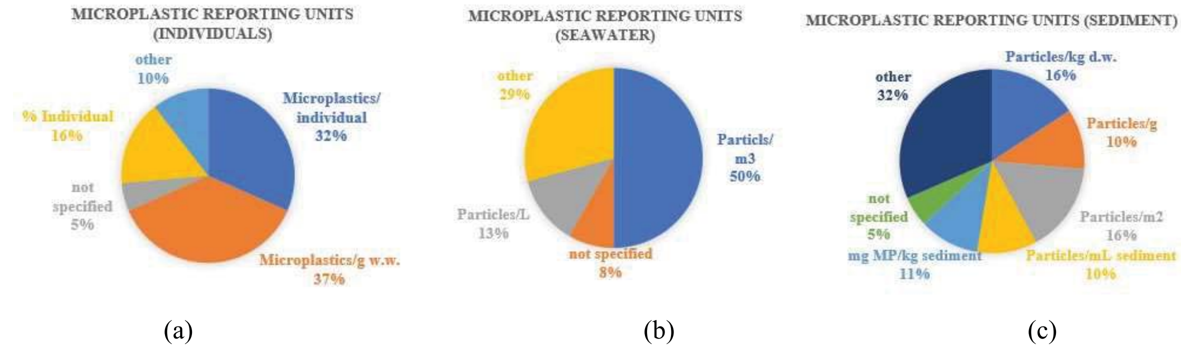

Fig. 1 Statistical graphs representing the various reporting units used in recent articles focusing on methodologies for microplastic extraction and analysis. The percentage of articles that did not specify reporting units are included in each chart. a) Reporting units used in studies focused on MPs found in individuals. b) Reporting units used in studies focused on MPs found in seawater. c) Reporting units used in studies focused on MPs found in sediment.

community the importance of this detail in ensuring that valuable findings can be used to foster the development of larger scale risk assessment of the presence of MPs in marine ecosystems.

Another crucial aspect to be considered in MP research is whether the results of a study discuss the morphology (size, shape), color, and polymer types found. The literature review showed that, in several cases, the shapes and colors of the microplastic particles were not specified (Figures 2 and 3, respectively). Color could be useful information for researchers to investigate the pollution source of MP particles (Wagner et al., 2018) and shape has been shown to be relevant in understanding the behavior of MP particles in the environment (Khatmullina et al., 2019). While these pieces of information might not be directly related to the research study which presented the data, it could be useful for other researchers in the field and, therefore, it might be worthwhile to report characteristics like shape and color if available.

Most studies in the review discussed the size of the particles, but the sizes are typically provided in the form of a range and there is not always clarity on whether the size is diameter, length, or some other measurement (Figure 4). While the morphology of MP particles is complex, size has been shown to be relevant when considering the probability and consequences of a marine species interacting with MPs (Courtene-Jones et al., 2017; Li et al., 2016; Hartmann et al., 2019). Furthermore, the polymer types are not always reported, despite some MP experts expressing its importance in understanding the origin and fate of plastics (Eerkes-Medrano and Thompson, 2018; Li, 2018) and others highlighting the relevance of polymeric composition in terms of the interaction between MPs and sediment and marine organisms (Haegerbaeumer et al., 2019; Porter et al., 2018; Sharma and Chatterjee, 2017).

The literature review also demonstrated that there is not a univocal definition for “microplastics”. In some cases, different researchers utilized a definition from the same source, but displayed or interpreted the definition in different ways. This result can likely be attributed to the difficulties that MP experts face when searching to agree on a definition and characterization of this form of marine litter (Hartmann et al., 2019). While a univocal definition can be helpful in ensuring that members of the scientific and regulatory communities are on the same page during discussions of marine litter focused on MPs, it remains a challenge for experts to reach a consensus given the complexity of the particles.

The specifics of size, morphology, color, and polymer type are crucial information for understanding the many possible implications of ingestion of the microplastics by marine organisms or the ability of the particles to release toxins into the environment or adsorb other chemical compounds in the marine environment (Santana et al., 2016).

Following the performed review of existing studies on marine MPs, an outline for a General Reporting Protocol (GRP) is proposed that can be used by researchers to standardize the reporting of data on microplastics while supporting modelers to assess the impacts of plastic pollution on marine ecosystems.

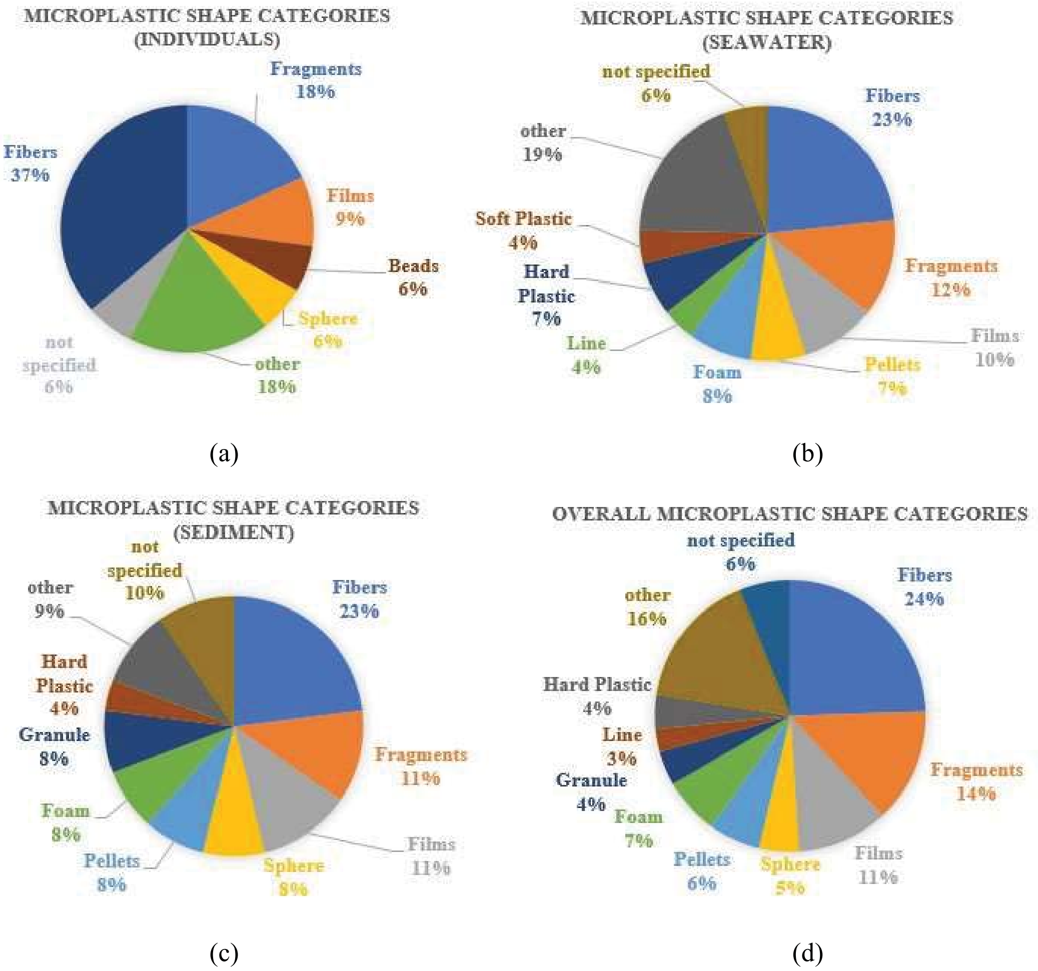

Fig. 2 Statistical graphs representing the various shape categories reported in recent articles focusing on methodologies for microplastic extraction and analysis. The percentage of articles that did not specify shape categories is also displayed. a) Shape categories used in studies focused on MPs found in marine organisms. b) Shape categories used in studies focused on MPs found in seawater. c) Shape categories used in studies focused on MPs found in sediment. d) Overall variation in shape categories considering all types of samples.

3 General reporting protocol recommendation

3.1 Microplastic classifications

The microplastic classifications that are considered in the proposed GRP outline are developed based on categorizations regarding polymers, morphology, sizes, and colors which have been used to report MP findings in the literature (for example, the polymer library created from the TARA expedition and presented in Kedzierski et al. (2019)). These polymer classifications have their own μFTIR library available with the POSEIDON microplastic analysis software (Kedzierski et al., 2019). The reason for using this particular library is due to its connection with the Mediterranean Sea which is where the researchers are currently investigating marine MPs. Meanwhile, the suggested size range categories are based on Frias and Nash (2018) but altered to avoid double counting sizes. The reason for considering the Frias and Nash (2018) size category recommendations is to encourage comparability among studies. Shape classifications are determined based on Porter (2018) and Khatmullina et al. (2019). Finally, color classifications are determined based on the RAL color chart for plastics which is used for the coloration of plastic products in European industries (RAL PLASTICS, 2020).

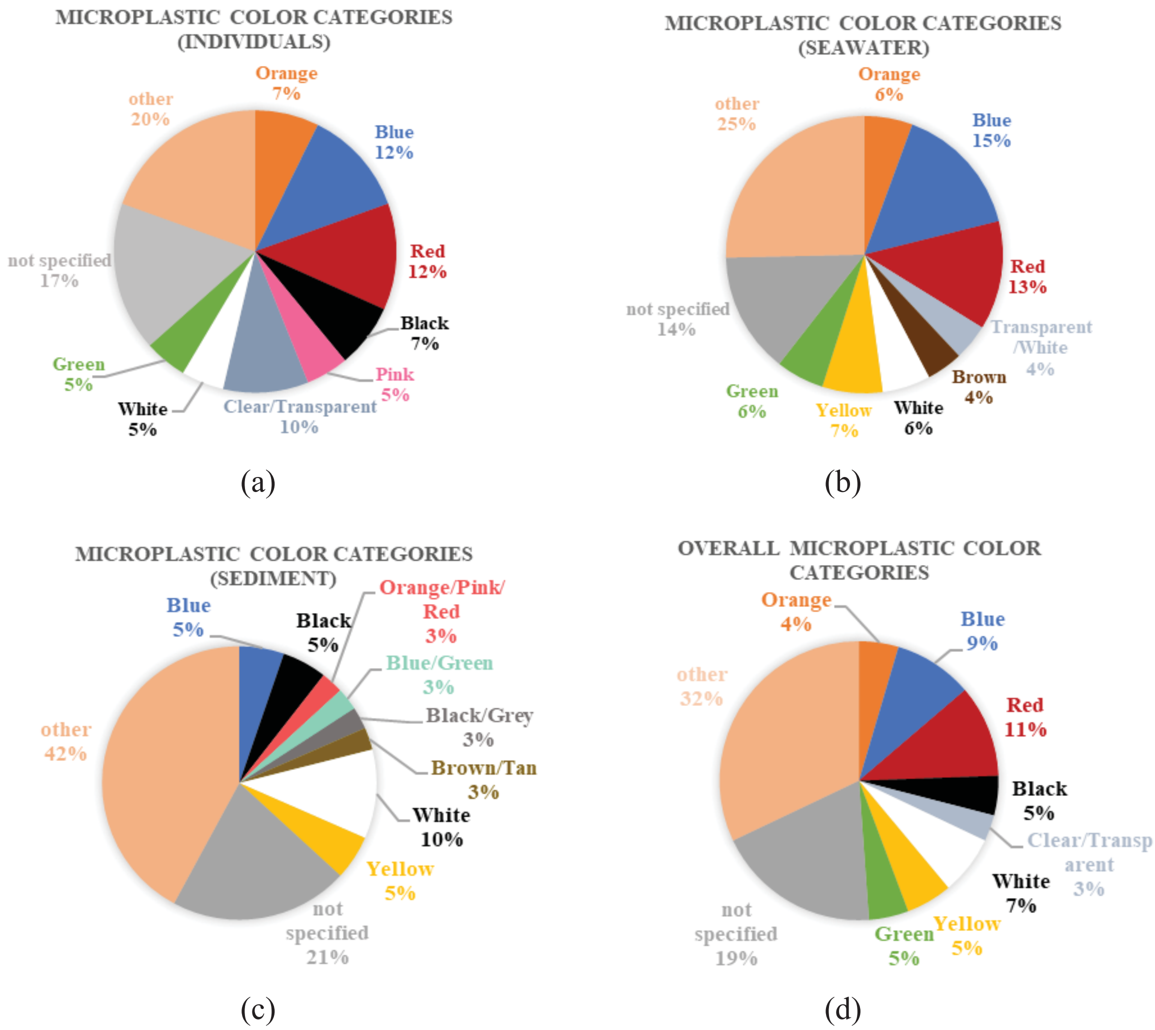

Fig. 3 Statistical graphs representing the various color categories used for reporting microplastics and the frequency of use of these categories for samples of a) marine organisms, b) seawater, and c) sediment. Chart d) represents the overall variation in shape categories considering all types of samples. The "other" category includes the color categories which had a low frequency of use with respect to the other categories; each color category used in the articles reviewed can be found in Appendix I.

3.1.1 Size range

When the MPs are categorized it could be useful from a reporting point of view to first discuss size. From an experimental point of view, size is the only characteristic that can be used to separate MPs without visual analysis which is time consuming and can introduce bias. Filtration or density separation can be used to initially divide the particles, while a visual check can be used to verify the results. The size ranges presented here are derived by the categories presented in Frias and Nash (2019) and have been altered in such a way to avoid overlapping of the sizes included in each category: 1 μm $\leq$ Size $<$ 100 μm, 100 μm $\leq$ Size $<$ 350 μm, and 350 μm $\leq$ Size $<$ 5 mm. The Frias and Nash (2019) size categories are considered here because they were developed with the hope of encouraging comparability among research studies. The debate on size likely will continue (Hartmann et al., 2019), therefore, the size categories suggested here are not intended to represent a final decision on this area of characterization.

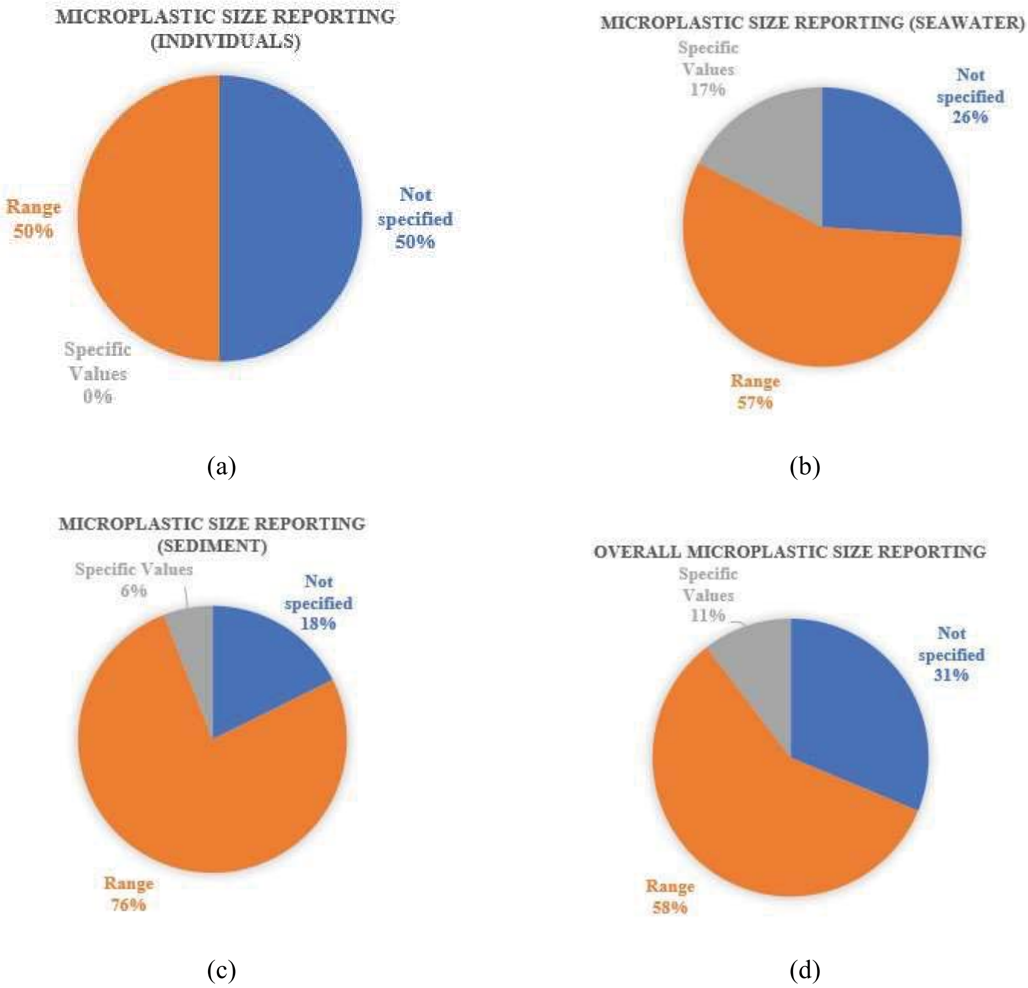

Fig. 4 Statistical graphs representing the various methods for reporting MP sizes, specifically, as a range, specific values, or not specified. The frequency of use of these methods are shown for samples of a) marine organisms, b) seawater, and c) sediment. Chart d) represents the overall variation in reporting MP sizes considering all types of samples.

3.1.2 Color

Within each size range, the particle colors should be recorded. Color is an important characteristic to be recorded because it is useful for the determination of the pollution source (Wagner et al., 2018). In addition, color can be important in terms of ingestion by animals or with regards to its influence on the thermal and UV stability of a plastic particle after weathering (Wagner et al., 2018). For this reason, colors should not be grouped together (i.e., blue/green) to avoid a pre-aggregation of the data. To start color recording, it could be useful to refer to the methods used in plastic recycling, for example, by using computer vision algorithms (Ramon et al., 2018). Determining colors visually creates an opportunity for bias, especially if only one analyst has classified the MP particles (GESAMP, 2019). Furthermore, the results from the literature review indicate that there is a lack of consistency in color categories, i.e. red and pink vs. red/pink, transparent vs. clear. The computer vision algorithm described in Ramon et al. (2018) refers to the RAL color library consisting of specific values which correlate to the colors used in industry. It could be effective to categorize the MP particles found in future studies with respect to the RAL color library for plastics (RAL PLASTICS, 2020).

3.1.3 Morphology

Fragment, line, film, and bead are relevant shape (morphology) categories to be reported because the shape of a MP particle can affect its behavior in the environment (Khatmullina et al., 2019) and their risk to marine organisms (Porter et al., 2018). However, shapes should still be clearly defined and photos of variations of the different shape categories would be effective in ensuring appropriate sorting. Moreover, it appears that more discussion is needed regarding shape categories to avoid over-counting MP concentrations. Given the importance of morphology on the movement of microplastics in the environment (Khatmullina et al., 2019; Porter et al., 2018), it appears that details regarding MP particle shape could be relevant for researchers to assess the risk of this type of marine litter.

3.1.4 Polymer type

Given the existing POSEIDON software (Kedzierski et al., 2019) that could increase the efficiency of MP polymer classification, the polymer types available in the software can be considered for future studies. These polymer types include: Cellulose acetate, cellulose like, ethylene propylene rubber, morphotype 1, morphotype 2, PEVA, PMMA, poly(amide), poly(ethylene), poly(ethylene) + fouling, poly(ethylene) like, poly(propylene), poly(propylene) like, poly(styrene), and poly(urethane). The POSEIDON software is referred to here because of its connection to MPs studies in the Mediterranean Sea.

3.2 What should be standardized?

Since plastics are so widespread throughout the environment, they can be now considered as markers of the Anthropocene (Villarrubia-Gómez et al., 2018). Although the implications of excessive plastic waste in the environment have not yet been completely assessed, MPs do appear to have an impact on organisms (Haegerbaeumer et al., 2019) and potentially on ecosystems (Anbumani and Kakkar, 2018) and human wellbeing via socioeconomic sectors such as tourism, aquaculture, and navigation (Villarrubia-Gómez et al., 2018). However, to effectively understand the impacts of MPs at the ecosystem scale, large datasets are required to develop models capable of predicting how ecosystems can be affected by increasing levels of plastic pollution. How can these data be retrieved?

Microplastics data are collected in many countries worldwide. An initial step that could aid in microplastic data availability is a clear and accepted definition for the term “microplastics” because this could help to create a more defined boundary in which data can be used collectively and for effective decision making (Frias and Nash, 2019). However, it is important to note that this may not be feasible or effective from the perspective of the MP researcher (Hartmann et al., 2019). Some experts suggest that the definition of “microplastics” should encompass the key characteristics which make them potentially harmful for the environment, namely size, shape, color, and type (polymer) (Cincinelli et al., 2019; Frias and Nash, 2019). In addition, comprehensive definitions of microplastics have been developed and continue to evolve as does the research of MPs (Hartmann et al., 2019).

An additional step in developing a univocal definition of the term “microplastics” would be to consider the characteristics which are also significant from an inventory point of view. To be more specific, characteristics that can allow for a better understanding of which source contributed to the particles found in an *in-situ* sample. For example, color is not only important from the ecological harm perspective, but it can also be an indication of which industry the particle came from (Wagner et al., 2018).

There are six main types of plastics found in the form of MPs, referred to as the “big 6”. However, these polymer types often have different abbreviations from researcher to researcher. For example, polyurethane was abbreviated as PU in de Carvalho and Baptista Neto (2016), while in Dehaut et al. (2016) it was abbreviated as PUR.

Sampling is another aspect of MP research that should be urgently standardized. There are many opportunities to lose microplastics or experience contamination, therefore a simple and efficient sampling technique is imperative for accurate and consistent data. There have been several reviews on sampling methodologies

Table 1 Example of potential units for marine seawater, sediment, and organisms.

Sample Type	Reporting Unit
Seawater	n. of particles/L or mass/L
Sediment	n. of particles/kg wet weight or mass/kg wet weight
Individual	n. of particles/individual or mass/individual

discussing relevant parameters to measure in the field and quality control practices in the lab. However, these reviews lack recommendations for sampling regarding the pretreatment of organisms, seawater, and sediment. For example, organisms could be cleaned and divided at the sampling site to ensure that the organisms do not need to be cleaned and re-jarred in the laboratory (where there are other potential contaminants and risks) before digestion begins. Cleaning and re-jarring in the laboratory also creates another opportunity for loss of microplastic concentrations within the sample because living organisms tend to expel their interior fluids postmortem. In 2019, GESAMP published the "Guidelines for the monitoring and assessment of plastic litter in the ocean", a thorough outline of best practices in sampling for biota, seawater, and sediment.

Finally, the units used for reporting the concentration of MPs found in samples should be standardized (Table 1). The units used to depict concentration should provide an adequate level of detail with respect to the surrounding environment to allow for a more accurate understanding of the temporal and spatial contributions to the concentration found (Cowger et al., 2020). It could be useful for the reporting units to be decided upon by experts of various disciplines, including data scientists who may provide some useful input regarding data needs for assessing MP impact at the ecosystem scale (Faghmous and Kumar, 2014; Blair et al., 2019).

3.3 An example for MP research to follow

The history of the development of GHG emissions inventories has many similarities with the current development of MP research and the challenges that policy makers are facing. The IPCC was created in 1988 and the first assessment report was published before the first general reporting protocol (GRP) of GHG was developed. At that time, the IPCC was certain of two impacts of GHG emissions (Watson et al., 1990):

1) "there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be";

2) "emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases carbon dioxide, methane, chlorofluorocarbons (CFCs), and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapor, will increase in response to global warming and further enhance it".

Their predictions contained some uncertainties mainly due to incomplete understanding of:

1) "sources and sinks of greenhouse gases, which affect predictions of future concentrations"

2) "clouds, which strongly influence the magnitude of climate change"

3) "oceans, which influence the timing and patterns of climate change"

4) "polar ice sheets which affect predictions of sea level rise. These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises".

These uncertainties, however, did not stop the IPCC from providing the world with useful predictions. The IPCC was aware that to improve their predictive capability, they needed:

1) to understand better the various climate-related processes, particularly those associated with clouds, oceans, and the carbon cycle;

2) to improve the systematic observation of climate related variables on a global basis, and further investigate changes which took place in the past;

3) to develop improved models of the Earth's climate system;

4) to increase support for national and international climate research activities, especially in developing countries;

5) to facilitate international exchange of climate data.

3.4 The utility of a microplastic GRP and inventory guidelines

The purpose of a GRP is to generate relevant data inventories that are transparent, complete, consistent, comparable, and accurate (Todorova et al., 2003). The GHG inventories are essential to ensure local, national, and global commitment to the monitoring of emissions' changes and to facilitate monitoring practices (Boitier, 2012). The development of a GRP by a diverse group of specialists, including data scientists, for microplastic research could improve the consistency of experiments regardless of the inevitable differences in the sampling and digestion methodologies adopted for organisms, sediment, and seawater. A GRP could also allow for more efficient local data acquisition which can result in datasets at a level of detail useful for assessing the impacts of microplastics at larger scales.

In addition to the variation among sampling and experimentation methodologies, there is huge variation in the types of plastics found. The different types of plastic can help in identifying what industries represent the biggest "problem area" for marine ecosystems. A GRP could help ensure that these diverse MP types are recorded individually to allow for a more accurate understanding of the consequences resulting from each industry. In other words, knowing the biggest MP "culprit" in the study area of interest can help decision makers to address the problem of microplastics adopting precautionary principles. Nowadays, the most common polymers found in the Mediterranean Sea are PE, HDPE, LDPE, PP, PS, PET, and PVC (Figure 5), which are also known as "The Big 6" (Cincinelli et al., 2019).

4 Sampling protocols for microplastics

Characteristics such as polymer density, shape, position in water column, and possible interaction with other organisms should be reported in a standardized manner. This information could be relevant as these characteristics contribute to the fate of MPs (Cincinelli et al., 2019). Characteristics that are more difficult to detect directly, like the position in the water column and the possible interaction with other organisms, could be predicted in models based on size, shape, color, and type data, assuming adequate quantity and quality of data is provided. Therefore, sampling techniques should ensure that these data are available.

Current sampling protocols for sediment, seawater, and organisms tend to require many steps in the laboratory before pretreatment of the sample occurs. This increases the probability of contamination by nanoplastics, other microplastics, and other particulate matter that can enter experimental samples. However, a standardized sampling protocol that can be easily followed can help to reduce spending too much time preparing samples before they can be pretreated for MP extraction and analysis (Cincinelli et al., 2019; Lusher et al., 2017; Prata et al., 2019).

4.1 Recommended study areas

Porter (2018) highlighted the importance of choosing a study area with high biological productivity and reasonably high microplastic concentrations. High biological productivity can be identified considering areas with high Chlorophyll-a concentrations indicating in turn high concentrations of marine phytoplankton. In the case of the Mediterranean Sea, high Chlorophyll-a concentrations are detected at the coast lines which is convenient for

Fig. 5 Plastic types and industries that use them (World Economic Forum et al., 2016).

microplastics assessment since coastal areas are more exposed to pollution and, therefore, there is high potential for high microplastics concentrations (Desforges et al., 2014). As shown in Figure 6, there are several areas in the Mediterranean Sea which could have high biological productivity given the larger presence of Chlorophyll-a and high microplastic concentrations given that they are coastal areas.

4.2 Possible sampling methods

Table 2 lists some potentially adequate sampling methods for seawater, sediment, and organisms. Remotely operated vehicle (ROV) dive sampling is listed as a possibly useful sampling method for seawater because it can reflect the concentration of microplastics at different depths, showing the distribution of the MPs in the water column (Choy et al., 2019). However, if ROV sampling is not an available method, grab sampling could be useful given that it is not based on particle size like trawling is because filtering is not performed during the sampling process (Barrows et al., 2017). However, this method would not provide an adequate representation of the water column.

Sediment sampling should follow a protocol, which allows for reporting units to be given in mass or particles per volume since all toxicity tests are reported in these units. Ensuring that the results match those of toxicity reports allows the final results to be compared with impact studies for the development of an ecological harm assessment framework that can be effectively applied to decision-making regarding microplastics (Everaert et al., 2018).

It could be useful for marine organisms to be sampled with a standardized quantity of seawater decided upon

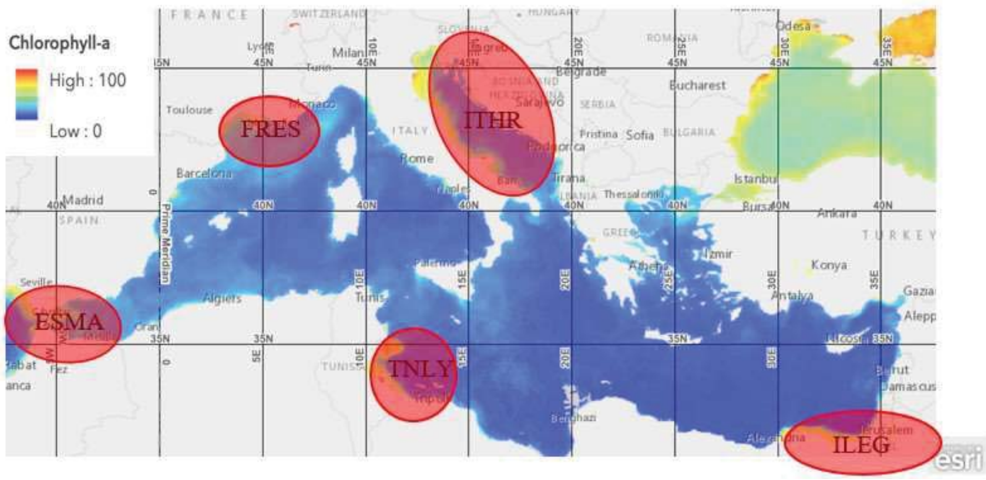

Fig. 6 Daily Chlorophyll-a concentrations (mg/m^2) in the Mediterranean Sea (NASA et al., 2018). Recommended sampling areas are highlighted with red and show the created region code.

Table 2 Possible sampling methods for seawater, sediment, and biota.

Sample Type	Sampling Method
Seawater	ROV sampling if available or grab sampling
Sediment	Core sampling
Biota	Grab sampling (with standardized quantity of water)

Table 3 Example of recommended sampling region codes and locations in the Mediterranean Sea.

Region Code	Latitudinal Range	Longitudinal Range
ITHR	41N to 45N	12E to 16.5E
ILEG	31N to 33N	29.8E to 35.1E
TNLY	32N to 35.8N	10E to 12.7E
ESMA	35.2N to 36N	5W to 3.5W
FRES	42.3N to 43.2N	3E to 5.4E

by experts in the field to avoid the possibility of losing microplastics if the animal begins to regurgitate upon leaving the water.

Environmental characteristics, which describe the sampling site, should be recorded to allow for more accurate organization and aggregation of data. This information is also required when developing prediction models simulating marine ecosystems. Recording sheets developed by the JPI-Oceans BASEMAN project should be used when sampling sediment and seawater (Frias et al., 2018; Gago et al., 2019). When sampling organisms, either the sediment or seawater recording sheets could be used depending on the target species. However, it would be useful for a biota specific recording sheet to be developed. The latitude, longitude, and the region code of the sampling site should be also recorded as displayed in Table 3.

4.3 Recommended pretreatment/digestion methods

MPs can be deformed or further fragmented in separation/extraction procedures if the sediment samples are dried at a too high temperature (Qiu et al., 2016). The heat deflection temperature (HDT) of each polymer should be known and respected to avoid over or under estimations of MP particles found in sediment samples (Qiu et al., 2016). The most common polymers found in the marine environment are PE, HDPE, LDPE, PP, PS, PET, and PVC (Cincinelli et al., 2019). Therefore, pretreatment techniques used in MP analysis should not be

Table 4 Possible sampling methods for seawater, sediment, and organisms.

Sample Type	Pretreatment Method
Seawater	Pre-filter
Sediment	Pre-filter
Organisms	5% or 10% sodium dodecyl sulphate followed by enzymatic digestion (GESAMP, 2019)

Table 5 Possible separation methods for seawater, sediment, and biota.

Sample Type	Separation Method
Seawater	Density separation (saturated NaCl) 3 washes
Sediment	Density separation (saturated NaCl) 3 washes
Biota	Filtration of digested solution followed by density separation (saturated NaCl) 3 washes

capable of damaging these polymers. Table 4 lists some possible pretreatment methods for seawater, sediment, and organisms based on the researchers' currently unpublished experimentation and the GESAMP (2019) plastic litter monitoring method guidelines.

4.4 Recommended separation methodology

The most common polymers found in the Mediterranean Sea are PE, HDPE, LDPE, PP, PS, PET, and PVC (Cincinelli et al., 2019). Therefore, separation techniques used in MP analysis should not damage these polymers. Table 5 lists the recommended separation methods for seawater, sediment, and biota. Creon is a cost-effective enzyme that digests the organism completely (Catarino et al., 2016).

4.5 Detection methodology

Burns and Boxall (2018) showed that 42% of current microplastic studies (up until 2018) only used visual identification. This type of detection practice only allows for visibility lower than 500 μm and has an error ranging from 33% to 70% which is not an acceptable level of uncertainty. Instead, 58% of current microplastic studies use RAMAN or μFTIR in addition to visual identification, allowing for size detection lower than 1 or 10 μm, while the confidence in the detection decreases at < 131 μm. Concentrations can differ by orders of magnitude depending on the method used for detection. Table 6 lists the recommended detection methods for seawater, sediment, and biota. For studies in the Mediterranean Sea, it could be useful to use visual sorting along with μFTIR identification for MPs extracted from marine sediment, seawater, and organisms given the corresponding POSEIDON libraries (Kedzierski et al., 2019).

5 Conclusions

As microplastic research evolves, it could be useful for future studies to report data from sediment, sea water, and organisms. It is worth noting that the data reported is the result of sampling, analysis, and identification activities. This means that valuable pieces of information in each dataset come from each aspect of a microplastic study. Although the classifications described above are intended as suggestions for development in this aspect of microplastic research, recent work has been done to provide the scientific community with thorough guidelines in sampling, analysis, and reporting (Cowger et al., 2020; GESAMP, 2019). Classification recommendations that have been provided by experts in the field should not be overlooked. Furthermore, microplastic quantities that are not clearly defined or well organized should not be included in reported results; it is preferable to characterize particles as "undefined" if they cannot be characterized by the suggested classifications to avoid any confusion.

The geographical location of the sampling sites is a crucial aspect of microplastic research studies and should be clearly defined in published documentation associated with the data. Results should be provided in agreed upon units of measure to ensure for comparability among various research studies.

The lack of consistency in reporting units appears to be a significant contributor to the current lack of comprehensive knowledge on MP interactions with the environment. Consistency in reporting units facilitates the comparison of data on marine microplastics and their potential integration in models capable of predicting the impacts of microplastics at local and global scales.

Appendix I

Source	Sediment, Seawater, Biota	Color
Catarino et al., 2017	biota	not specified
Claessens et al., 2013	biota	not specified
Courtene-Jones et al., 2017	biota	not specified
Dehaut et al., 2016	biota	not specified
Devriese et al., 2015	biota	purple-blue (43%), yellow-greenish (50%), translucent (15%) and orange (12%) fibers, but also transparent (8%) and pink (2%) fibers
Jamieson et al., 2019	biota	blue, twisted blue, red, dark/black, dark/blue, black, pink, purple
Li et al., 2016	biota	not specified
Mathalon and Hill, 2014	biota	brightly colored or clear
Remy et al., 2015	biota	blue, red
Santana et al., 2016	biota	white
Taylor et al., 2016	biota	not specified, only to describe what was shown in the images
Van Cauwenberghe and Janssen, 2014	biota	red, blue
von Moos et al., 2012	biota	not specified
Thompson et al., 2004	biota	not specified
Courtene-Jones et al., 2017	biota and seawater	deep sea water: blue, red, transparent; benthic macroinvertebrates: blue, red, black, orange, green, transparent, multicolored
Cole et al., 2014	biota and seawater	white or clear, black, red, orange or yellow, green, blue, brown
Courtene-Jones et al., 2017	biota and seawater	deep sea water: blue,red, transparent
Cole et al., 2014	biota and seawater	white or clear, black, red, orange or yellow, green, blue, brown
Brandon et al., 2016	seawater	not specified
Cincinelli et al., 2017	seawater	blue and red
Desforges et al., 2014	seawater	blue, red, black and purple most common
Dubaish and Liebezeit, 2013	seawater	not specified
Dyachenko et al., 2017	seawater	pink, blue
Enders et al., 2015	seawater	not specified

Source	Sediment, Seawater, Biota	Color
Frias et al., 2014	seawater	not specified
Gallagher et al., 2016	seawater	black, white, clear, blue, white/blue, grey, blue/black, brown, orange, red, yellow, green
Hall et al., 2015	seawater	not specified
Ivar do Sul et al., 2014	seawater	Transparent/white, blue/green, black/grey, yellow, red
Lima et al., 2014	seawater	soft and hard plastics: white, green and blue, threads: red and blue, paint chips: blue, green and yellow
Lusher et al., 2014	seawater	black, blue, grey, brown, red/pink, orange, green, yellow, white
Maes et al., 2017	seawater	white, transparent/translucent, black/grey, blue/green, brown/tan, orange/pink/red, yellow
Majewsky et al., 2016	seawater	not specified
Masura et al., 2015	seawater	not specified
McCormick et al., 2014	seawater	not specified
Mintenig et al., 2017	seawater	not specified
Reisser et al., 2013	seawater	white/transparent, blue, other colors
Sutton et al., 2016	seawater	multi-colored
Thompson et al., 2004	seawater and sediment	not specified
Guven et al., 2017	seawater and sediment	many
van Cauwenberghe et al., 2015	Seawater	blue
Thompson et al., 2004	seawater and sediment	not specified
Guven et al., 2017	seawater and sediment	many
Browne et al., 2010	sediment	not specified
Claessens et al., 2011	sediment	not specified
Claessens et al., 2013	sediment	not specified
Crichton et al., 2017	sediment	dark, red, yellow, blue, white, green
de Carvalho and Baptista Neto, 2016	sediment	translucent, black, white, yellow-brown, various pigments
Frias et al., 2010	sediment	black, white, and color
Fuller and Gautam, 2016	sediment	not specified
Horton et al., 2017	sediment	dyes: copper phthalocyanine, mortoperm blue, hostasol green, and chrome yellow
Maes et al., 2017a	sediment	not specified
Maes et al., 2017b	sediment	white, transparent/translucent, black/grey, blue/green, brown/tan, orange/pink/red, yellow
Martins and Sobral, 2011	sediment	white and colored
Masura et al., 2015	sediment	n/a
Mathalon & Hill, 2014	sediment	brightly colored or clear
Nor and Obbard, 2014	sediment	only mentioned in photos of particles
Quinn et al., 2017 (laboratory experiment)	sediment	
Thompson et al., 2004	sediment	not specified
van Cauwenberghe et al., 2015	sediment	blue
Wessel et al., 2016	sediment	not specified

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Journal of Environmental Accounting and Management 10(3) (2022) 299-303

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Oil Extraction from Macrophytes: Effect of Environmental Factors on Efficiency and Oil Quality in Coastal Lagoon

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Submission Info

Communicated by Pier Paolo Franzese
Received 31 May 2021
Accepted 19 July 2021
Available online 1 October 2022

Keywords

Biofuels
Macrophytes
Oil quality
Total oil production
Lesina Lagoon

Abstract

Macrophytes represent interesting matrices for oil extraction with biodiesel production purposes, particularly in eutrophic coastal lagoons. This short note reported results on bio-oil extraction efficiency in two different species of macrophytes in a Mediterranean lagoon (Lesina lagoon, south-eastern Italy), by testing effects of different factors (year, season, species of macrophytes) on oil production and oil quality. Extracted total oils values ranged from 0.65 % (*Chara* spp.) to 2.35 % (*Chaetomorpha linum*) and a significant difference ($p < 0.01$) between the two species was reported in relation to the variability of diene production with seasons. Compared to the available literature, higher oil extraction efficiencies are reported in this paper for the species *C. linum*, mainly due to the pressure optimization before extractions.

1 Short note

The growing interest of international worldwide Governments towards the reduction of greenhouse gas emissions, let to the development of new more sustainable strategies to obtain energy from other sources over fossil fuels (Bastianoni and Marchettini, 1996) and give a great boost to the production of energy from renewable sources.

Recently, many industries were developed to obtain biofuels by oils extracted from aquatic microalgae; represents a concrete alternative to petrol (Chisti, 2007; Mata et al., 2010; Cooney et al., 2011) and, actually, 78% of production companies in USA extract oils from microalgae (Singh and Gu, 2010). Macroalgae represent interesting matrices for biofuels production purposes due to the real chance to transform huge expense related to macroalgae harvest in transitional ecosystems into a possible resource (Bastianoni et al., 2008; Renzi et al., 2013).

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials
DOI:10.5890/JEAM.2022.09.007

Recent studies showed that, under natural uncontrolled conditions, the oil production efficiency is lower than in microalgae industrial plants (Harun et al., 2010; Renzi et al., 2013). Nevertheless, a recent research demonstrates that with improvements of oil extraction methodology, macroalgae could be considered a feasible matrix for biofuel production (Bastianoni et al., 2008). Furthermore, Renzi et al. (2013) tested oil extraction efficiencies from different macroalgae and phanerogams tissues sampled from a natural eutrophic lagoon. The oil extraction efficiency instead of different tissues pre-treatments and extraction methods, were tested on the same species and results evidenced higher efficiencies for phanerogams (*Ruppia cirrhosa*) than for macroalgae. A recent research highlights that these matrices show high variability of the quality of the biomass produced due to the high variability of natural ecosystems (Harun et al., 2010). In spite of that, field studies that show the variability of the oil extraction efficiency on phanerogams are lacking.

The aim of this study is to evaluate the effects of different species and factors as seasonal-yearly variability on oil production and oil quality in macrophytes collected in a reserve of a South-eastern Italian lagoon (Lesina).

The study area is a natural reserve, Sacca Orientale, confined in the easternmost part of the eutrophic Lesina lagoon (south Italy); Ferrarin et al., 2013. Details on environmental and ecological settings of the lagoon are reported in Specchiulli et al. (2010; 2016) and Basset et al. (2013).

Macrophyte samples (*Chara* spp. and *Chaetomorpha linum)* collection was performed from 2010 to 2012 during spring, summer and autumn at 13 sampling sites (see information about experimental design in Specchiulli et al., 2016), using a box corer (15 cm^3), and then stored at +4 °C until laboratory processing.

Oil content and oil characterization was performed by extractions using Accelerate Solvent Extraction (ASE, Dionex) technique that resulted much more efficient than Sohxlet for the extraction of lipids and organic chemical by biological tissues (Dionex, 1997). Oil extraction efficiency was evaluated according to literature (Renzi et al., 2013) following the extraction procedure n. 3. According to this procedure, tissues were firstly lyophilized and finely powdered before the extraction. Concerning to ASE, the following run program was set as follow: 5' of pre-heating time, 5' of two-times static extraction, 60% volume of rinsing, 90" of samples purging time. Temperature of extraction was 100 °C and solvent mixture was Hexane – Dichloromethane (1:1 v/v). On the contrary, pressure was optimized testing both oil extraction efficiency and the procedure reproducibility under different pressure conditions (1,000; 1,500; 2,000 psi). Pressure of 2,000 psi (1 psi = 6,894.76 Pa) showed better QA/QC performances on tested matrices and this value was used in this study (+50% oil extraction efficiency, reduction of standard deviation of 1/2 for 2,000 psi compared to performances obtained setting 1,000 psi). As oil absorbance at different wavelength is representative of different fatty acids compounds, extracted oils were characterized by spectrophotometry (PerkinElmer, mod. Lambda 25), setting wavelength within 190-300 nm and performing lectures on opportune *2,2,4*-trimethilpentane dilutions of extracted samples. Qualitative and quantitative comparisons of collected spectra were performed in order to assess oil features. Qualitative analyses were performed to evaluate seasonal changes (for a fixed species and sampling station) and species differences (season and sampling station fixed). Quantitative analyses were performed at 232 nm (indicative of diene), 262 nm, 268 nm e 274 nm (indicative of triene), and the amount of lipids (g) per grams of the total extracted oil was calculated. Calibration was performed by using multipoint external curve with different dilution samples of olive oil. The analyses t-test and F-test were used to evaluate differences of mean and variance between couples of tested variables. The Euclidean distances resemblance matrix was calculated after the application of square root ($\sqrt{}$) and successively the log (x+1) transformations of collected data, according to literature (Clarke and Warwick, 2001). A non-metric Multi-Dimensional Scale (*nm*-MDS) analysis superimposed to the cluster-analysis results was performed to visualize significant (Simper test) data segregations. Multivariate ANOSIM one-way test was run in order to highlight significant differences between factors of variability represented by considered years, seasons, and species (Somerfield and Clarke, 1995). Univariate analyses were performed using Prism v.4.0. Multivariate analyses were performed by using Primer E Software package version 6.0 (Plymouth Marine Laboratory, UK).

Obtained results in this study, highlight that both species showed the highest mean of total oils (%) in summer 2011 that resulted: 2.33 ± 1.59 % (*Chara* spp.*)* and 2.26 ± 1.13 % (*C. linum)*. The lowest mean

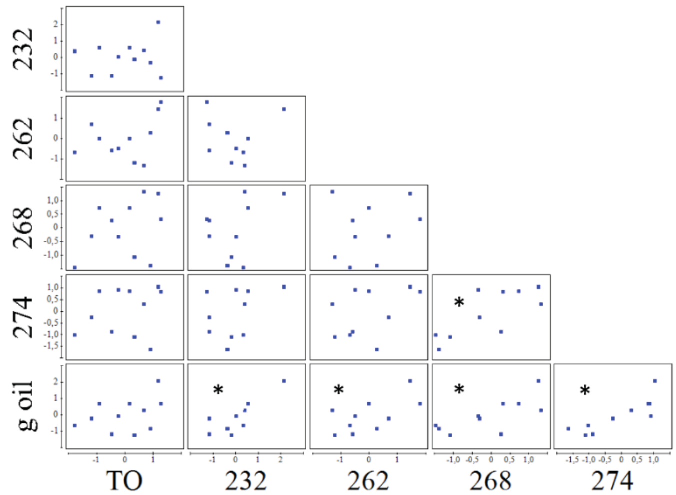

Fig. 1 Univariate Pearson's correlation between couples of variables. Numbers indicate wavelength of absorbance (nm) imposed during quantitative analyses (232 nm is typically associated to diene while 274 nm is associated to triene). Notes: g oil = total grams of oils quantified at selected wavelength; TO = total oil extracted (g). Significant relationships and their values are superimposed in figure (*).

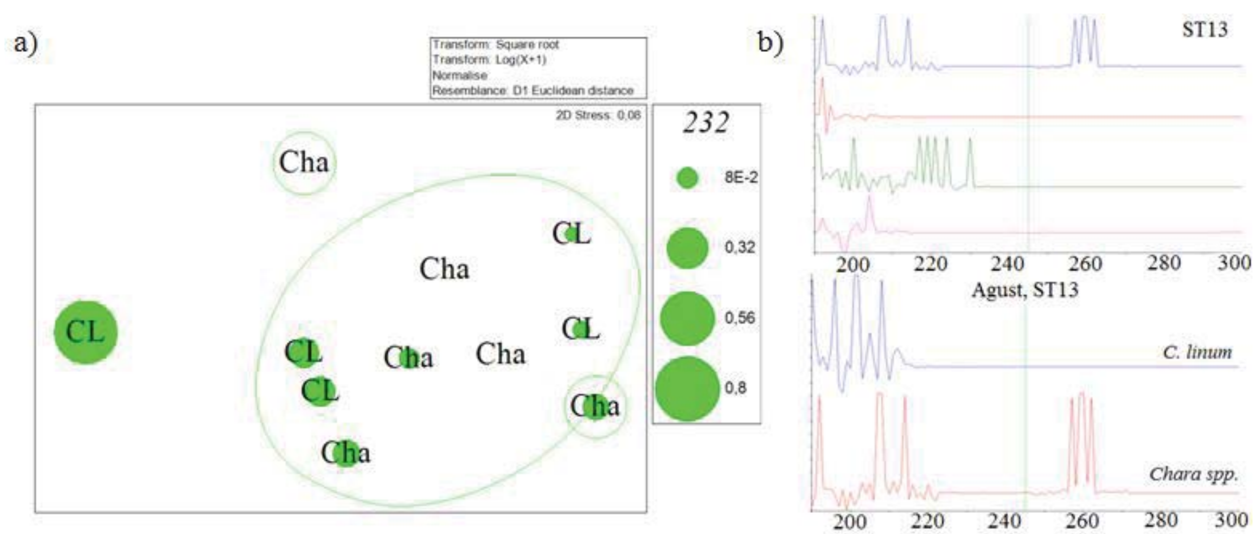

Fig. 2 Multivariate statistical analyses and UV-spectra. a) MDS 2D-ordination diagram superimposed to Cluster Analysis; green dotted line, Simper significant segregation, highlighted with distance = 2.3. Furthermore, grams of diene (232 nm) measured in both species (Cha = *Chara* spp.; CL = *C. linum*) are also highlighted by the 2D-bubble routine (green bubble). b) UV-VIS scatterplot along wavelength of absorbance (nm) imposed during quantitative analyses are also exemplified on the right in the picture; on the top is reported the seasonality of both species at the site 13, and below are reported the values of the both species in August at the site 13.

values were measured in spring 0.70 ± 0.04 % (*Chara* spp.*;* year 2010) and 1.03 ± 0.03 % (*C. linum,* year 2012). The highest percentages of oils in *Chara* spp. (3.97 %) and *C. linum* (2.35 %) were recorded in summer 2011; in the same season the highest variability was recorded. Total oils ranged within 0.65% (*Chara* spp.) - 2.35% (*C. linum*). Spectral analyses performed on the extracted oil were plotted in Figure 1; univariate Pearson's correlation between couples of variables and their significant level (*) are highlighted. Results of multivariate statistics are represented in Figure 2.

In Figure 2, eigenvalues calculated for Principal Component Analyses (PCA) showed that the first three axes explained the 86.7% of the total variance (PC1 55.6%; PC2 18.4%; PC3 12.7%) and that PC1 was strongly related to 274 nm (-0,481) and PC2 highly correlated with 232 nm (-0,561). ANOSIM test, considering the entire data set, highlighted no significant difference for tested factors (species, year, season), suggesting uniformity of the oil quality according to tested factors of interest. In spite of that, considering total grams of diene and triene oils, t-test showed significant differences between *Chara* spp. and *C. linum* only in spring ($p = 0.04$), mainly due to diene's contribute (232 nm) that was, also, responsible of the significant differences observed in spring ($p = 0.01$), as emphasized by the *nm*-MDS superimposed to cluster analysis (Fig. 2a). A significant difference between the two species was reported in relation to the variability of diene production with seasons (Fig. 2b). F-test resulted significant for diene concentrations ($p < 0.01$). Higher oil extraction efficiencies are reported in this paper compared to the available literature for the species *C. linum* (Bastianoni et al., 2008; Renzi et al., 2013). These results are due to optimization of the pressure parameter performed in this study before testing samples. In transitional water ecosystem, macrophytes production shows a clear seasonal trend with maxima biomass values during spring-summer seasons and lowest values in winter. This result is supported by the scientific literature for transitional ecosystems at the same latitudes (Renzi and Guerranti, 2018) due to local temperatures and daily light cycles. Polyunsaturated fatty acids are characterized by the presence of conjugated diene while a dominance of triene is associated to higher absorption closed to 270 nm wavelength.

Results reported in this study evidence a very good recovery performance compared to literature (Renzi et al., 2013 and citations therein). Nevertheless, oil extraction techniques for biodiesel production from lagoon macrophytes should be improved in term of efficiency to become of some industrial interest. Aquatic macrophytes propagate causing environmental stress due to eutrophication (O'Sullivan et al., 2010), especially in lagoon areas, often as consequence of human activities such as industrialization, agriculture, and aquaculture (Jones et al., 2001). In lagoon areas, therefore, the use of macrophytes for biodiesel production could have many ecological benefits, as rapid reproduction rate, no land use change, no competition with "food" products, as well as representing a source that could be used for the aquatic environment reducing eutrophication. This type of feedstock does not compete with the "food" products and it could lead to the production of second-generation biofuels. Indeed, this reality is at pilot scale to date, but it could be fully productive in a near future, as suggested by the European Union.

Acknowledgements

This research was performed within a research program, Pilot project for the evaluation of the biodiesel production from algal biomass in Lagoons of Lesina (Foggia) and Orbetello (Grosseto), funded by the Italian Ministry of Agriculture and Forestry. We wish to thank the forest wardens' group for their essential help in the sailing and sampling of vegetation.

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Journal of Environmental Accounting and Management 10(3) (2022) 305-319

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Chitosan as Potential De-coloring Agent for Synthetic and Textile Industrial Wastewater

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Submission Info

Communicated by Pier Paolo Franzese
Received 26 May 2021
Accepted 19 July 2021
Available online 1 October 2022

Keywords

Chitosan
Biosorption
Remazol brilliant blue R
Textile wastewater
Kinetic models
Corrosion behavior

Abstract

In today's ages, the chitosan biopolymer has ample applications in drinking and wastewater treatment, which is the reason for its large occurrence and fair cost. The potential adsorbent properties are back to its structure since, in addition to its porosity effect, it contains $–NH_2$ and $-OH^-$ groups. In this analysis, the powdered chitosan biopolymer is used as an adsorbent for the abstraction of Remazol Brilliant Blue R (RBB-R). Many variables are studied to enhance the progression of adsorption such as adsorbent dose, pH, interaction time, initial concentration of adsorbents. In addition, the kinetic model's several adsorption isotherms are added to highlight the mechanism and the process of adsorption. Additionally, the degradation efficiency of the actual wastewater treated and untreated was achieved. Finally, to protect the municipal networks, the corrosion of steel pipeline was subjected to evaluation for untreated and treated wastewater to enhance their inhibition of the corrosion process.

1 Introduction

Attributable to the value of water for life, the researchers concentrate on purifying intake water and treating the domestic and manufacturing wastewater that can enter the surface water in its process during the matching time. Over the past few years, the possessions of water have been subjected to continuous depletion outstanding for industrial production, sanitation, and agricultural drainage. In industrial wastewater, such as chemical, inorganic and biological pollutants, there are large quantities of contaminants. every type of pollutant requires a specific and possible treatment technique to make total wastewater toxicity, so many pathways have been developed and optimized for application (Abdelfattah et al., 2016a; El-Awady et al., 2015). Mainly, there are three conventional water and wastewater treatment technologies. There are physical, chemical, and biological therapy. In physical treatment the most plentiful and rational technology is adsorption. This technique can dispose of varying pollutant varieties. This technique's comprehensive banquet is back to the ease of a large range of adsorbents and simplicity of use. Many forms of adsorbents exist, such as organic, inorganic, and bio-sorbent materials

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials
DOI:10.5890/JEAM.2022.09.008

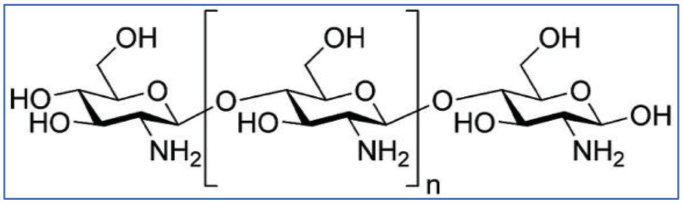

Fig. 1 Scheme of the chemical formula of chitosan.

(Amerkhanova et al., 2017; Ibrahim et al., 2016; Wang & Chen, 2006; Stawinski et al., 2017). Activated carbon, silica gel, vermiculite, and montmorillonite are the most common adsorbent materials. The need to find adsorbents for manufacturing wastewater handling is critical and growing day by day, with the rapid growth in many industrial fields and with the strict environmental constraints forcing industries to handle their waste. It has been recognized that certain conditions control the effectiveness and measurements of the adsorbent in carrying out this mission. One and only of the greatest significant rewards of choosing a good adsorbent is that it has a high, ideally selective, absorption capacity and good mechanical stability. It is classified also by the abundance of resources. It was originated that chitosan has these advantages that make it the best option for this mission to be carried out (Abu-Saied et al., 2017). Chitosan is relatively soluble in dilute solutions such as H_2SO_4 and H_3PO_4. The growth of numerous industries, including the clothing, food, paper, printing, leather, and plastics industries involved in the dyeing industry, has caused the development of increasingly poisonous and colored substances to be removed from the atmosphere. Due to their high visibility, resistance, and toxic effects, the harmful affinity of the dyes has aroused public concern. Even the low concentration of colorants in water can prevent light and oxygen from entering, which not only makes it highly visible causing visual issues but also decreases photosynthetic activities in aquatic habitats, endangering the aqueous species and ecology. It may also arouse toxic effects on humans, such as inflammation of the skin, tumors, and allergies, by direct or indirect means. With stable aromatic structures, in different conditions, the colorants are non-biologically degradable and stable (Wang & Xu, 2012). For this experiment, chitosan is used as a bio-sorbent to extract the toxic anthraquinone dye, Remazol Brilliant Blue R (RBB-R), from wastewater, to test optimal conditions, and to carry out absorption kinetics. In addition, it can induce corrosion activity in the treated and untreated wastewater.

2 Materials and methods

2.1 Materials

Chitosan biopolymer (Degree of Deacetylation, DDA-85 %, Viscosity =1000 mPas and Ash content 1%) was used as an adsorbent obtained by Bio Log Biotechnologies und Logistic GmbH, Germany sees Fig. 1. Remazol Brilliant Blue R (RBB-R) also called Merck's anthraquinone dye product Reactive blue-19, is selected as an anionic dye and used as a dyeing agent in the selected textile multi-product company see Fig. 2. True textile wastewater was chosen for the decoloring test. In addition to the auxiliary substances, these wastewaters contain harmful refractory compounds including reactive, acidic, and disperse dyes, and other bleaching, cleaning, and softening chemicals. The company is located at Sadat Industrial Area, Egypt, and after proper treatment, discharges its wastewater into the sewerage system. Double distilled water (Bopel Bi-Hydro Still method 4.1) has been applied in the investigations. The pH meter was calibrated with ordinary buffer solutions (pH 4, 7, and 9), and with diluted H_2SO_4 and NaOH solutions, the initial pH for all tests was modified to the appropriate value.

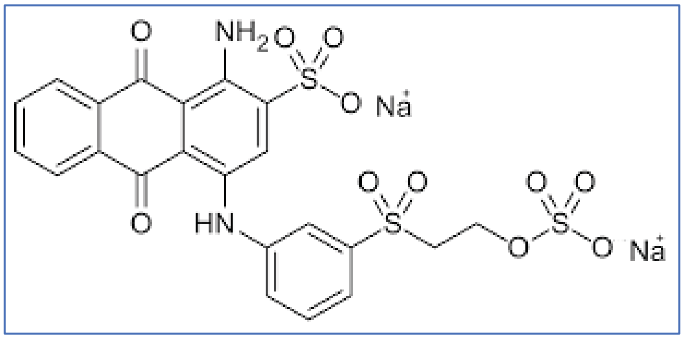

Fig. 2 Scheme of the chemical formula of the Remazole Brilliant Blue R.

2.2 Methods

For all subsequent experiment's consignment tests is considered. Chitosan biopolymer tests were carried out using a laboratory shaker to shake the suspended solutions, Wiseshake, SHO-2D, South Korea. A pH-meter, WTW-inolab, Germany, was used to fine-tune the solutions' pH levels. For both tests, 100 ml of synthetic wastewater and the selected quantity of chitosan were applied to properly fresh and dehydrated crystal flasks, the pH value of the wastewater tests was accustomed to the anticipated value through H_2SO_4 (1 M) and NaOH (1 M). Using the shaker, the blends were traumatized at 150 rpm. Interaction time was subsequently required, trials were subjected to filtration, membrane filtration (0.45 μm) was considered, the rest was formerly imperiled for further analysis and categorization. The effectiveness of the handling was accompanied by the elimination of color. Dimensions. After treatments were calculated using the Agilent Technologies-Carry Series UV-Vis spectrophotometer, the residual dye concentrations remained in solutions. Real categorizations of wastewater were made which conferred on the standard technique. The data obtained from the adsorption experiments were analyzed using different isotherms for adsorption. Using the following equations (1 and 2), the removal percentage (either percent) or the equilibrium adsorption capability q_e (mg.g^{-1}) of dye in solutions were calculated:

$$\eta\% = \frac{(Co - Ce)}{Co} \times 100, \tag{1}$$

$$qe = \frac{(Co - Ce)V}{M}. \tag{2}$$

Where C_e: concentration of adsorbed metal ions in equilibrium (mg L-1), C_o: initial concentration of metal ions in solution (mg L-1), V: volume of solution (L), M: weight of used bio-sorbent (g), q_e: efficiency of bio-sorbent in metal adsorption, and q_e: quantity of metals adsorbed in equilibrium by 1 g of bio-sorbent (mg g^{-1}).

3 Results and discussion

3.1 Effect of pH

The effects of pH on the chitosan biopolymer adsorption measurements were investigated using 100 ml RBB-R dye solution (100 mg / L). The 1 g / L dose of chitosan was added to a 200 ml glass bottle. In a thermos-designated shaker, bottles were agitated for 300 min to ensure removal state of equilibrium. Finally, filters separated the adsorbent and solution, and then analyzed the filtrates to monitor the remaining concentrations of RBB-R. The belongings of pH on eliminating pollutants were examined with the pH ranges of 2.0 $\pm$ 0.2 to 10.0 $\pm$ 0.2 with other parameters being held stable. The effect of pH sorption on dye is present in Fig. 3. The percentage adsorption increases with pH upsurge up to 3.0 $\pm$ 0.2 and 4.0 $\pm$ 0.2 correspondingly for dye and then decreases with pH upsurge. By hydrolysis of dye molecules, the dye adsorption process was influenced by

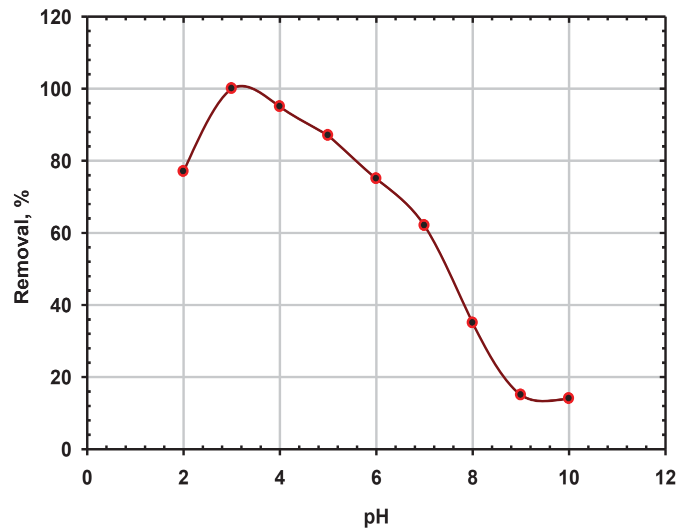

Fig. 3 Consequence of preliminary pH on dye exclusion from aqueous media, C_o = 100 mg/L, V = 100 ml, time = 2 hours, temp. = 25 ° C. dose of chitosan = 1 g/L.

the pH of the aqueous solutions. This is in line with the findings of other research (Ngah & Musa, 1998; Guibal et al., 1998).

3.2 Effect of contact time

The consignment tests were seen using the primary dye load of 100 mg / L and the dose of 1 g / L of chitosan biopolymer using 100 ml solution in an aquatic immersion at a fixed temperature of 25^o C at various contact times. The samples were taken at different time intervals, the adsorbent, and the solution isolated, and the spectrophotometer screened the filtered solution to determine the remaining concentrations of the dye see Fig. 4. Dye adsorption was investigated on chitosan biopolymer as a function of time, 360 minutes of contact time was tested after just 35 minutes to achieve 100 percent of the removal of dye. This meant the presence of abundant active sites of the chitosan concentration used, which remained unbounded with RBB-R. The next subtitle deals with the use of different doses of chitosan.

3.3 Effect of adsorbent dose

The product of adsorbent dosage was inspected using 100 ml 100 mg/L dye solution at pH 3 at 25^o C, the dose of chitosan ranged from 0.1 g/L to 2 g/L and the agitation was assisted for 35 min Fig. 5. The adsorbent and solution were separated with membrane filters, and the UV/VIS spectrophotometer calculated a load of dye in the filtrates. Previously, these spectra of the raw mixed textile dye waste and subsequently, chitosan decolorization were applied to test its decolorizing ability for textile wastewater, and the results are described in Fig. 5. The ability of dye effluent to decolorize decreased across the entire visible spectrum range (Trung et al., 2003). The decrease in biosorption potential with increasing dose may be due to the increase in the bio-sorbent dose leading to an increase in the length of the diffusion path related to the aggregation of bio-sorbent particles around the dye molecules, in addition, the increase in the dose of chitosan can lead to unsaturation of active biosorption sites at constant dye concentration (Mansuri et al., 2014).

3.4 Effect of initial concentration

Lastly, the effect of primary contaminant concentration on removal capability was also investigated using 100 ml dye media using a variety of primary load rates (10 mg/L to 200 mg/L) at 25^o C temperature by considering certain fixed constant parameters (e.g. pH and time doses) and the results could be realized in Fig. 6.

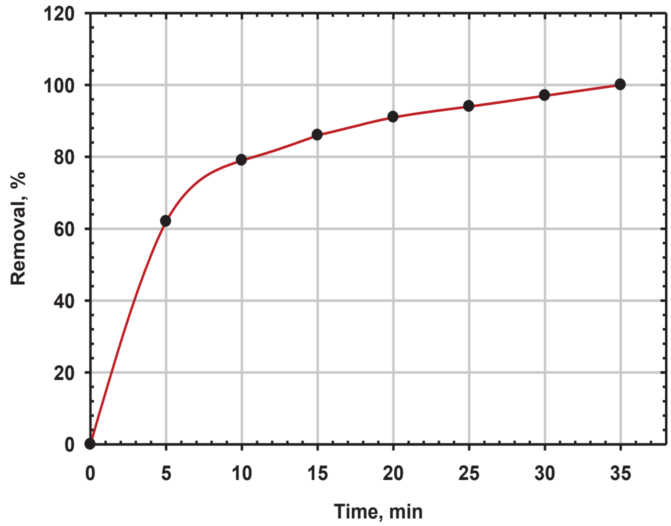

Fig. 4 Consequence of interaction period on the exclusion efficacy of dye by chitosan: C_o = 100 mg/L, V = 100 ml, pH = 3, temp = 25 ° C. dose of chitosan = 1 g/L.

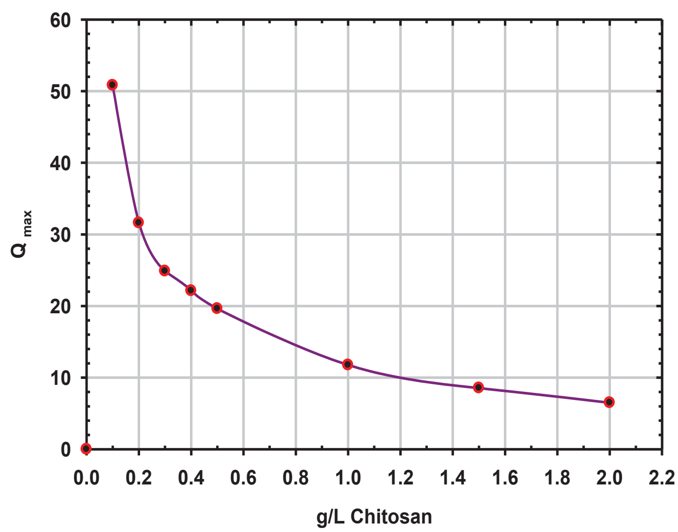

Fig. 5 Effect of chitosan dose on the exclusion efficacy of dye: C_o = 100 mg/L, V = 100 ml, pH = 3, time = 35 min. temp = 25 ° C.

3.5 Adsorption isotherm and kinetic studies

3.5.1 Langmuir isotherm

Primary application of the Langmuir isotherm model was to classify the adsorption of gas fragments on metal surfaces (Gok & Aytas, 2009; Shehata et al., 2019). Even this model has been proved successfully for many other processes of sorption. Langmuir isotherm, which includes, relies on several assumptions (El-Shamy et al.,2017a; El-Shamy et al.,2018; Jacques & Eric, 2018; Saad et al., 1997). The energy is distributed uniformly over the superficial adsorbent. Contaminant molecules are adsorbed and do not migrate across the surface at different locations. The adsorption takes place in the adsorbent material's monolayer surface, and adsorbent molecules do not interfere with each other. The shape of the Langmuir isotherm is a slowly positive curve that flats to a constant value. This approach was commonly used to determine the mode of action of the adsorbent

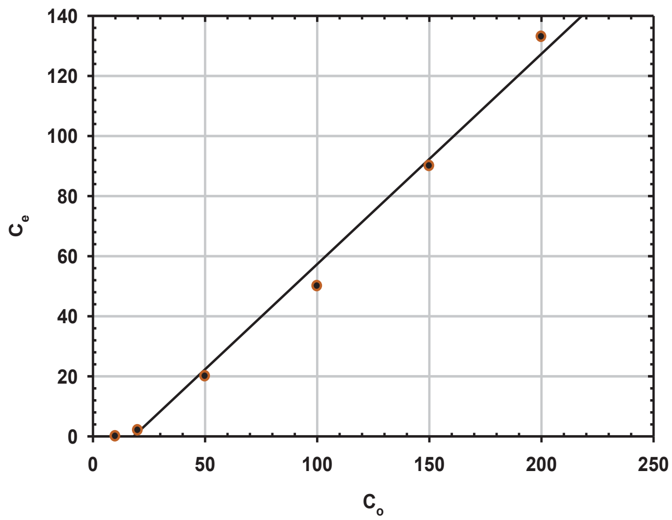

Fig. 6 Effect of dye primary load on its the removal efficiency: dose of chitosan = 1 g/L. V = 100 ml, pH = 3, time = 35 min. temp = 25 ° C.

constituents for adsorption. The isothermal Langmuir model Fig. 7 is built up from the subsequent equation 6:

$$q_e = \frac{q_{\max} * K_l C_e}{1 + K_l C_e} \tag{3}$$

linearized form is:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_l} + \frac{1}{q_m} * C_e \tag{4}$$

Slope $= \frac{1}{q_m}$

$$\text{Intercept} = \frac{1}{q_m K_L} \tag{5}$$

$$\frac{1}{q_e} = \frac{1}{q_m K_L}\frac{1}{C_e} + \frac{1}{q_m} \tag{6}$$

where q_e is the chitosan biopolymer adsorption power, q_m is equivalent to the monolayer adsorption power (μg/g), K_L is the Langmuir equilibrium sorption constant (L/μg) and C_e (μg/L) is the equilibrium concentration of the solution contaminant. The plots in Fig. 7 indicate that the Langmuir adsorption isotherm model could well describe the adsorption mechanism. The parameters derived from models and the correlation coefficient are shown in Table 1. The results showed that adsorption was a complex process, including chemical and physical adsorption, and that the processes of adsorption by chitosan could be expressed as homogeneous monolayer adsorption. The adsorption mechanism can be described with the separation factor (R_L), a dimensional was less constant. The R_L dividing factor is defined as:

$$R_L = \frac{1}{1 + K_L C_o} \tag{7}$$

In which K_L is the constant model (L/μg), and the initial concentration (μg/L) is C_0. The R_L value is graded as unfavorable (R_L>1), linear (R_L=1), favorable (0<R_L<1), or irreversible (R_L=0). The R_L (Table 1) value for dye was within $0 < R_L < 1$ which means the uptake was favorable for chitosan biopolymer.

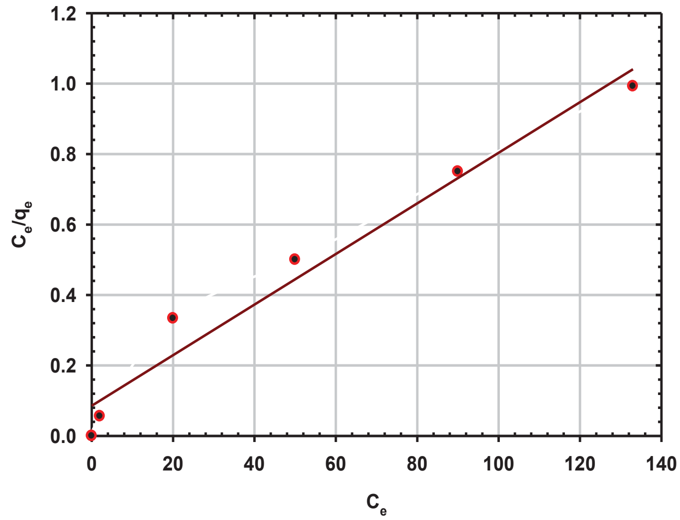

Fig. 7 Langmuir adsorption isotherm plot for dye adsorption by chitosan biopolymer.

Table 1 Langmuir isotherm constants for the sorption of RBB-R dye onto chitosan.

Slope	Intercept	q_m	K_L	R_L	R^2
0.0073	0.087	11.918	0.084	0.056 - 0.54	0.966

3.5.2 Freundlich isotherm

The Freundlich isotherm model is one of the oldest pragmatic equations used to explain data on the adsorption equilibrium and is used to explain a cycle of non-linear sorption. It is also used to describe the initial surface adsorption tracked by the process of condensation that occurs as a result of heavy solute-solute interactions. The Freundlich isotherm model is commonly used to describe the non-ideal adsorption on heterogeneous surfaces; it is also used for explaining the multilayer sorption mechanism (Milmile et al.,2011). Project comfortable Fig. 8 Can be expressed in Equation 12 below.

$$q_e = C_e^{\frac{1}{n}} \tag{8}$$

And in linearized form is:

$$\ln q_e = \ln K_F + (\frac{1}{n})\ln C_e \tag{9}$$

$$\text{Slope} = \frac{1}{n} \tag{10}$$

$$\text{Intercept} = \text{lin } K_F \tag{11}$$

$$\text{Log}(q_e) = \frac{1}{n}\text{Log}C_e + \text{Log}(K_F) \tag{12}$$

Where q_e (mg/g) is the chitosan biopolymer adsorption power, C_e (mg/L) is the solution concentration of the equilibrium contaminant, n is the Freundlich constant which indicates the degree of adsorption favorability and K_F is isotherm constant. The findings of the Freundlich isotherm analysis of dye adsorption on the bio-sorbent chitosan (the correlation coefficient R2, Freundlich constants K_F and n) were evaluated from the plots Fig. 8. The Freundlich constant n value is between 1 to 10 (Table 2), which was an indicator of the ions' beneficial adsorption (Abdelfattah et al., 2016b).

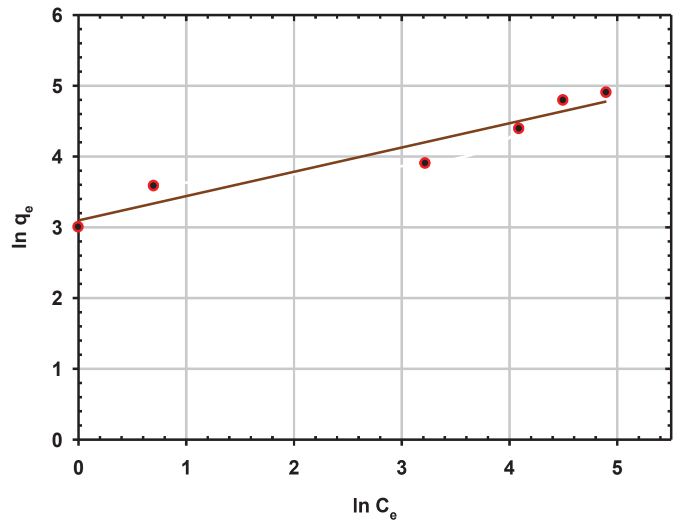

Fig. 8 Freundlich adsorption isotherm plot for dye adsorption by chitosan biopolymer.

3.6 Kinetic studies

To understand the dye adsorption control mechanism by chitosan biopolymer, the most widely used pseudo-first-order and pseudo-second-order kinetic model was tested to interpret the adsorption data on the assumption that the measured concentration is equal to the surface concentrations. The main influencing factors for the metal sorption kinetics are reaction and the mass transfer phase. Such two steps are also critical for regulating the transfer of metal ions to the adsorption sites from the bulk solution. This mechanism depends on the physical composition particle size, the intrinsic structure of the adsorbent chitosan degree of deacetylation, crystallinity, molecular weight, viscosity and ash content), and the presence of contaminants in the solution and adsorption temperature and pH process conditions. The simplified pseudo-first-order Lagergren and pseudo-second-order model are commonly used to describe the adsorbent materials' metal ions sorption.

3.6.1 Pseudo first order kinetics

The first-rate equation for sorption (liquid/solid system) based on solid capacity was the Lagergren pseudo-first-order rate equation, this equation can be defined by eq. 13 (Ho & Mckay, 1999):

$$\mathrm{Log}(q_e - q_t) = \frac{K_1}{2.303}t + \mathrm{Log}q_e \tag{13}$$

In which q_e and qt reflect the metal concentration (μg/g) at equilibrium and correspondingly at any time, t(h); This kinetic model is ideal for illustrating the mechanism of adsorption although it has the following disadvantages.

- The above equation does not provide the theoretical q_e values derived from realistic q_e values and
- The plots are linear up to approximately the first 30 minutes, and after this time the theoretical results and experimental data do not correspond as predicted.

According to pseudo-first order rate equation of the Lagergren and $\log(q_e - q_t)$ vs. t plots slope Fig. 9. The rate constant K_1 was determined as -0.014 and -0.0046 hr^{-1} for dye respectively Table 2 which indicates that the chitosan biopolymer adsorption of ions did not obey pseudo-first-order kinetics. The pseudo-second-order Lagergren results in Fig. 9 and Table 2 indicate that the adsorption of dye to chitosan biopolymer follows a pseudo-second-order kinetic model where the second-order constants were determined as 10,575 and 0,0 $\mathrm{g}.\mu\mathrm{g}^{-1}\mathrm{hr}^{-1}$ with the 0,9959 and 0,9672 respectively regression coefficients (R^2). These findings suggested that

Table 2 Freundlich isotherm constants for the sorption of RBB-R dye onto chitosan.

Slope	Intercept	n	Lin K_F	K_F	R^2
0.343	3.107	2.92	3.107	12.34	0.921

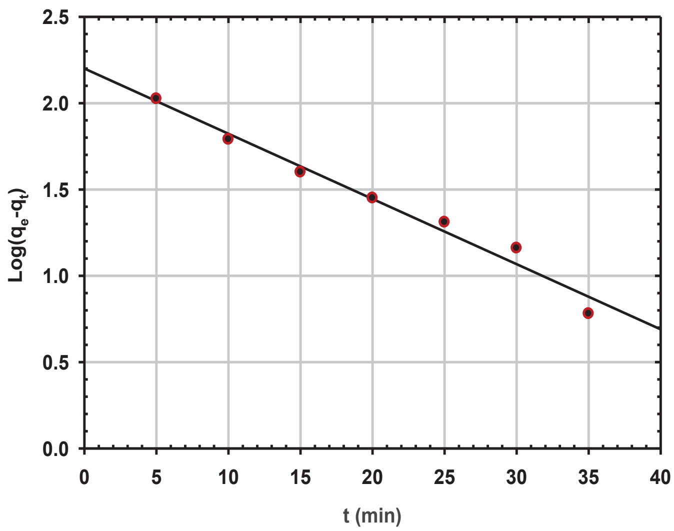

Fig. 9 Pseudo first-order kinetic model of adsorption kinetic experimental data of dye onto chitosan.

the kinetic sorption reaction between ions and chitosan biopolymer depends on the concentration of contaminants in the batch solution, as well as the adsorbent doses required to absorb the limit in equilibrium.

3.6.2 Pseudo-second-order kinetics

The linear equation for the Lagergren pseudo-second order rate can be given as:

$$\frac{1}{q_t} = \frac{1}{q_e}t + \frac{1}{K_2 q_e 2}. \tag{14}$$

In which q_e (1/slope) and K_2 (slope / intercept) are the concentration of the equilibrium contaminant and the adsorption rate of the second order constant, and these values were determined from t/q_t versus t plot. This model is ideal for determining an efficient q_e, since $q_{e,}$ $k_{2,}$ slope and intercept are determined from the plot Figs. 10 and 11.

3.7 Removal of organic content from real industrial wastewater

For the application of the treatment process using chitosan, industrial wastewater was collected from Sadat industrial area. Full-color reduction and reduction of more than 90 percent of organic materials in the form of COD at optimum pH 3, this was the same optimal pH of RBB-R treatment, Fig. 12, and the presented findings agree with the previously reported results (Abdelfattah et al.,2016c; Wang & Chen, 2009). The findings in this article demonstrated that; chitosan proposed a real method of eliminating the contaminants from industrial textile wastewater.

3.8 Corrosion experiment

The electrochemical measurements were performed using a cell with three electrodes. A mild steel working electrode was inserted into an epoxy resin leaving an uncovered surface area of 0.75 cm^2. A platinum sheet was used as a counter-electrode, and as a reference to a saturated Calomel electrode (SCE). The cell was attached to a potentiostat/galvanostat of Meinsberg, Germany. The electrode's open circuit potential (OCP) was reported to

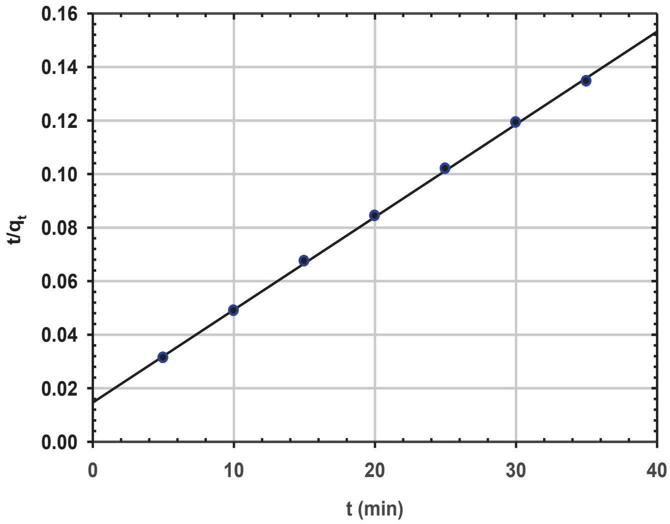

Fig. 10 Pseudo second-order kinetic model of adsorption kinetic experimental data of dye onto chitosan.

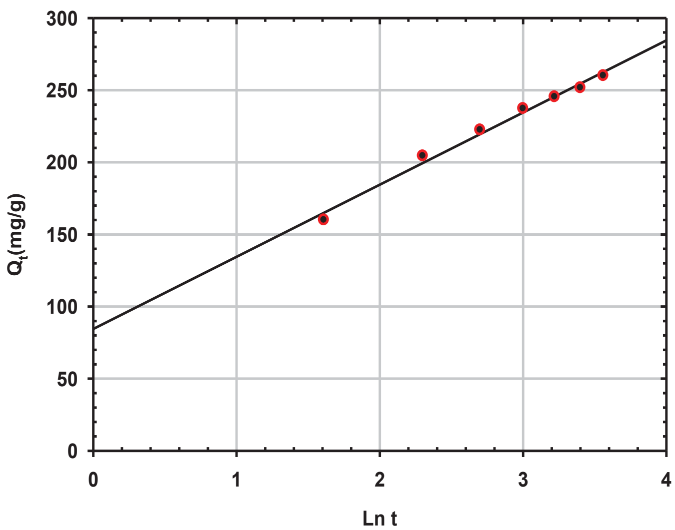

Fig. 11 Elovich kinetic model of adsorption kinetic experimental data of dye onto chitosan.

reach steady-state potential for 30 min. Potentiodynamic polarization measurements were obtained with a scan rate of 1 mV/S starting from -100 mV of the steady-state potential. In the presence and absence of inhibitor, weight loss measurements were conducted on mild steel coupons for 2, 4, and 6 days in treated wastewater. It will also examine the effect of biocide on the corrosivity of treated wastewater.

3.8.1 Open circuit potential

The open-circuit potential (OCP) can be defined as potential generated on the carbon steel without any peripheral current or potential in nature. Fig. 13 characterizes OCP curves against time for carbon steel coupons before and after chitosan treatment at 1800 s. Commonly, the development of traditional curves with straight lines for OCP versus time implies the deterioration of the metal oxide surface layer and the establishment of the corrosion inhibitor protective film at the metal and surrounding electrolyte boundaries (Verma et al., 2018). It is clearly noted that, during the study, the OCP versus time plots were basically straight as it obviously recommends the development of steady-state potential after immersing carbon steel samples in wastewater before and after chi-

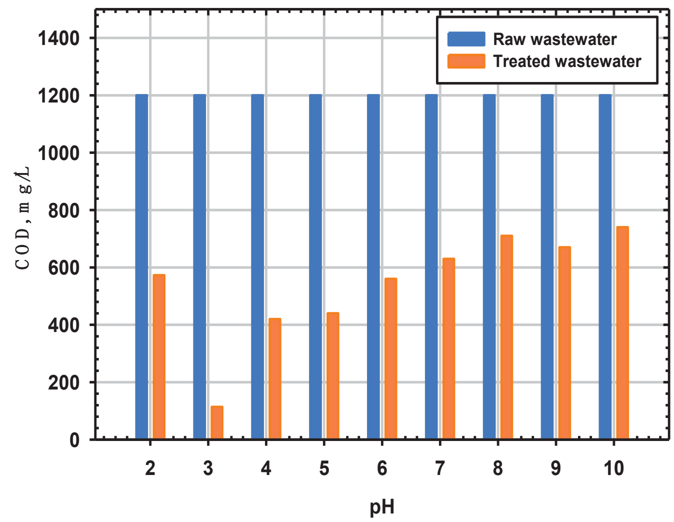

Fig. 12 COD results before and after wastewater treatment by chitosan biopolymer.

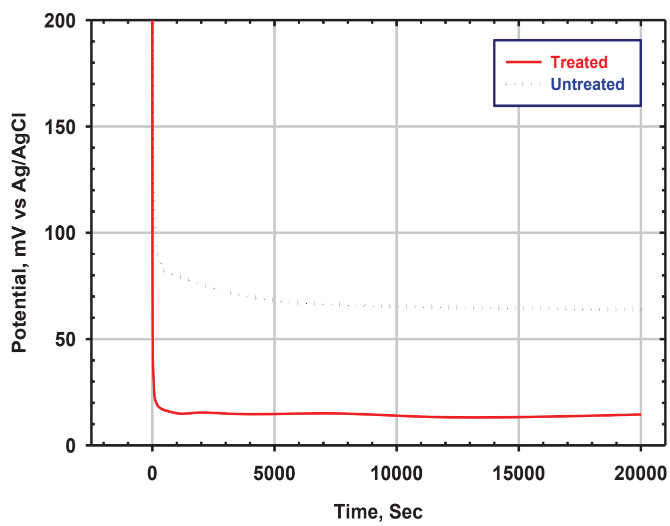

Fig. 13 Open circuit potential curves of mild steel coupons before and after treatment by chitosan.

tosan treatment for 1800 s. This reflection refers to the complete detachment of surface iron oxides and the adsorption of existing organic material has been realized. Watchful analysis of the OCP plots showed that the curve is moved to additional positive potential in untreated wastewater by chitosan compared with the untreated wastewater sample. The results indicate that the untreated wastewater is having more corrosion-inhibitory influence, so this process helps municipal networks cope with corrosion and prolong their lifetime (El-Shamy et al., 2017b; El-Kashef et al., 2019).

3.8.2 Potentiodynamic polarization measurements

The measurements of polarization were aimed at assessing the kinetics of cathodic and anodic reactions. Fig. 14. shows Tafel plots require a corrosion inhibition mechanism as a fortitude. Table 3 gartered the electrochemical parameters and the performance of inhibition. The data shown in Table 3 indicate that untreated wastewater reduces the current density of corrosion as a result of the improvement in inhibition efficiency (I.E, percent) to 57.12 percent. Especially in the absence of any corrosion inhibitor, this value is considered promising. As

Table 3 Electrochemical parameters of carbon steel in untreated and treated wastewater by chitosan by using potentiodynamic polarization technique.

Experiment	E_{corr}*(mV/SCE)*	I_{corr} *(mA/cm2)*	β_a *(mV)*	β_c *(mV)*	*EI, %*
Treated	-780	1.71	84.13	-347.97	——
Untreated	-765	1.68	82.65	-341.85	57.12

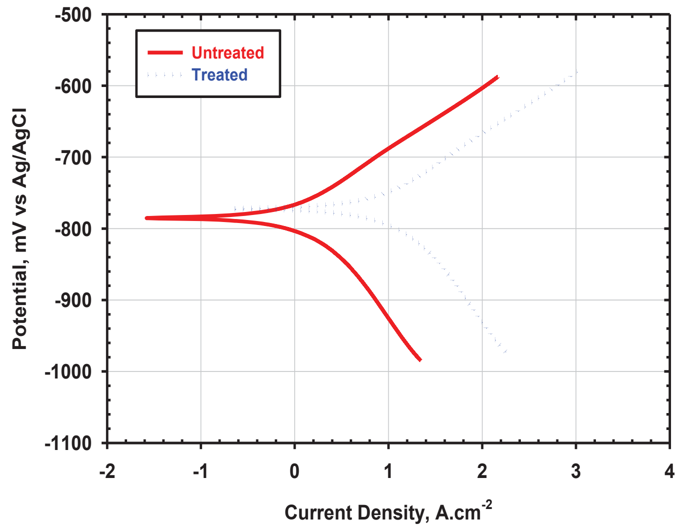

Fig. 14 Potentiodynamic polarization curves of mild steel coupons before and after treatment by chitosan.

shown in Fig. 14 the untreated wastewater sample induces a change in the potential value of corrosion to the anodic area. This states that the anodic reaction was congested by the untreated sample. In addition, the anodic and cathodic lope of the polarization curves have the same behavior in untreated and handled samples, as the corrosion current density (I_{corr}) in the untreated test solution is observed in the anodic branch while the inhibition capacity (I.E, percent) increases to its high value of 57.12 percent. Treatment of wastewater samples moves the corrosion potential (E_{corr}) to the anodic direction to some degree. However, chitosan wastewater treatment behaves like the same mixed form inhibitor activity (Shehata et al., 2020; El-Shamy et al., 2016; Shehata et al., 2019).

3.8.3 Electrochemical impedance spectroscopy

The aim of using electrochemical impedance spectroscopy (EIS) is to obtain numerical information on the characteristics and kinetics of the electrochemical processes taking place at the interface between carbon steel and electrolyte. In addition, to test the effect of chitosan wastewater treatment against corrosion behavior. In order to send trepidation signals on the working electrode, this technique depends on the smearing frequencies and low amplitude sinusoidal voltage wave. Fig. 15 shows the Nyquist carbon steel estimates in untreated and chitosan-treated wastewater. As illustrated in Fig. 15, The appearance of a single circle in Nyquist diagrams indicates that carbon steel corrosion is assessed under load transfer control (Verma et al., 2019). It should be noted that, in dissimilar circumstances, the circlets have a comparable shape, which means that the presence of dye has a particular impact against the regulation of corrosion, and the inhibition mechanism is mainly through its adsorption on the surface of carbon steel, which is in accordance with the obtained experimental result (Behpour et al.,2010). Furthermore, the diameters of capacitive semicircles on the surface of carbon steel electrode can be attributed to the growth of impedance in untreated wastewater and the formation of a defensive layer on the surface of carbon steel electrode, resulting in respectable inhibitive results. From the data obtained in Table 4, the rise in efficiency in untreated wastewater to achieve its high value of 63.16 percent and the

Table 4 Electrochemical parameters of carbon steel in untreated and treated wastewater by chitosan by using electrochemical impedance spectroscopy.

Experiment	R_t ($\Omega{\cdot}cm^2$)	C_{dl} ($\mu F{\cdot}cm^2$)	ER %
Untreated	1200	150.92	63.16
Treated	880	110.67	——-

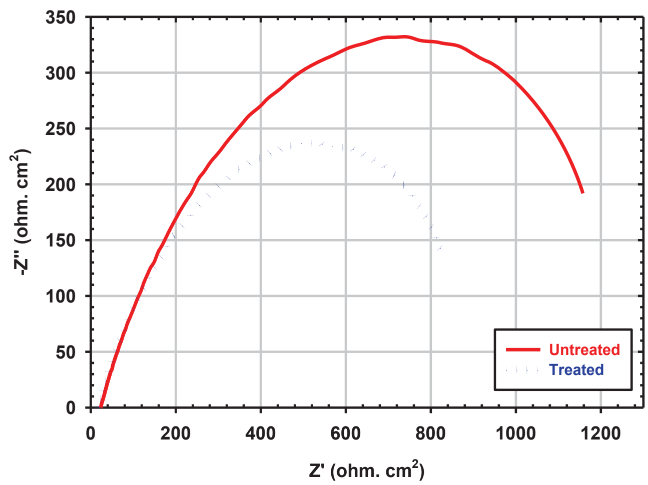

Fig. 15 Nyquist plots for the mild steel coupons before and after treatment by chitosan.

decrease in double-layer capability (C_{dl}), this result is due to the adsorption of the dye molecule on the surface of carbon steel (Bouyanzer et al.,2006).

4 Conclusions

Chitosan is effectively used to extract poisonous RBB-R dye from synthetic wastewater. Chitosan is effectively used in color removal as well as more than 90 percent of COD from actual textile wastewater. The results introduced chitosan in wastewater treatment as a possible eco-friendly alternative, at low pH, which can predominate in possible wastewater effluents. Langmuir isotherm adsorption has been found to follow the removal of dye from wastewater. From the electrochemical techniques open circuit potential OCP, potentiodynamic polarization measurements, and electrochemical impedance spectroscopy EIS all measurements indicated that the presence of dye in untreated wastewater reduces the current density of corrosion, and this dye acts as a mixed inhibitor form. Results have shown that the carbon steel corrosion mechanism in untreated and treated wastewater is regulated by the method of charging.

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Journal of Environmental Accounting and Management 10(3) (2022) 321-333

Journal of Environmental Accounting and Management

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Analysis of Pollutant Transport Around a Circular Cylinder in Subcritical Regime Using Lagrangian Coherent Structures

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Submission Info

Communicated by Jiazhong Zhang
Received 5 January 2022
Accepted 30 January 2022
Available online 1 October 2022

Keywords

Pollutant transport
Lagrangian coherent structures
Circular cylinder
Subcritical regime

Abstract

Lagrangian coherence structures (LCSs) are introduced to study the pollutant transport process in detail, more powerful than traditional Eulerian method in describing the mass transport in transient flow. First, pollutant transport in air around a circular cylinder in the subcritical regime with Reynolds number of 140000 is numerically simulated using DES Turbulence Model. Then, the complex turbulent flow and the accompanying transport process in the cylinder wake are revealed from Lagrangian viewpoint, through the analysis of LCSs which are extracted utilizing the ridges in the finite-time Lyapunov exponent fields. Further, a comparison between flow in the laminar and subcritical regime is carried out, and the factors for the intense mixing and quasi-periodical characteristic of the subcritical regime are discovered. Finally, based on lobe dynamics, the flow field is partitioned into several regions with different physical properties, so the mass and energy transport and mixing between those regions can be precisely described and captured. The results show the application of LCSs in uncovering the structures of complex turbulent flow in environmental problems, as well as the potential of LCSs to quantitatively analyze the pollutant transport process, could provide an efficient way for the optimal control of the pollutant.

1 Introduction

As a fundamental and practical model, circular cylinder is frequently chosen to study the pollutant dispersion or sediment in the flow around the blunt body in environmental engineering. Such kind of problem include the trap of sediment or pollutant in the wake of islands (Choi, 2021), the traffic emission dispersion around buildings (Ahmad, 2005), the effects of urban vegetation on air quality (Wania, 2012 and Hofman, 2020), the surface coating dispersion of marine pipelines and risers. As it is well known, the structures of the flow around the circular cylinder at different Reynolds number vary a lot (Williamson, 1996). As Reynolds number is below 40, the flow keeps stable with a steady recirculation zone downstream the cylinder, containing two vortices of

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ISSN 2325-6192, eISSN 2325-6206/$-see front materials
DOI:10.5890/JEAM.2022.09.009

the same size but different direction. For Re=40-150, as the result of a Hopf bifurcation, the flow becomes unsteady, and pairs of counterrotating vortices are generated and shed periodically. In this regime, the whole flow field keeps laminar. As Reynolds number increases further, the flow in the cylinder wake is transitioned to turbulence gradually, until it reaches 300, when the cylinder wake becomes fully turbulent and the flow shows distinct irregularities. This regime is referred to as subcritical regime and its corresponding Reynolds number range is approximately from 300 to 250000.

Because many flows around blunt body are in the subcritical regime, it has been studied since few decades ago. Among those studies, 3900 and 140000 are two main Reynolds number chosen, mainly due to the availability of previous data. Experiments with Re=3900 were conducted by Ong (1996) and Beaudan (1994), while the works of Cantwell (2015) and Norberg (2003) focused on the higher Reynolds number of 140000. A large amount of flow data was measured by these researchers, such as the drag and lift coefficient, time-averaged velocity profile, Strouhal number, length of recirculation zone, providing rich resources for the following researchers. PIV method is the most welcomed while other devices such as hot-wire and X-ray are also used. However, due to the limitations of these devices, the details of the flow, especially in the near wake region, are difficult to capture. Moreover, in such Reynolds number range, the flow in the wake becomes turbulent, which is critically sensitive to perturbations. Consequently, the results of the experiments by different researchers, even at the same Reynolds number, are different from each other considerably, especially in the length of recirculation zone and average-velocity profile. This issue was pointed out by Kim (Kim, 2006), who attribute the deviation to structural vibration, blockage ratio, aspect ratio of the cylinder, mainstream turbulence and surface roughness.

The use of computational fluid dynamics (CFD) shed much light on the problems mentioned above, making the study of the near-wake region feasible. Using Large Eddy Simulation (LES), Mittal (1997), Breuer (1998) and Guo (Guo, 2016) predict the flow at Reynolds number of 3900. By comparing the flow quantities such as the drag coefficient, the Strouhal number and the velocity profile with experiments, these simulations were proved to successfully reproduce the flow. Similarly, Breuer (2000), Kim (2006) and Ouvrard (2008) simulated the flow at a higher Reynolds number of 140000 using LES or a hybrid RANS/LES method called Detached Eddy Simulation (DES), and the results implied that they are able to predict the global parameter of the flow and the turbulence in the wake accurately. A comparison between the two-dimensional RANS with three-dimensional LES and experiment of a flow at Reynolds number 22000 was given by Casalino (2003), the result indicated that RANS underestimated the length of recirculation zone and overestimated the vortex shedding frequency. The author explained that part of energy extracted from the mainstream in three-dimensional flow was used to maintain the turbulent fluctuation in spanwise direction, weakening the Reynold stress and inducing shorter recirculation bubble. Also, the same conclusion was drawn by Orselli (2006), who found that in RANS methods the SST transition turbulence model is more suitable for its precise prediction of the transition point. However, LES or DNS are still needed as the details of the turbulent flow are concerned.

The numerical simulations above essentially focused on reproducing the experimental results, but paid less attention to the flow field structures. The Proper Orthogonal Decomposition (POD) analysis was carried out by Perrin (2008) to evaluate the phase-averaged velocity and phase-averaged turbulent components, such as turbulent stress and turbulent kinetic energy. The studies show the effects of coherent structure motions on structural properties of turbulence, laying a foundation to turbulence modeling. Based on PIV methods, the streamlines were obtained and their topology were analyzed by Cantwell (1983), and the results imply that the turbulence energy in the wake of cylinder is generated in the small structures near the saddle point and then stretched and advected to the centers in the flow pattern through the unsteady manifolds. However, it is worth noting that the majority of the analyses are from Eulerian frame, using the pressure distribution, streamlines pattern, contours of velocity or its gradient. Eulerian approaches are relatively easier to implement. Nevertheless, they describe only the instantaneous state of the flow rather the dynamic characteristics. That is to say, Eulerian approaches are kinetic description, and hence are difficult to accurately describe complex dynamic motions, such as the mass transport in transient flow (Shadden, 2005), which is the focus of this paper. Hence, Lagrangian approaches have become increasingly popular (Wiggins, 1992), and among them, Lagrangian Coherent Structures (LCSs) attract lots of researchers and have been a research hotspot in recent years.

Traditionally, manifolds in nonlinear dynamics are defined in an infinite time range. However, the assumption of infinite time fails in flow problems. To address this issue, Finite-time manifolds, which were proved to approach the traditional manifolds as time tends to infinite (Haller, 2000), were proposed by Haller (1998). Then material lines with locally the most attracting or repelling properties are introduced to delineate the finite-time manifolds (Haller and Yuan, 2000). Thereafter, finite-time Lyapunov exponents (FTLE), which are used to describe the average exponential divergence rate of adjacent trajectories in phase space in traditional nonlinear dynamics, are introduced to evaluate the hyperbolic properties of material lines numerically (Haller, 2002), and then LCSs are defined as the ridges of FTLE field. LCSs process two main properties: First, they serve as the transport barriers in the flow fields, and the flux across a LCS is negligible (Shadden, 2005). Second, particles in opposite side of LCSs separate hyperbolically in the flow. Hence, with LCSs the flow field can be partitioned into regions with different dynamic characteristics, and lobe dynamics can be utilized to analyze the transport process of the flow, and further to quantify the mass transport exactly (Haller, 2015). In the past decades, as a powerful tool for uncovering the mass and energy transports in the flow, LCSs have been applied to the studies of oceanic flow (Beron-Vera, 2008 and Shuckburgh, 2012), atmospheric flow (Tang, 2011 and BozorgMagham, 2013), flow separation (Cao, 2020), turbulence (Mathur, 2007) and so on.

In recent years, LCSs are also introduced to study the flow around the cylinder. The first attempt was made by Jens Kasten (2010), who discovered that the mixing in the wake of cylinder was characterized by LCSs, especially the Lagrangian saddle points. The LCSs of an impulsively started circular cylinder at Reynolds number of 200 were extracted by Peng-Fei (2014), and further the generation of separation, burst of separation bubbles, vortex shedding process and the accompanying mass transport process were analyzed. His study provided a new insight into the targeted control of flow around a bluff body. Following their works, the flow around the circular cylinder at a higher Reynolds number of 9000 was investigated using LCSs by Rockwood (2017), and the results indicated that the saddle points in the flow field characterized the motion of vortex. An asymmetric P+S wake for a transversely oscillating cylinder was studied numerically and the corresponding LCSs were extracted by Wang (2018), and the generation of new vortex structures was studied from Lagrangian point of view. The results implied that LCSs can be able to reveal more details of vortex comparing to Eulerian methods. In addition to mass transport, LCSs were also introduced by Cao (2021) to study the forced convection heat transfer around a circular cylinder at Reynolds number from 20 to 180. The result show that the effects of convective heat transfer gradually exceeded that of heat conduction and LCSs became more and more coincident with the boundaries of the heated/cooled fluid, as Reynolds number increases, indicating the ability of LCSs to describe the heat transfer process.

Those studies mentioned above could gain key understanding of the vortex motions and mass transport process in the laminar regime. Hence, following their works, the complicated flows of air with pollutant around the circular cylinder at Reynolds number of 140000, which is corresponding to conditions of many practical environmental cases, are numerically studied in this paper. Then the LCSs at different instant are extracted and analyzed to indicate its ability to reveal the coherent structures and mass transport process in such complex turbulent flow, as well as the ability to quantitatively analyze the pollutant diffusion.

2 Fundamental theories

2.1 Lagrangian coherent structures

From Lagrangian frame, the fluid particles in the flow field constitute a nonlinear dynamic system. Therefore, the theories of nonlinear dynamics can be introduced to reveal the skeletons of the flow patterns through analyzing the motions of the fluid particles, so that the nature of the flow can be understood well.

For a certain flow, a dynamic system in the following form is considered,

$$\dot{\mathbf{x}}(t;t_0,x_0) = \mathbf{u}(\mathbf{x},t), \mathbf{x} \in U \tag{1}$$

with $\mathbf{x}(t;t_0,\mathbf{x}_0)$ representing the trajectory of the fluid particle passing through a point $\mathbf{x}_0$ at initial time t_0, and with $\mathbf{u}(\mathbf{x},t)$ denoting the velocity vector and U the flow domain.

The flow map for the system Eq. (1) from time t_0 to t can be defined as

$$F_{t_0}^{t}(\mathbf{x}_0) = \mathbf{x}(t;t_0,\mathbf{x}_0), \mathbf{x} \in U \tag{2}$$

Considering two fluid particles being separated by a small distance $\delta\mathbf{x}_0$ at time t_0, then their positions can be written as $\mathbf{x}_0$ and $\mathbf{x}_0 + \delta\mathbf{x}_0$, respectively. Advected by the flow, the new distance between these two particles at time t can be expressed as

$$\begin{aligned} \delta\mathbf{x} &= \mathbf{x}(t;t_0,\mathbf{x}_0+\delta\mathbf{x}_0) - \mathbf{x}(t;t_0,\mathbf{x}_0) \\ &= F_{t_0}^{t}(\mathbf{x}_0+\delta x_0) - F_{t_0}^{t}(\mathbf{x}_0) \\ &= \nabla F_{t_0}^{t}(\mathbf{x}_0)\delta\mathbf{x}_0 + \mathrm{O}(\|\delta\mathbf{x}_0\|^2) \end{aligned} \tag{3}$$

with ∇F denoting the Jacobean of F. The distance between two particles is

$$\begin{aligned} |\delta\mathbf{x}| &= \sqrt{\langle \nabla F_{t_0}^{t}(\mathbf{x}_0)\delta\mathbf{x}_0, \nabla F_{t_0}^{t}(\mathbf{x}_0)\delta\mathbf{x}_0 \rangle} \\ &= \sqrt{e^* \cdot \nabla F_{t_0}^{t}(\mathbf{x}_0)^* \cdot \nabla F_{t_0}^{t}(\mathbf{x}_0) \cdot e}\ |\delta\mathbf{x}_0| \end{aligned} \tag{4}$$

where $e = \delta x_0 / |\delta x_0|$ and the star refers to matrix transposition. Therefore, the stretch or shrink ratio of the fluid between two particles can be expressed as

$$\begin{aligned} \lim_{|\delta\mathbf{x}_0|\to 0} \frac{|\delta\mathbf{x}|}{|\delta\mathbf{x}_0|} &= \sqrt{e^* \cdot \nabla F_{t_0}^{t}(\mathbf{x}_0)^* \cdot \nabla F_{t_0}^{t}(\mathbf{x}_0) \cdot e} \\ &= \sqrt{e^* \cdot C(\mathbf{x}_0) \cdot e} \end{aligned} \tag{5}$$

with $C(\mathbf{x}_0)$ representing the right Cauchy-Green tensor defined as

$$C(\mathbf{x}_0) = \nabla F_{t_0}^{t}(\mathbf{x}_0)^* \cdot \nabla F_{t_0}^{t}(\mathbf{x}_0) \tag{6}$$

The deformation of fluid includes stretch, shrink and rotation, and $C(\mathbf{x}_0)$ describes the stretch and shrink of fluid. For a two-dimensional flow, the tensor is a 2x2 symmetric positive definite matrix and hence admits two real positive eigenvalues, defined as λ_i, with their corresponding eigenvectors ξ_i. The eigenvalue represents the stretch or shrink ratio of the fluid in the direction of the eigenvector from time t_0 to t.

Lyapunov exponent, used to evaluate the average exponential expansion or contraction rate of a system in nonlinear dynamics, shares the same physical meaning with Cauchy-Green tensor. So FTLE can be expressed by the maximum eigenvalue $\lambda_{\max}$ of $C(\mathbf{x}_0)$ in the time interval $[t_0,t]$ as

$$\sigma_{t_0}^{t}(\mathbf{x}_0) = \frac{1}{|t-t_0|} \ln \sqrt{\lambda_{\max}} \tag{7}$$

By integrating the velocity obtained from numerical simulation or experiment, the trajectories of fluid particles as well as the flow map $F_{t_0}^{t}$ are obtained. Then, FTLE can be calculated at each point in space with the maximum eigenvector of Cauchy-Green tensor. As mentioned above, FTLE evaluates the maximum rate of separation over time interval $[t_0,t]$ of two particles initially separated by a finitely small distance, so the ridges of FTLE field represent the material surfaces/lines with locally the most repelling properties, which were coined by Haller and Yuan (2000) as repelling LCSs (rLCSs). Similarly, the attracting LCSs (aLCSs) are extracted from the ridges of FTLE field calculating backwards in time.

Repelling LCSs, corresponding to the finite-time stable manifold, contain the tendency of the flow, while the attracting LCSs, corresponding to the finite-time unstable manifold, contain the historical information of the

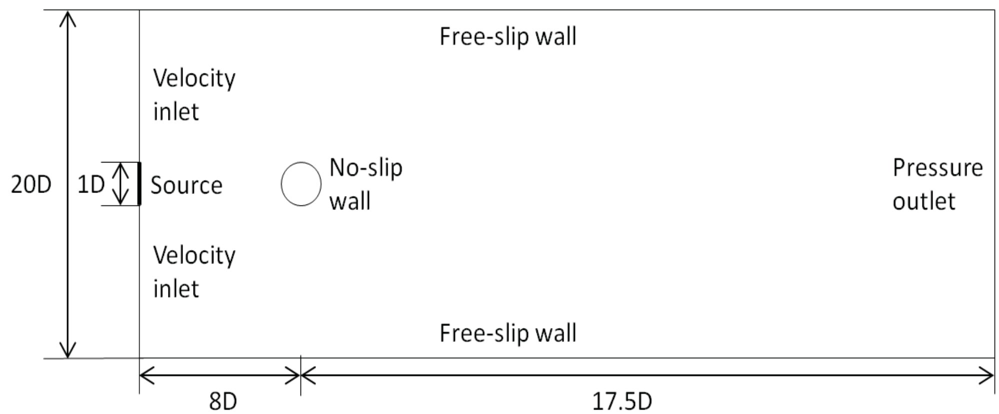


Fig. 1 Schematic diagrams of the computational domain and model.

flow. Obviously, there are a large number of material lines near the attracting LCS, but attracting LCS is locally the most attractive material line that continuously attracts the surrounding fluid. Similarly, the repelling LCS is the most repelling material line locally that continuously repels the surrounding fluid.

It is worth noting that the integration time $|t-t_0|$ has an impact on the LCSs obtained. As the integration time is short, only less flow information is covered, and as a result, the LCSs are short and blurred. However, if the integration time is too long, the fluid particles initially near the material line are advected too far. As a result, their motions are mainly dominated by other coherent structures rather than the studied material line. In such a case, the LCSs become too complicated to analyze, and hence choosing integration time properly is of great importance.

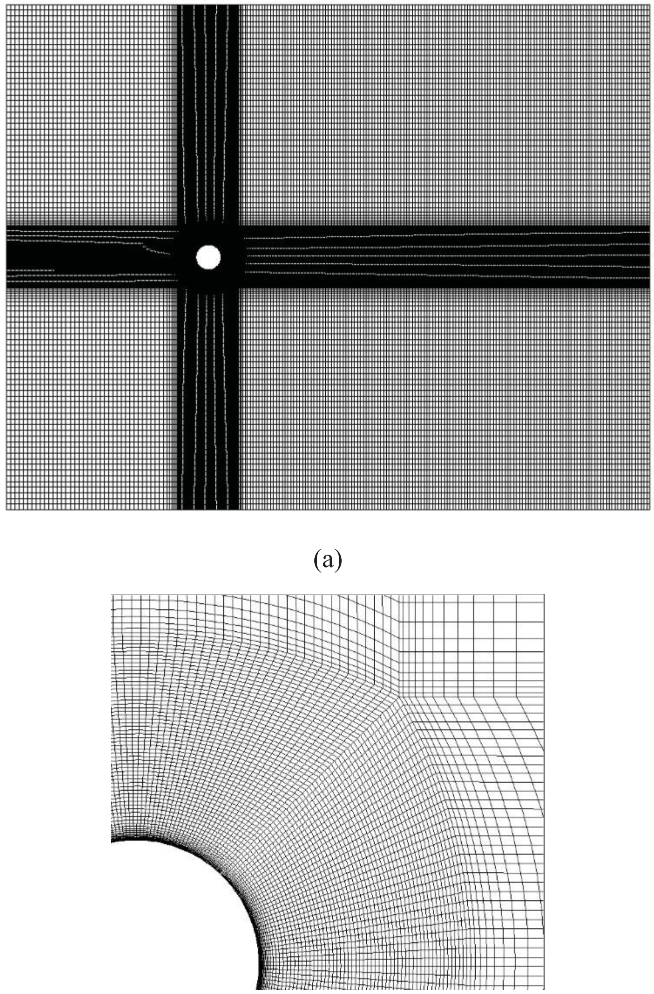
2.2 Numerical simulations

In this study, the flow around a cylinder in the subcritical regime is simulated using the commercial software Ansys Fluent. In this regime, the flow downstream the shearing layer is fully turbulent, which has complex structures, showing a quasi-periodic characteristic. As mentioned above, the previous studies indicate that $RANS$ turbulent models can only capture the main unsteady flow structures, deriving a periodical behavior. Therefore, a $DDES$ model, which is a hybrid $RANS/LES$ model, is adopted to get the details of turbulent flow. For the $RANS$ part, $SST\ k-\omega$ model, which uses $k-\varepsilon$ model in fully turbulent region and k-ω model in near-wall region, is chosen for its high performance in the flow characterized by adverse pressure gradient boundary layers. The mixing and transport of pollutant and air are simulated numerically through solving conservation equations describing convection and diffusion of each species.

The schematic diagram of the flow field is illustrated in Fig.1. The flow domain is modeled as a square zone with sufficiently large size to make sure that the cylinder is affected as slight as possible by the boundaries. In the streamwise direction, the cylinder is located at $8D$ downstream of the inlet and $17.5D$ upstream of the outlet. The distance between the upper and lower walls is $20D$ and the cylinder is located at the middle, thus the blockage ratio being precisely 5%. Mixture of air and pollutant is injected through a $1D$ long line source positioned in the middle of the velocity inlet, with its velocity being the same as the inlet and the mass fraction of the pollutant being 1%.

At the inlet, a uniform and constant velocity and the concentration of the pollutant is prescribed. At the outlet, the static pressure is set as the same as that of the inlet. The top and the bottom boundaries are modeled as non-slip walls, where the normal velocity is zero and the tangential velocity is not affected by the wall. The cylinder surface is considered to be a non-slip wall.

As shown in Fig.2, the flow field is divided into 9 blocks to get structurally meshed, and the meshes around the cylinder are fined with O-type grid. In order to meet the need of the SST model, the first layer of the grid



(a)

(b)

Fig. 2 Mesh for the numerical simulation: (a) global view; (b) enlarged view near the cylinder.

Table 1 Effects of grids on the drag coefficients and the Strouhal numbers.

	Number of nodes	Number of elements	$C_{d,mean}$	St
Mesh_1	83214	82567	1.152	0.232
Mesh_2	115992	115197	1.188	0.230
Mesh_3	145874	144473	1.176	0.230

is placed in the viscous sublayer. Thus, the height of the first layer of the mesh at the wall is set as 2×10^{-4} to make sure that the wall distance estimation *Yplus* is constantly less than 1.

For the verification of the grid independence, three meshes with different grids are used. The number of nodes and elements of the grids, the drag coefficient ($C_{d,mean}$), the vortex shedding frequency (St) are listed in Table 1. As shown in the table, the drag coefficient and the vortex shedding frequency obtained by the three meshes varies slightly. Therefore, to save the computational resources, mesh_2 is used in the following simulations as shown in Fig.2.

The accuracy of the numerical simulation is evaluated by comparing with existing results. Table 2 presents the experimental results obtained by Cantwell (1983), Breuer (2000) and Orselli (2009) and the numerical results

Table 2 Aerodynamic quantities of present and previous studies at Reynolds number near 140000.

	Re	$C_{d,mean}$	*St*	L_r/D	θ_s
DES (present)	140000	1.176	0.23	0.4	98
EXP. (Cantwell)	140000	1.24	0.18	-	-
EXP. (Breuer)	140000	1.2	0.2	0.44	91.45-96.6
EXP. (Orselli)	90000	1-1.4	0.18-0.191	-	80
LES (Kim)	140000	1.21	0.203	0.54	-
LES (Orselli)	90000	1.08	0.191	-	81
RANS (Casalino)	22000	0.95	0.23	1.2	91
RANS (Orselli)	90000	1.09	0.235	-	88

by Kim (2006), Orselli (2009) and Casalino (2003).

As is listed in the table, the drag coefficients obtained in the present study are in good agreement with that obtained by both *LES* method and experiment, which is higher than the result by *RANS* method. However, the Strouhal number that characterizes the vortex shedding frequency is slightly overestimated and the length of recirculation L_r is underestimated compared to experiments and results by *LES* method, but both of them are similar to those obtained by Casalino (2003) and Orselli (2009) using two-dimensional *RANS* approach. As mentioned by Roshko (1993), this is a common phenomenon in two-dimensional *CFD* results. Because the turbulent fluctuation in the spanwise direction is ignored by the two-dimensional numerical simulation, thus all the energy extracted from the mainstream is used to maintain the turbulent fluctuation in plane, leading to the higher Reynolds stress $\rho\overline{u'v'}$, the smaller recirculation zone and the greater Strouhal number.

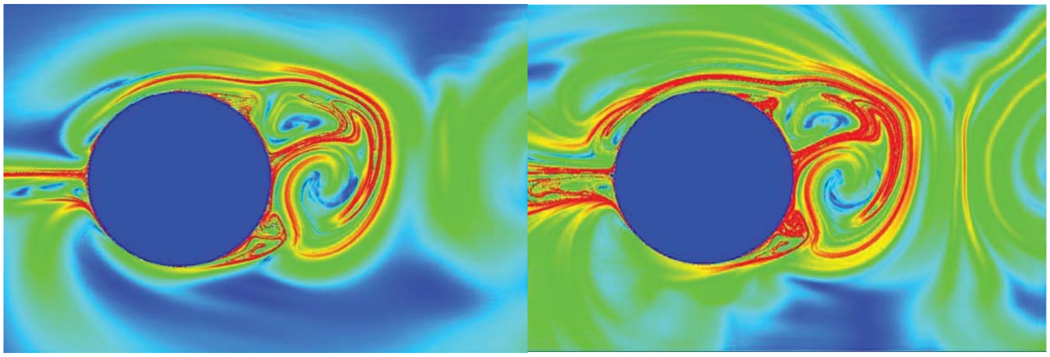
Consequently, this study focuses on using LCSs to describe the turbulent flow and the accompanying transport processes in complex turbulent flow, the deviation is considered acceptable.

3 Results and discussions

At the beginning of the study, the integration time independence of the LCSs calculation is verified. The FTLE fields, derived by integrating the particle velocity for one and two quasi-periods, are demonstrated in Figs. 3(a) and 3(b), respectively. As shown in the figures, it is clear that the ridges of the FTLE field near the cylinder, except for the leading edge, are almost the same, despite the different integration time. This is because the LCSs in the leading edge will be advected to the boundary between the wake and the mainstream so that the fluid particles at different side of the LCS remain close for whole quasi-period. In this way, the hyperbolicity of the LCS has not revealed until the second quasi-period, resulting the missing in Fig. 3(a). However, most of the ridges are captured by the shorter integration time and the ridges in Fig. 3(b) are too blurred and thick, so the shorter integration time is chosen for the following study. Meanwhile, it is also necessary to refer to the structure obtained with the longer integration time, as the fluid particles in the leading edge are concerned.

In order to study the transport of pollutant in the wake, the first quasi-period after the pollutant arrives the cylinder is studied, and the FTLE fields is calculated at 9 time points of the period. Fig. 4 displays the contours of pollutant concentration with the corresponding attracting and repelling LCSs at different instances of the first quasi-period. In those figures, the background is the contour of pollutant concentration, the attracting LCSs are represented by white lines, and the repelling LCSs are represented by black lines.

As shown in the figures, LCSs are coincident with the boundaries between high-concentration and low-concentration area. Within the acceptable error, no pollutant passes through the LCSs surrounding and mixes with fluid elsewhere, proving that LCSs successfully depict the transport boundaries in the wake of flow around circular cylinder. By analyzing the flow in the wake using LCSs, we gain insight into the generation, development and shedding of the vortexes, as well as their interaction with each other and with the shearing layer. In this way, the mass transport induced by those phenomena can be visualized and better understood. Moreover, by



(a) (b)

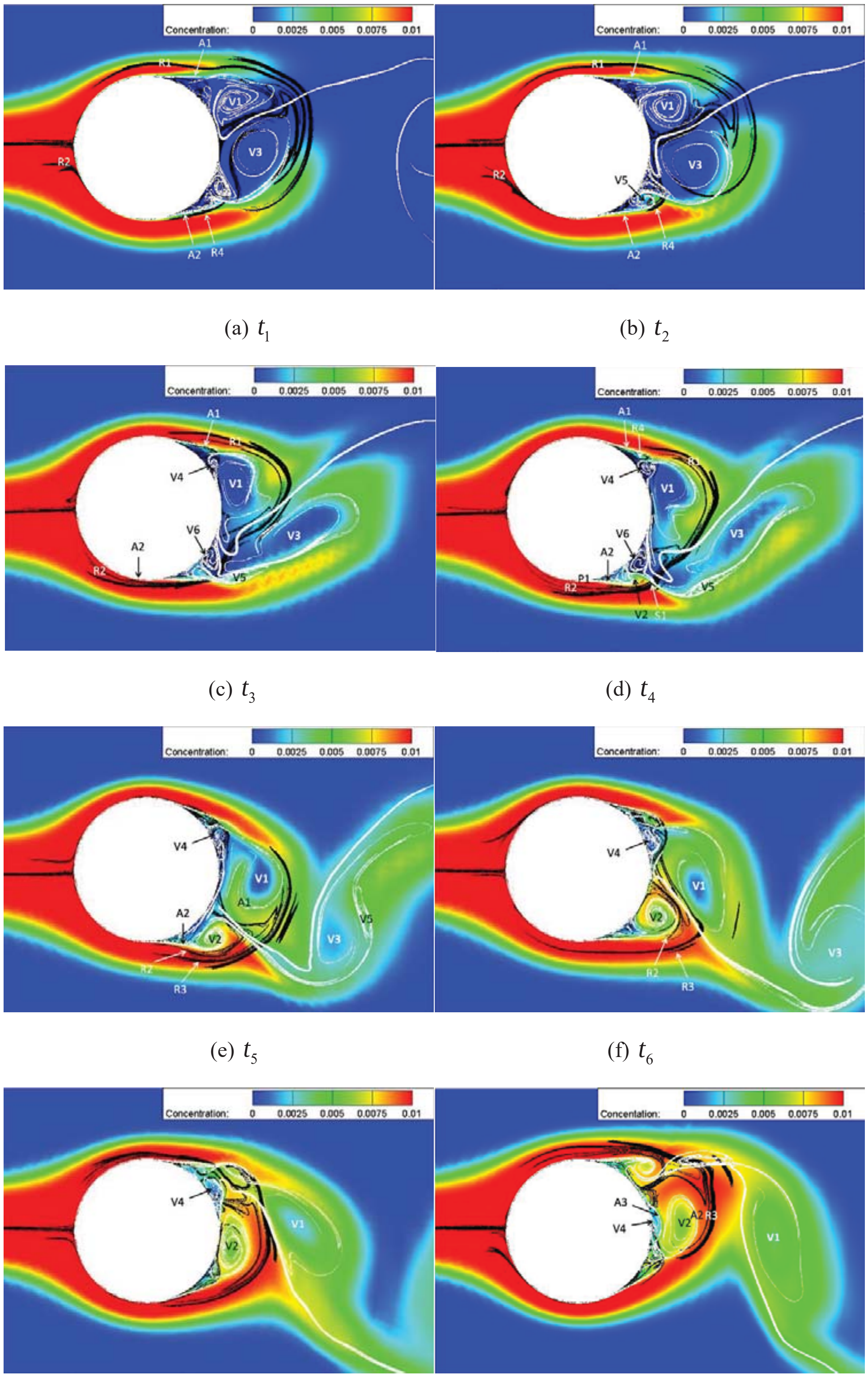
Fig. 3 FTLE contours derived by different integration time: (a) one quasi-period; (b) two quasi-periods.

investigating the motion of lobes formed by the entanglement of the aLCSs and the rLCSs, the near wake region of the cylinder can be defined, and the input and output of mass from the near wake region can be quantitatively studied.

At time t_1, a rLCS on the upper side of the cylinder denoted as R1 divides the flow field into two parts. The flow below R1 enters the near wake region through the channel between R1 and attracting LCS A1, while the fluid above R1 will directly pass the cylinder and enter the far wake region. In this process, A1 serves as a boundary that separates the low-concentration fluid in the near wake region from the high-concentration fluid from the main stream. With A1 being stretched and folded, the fluid wrapped in A1 and R1 is taken into the wake vortex V1 through the channel. Since the concentration of the fluid is not uniform and there is no LCS that prevents the transport, it is mixed and the concentration gradually becomes uniform. At time t_5, with the break of A1, the high-concentration fluid of the main stream is connected to the low-concentration fluid in the near wake region, which characterizes the mixing of the two parts of the fluid, resulting in a further decrease of concentration. Thereafter, R1, which now separates the vortex V1 from the downstream flow, gradually fades away. Without being blocked by it, V1 sheds off from the cylinder and enters the far wake region. With the dissipation of V1, the fluid in V1 mixes with the downstream fluid and the concentration increases again.

The motions of the fluid in the lower part of the mainstream are quite different. There is no channel formed by aLCS and rLCS at the beginning, so all the fluid from the mainstream straightly passes the cylinder and moves into the far wake region, despite minute quantity of fluid entering the vortex V5 through the narrow channel between A2 and R4. As a result, the concentration of the lower part of the near wake region stays at a low level. However, as R2 moves downstream and separates from the cylinder wall, a channel between R2 and A2 is formed, through which part of mainstream high-concentration fluid entrains the near wake. At time t_4, vortex V2 is generated due to the Kelvin-Helmholtz instability of the shearing layer. The flow from mainstream is constantly injected into V2, providing the vortex with momentum and mass. Therefore, V2 grows larger in size and starts to absorb the fluid in the near wake of the cylinder, breaking the aLCS enveloping V6 and merging with V6 later. At time t_5 the leading edge of R2 falls on A2 so the channel between them is closed, the mainstream fluid can no longer entrain V2 through the channel. Instead, the mainstream flow is drawn into the near wake region through the new channel between R2 and R3. Being blocked by A2, this part of the flow does not mix with the fluid in wake vortex V2; being blocked by R3, it isn't advected to the far wake region; and being blocked by A3, it does not mix with the fluid in near wall vortex V4 as well. Therefore, it temporarily maintains a high concentration of mainstream fluid. It is worth noting that during this process, A2 is repeatedly stretched and folded. Eventually, A2 break apart at time t_9 and a new channel to V2 is formed. It can be foreseen that this part of the high-concentration fluid will mix with the relatively low concentration fluid of V2 and shed off into the downstream together.

In the laminar flow regime as shown in the studies of Peng-Fei (2014) and Cao (2021), the shearing layers are



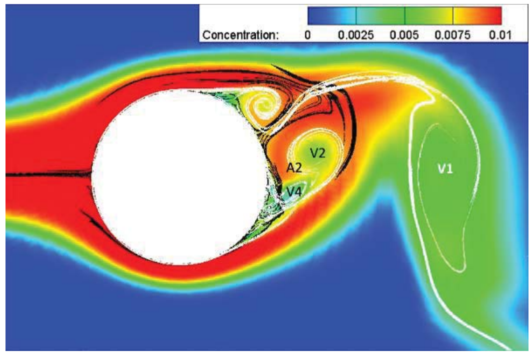
(a) t_1 (b) t_2

(c) t_3 (d) t_4

(e) t_5 (f) t_6

(g) t_7 (h) t_8

Fig. 4 Instantaneous concentration contours and LCSs around the circular cylinder.



(i) t_9

Fig. 4 Continued.

robust. Hence, the vortexes, the results of the Kelvin-Helmholtz instability of the shearing layer, are generated relatively downstream the cylinder. Therefore, it directly shed off without affecting the cylinder and its adjacent region. Instead, a so-called "dead-air region" with low velocity occupied the near wall region, weakening the mass and energy exchange between the mainstream and the immediate vicinity of cylinder.

In comparison, the shearing layers in the subcritical flow regime are much more unstable and the corresponding destabilizing position shift upstream. As a result, wake vortexes are rolled up near the cylinder wall, taking the pollutant from the mainstream to the near wall region and squeezing the "dead-air region" to the corner of the shearing layers and the cylinder wall. In a word, the transport between the mainstream and the cylinder wake is enhanced.

Furthermore, due to the large shearing velocity on the interface between the wake vortex and the "dead-air region", some small vortexes are generated as a consequence of the K-H instability. For instance, at time t_3, a vortex named as V4 is newly generated between the "dead-air region" and vortex V1. Because it is a vortex rotating counterclockwise, it should not be generated by shearing layer of the cylinder, but that of the "dead-air region" and V1. Different from other vortexes in the near wall region, V4 does not dissipate or be absorbed, but merges with the fluid enveloped by R4 and grows gradually. Tracking this vortex, it can be found that it is squeezed to the lower side of the cylinder by the wake vortex V1 after about half a period, then merging with the wake vortex V2, and finally being carried downstream with V2. From viewpoint of mass transport, the vortex V4 brings the fluid in the "dead-air region" to the near wake and finally to the far wake region, enhancing the mass transport. The generation of this kind of vortex is irregular, for example, no such vortex is generated near the lower part of the cylinder. As a result, the flow at the lower and upper side of the circular cylinder becomes asymmetric, so it may be one of the reasons for the quasi-period behavior of the flow.

Another noteworthy phenomenon is that, in the laminar regime, the frequency of the shearing layer instability is the same with the vortex shedding frequency, so the flow is perfectly periodic. However, in the subcritical regime, the two processes are not harmonious. For example, in the quasi-period studied, both the upper and lower shearing layer experience the destabilization twice, and as a result, two vortexes are generated in one quasi-period at each side. One of them, like V2, grows and then influences the flow in the near wake greatly. While another one, like V5, just takes a little bit of the fluid in the near wake downstream. This may be the second reason for the quasi-period behavior.

Based on the transport process analyzed above, the whole flow field can be divided into regions with different physical properties. Take time t_1 for example, the flow field as illustrated in Fig.5 is divided into five parts, namely, the yellow part that is about to entrain the near wake region from the mainstream, the red part that is a wake vortex about to shed off, the near wake region painted blue, and the mainstream and the far wake region that are still colored by the contour of concentration. Since the flow is incompressible, the area of each region

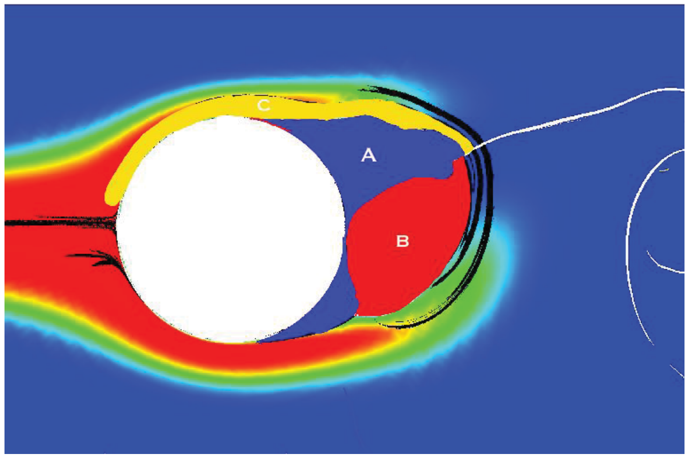


Fig. 5 A flow field segments based on the LCSs at time t_1.

represents its mass. In this way, the mass of the fluid entraining the wake region or flowing out of it can be derived simply through calculating the area. Furthermore, if the concentration is also considered in the surface integration, the mass of pollutant entering the wake or discharged from the wake can be precisely confirmed. Similarly, the source or the destination of a certain cluster of pollutant can be known by tracking the lobe it belongs. In a word, this provides a new method of quantitative analysis of pollutant transport.

Moreover, based on the theories in nonlinear dynamic, the saddle points are extremely sensitive to disturbances. Inspired by this, flow control measures can be applied to the stable manifold of the saddle point, which is clearly illustrated by the intersection of rLCS and aLCS, to achieve the most significant control effect, for instance, to enhance or weaken the ventilation, with the least energy. For example, flow control measures can be applied upstream the separation point P1 in Fig.4(d), so the energy will be transferred along R2 to the saddle point S1 and then along its unstable manifold A2 to the wake vortex, promoting the mass transport between the mainstream and the wake.

4 Conclusion

Pollutant transport around a circular cylinder in the subcritical regime is numerically simulated based on DES Turbulence Model. Subsequently, Lagrangian Cohenrent Structures are extracted to study the coherent structures and mass transport process in the cylinder wake. Based on the results, the following conclusions can be drawn,

1) In the flow regime studied, LCSs are in good agreement with the boundaries between high-concentration and low-concentration area, no observed pollutant passes through the LCSs, proving the ability of LCSs to depict the transport boundaries of pollutant.

2) The mass transport in the subcritical regime is more intense than that in the laminar regime, which can be explained essentially in two aspects. First, the wake vortexes are generated closer to the cylinder wall, which takes the place of the “dead-air region” in the laminar regime. Moreover, some small vortexes are formed near the cylinder wall, as they are advected to the far wake region, the fluid in the near wake is carried downstream.

3) Combined with lobe dynamics, the complex turbulent flow and the transport process in the cylinder wake can be visualized, and the mechanism can be analyzed and understood feasibly. Through the analysis, two factors for the quasi-periodical characteristic of the flow are discovered. First of all, vortexes are irregularly generated because of the K-H instability in the near wake region, some of them dissipate quickly, but others

influence the flow in the wake greatly. Second, the frequency of the shearing layer instability is not equal to the vortex shedding frequency, and more than one vortex is generated in the shearing layer in a quasi-period, breaking the periodicity of the flow.

4) Compared with the traditional Eulerian approaches, LCSs are able to clearly and objectively divide the flow field into regions with different physical properties. Hence, if the concentration field of the flow is known, the quantitative analysis of the pollutant transport process can be carried out. Moreover, the saddle points in the flow field are illustrated by the intersection of rLCSs and aLCSs, using the property could realize the optimal control of pollutant.

Acknowledgments

This work is supported by the projects of the manned space engineering technology (No.2020-ZKZX-5011), National key fundamental research project (No.2019-JCJQ-ZD-177-01), National major project (No.7796080000-00200007) and National Natural Science Foundation of China (No.51775437).

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