Wide-scale assessment of cultural ecosystem services in coastal areas using graph theory on social media data

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Running page head: Wide-scale assessment of CES using Graph Theory

Abstract

Cultural Ecosystem Services (CES) assessment at large scales is crucial in marine ecosystems as they reflect key physical and cognitive interactions between humans and nature. The analysis of social media data with graph theory is a promising approach to provide global information on users' perceptions for different marine ecosystems. Fourteen areas were selected to illustrate the use of graph theory on social media data. The selected areas, known to protect key recreational, educational and heritage attributes of marine ecosystems, were investigated to identify variability in users' preferences. Instagram data (i.e., hashtags associated to photos) was extracted for each area allowing an in-depth assessment of the CES most appreciated by the users. Hashtags were analysed using network centrality measures to identify clusters of words, aspects not normally captured by traditional photo content analysis. The emergent properties of networks of hashtags were explored to characterise visitors' preferences.

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(e.g., cultural heritage or nature appreciation), activities (e.g., diving or hiking), preferred habitats and species (e.g., forest, beach, penguins), and feelings (e.g., happiness or place identity). Network analysis on Instagram hashtags allowed delineating the users’ discourse around a natural area, which provides crucial information for effective management of popular natural spaces for people.

**Key words:** Instagram, Network analysis, Centrality measures, Recreational services, Marine ecosystems; Coastal users.

**Introduction**

Marine and coastal areas are extremely important for peoples’ wellbeing and yet, management plans rarely consider Cultural Ecosystem Services (CES) in their formulation (Chen et al., 2020; Rodrigues et al., 2017). CES are recognized as a main pillar in ecosystem services frameworks (Liquete et al., 2013), however, CES are the most challenging group of ecosystem services to study, principally due to their intangible and subjective nature (Daniel et al., 2012; Kirchhoff, 2012). Additionally, research targeted at marine CES has mostly focused on the economic valuation of recreational activities, tourism, or seascape scenic beauty (Milcu et al., 2013; Teoh et al., 2019), setting aside the non-material benefits people obtain from ecosystems that have symbolic, cultural or intellectual significance (Haines-Young and Potschin, 2010). During the past decade, the understanding of CES has evolved to acknowledge the importance of the relationship between people and nature, as CES are the outcome of the interaction between these two ecosystem components (Chan et al., 2012). Despite the challenges associated to CES assessment, current management schemes should incorporate the multi-dimensional CES valuation at scales relevant for management, particularly in marine and coastal areas where there is high economic and cultural dependency on marine ecosystems (Russell et al., 2013).

The monitoring of CES at large spatial scales is particularly difficult because, among others, they often have been based on methods developed for small spatial scales. Field survey methods have been generally used (Gosal et al., 2019), including interviews, face-to-face questionnaires and participatory mapping (e.g., Klain et al., 2014; Oteros-Rozas et al., 2014; Plieninger et al., 2013; Ruiz-Frau et al., 2011). These studies generally focus on local scales (Clemente et al., 2019), whereas management generally needs information at regional scales. In this context, new methodological approaches are needed to assess the multiple cultural values provided by marine ecosystems at scales larger than the local case study. There are several studies that adopt global approaches (Chen et al., 2020; Costanza et al., 2014), but generally these imply low cost-effectiveness that is a requirement for widely adopted assessments.

The volume of information uploaded to online social media platforms, like Instagram or Flickr, can provide an important source of information to assess
peoples’ preferences and values through a cost-effective approach (Clemente et al., 2019; Retka et al., 2019; Vaz et al., 2019). Social media platforms continuously store information people upload from any location in the planet. These sites are used for socializing and communicating, frequently focusing on recreational activities, including tourism (Figueroa-Alfaro and Tang, 2016). As part of the information uploaded, people often express their perceptions and feelings about places (Hale et al., 2019), including natural spaces. In the internet era, there are many social network platforms with millions of users that are an important source of big data (Liu et al., 2014). In the quest to avoid the time-consuming nature of field surveys and to identify alternative methods, there has been an increasing number of scientific studies that use social media to assess CES (Figueroa-Alfaro and Tang, 2016; Gosal et al., 2019; Oteros-Rozas et al., 2018). These studies have generally proved to be comparable to traditional surveys (e.g., Hausmann et al., 2018).

Social media data allows an indirect assessment of peoples’ perceptions and preferences. It provides large sample sizes and data is available at global scales. The predominant approach in social media data analysis generally relies on photo content assessment (but see Geboers and Van De Wiele, 2020). The context and content of the photographs is classified into CES categories based on the presence or absence of specific elements in the photos, such as views of flora and fauna, historical buildings, or touristic infrastructure and facilities (Ghermandi et al., 2020). Most works conducted up to date tend to use Flickr as source of data and analyse the photo content manually (Jeawak et al., 2017) or through automatic identification (Lee et al., 2019). An advantage associated to the use of Flickr is the availability of geolocalised photos. The downside of this platform, however, is a relatively low number of users, its decreasing popularity, and a photo content strongly dominated by biodiversity and landscape aspects (Oteros-Rozas et al., 2018), limiting the scope of the CES assessment. Conversely, Instagram is generally used to post photographs and thoughts in real-time often related to activities or social recreation, but also to culture and wildlife appreciation (Ruiz-Frau et al., 2020). Instagram users’ demographics, however, are dominated by younger generations (Hausmann et al., 2018). An advantage associated to Instagram is the frequent inclusion of hashtags as part of the photo post. These hashtags are used as keywords to mark messages or form conversations, and thus they provide an additional way to connect visual content (i.e., photos) and semantically related words to a discourse. The user-generated hashtags provide a great opportunity to analyse the discourse linked to the posted photos and minimize the subjectivity and low-cost effectiveness associated to photo content analysis.

Recent developments in the analysis of social media data have applied graph theory to the analysis of hashtags associated to posts providing a promising approach for the remote assessment of CES relying on social media data (Ruiz-Frau et al., 2020). Initial results indicate that the use of this cost-effective approach reveals, besides the more tangible set of CES such as recreational activities, a set of intangible CES aspects such as relational values (Ruiz-Frau et
al., 2020), providing a more encompassing view of CES provision. The application of this approach, however, has been so far limited to the regional scale while it offers an untapped potential to be applied at a global scale, providing comparative information on the type of CES contribution that marine and coastal areas make around the world.

Graph theory, as the mathematical study of the interaction of a system of connected elements, is a suitable approach for analysing user behaviour in social networks. It provides a simplified and quantitative view of the multiple factors involved in the exchange among system elements (Freeman, 1979). A system of connected elements can be defined as a network, also called a graph. In a network of keywords posted with the photos, graph theory provides insights into the system properties and identifies critical nodes with high centrality (i.e., words connected to many other words) or clusters of well-connected nodes (Maiya and Berger-Wolf, 2010; Roth and Cointet, 2010; Topirceanu et al., 2018). In this study, the working hypothesis was that data extracted from online social networks and analysed by calculating different measures of centrality from graph theory can be used to understand peoples’ preferences for nature and nature-based experiences in marine and coastal areas worldwide. The hypothesis was tested in 14 marine and coastal areas that are expected to provide a wide diversity of CES and the methodology was applied to determine whether different areas of the world were delivering different arrays of CES. This approach is expected to contribute to cost-efficient large-scale assessments of the contribution of marine and coastal areas to society well-being.

Materials and Methods

Case studies

In order to encompass a wide diversity of marine and coastal ecosystems across regions, and the potential diversity of CES provided by these areas, 14 marine and coastal areas were chosen for the study (Table A1). These areas span over the 12 marine realms established by (Spalding et al., 2007) and are expected to provide a wide diversity of CES (e.g., recreation, cultural heritage, nature and wildlife observation) and to be visited by a wide diversity of users. The areas chosen had to comply with two criteria: 1) the area had to be sufficiently popular to contain enough data for the analysis; 2) the name of the area had to be sufficiently characteristic to provide a unique identifier within Instagram (Table 1). The adoption of these criteria meant that no area in the Arctic (marine realm 1) could be identified with enough social media data. Some of the realms established by Spalding et al. (2007) are too broad to capture existent variability across systems (e.g., temperate Northern Atlantic and Mediterranean Sea), when the authors considered this was the case, more than one study areas were selected to capture this variability (Fig. 1).
Table 1: Case study name, location, query and number of downloaded for the study

| Case study         | Location      | Query                  | Number of posts |
|--------------------|---------------|------------------------|-----------------|
| Galapagos          | Ecuador       | #galapagos             | 10,000          |
| Glacier Bay Reef   | Alaska        | #glacierbayalaska      | 1,811           |
| Great Barrier Reef | Australia     | #greatbarrierreef      | 9,960           |
| Isole Egadi        | Italy         | #isoleegadi            | 9,969           |
| Macquarie Island   | Australia     | #macquarieisland       | 1,430           |
| Peninsula Valdez   | Argentina     | #peninsulavaldes       | 9,971           |
| Easter Island      | Chile         | #easterisland, #rapanni, #islandepascua | 10,000 |
| Sandwich Harbour   | Namibia       | #sandwichharbour       | 2,807           |
| Skomer             | United Kingdom| #skomer                | 4,911           |
| Tawharanui         | New Zealand   | #tawharanui            | 6,832           |
| Tayrona            | Colombia      | #tayrona               | 10,000          |
| Togean Island      | Indonesia     | #togeanisland          | 9,467           |
| Vanizi             | Mozambique    | #vanizi                | 1,367           |
| Ytrehvaler         | Norway        | #ytrehvalernasjonalpark| 1,019           |

Social media data

Data collection and analysis were carried out according to the methodology established in Ruiz-Frau et al. (2020). Instagram posts were downloaded through the Application Programming Interface (API), with a specific development for the R language and environment for statistical computing version 3.6.0, released 2019-04-26 (R Development Core Team, 2009). The Instagram API is suitable for a hashtag-based data extraction and, for each case study, a search query was executed (Table 1). Query terms were based on the hashtags of the geographical name of the study areas; therefore, the post download was related to a specific query, or name of the study area (e.g., Galapagos), with all downloaded posts including this query. We downloaded 10,000 posts per case study in June 2019. No specific period was defined. The data download started with the most recent post and was followed by the previous post until reaching the cut-off (i.e., 10,000). Some of the case studies had fewer than the established threshold (i.e., 10,000 posts), in such cases we downloaded all available posts (Table 1). Query search was limited to English, the most common language amongst tourists; this, however, might have overlooked posts where the name of the place was in a different language. For most marine areas, this was considered irrelevant as the name of the place is not translated to other languages (e.g., Tayrona, Vanizi, Vamizi).
Figure 1: The fourteen case studies selected across the twelve marine realms proposed by Spalding et al. (2007)
Skomer). In some of the cases the name of the place could appear in a variety of languages (e.g., Great Barrier Reef), however the use of non-English place hashtags as queries generally retrieved a significantly lower number of posts (e.g. Gran Barrera de Coral in Spanish with 1,900 posts, or Grand Barrière de Corail in French with 14 posts, while Great Barrier Reef had over 10,000 posts). In the specific case of Easter Island, we observed that the use of three particular queries was linked to a high number of posts: Easter Island and the local name Rapanui had over 10,000 posts each, and Isla de Pascua in Spanish had 8,700 posts. In this case, three separate posts’ downloads were performed, and data were merged for subsequent analysis.

Downloaded posts for each case study were stored locally and datasets were filtered and cleaned in order to retain only relevant information for further analysis (Di Minin et al., 2018; Varol et al., 2017). Posts often contain non-relevant information as social media platforms are frequently used as marketing and advertisement tools to reach a wider public and often bots (automated data generating algorithms and advertisements) are used to created large volumes of automated posts. In our case, irrelevant posts, mostly related to advertisement (e.g., posts related with a trading mark named Galapagos or Rapanui), were discarded from the analysis. Discarded photos were done through excluding posts with a specific hashtag (e.g., #chocolate, frequently linked with #rapanui due to a trademark) or a specific user (i.e., those users identified as posting marketing). Dataset cleaning also consisted in merging similar words (e.g., #travelgram, #instatravel, #igtravel) and misspellings (e.g., #travel, #travell). Highly frequent non-English words were translated to English (e.g., #statue, #steinfigure, #estatua; for Easter Island statue in different languages) to homogenise the network language and avoid numerous duplicates. However, in some networks with a prevalence of non-English language (e.g., Ytrehvaler in Norwegian) words were not translated to English to capture users’ characteristics.

**Graph theory**

The analysis of networks using graph theory can be described as the analysis of existing relationships between the different elements contained in a network. The term *vertex* is used to describe the elements in a network, while the term *edge* is used to refer to the connections between the different vertices in a network. In our case, vertices are represented by hashtags, while edges illustrate the connections between hashtags (e.g., the hashtags included in the same posts and the frequency of those connections). To assess relationships between hashtags and identify emerging themes within the networks, we used and expanded the centrality measures and community algorithms established in Ruiz-Frau et al. (2020).

The concept of *centrality* is a commonly used metric in the analysis of networks. The identification of important, or *central*, vertices in a network is a key aspect in the definition and description of networks (Bodin et al., 2006). However,
there are multiple interpretations of what makes a vertex important and there are therefore many measures of centrality (Freeman, 1979). In this work, we will focus on the use of betweenness and eigenvector centrality to illustrate and interpret the structure of the social networks.

Eigenvector centrality measure (Bonacich, 2007) takes into consideration not only how many connections a vertex has, but also the centrality of the vertices that it is connected to. Eigenvector centrality, hereafter eigenvector, ranks higher those vertices that are connected to important neighbours, i.e., other vertices that are connected to many other vertices. It is a measure of the influence of a vertex in a network. In our study context, hashtags with high eigenvector values are high frequency hashtags that in turn are connected to other high frequency hashtags, and so on. Therefore, this measure allows identifying those hashtags that are frequently posted with other hashtags also frequently posted, and it can be interpreted as the pairs or groups of features more frequently related to the case study by the users.

Betweenness centrality (Freeman, 1979) is a measure of the influence of a vertex over the flow of information between every pair of vertices under the assumption that information primarily flows over the shortest paths between them. Betweenness centrality indicates nodes that have a high probability of having routes that connect them to other nodes in the network. Alternatively, it indicates nodes in an intermediate position between groups of very well-connected neighbouring nodes. Nodes with high betweenness centralities have been termed bottlenecks or bridges and they prevent the fragmentation of the network. Similarly, edge betweenness centrality is defined as the number of the shortest paths that go through an edge in a graph or network (Girvan and Newman, 2002). Each edge in the network can be associated with an edge betweenness centrality value. An edge with a high edge betweenness centrality score represents a bridge-like connector between two parts of a network, the removal of which may affect the communication between many pairs of nodes through the shortest paths between them. In our context, betweenness centrality (hereafter betweenness) and edge betweenness centrality (hereafter edge betweenness) provide information on hashtags and links between hashtags that are essential to structure the network in sub-communities; the removal of those links would fragment the network and disconnect the hashtags that have higher betweenness. High betweenness hashtags are those that appear in a large number of posts and represent concepts that people often identify as ideal descriptors of a network. Edge betweenness evidences those edges that connect the most frequent hashtags with other less frequent hashtags. Therefore, they might show the parallel or additional discourse to the main discourse of the users, allowing to identify less frequent activities or perceptions but equally important to understand the network as a whole.
Data analysis

To illustrate the most relevant information contained as part of the 10,000 posts for each of the 14 areas, we selected the 150 most frequent hashtags from each dataset in order to create the network graph. The first 150 hashtags (frequency > 1.5% when 10,000 posts are retrieved) had a probability of more than 90% of occurring with any other of the first 150 hashtags in the same post. Therefore, this criterion was used to create networks with great cohesion and connectedness, representing a dominant discourse in relation to the area in question. Network graphs were delineated using eigenvector, betweenness and edge betweenness as centrality measures. These metrics were selected as they provided a visualisation of the central hashtags in the social media discourse, as well as peripheral hashtags that where nevertheless often related with these central hashtags; therefore, these provide information on the periphery of the dominant discourse.

In order to find emerging patterns within the 14 case study networks, hashtags were assigned to communities through the use of Fast-Greedy community algorithm (Ruiz-Frau et al., 2020). Fast-Greedy algorithm makes the best choice at each small step in the hope that each of these small steps will lead to a globally optimal solution (Newman, 2004). Relevant hashtag communities based on Fast-Greedy algorithm were assessed to provide a detailed assessment of the type of CES provided by each of the case studies.

In order to visualise potential similarities in the social media discourse across the 14 case studies, all the data was merged, and the 1400 most frequent hashtags pairs were retained for analysis in a single network graph. Similar to what was previously described for the individual networks, these 1400 pairs of hashtags accounted over 90% of the linkages between hashtags, representing the dominant discourse on CES across the 14 areas. Eigenvector centrality was used as the measure of vertex influence in the network and connections were represented with a backbone layout (Brandes and Wagner, 2004). This layout has proven effective to illustrate networks with most vertices in a central position that result in high overlap in large networks (Nocaj et al., 2015).

To conduct the analysis, we used the open source graphics manipulation software igraph (Csardi and Nepusz, 2006) to obtain the centrality measures and communities aggregations. Graphics and figures were generated using the visualization software ggraph and ggtree. All of the above software can be used as extension packages of the R language and environment for statistical computing (R Development Core Team, 2009) freely available online.
Results

Network centrality measures

Results indicated that network graphs captured information on distinct types of CES, for example those based on wildlife and nature; heritage; or beach tourism. In areas such as Galapagos, popular hashtags were `nature`, `wildlife`, `photography`, `travel` and `adventure`, evidencing a preference for wildlife and nature based CES. In this area, betweenness evidenced the connections between the most frequent hashtags group with other hashtags like `waves`, `crab`, `endemic`, `evolution` and `happy`, and provided information on the discourse of Galapagos’ visitors (Fig. 2).

Other areas providing wildlife and nature based CES were Skomer nature reserve, characterised by the hashtags `birds` (particularly `Puffin`), `nature` and `wildlife photography`, and Península Valdés, characterized by many locality names and by fauna, with the hashtags’ `wildlife`, `whales` and `nature` holding high eigenvector and funnelling most connections to other hashtags and providing a full picture of the post (e.g., `wind`, `hiking`, `relax`). Three networks, Sandwich Harbour, Glacier Bay and Macquarie Island also included popular hashtags related with `nature`, `wildlife` and `photography`; however, most hashtags had low betweenness and edge betweenness limiting the diversity of the posts (all network graphs included in Appendix, Fig. A1).

Regarding cultural heritage, Easter Island was characterised by popular hashtags related with Easter Island stone statues and with travel, and edge betweenness evidenced a diversity of peripheral nodes that describe other cultural elements, like `design`, `music` and `food`. Other areas reflected cultural identity by the frequent post of local names (e.g., Ytrehvaler), of words related with the country’s identity (e.g., Isole Egadi) and positive feelings about this identity (e.g., Tawharanui). In Tayrona National Park network, the full discourse identified cultural identity like `Kogui` (indigenous village) linked with the popular posts. However, the most frequent hashtags in Tayrona network, and also in Tawharanui and Isole Egadi, were related with `beach`, `nature` and `summer`. In some of these networks, like Isole Egadi and Ytrehvaler, locality names are frequently posted, allowing to identify connections between places and activities, wildlife or natural structures.

A group of areas were appreciated by their underwater ecosystems. For Great Barrier Reef, popular hashtags were related with the coral reef: `ocean`, `diving`, `underwater photography`, `travel`, `nature`, `coral` and `reef`; whereas betweenness highlighted a set of hashtags related with conservation: `science`, `sustainability`, `save the reef`, `4 ocean` (Fig. 3). In Toguean Island network, the frequent hashtags `beach`, `wonderful` and `charming` are connected to peripheral hashtags related with the sea (e.g., `sea life`, `diving`). In Vamizi, popular hashtags were related with tourism, `private island`, `travel`, `luxury travel`, and were connected to less frequent hashtags linked to the sea, including recreational fisheries.
Figure 2: Example of network graphs in Galapagos case study. In plot A) vertex size represents the Eigenvector centrality and edges represent strength. In plot B) vertex size represents Betweenness centrality and edges represent Edge betweenness.
Figure 3: Example of network graphs in Great Barrier Reef case study. In plot A) vertex size represents the Eigenvector centrality and edges represent strength. In plot B) vertex size represents Betweenness centrality and edges represent Edge betweenness.
Network communities

The division of hashtags in communities allows for a more detailed exploration of the words included in the 150 most frequent hashtags selection, independently of their centrality measures, and allowed a categorisation of hashtags within CES classes in each area (Table 2). Hashtags were grouped in 3 to 5 communities, with some communities relatively constant across case studies, e.g., aesthetics, wildlife and nature appreciation (Fig. 4, Fig. A2).

In some of the areas, the communities were diverse in hashtag composition, for example, in Galapagos, *wildlife* (and related words) was distinctive of several communities, but other communities were characterised by different concepts: *beach, holidays, happiness, snorkelling* and *diving*. In Easter Island network the hashtags related with the stone statues and cultural heritage characterise one community, while the other communities include a diversity of hashtags classified under adventure, nature, underwater recreational activities. Tayrona (Fig. 4) is also a diverse network with one community characterised by hashtags like *beach, summer, happiness* (wellbeing), but other communities containing a diversity of hashtags like *forest, hiking, indigenous* and *wildlife* (classified in recreational, cultural heritage, nature and aesthetics; Table 2).

In some areas, the communities were not so diverse, but provided additional information on the posts. For example, in MacQuarie Island the communities highlighted iconic fauna, including several penguin species, and biodiversity conservation. In several areas, network communities informed of the iconic fauna and specific places: puffins and other bird species in Skomer; southern right whale, sealions and penguins in Península Valdés; glaciers and mountains in Glacier bay (Fig. 4); desert and dunes in Sandwich harbour. Finally, Ytrehvaler is a network characterised by many local names (in Norwegian), evidencing a national tourism, and hashtags related with scenery.

Table 2: Cultural Ecosystem Services’ types depicted from the community analysis (Fast Greedy algorithm). The order of the CES class does not imply a priority rank.

|                  | CES 1                  | CES 2                  | CES 3                  | CES 4                  | CES 5                  |
|------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Galapagos        | Nature and wildlife appreciation | Recreational (beach)   | Other (travel)         | Underwater wildlife and recreational (underwater) | Aesthetic and wellbeing |
| Glacier Bay      | Aesthetic and nature appreciation | Aesthetic (hiking)     | Recreational (hiking)  | Other (National Park and Glaciers) |                       |
Table 2: Cultural Ecosystem Services’ types depicted from the community analysis (Fast Greedy algorithm). The order of the CES class does not imply a priority rank.

| Site                | Underwater wildlife and recreational (underwater) | Other (travel) | Aesthetic and nature appreciation | Cultural identity | Other (travel) |
|---------------------|-------------------------------------------------|----------------|---------------------------------|------------------|----------------|
| GBR                 | Recreational wildlife                           | Aesthetic      |                                 | Cultural         | Other          |
| Isole Egadi         | Water activities                               |                |                                 | Identity         | (travel)       |
| Macquarie Island    | Nature and wildlife                             |                |                                 | Recreational     | Wildlife       |
|                     | and wildlife appreciation                      |                |                                 | and conservation| (bird watching)|
| Peninsula Valdez    | Wildlife conservation                           |                | Aesthetics                       | Wildlife         | (iconic fauna) |
|                     | (sea life) and recreation                       |                | and recreational                | (bird watching)  |                |
| Easter Island       | Cultural heritage                              | Other          |                                 | Nature,          | Recreational   |
|                     | (adventure and travel)                          | (adventure and travel) |                                 | aesthetics       | (underwater)   |
| Sandwich Harbour    | Aesthetics                                     | Wildlife,      | Wellbeing                        | Wellbeing        |                |
|                     |                                                | aesthetics and| and recreational               | and recreational|                |
|                     |                                                | recreational   | (safari)                        | (water activities)|                |
| Skomer              | Aesthetic and recreation                        | Wildlife       | Wildlife                         | Birds            |                |
|                     | (hiking)                                       | (birds)        |                                 | (hiking)         |                |
| Tawharamui          | Recreational (beach)                           | Nature,        | Cultural                         | Wildlife         |                |
|                     |                                                | aesthetic and  | identity                         | conservation     |                |
|                     |                                                | wellbeing      |                                 |                  |                |
| Tayrona             | Wellbeing and aesthetics                       | Recreational   | Nature                           |                  |                |
|                     |                                                | (hiking)       | and                             |                  |                |
|                     |                                                | cultural       | aesthetics                       |                  |                |
|                     |                                                | heritage       |                                 |                  |                |
Table 2: Cultural Ecosystem Services’ types depicted from the community analysis (Fast Greedy algorithm). The order of the CES class does not imply a priority rank.

| Togean Island | Other (travel) | Underwater wildlife and recreational (underwater) | Aesthetics, wildlife (underwater) and recreational (underwater) |
| Vamizi | Nature, wildlife and conservation | Recreational (underwater) and other (luxury tourism) | Aesthetics and wellbeing |
| Ytrehvaler | Nature and cultural identity | Nature and recreational (hiking and kayak) | Recreational (fishing) and Nature and aesthetics |

**Merged network of the 14 case studies**

The network that integrates the 14 areas, highlighted several hashtags that act as bridges between communities of hashtags (Fig. 5). *Nature, travel, photo* and *travel photography* are key to structure the global network. However, the integrated network evidenced other hashtags with lower eigenvector that also connect smaller groups. The hashtags *sunset* and *island* connect the subgroups from Easter Island, Isole Egadi and Vamizi; Tayrona is connected to this group thought *travelling* and to the central vertex through *travel photography*.

From this hashtag (*travel photography*) diverges another branch that connects 7 areas through *adventure*; a small group of hashtags deriving from this node represent Sandwich harbour and Vanizí, connected through *Africa*. The hashtag *Ocean*, connected to *adventure*, relates Great Barrier Reef with Tawharanui, and to *wanderlust* (a German expression for the desire to explore the world) that connects Península Valdés, Skomer and Macquarie Island. These three areas are also connected through the central hashtag *travel photography*, and Skomer and Macquarie Island through *wildlife photography*. The hashtag *adventure* is also connected to a group of hashtags from Galapagos that also derive to the high eigenvector hashtag *nature*.

The hashtag *nature* is key to include the fragile sub-network Ytrehvaler, and also
Figure 4: Example of Fast-Greedy community algorithm for the case studies Glacier Bay (A) and Tayrona (B).
derives to other high eigenvector hashtag, *travel*, that in turn, connects to the small sub-network from Glacier bay. *Travel* is connected to many less relevant hashtags that are common to many of the areas: *friends, tourist, happiness*, and derives to *photo*, another central hashtag. *Photo* connects to *paradise*, that is key to integrate Toguean Island, a few hashtags from Tayrom related with the Caribbean and beach, and a group of hashtags from Peninsula Valdez related with whale watching. Some other small hashtags, that are connected to high eigenvector hashtags but are not included in any particular area are shared by many of the areas, e.g., *sun, relax, landscape photography, nature lovers, sunset, sky.*
Figure 5: Global network graph including the fourteen case studies where the vertex size represents the Eigenvector centrality and edges represent strength. The coloured clusters arrange the case studies to facilitate the visual identification of related areas.
Discussion

Social media provides a powerful source of information to monitor visitors’ preferences and perceptions in marine and coastal areas globally. In our study, the analysis of Instagram data confirmed these expectations, with underwater activities and underwater life appreciation prioritized by visitors in iconic diving destinations (e.g., Great Barrier Reef or Toguean Island), whereas case studies known to be small natural reserves for wildlife watching were confirmed to be mainly visited for their iconic fauna (e.g., Península Valdés) or protected species (e.g., Skomer Island). However, this study differs from previous studies in the methodology adopted to analyse data stored in social media platforms. The analysis of photo content is known to be time consuming and subjected to the researcher’s interpretation (Ruiz-Frau et al., 2020). Conversely, the text linked to each photo illustrates users’ perceptions, preferences, feelings, and emotions. The analysis of users’ posts with Graph Theory allowed the identification of emergent discourse patterns in Instagram. It identified the most frequent words related with a specific area (e.g., nature, wildlife and photography in Galapagos), and other less frequent words connected to the principal ones, delineating a discourse in each case study, for example information on specific knowledge, like endemic and evolution, and also feelings, happy, related with wildlife and nature in Galapagos. The primary and secondary information provided by the network analysis is of high value for conservationists and managers, as it delineates visitors profile and preferences. Importantly, our approach allowed to gather this individualised information remotely from a wide variety of marine and coastal case studies globally.

It has been acknowledged that the use of information from social media platforms has an inherent bias associated to both the type of user and the type of content posted on the platform. Hausmann et al. (2018) observed that while most of the pictures posted on Flickr focused on biodiversity, Instagram, additionally, was popular for sharing pictures about activities and people. On the other hand, Ruiz-Frau et al. (2020) observed that Twitter posts reflected social awareness and discussions around current global concerns such as climate change and youth movements. Therefore, different social media platforms may be used by different groups of visitors and, aiming to maximize the representation of the wider society, we considered Instagram to be a good candidate for a global assessment of CES covering a wide diversity of natural spaces. Instagram provides information on what calls the attention of visitors, but also on activities and feelings. For example, many users on Instagram linked natural spaces with conservation (e.g., Great Barrier Reef), nature excursions (e.g., Glacier Bay), bird watching (e.g., Skomer), views of natural fauna (e.g., Península Valdés), but also, and not least, the scenic beauty (e.g., Sandwich harbour), the relaxation and happiness provided by open spaces (e.g., Galapagos), or some luxury accommodations within national parks as wellness spaces (e.g., Vamizi). The main activities reported in each case study were generally related with the dominant habitat, e.g., diving in Great Barrier Reef or Toguean Island, with prevalence of coral reefs; hiking in Glacier Bay or
Tayrona, characterized by forests and mountains; beach recreation in Tawharanui or Isole Egadi, characterized by sandy beaches. Nevertheless, the posts’ discourse in each area is markedly defined by the visitor profile, and access to the area. For example, Vamizi is characterized by luxury and international tourism that visit the area for the opportunity to enjoy the underwater life, recreational fishing and beach. Other areas like Skomer and Ytrehvaler are mainly visited by locals that enjoy the wildlife and nature of the place. This implies the CES enjoyed by visitors are highly conditioned by its logistical accessibility, with remote places like Macquarie Island or Galapagos visited by international tourists that travel (travel, being one of the most common hashtags) to these areas to find adventure, recreation, or scenery, amongst others. More accessible areas (i.e., those easily accessible from large cities), like Tawharanui, Ytrehvaler or Isole Egadi, appear to be predominantly visited by locals in search of the relaxation of the beach, sighting of emblematic local fauna, or nature recreation. The merged network evidenced that central hashtags to all areas were nature, travel, photo, however, less popular hashtags appear key to connect smaller groups of areas and were related with general concepts posted in these areas and not with principal activities or focus. For example, sunset and island connected Easter Island, Isole Egadi and Vamizi, wanderlust (a German expression for the desire to explore the world) connects Peninsula Valdés, Skomer and Macquarie Island, paradise connects Toguean Island and Tayrona, ocean connects Great Barrier Reef and Tawharanui. These results imply that the perception of visitants to the areas is not exclusively conditioned by the main activity or ecosystem type, but by higher level concepts like paradise or wanderlust.

What becomes evident from this global assessment is that an area does not need to be an iconic destination to provide essential services to society. Galapagos, Great Barrier Reef or Easter Island provide essential services like nature appreciation, wildlife watching or cultural identity, however, such services have also been identified in less iconic areas often visited by local tourists like Skomer Island, Tawharanui and Ytrehvaler. Similarly, wellbeing related with relax and happiness is recorded in remote and iconic areas like Galapagos, but also in quite different places such as Vamizi, Tawharanui or Isole Egadi. The frequent post of the word happiness (and similar words) denotes the importance of nature’s contribution to people’s wellbeing, as emphasised by Russell et al. (2013), Pascual et al. (2017) and Díaz et al. (2018) that stated that the benefits arising from human connections with nature include sense of place, identity, mental health and sense of belonging. These benefits were independent of its location, ecosystem or main activity provided. A series of CES bundles could be identified in each case study, evidencing areas with high diversity of benefits and perceptions, whereas other areas were relatively homogenous in users’ activities and perceptions. Frequent CES groups were related with aesthetics and wildlife and nature appreciation, which is expected as information is obtained from a photography-based social media platform. However, the classification of the popular hashtags in CES types, despite providing standardised information that allows the comparison with other studies, limits the information provided by the networks. The analysis of social
media data with Graph Theory allowed identification of users’ prioritization (e.g., landscape, heritage, wildlife), but also activities (e.g., diving, hiking, relaxing), preferred habitats/species (e.g., forest, beach, penguins), and feelings (e.g., happiness, beach lifestyle, place identity). Network analysis allowed moving beyond the state of the art by mere hashtag frequency to the exploration of inter-relations between hashtags, delineating the users’ discourse. For example, animal species connected to local names provides information on places for wildlife watching, e.g., puffins in Skomer Island – place, or penguin species in MacQuarie Island. Hashtags also evidenced environmental awareness, e.g., conservation in Macquarie Island or climate change in Great Barrier Reef, which should be considered key to promote transformative changes for policy makers (Hughes et al., 2018). Therefore, relevant words like nature watching can be linked to a place or to a species name, conservation can be linked to a place or ecosystem component, and so on.

The methodological approach developed in Ruiz-Frau et al. (2020) and used in this work can become an important tool in the assessment of CES, a key ecosystem services’ category that is generally poorly addressed in management and conservation plans (Chan et al., 2016; IPBES, 2018). However, the use of this methodology is not exempt of challenges. Results showed that a manageable sample of posts can provide valuable information about the CES in a natural area. Nevertheless, a sufficient volume of posts might not be available for particular areas. In addition, the application of this methodology is restricted to those areas with a unique name to be used as a query in order to avoid downloading information from other areas which might have the same name. In the present study, we initially explored areas such as Table Mountain in South Africa or Banc d’Arguin in Mauritania but were finally discarded as the query downloaded many unrelated posts. When using social media data as a proxy for CES there is an inevitable bias towards aesthetic values (Calcagni et al., 2019) and, in the particular case of Instagram, a strong dominance of content related with social recreation. Ultimately, photographs tend to express pleasant and beautiful features (Yoshimura and Hiura, 2017) and Instagram is not an exception as in most case studies only positive feelings were reported, with few exceptions where conservation awareness was identified in the social media discourse. Representativeness can also be a challenge (Guerrero et al., 2016; Tenerelli et al., 2016), and Instagram is mostly representing the younger generations (Abbott et al., 2013). Perceptions from people that do not post on Instagram, remarkably from older generations, people without or limited access to technology or people from countries where Instagram is not sufficiently dominant are not adequately represented in our approach. Nationality is also relevant, as CES identified by local visitors can differ from international tourists (Clemente et al., 2019). This can be partially solved by using words in different languages as queries, like for Easter Island (e.g., Rapanui, Isla de Pascua and Easter Island), or by including words in different languages in the network, like in the Norwegian reserve of Ytrehvaler. However, social media platforms are sometimes restricted in certain countries, for example Instagram is not
available in China, or Russian Federation and eastern EU dominant social network is Vkontakt. This might imply an important bias in the nationality of tourists encompassed in the analysis. Despite these limitations, our study approach provides many advantages, including 1) cost and effort effectiveness, 2) minimization of researchers’ subjectivity, 3) remote collection of information that allows large scale studies. The assessment of visitors’ perceptions in natural spaces is generally conducted during peak visitation season and restricted to frequently visited locations (Gosal et al., 2019), while the remote collection of social media data can encompass any temporal dimension, and, in principle, it covers visitors to all locations within the natural areas. The variability in visitors’ preferences can assist managers and policy makers design tailored strategies to promote CES conservation for visitors’ enjoyment, which is of high relevance when destination sites are often ecologically or culturally fragile (Balmford et al., 2004; Ghermandi et al., 2020). The continuous low cost-effective monitoring of social media can allow a better understanding of spatial-temporal changes in visitor preferences (Hausmann et al., 2016), and this approach can now materialise with the prevalence of smartphones and the posting of experiences in social media facilitating the remote access to large scale information on peoples’ perceptions and use of natural spaces.

Conclusions

It is recognised that effective marine and coastal conservation requires a large-scale approach and our novel approach has allowed us to collect data on CES on a wide diversity of marine and coastal areas globally. The emergent properties of networks of hashtags were explored to characterise visitors’ preferences (e.g., cultural heritage, wildlife and nature appreciation), but also activities (e.g., diving, hiking, relaxing), preferred habitats or species (e.g. forest, beach, penguins), and feelings (e.g., happiness, beach lifestyle, place identity). Our approach allowed to identify places valued for their cultural heritage (e.g., stone statues in Easter Island status), but also for their iconic species (e.g., puffins in Skomer island) or natural monuments (e.g., sand dunes in Sandwich harbour), and sense of place and identity (e.g., Isole Egadi and Tawharamui). Moreover, the frequent post of the word *happiness* represents the importance of nature’s contribution to people. Cultural interactions between humans and nature are fundamental, including cultural heritage, the iconic status of certain species or the contributions these make to human well-being through a sense of place or place identity. The novel approach introduced here allow to capture these intangible benefits we obtain from nature in a cost-effective but holistic way, for an effective management of natural areas, by promoting the integration of CES into decision making by identifying CES hotspots.
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SUPPLEMENTARY MATERIAL

1A)

1B)
FIGURE A1 - Network graphs in the case studies: 1, Eastern Island; 2, Glacier Bay; 3, Isole Egadi; 4, Macquarie Island; 5, Peninsula Valdes; 6, Sandwich Harbour; 7, Skomer; 8, Tawharanui; 9, Tayrona; 10, Togean Island; 11, Vamizi; 12, Ytre Hvaler. A) represents the Eigenvector centrality, B) represents Betweenness centrality and Edge betweenness.
SUPPLEMENTARY MATERIAL

1)

2)
FIGURE A2 – Fast-Greedy community algorithm for the case studies: 1, Eastern Island; 2, Galapagos; 3, Great Barrier Reef; 4, Isole Egadi; 5, Macquarie Island; 6, Peninsula Valdes; 7, Sandwich Harbour; 8, Skomer; 9, Tawharanui; 10, Togean Island; 11, Vamizi; 12, Ytre Hvaler
### Table A1 – List of marine and coastal areas selected across the 12 marine realms after Spalding et al. (2007)

| Marine realms               | Protected area   | Country       | Region                         |
|-----------------------------|------------------|---------------|--------------------------------|
| 2. Temperate northern Atlantic | Ytre Hvaler       | Norway        | NE Atlantic                    |
|                             | Skomer            | United Kingdom| Celtic Sea                     |
|                             | Isole Egadi       | Italy         | Mediterranean Sea              |
| 3. Temperate Northern Pacific | Glacier Bay      | Alaska        | NE Pacific                     |
| 4. Tropical Atlantic        | Tayrona           | Colombia      | Caribbean                      |
| 5. Western Indo Pacific     | Vamizi            | Mozambique    |                                |
| 6. Central Indo Pacific     | Great Barrier Reef| Australia     | Coral Sea                      |
|                             | Togean Island     | Indonesia     | Molucas Sea                    |
| 7. Eastern Indo Pacific     | Eastern Island    | Chile         | SE Pacific                     |
| 8. Tropical Eastern Pacific | Galapagos         | Ecuador       | central-east Pacific           |
| 9. Temperate South America  | Peninsula Valdes  | Argentina     | SW Atlantic                    |
| 10. Temperate Southern Africa | Sandwich Harbour | Namibia       | SE Atlantic                    |
| 11. Temperate Australasia   | Tawharanui        | New Zealand   | SW Pacific                     |
| 12. Southern Ocean          | Macquarie Island  | Australia     | SW Pacific                     |