A big data approach to identify the loss of coastal cultural ecosystem services caused by the 2019 Brazilian oil spill disaster

Azevedo, Anna Karoline

2022

Azevedo , A K , Vieira , F A S , Guedes-Santos , J , Gaia , J A , Pinheiro , B R , Bragagnolo , C , Correia , R A , Ladle , R J & Malhado , A C M 2022 , ' A big data approach to identify the loss of coastal cultural ecosystem services caused by the 2019 Brazilian oil spill disaster ' , Anais da Academia Brasileira de Ciências , vol. 94 , no. suppl 2 , 20210397 . https://doi.org/10.1590/0001-37652022

http://hdl.handle.net/10138/347414
https://doi.org/10.1590/0001-3765202220210397

An Acad Bras Cienc (2022) 94(Suppl. 2): e20210397 DOI 10.1590/0001-3765202220210397
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

1916 • 2021

ECOSYSTEMS

A big data approach to identify the loss of coastal cultural ecosystem services caused by the 2019 Brazilian oil spill disaster

ANNA KAROLINE AZEVEDO, FELIPE A.S. VIEIRA, JHONATAN GUEDES-SANTOS, JOÃO ARTHUR GAIA, BARBARA R. PINHEIRO, CHIARA BRAGAGNOLO, RICARDO A. CORREIA, RICHARD J. LADLE & ANA C.M. MALHADO

Abstract: In August 2019, the Northeast coast of Brazil was impacted by an extensive oil spill, with immediate effects on marine and coastal ecosystems and significant impacts on tourism and food security. The human dimension of those impacts also includes the loss of cultural ecosystem services (CES); the non-material benefits stemming from strongly rooted cultural practices and relationships with nature. CES are of great importance for local residents and visitors that flock to Brazilian iconic beaches, however, they are difficult to measure using traditional assessment methods due to their subjective and non-tangible nature. Here, we use a big data approach to assess and map the loss of CES in the Northeast coast of Brazil caused by the recent oil spill. We analysed 2,880 digital images (published on the image sharing platform Flickr) taken before and during the disaster in affected locations, using a combination of automated techniques. Results showed a sharp decline in the number of users posting photos of locations affected by oil spill, and a decline in photos representing landscape and cultural appreciation. Our big data approach provides a fast and automated way to assess CES at large spatial scales that can be used to monitor the social impacts of environmental disasters.

Key words: big data, oil spill, culturomics, cultural ecosystem services.

INTRODUCTION

Oil spill events have significant impacts on ecological processes and social structures arising from complex interactions in socio-ecological systems (Chang et al. 2014). Beside ecological damages, oil spill events are characterized by a wide variety of impacts on humans, including reduced food security, economic losses (mainly commercial fishing and tourism), and interrelated effects on health of individuals and the well-being of communities (de Oliveira et al. 2021). This complexity impact has causal effects which should be considered in contingency planning to provide integrated and immediate responses to mitigate environmental damages, recover the ocean economy and compensate local communities (Lord et al. 2012, Chang et al. 2014).

In August 2019, an enormous amount of crude oil appeared on the Northeast coast of Brazil (Escobar 2019, Lourenço et al. 2020). The origin of this oil spill disaster remains unclear more than a year after the onset of its appearance on the coast (Zacharias et al. 2021), the oil spill was the most extensive ever documented in tropical oceans. More than 5000 tons of oil residue were removed from the landscape, having reached more than 800 beaches across more than 3,000 km of coastline, with immediate impacts on biodiversity, tourism and food security (de Oliveira Soares et al. 2020, Ribeiro et al. 2020, Câmara et al. 2021, Zacharias et al. 2021). The vertiginous drop in tourism revenue and fish trade caused by this tragic event severely affected coastal communities' health, well-being and economies (de Oliveira Soares et al. 2020), the effects of which may be felt for generations (Ladle et al. 2020).

The uncertainties, doubts, and lack of information about the disaster were exacerbated by a weak and delayed response by federal institutions (Gonçalves et al. 2020; Zacharias et al. 2021, Brum et al. 2020, Soares et al. 2020). Moreover, the negative impacts of the oil spill were further amplified by the COVID-19 pandemic, generating synergistic negative consequences on the economy (e.g., artisanal fisheries and tourism), public health and ecosystems (Magalhães et al. 2020). The interlinked social-ecological systems of the Brazilian coast (Diegues 1999) were severely threatened by this large-scale environmental disaster, impacting the economies and lifestyle of thousands of traditional communities and leading to a widespread loss of associated ecosystem services (MEA 2005) including Cultural Ecosystem Services (CES).

CES comprises diverse non-material benefits stemming from strongly rooted cultural practices and relationships with nature, including spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (reviewed in Milcu et al. 2013). CES has considerable importance for local residents and for the millions of visitors that flock to Brazil's iconic beaches, especially those in the Northeast of the country (Retka et al. 2019).

Due to their subjective and non-tangible nature, CES have been difficult to measure at large spatial scales using traditional assessment methods such as contingency analysis, structured interviews and participatory mapping techniques (Cheng et al. 2019). Such methods can provide high quality data, but are often costly, geographically restricted and lack standardization (Bragagnolo et al. 2016). Moreover they are time consuming which is in contrast with the immediate response that oil spill disasters demand. Some of these limitations may be overcome by the development of big data approaches that infer human value and sentiment towards the environment from the digital representation of words and images (Ladle et al. 2016, 2017, Sherren et al. 2017). Social media and computer science can provide new approaches, methods and tools to study and map CES at different scales (Richards & Friess 2015, Gliozzo et al. 2016, van Zanten et al. 2016, Vieira et al. 2018). Such methods potentially allow for a fast, cost-effective and large-scale approach to evaluating CES that can be used in isolation or to complement more traditional approaches (Richards & Tunçer 2018, Retka et al. 2019).

Here, we extend the big data approach developed by Retka et al. (2019) to assess the loss of CES during the 2019 Brazilian oil spill. Specifically, we analysed 2,880 digital images taken in 245 locations of the coastal region affected by the oil spill and posted by 237 users on the popular file-sharing platform Flickr. Downloading and analysis of images were carried out through automatized procedures based on Flickr and Google Cloud Vision's application programming interfaces using R software. Geographic coordinates of locations affected by the oil spill were retrieved from the official database of oil observations created by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).

MATERIALS AND METHODS

Data collection

Data collected included georeferenced images taken in areas of the Northeast coast of Brazil affected by the oil spill (Figure 1). We chose the widely used image-sharing platform Flickr (www.flickr.com) which allows free programmatic access to its database unlike other popular social media platforms such as Instagram and Facebook. Firstly, relevant photographs were identified and downloaded based on their location, through an automated interaction with Flickr via its Application Programming Interface (API) using R software (R Core Team 2021; See R codes in additional data available at https://osf.io/j8tr9/?view_only=6dddcd64641342af8b12b7495c4ccf3a). We downloaded all photos within a 1 km x 1 km grid correspondent to the region affected by the oil. Each square of the grid was used as a sample unit in our analyses. For each sample unit, we calculated the number of photos, users, and types of CES. Only photographs published in the period of 01/09/2018 to 11/03/2020 were downloaded, starting one year before the first oil record until the data collection date.

In total, we downloaded 4,730 photographs and their associated information, namely: i. link to the photograph; ii. geolocation (lat/long); iii. date and hour of capture; iv. date and hour of upload, and; v. username. After the identification and exclusion of users outliers (e.g., photos from professional/dedicated users), a total of 2,880 photographs from 237 users remained and were utilized for further analysis.

Furthermore, we also collected information about the oil presence along the northeast Brazilian coast through daily reports published

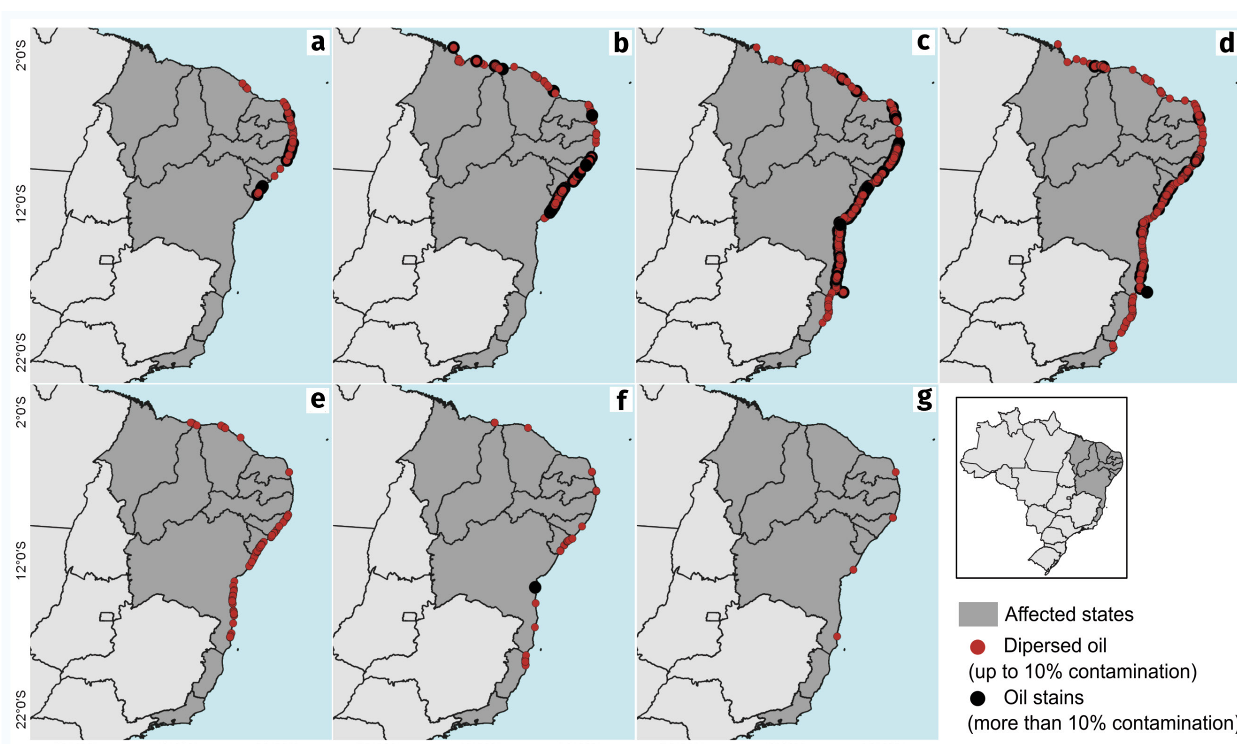

Figure 1. Non-cumulative observations of oil stains along Northeastern brazilian coast through months of the disaster. Note: biweekly observations. a: Aug-Sep; b: Sep-Oct; c: Oct-Nov; d: Nov-Dec; e: Dec-Jan ; f: Jan-Feb; g: Feb-Mar. Source: adapted from The Brazilian Institute of the Environment and of Renewable Natural Resources (Ibama 2020).

by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) (2020) for the period 30/08/2019 to 19/03/2020. The reports contained the geolocation of 4,154 observations of oil *in situ*. In order to avoid bias, we excluded all incomplete oil observations (e.g., without date and/or geographic coordinates). This step allowed us to define the dates in which each sample unit was first affected by the oil, which were later used as baseline for all exploratory and statistical analysis.

Cultural Ecosystem Services (CES) identification

In order to identify CES representations in our dataset, each photograph was analysed with the Google Cloud Vision's machine learning algorithm for label detection in images. This procedure returns 5 keywords per photo and allows the grouping of images based on their similarity using a hierarchical clustering technique for text analysis. The main output of hierarchical clustering is a matrix-based dendrogram in which the height where branches containing two objects are first fused represents their similarity (distance). Following 5 clustering simulations, we identified 16 clusters as the optimal number to identify specific groups of photos (e.g. photos of specific animals/plants or activities) which could then be broadly translated into CES categories. The authors analysed the 15 most frequent keywords in the photos of each cluster and independently classified them into CES categories, following the CES typology used by Retka et al. (2019). Then, a final classification was agreed in which 13 of the 16 clusters were considered to be associated with a CES category, corresponding to 84.6% of the total photos.

Data analysis

In order to assess the effect of the oil on beach cultural ecosystem services, we explored the temporal and spatial distribution of photographs and oil observations per month in each sample unit. Also, we tested the hypothesis that CES provision would be lower in the sampling units which had occurrence of oil by exploring if the frequency of photographs containing representations of CES was associated with oil presence. To do this, we assessed changes in the number of photos representing CES in each sample unit in two moments: *before* and *during* the event. We used an ANCOVA (Analysis of covariance) to estimate the effect of the event on CES values and Mann-Whitney tests to compare CES, users and photographs before and during the oil spill.

RESULTS

We identified four categories of Cultural Ecosystem Services (CES) in the photographs analysed: 15.9% of photos were associated with *nature appreciation*, 48.9% with *landscape appreciation*, 19.1% with *social recreation* and 16.1% with *artistic or cultural expressions*. From all photographs analyzed, 32.3% were not associated with any CES category and were not considered for further analysis.

The average number of photos taken by unique users during the oil disaster decreased when compared to the period before the spill, as expected. Also, the richness of CES represented in the photos of each user during the event was slightly lower than in the period before (Table I). Therefore, both the number of photos per user and the richness of CES per sample unit were significantly higher in the period before the oil spill. Despite this general pattern, the results pertaining to some individual CES showed a different and unexpected response, with the number of photos associated with social recreation and nature expression being slightly higher during the oil spill (Figure 2). However,

Table I. Photos, Users and Culture Ecosystem Services richness/count in sample units between the periods before and during the oil spill disaster.

	Before	During
	Mean/SD	
Photos / user	3,83 (6,60)	3,56 (5,39)
CES richness / user	0,95 (0,66)	0,94 (0,72)
CES richness / sample unit	1,27 (0,93)	1,19 (0,92)
User / sample unit	1,53 (1,49)	1,33 (0,84)

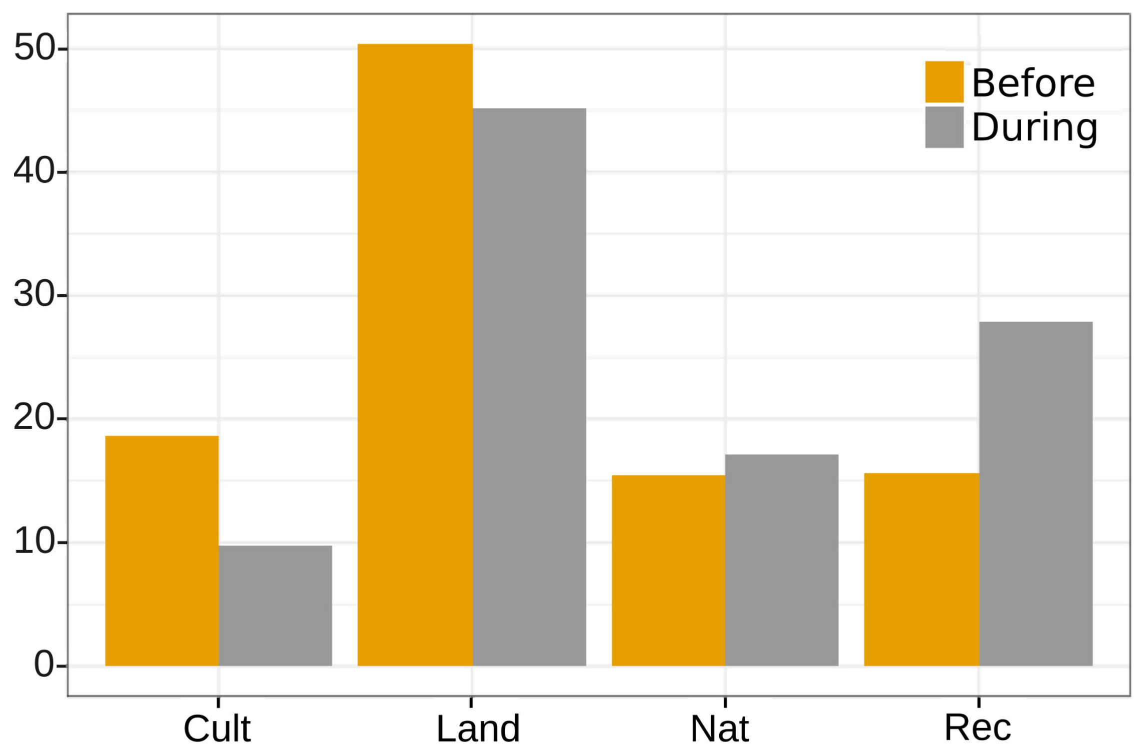

Figure 2. Percentage of Cultural Ecosystem Services represented along the Brazilian coast, before and during the oil spill.

the differences observed for these CES before and during the oil spill were not statistically significant according to a *Mann-Whitney U Test* (Table II).

Overall, the temporal distribution of CES was lower during the oil spill than before the event, with the exception of social recreation (Figure 3). The ANCOVA results indicate that the effect of number of photos and users on representation of CES is distinct between the two moments analyzed, before and during the disaster (Table III). That is, the regression lines representing the relationship of photos with CES and users with CES, have different slope coefficients. Thus, as the number of users and photos decrease, the

Table II. **Summary results of pair comparison with Mann-Whitney U test before and during the oil disaster.**

	Mann-Whitney	p-value
Users	28640	0.1879
Photos	27241	0.9909
CES Richness	28773	0.2545
Culture Expressions	27473	0.7952
Social Recreation	26668	0.6219
Landscape Appreciation	28861	0.2533
Nature Appreciation	28656	0.1919

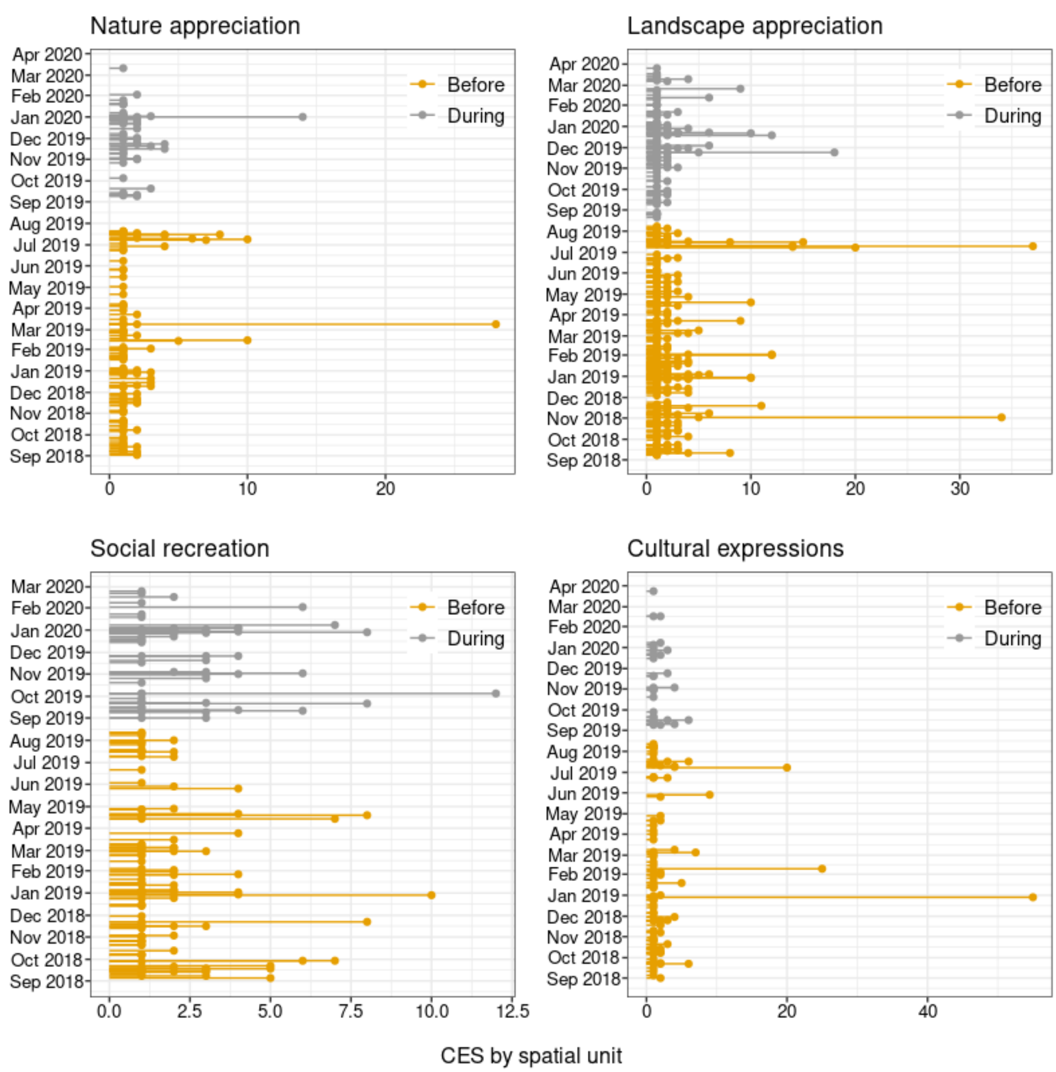

Figure 3. **Temporal representation of Cultural Ecosystem Services by spatial unit along the Brazilian coast, before and during the oil spill.**

Table III. ANCOVA carried out to verify differences on the cultural services assigned to users and their photos between the periods before and during the oil spill disaster.

	All Cultural Ecosystem Services			
	(Before)	(During)	(During)	(Before)
Photos	0.036*** (0.003)	0.080*** (0.008)		
	t = 12.138	t = 9.702		
	p = 0.000	p = 0.000		
Users			0.339*** (0.031)	0.573*** (0.073)
			t = 10.777	t = 7.894
			p = 0.000	p = 0.000
Adjusted R^2	0.309	0.361	0.260	0.271
Residual Std. Error	0.774 (df = 326)	0.741 (df = 164)	0.801 (df = 326)	0.792 (df = 164)
F Statistic	147.333*** (df = 1; 326) (p = 0.000)	94.122*** (df = 1; 164) (p = 0.000)	116.150*** (df = 1; 326) (p = 0.000)	62.322*** (df = 1; 164) (p = 0.000)
Note:			*p<0.1;> **p<0.05;> *** p<0.01	

provision of cultural Ecosystem Services also decreases.

DISCUSSION

As anticipated, our results confirmed that the 2019 Brazilian oil spill had a negative impact on the provision of coastal Cultural Ecosystem Services (CES) in comparison to baseline conditions. Several interacting factors are likely to have contributed to these results; i) a direct effect of the oil on the capacity of the coastal environment to provide CES. For example, the scenic beauty of the beaches is likely to have declined due to the presence of oil. Likewise, the oil may have physically impeded or diminish the quality of recreational activities such as surfing and snorkeling; ii) widespread negative publicity about the oil spill in traditional and digital media – much of it inaccurate (Lemos et al. 2020) – may have contributed to a decrease in the number of people visiting the affected coastal areas (Ribeiro et al. 2020), and may also have influenced visitor behavior. It is well known that tourism is 'hypersensitive' to oil spill events (Cirer-Costa 2015) and the 2019 event was extensively covered in the international and national media.

The behavior of local people and their access to CES was also likely affected, although this group is less likely to contribute to Flickr and therefore needs to be evaluated through alternative approaches (Vieira et al. 2018). In addition to losing CES, local people also had to contend with contaminated fish and shellfish stocks which significantly reduced markets for their products (Ribeiro et al. 2020, de Oliveira Soares et al. 2020) and created a public health emergency (Pena et al. 2020). Recent data suggest that fish and shellfish sales decreased by more than 50% in affected areas, impacting on food security, subsistence and cultural maintenance in these already socioeconomically vulnerable communities (de Oliveira Soares et al. 2020). To comprehensively assess the loss of CES and other ecosystem services on local people we recommend a multimethod approach that integrates social surveys and participatory methods, allowing the perceptions of local users to be explored and uncovered (Vieira et al. 2018).

More generally, our study demonstrates the potential utility of automatized assessment of CES at large scale for monitoring the social impacts of environmental change. Our machine learning approach (following Richards & Tunçer 2018) greatly simplifies and accelerates the processing of social media photos and has notable advantages over the manual classification of photos (cf. Retka et al. 2019), namely it is: (i) very fast; (ii) cheap; and (iii) can be applied at any spatial scale to very large datasets. However, our method still incorporates various biases that are characteristic of digital data (Correia et al. 2021) such as the identity of the people (mainly tourists) who take and share photos on file-sharing sites (Retka et al. 2019). As mentioned above, more robust assessment of CES requires a multiple-user (e.g. tourists, local residents, researchers) and multi-method (e.g. photo analysis and semi-structured questionnaires) approach (Hausmann et al. 2018, de Souza Queiroz et al. 2017, Vieira et al. 2018).

Another limitation of our method is that photos provided by a specific user group will only 'capture' a limited subset of CES (Retka et al. 2019). This is because sharing a photo on a website such as Flickr is dependent on the contributor's personal perspective, by that as a visitor, a religious adherent or an artist. The types of images uploaded by users in the internet also depend on the digital platform they use to share their photo and it is likely that sharing patterns on Flickr may differ from other platforms such as Panoramio or Twitter because the user profiles are different (Toivonen et al. 2019). While each platform may serve specific purposes on social media content research, Flickr has been extensively used in a range of nature-based tourism assessments, including CES spatial and temporal evaluations (Teles da Mota and Pickering 2020, Keeler et al. 2015). Furthermore, despite rapidly evolving algorithms for image content analysis, their utility ultimately depends upon the training datasets used for machine learning. These datasets influence the capability of the algorithms to recognise certain classes of image elements and thus, to detect elements that may represent CES. In the current study we use two-step processes of converting images into text and then associating text groupings to CES. In the future it may be possible to generate more accurate CES assessments by training algorithms to directly associate images with CES.

In conclusion, we were able to detect a fall in the provision of cultural ecosystem services during and after the 2019 oil spill off the northeast coast of Brazil using an innovative machine learning technique. Going forward, it will be important to evaluate the rate of recovery of coastal CES, especially in the context of the COVID-19 pandemic which has resulted in a loss of public interest in natural areas around the world (Souza et al. 2021). Our data clearly demonstrate the destructive impacts of the oil spill on the capacity of coastal environments to provide cultural services, significantly reducing the value of these areas for both visitors and local communities.

Acknowledgments

This work is part of the Long Term Ecological Research – Brazil site PELD-CCAL (Projeto Ecológico de Longa Duração -Costa dos Corais, Alagoas) funded by the Conselho Nacional de Desenvolvimento Científico e

Tecnológico (CNPq, #441657/2016-8, #442237/2020-0), Fundação de Amparo à Pesquisa do Estado de Alagoas (FAPEAL, #60030.1564/2016, #PLD2021010000001) and by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES, #23038.000452/2017-16). ACMM, BRP and CB are funded by CNPq, Brazil (#309879/2019-1, #309980/2018-6, #163711/2020-8, #103988/2019-0). RJL was supported via the European Union's Horizon 2020 research and innovation programme under grant agreement No 854248. FASV is funded by CAPES, Brazil (DIBICT fellowship). RAC is currently supported by funds from the University of Helsinki.

REFERENCES

BRAGAGNOLO C, MALHADO AC, JEPSON P & LADLE RJ. 2016. Modelling local attitudes to protected areas in developing countries. Conserv Soc 14(3): 163-182.

BRUM HD, CAMPOS-SILVA JV & OLIVEIRA EG. 2020. Brazil oil spill response: Government inaction. Science 367(6474): 155 LP-156. https://doi.org/10.1126/science.aba0369.

CÂMARA SF, PINTO FR, DA SILVA FR, DE OLIVEIRA MS & DE PAULA TM. 2021. Socioeconomic vulnerability of communities on the Brazilian coast to the largest oil spill (2019–2020) in tropical oceans. Ocean Coast Manage 202: 105506.

CHANG SE, STONE J, DEMES K & PISCITELLI M. 2014. Consequences of oil spills: a review and framework for informing planning. Ecol Soc 19(2).

CHENG X, VAN DAMME S, LI L & UYTTENHOVE P. 2019. Evaluation of cultural ecosystem services: A review of methods. Ecosyst Serv 37: 100925.

CIRER-COSTA JC. 2015. Tourism and its hypersensitivity to oil spills. Mar Pollut Bull 91(1): 65-72.

CORREIA RA, LADLE R, JARIĆ I, MALHADO AC, MITTERMEIER JC, ROLL U & DI MININ E. 2021. Digital data sources and methods for conservation culturomics. Conserv Biol 35(2): 398-411.

DE OLIVEIRA ME, LOPES PF, DE OLIVEIRA JÚNIOR JGC, JUNQUEIRA AB, DE OLIVEIRA SANTOS AP, DA SILVA LIMA JA & CAMPOS-SILVA JV. 2021. Immediate social and economic impacts of a major oil spill on Brazilian coastal fishing communities. Mar Pollut Bull 164: 111984.

DE OLIVEIRA SOARES M, TEIXEIRA CEP, BEZERRA LEA, PAIVA SV, TAVARES TCL, GARCIA TM & CAVALCANTE RM. 2020. Oil spill in South Atlantic (Brazil): Environmental and governmental disaster. Mar Policy 115: 103879.

DE SOUZA LQ, ROSSI S, CALVET-MIR L, RUIZ-MALLÉN I, GARCÍA-BETORZ S, SALVÀ-PRAT J & DE ANDRADE MEIRELES AJ. 2017. Neglected ecosystem services: Highlighting the socio-cultural perception of mangroves in decision-making processes. Ecosyst Serv 26: 137-145.

DIEGUES AC. 1999. Human populations and coastal wetlands: conservation and management in Brazil. Ocean Coast Manage 42(2-4): 187-210.

ESCOBAR H. 2019. Mystery oil spill threatens marine sanctuary in Brazil. Science: 672-672.

GLIOZZO G, PETTORELLI N & HAKLAY M. 2016. Using crowdsourced imagery to detect cultural ecosystem services: a case study in South Wales, UK. Ecol Soc 21(3).

GONÇALVES LR, WEBSTER DG, YOUNG O, POLETTE M & TURRA AR. 2020. The Brazilian Blue Amazon under threat: why has the oil spill continued for so long? Ambient Soc 23: e0077. Epub October 12, 2020. https://doi.org/10.1590/1809-4422asoc20200077vu2020l5id.

HAUSMANN A, TOIVONEN T, SLOTOW R, TENKANEN H, MOILANEN A, HEIKINHEIMO V & DI MININ E. 2018. Social Media Data Can Be Used to Understand Tourists' Preferences for Nature-Based Experiences in Protected Areas. Conserv Lett 11: e12343. https://doi.org/10.1111/conl.12343.

IBAMA - INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS. 2020. Manchas de óleo no litoral do Nordeste. Retrieved from. http://www.ibama.gov.br/manchasdeoleo.

KEELER BL, WOOD SA, POLASKY S, KLING C, FILSTRUP CT & DOWNING JA. 2015. Recreational demand for clean water: Evidence from geotagged photographs by visitors to lakes. Front Ecol Environ 13: 76-81. https://doi.org/10.1890/140124.

LADLE RJ, CORREIA RA, DO Y, JOO GEA-JAE, MALHADO AC, PROULX R, ROBERGE JEAN-MICHEL & JEPSON P. 2016. Conservation Culturomics. Front Ecol Environ 14(5): 269-275. doi:10.1002/fee.1260.

LADLE RJ, JEPSON P, CORREIA RA & MALHADO AC. 2017. The power and the promise of culturomics. Front Ecol Environ 15(6): 290-291.

LADLE RJ, MALHADO AC, CAMPOS-SILVA JV & PINHEIRO BR. 2020. Brazil's mystery oil spill: an ongoing social disaster. Nature 578(7793): 37-37.

LEMOS ALM, BITENCOURT EC & DOS SANTOS JGB. 2020. Fake news as fake politics: the digital materialities of YouTube misinformation videos about Brazilian oil spill catastrophe. Media Cult Soc 43(5): 886-905.

LORD F, TULER S, WEBLER T & DOW K. 2012. Unnecessarily neglected in planning: illustration of a practical approach to identify human dimension impacts of marine oil spills. J Environ Assess Policy Manag 14(02): 1-23.

LOURENÇO RA, COMBI T, DA ROSA ALEXANDRE M, SASAKI ST, ZANARDI-LAMARDO E & YOGUI GT. 2020. Mysterious oil spill along Brazil's northeast and southeast seaboard (2019–2020): Trying to find answers and filling data gaps. Mar Pollut Bull 156: 111219.

MAGALHÃES KM, DE SOUZA BARROS KV, DE LIMA MCS, DE ALMEIDA ROCHA-BARREIRA C, ROSA FILHO JS & DE OLIVEIRA SOARES M. 2020. Oil spill + COVID-19: a disastrous year for Brazilian seagrass conservation. Sci Total Environ: 142872.

MILCU AI, HANSPACH J, ABSON D & FISCHER J. 2013. Cultural ecosystem services: a literature review and prospects for future research. Ecol Soc 18(3).

MEA - MILLENNIUM ECOSYSTEM ASSESSMENT. 2005. Ecosystems and human well-being, v. 5. United States of America: Island press, p. 563.

PENA PGL, NORTHCROSS AL, LIMA MAGD & RÊGO RDCF. 2020. The crude oil spill on the Brazilian coast in 2019: the question of public health emergency. Cad Saude Publica 36: e00231019.

R CORE TEAM. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/.

RETKA J, JEPSON P, LADLE RJ, MALHADO AC, VIEIRA FA, NORMANDE IC & CORREIA RA. 2019. Assessing cultural ecosystem services of a large marine protected area through social media photographs. Ocean Coast Manage 176: 40-48.

RIBEIRO LCDS, SOUZA KBD, DOMINGUES EP & MAGALHÃES AS. 2020. Blue water turns black: economic impact of oil spill on tourism and fishing in Brazilian Northeast. Curr Issues Tourism: 1-6.

RICHARDS DR & FRIESS DA. 2015. A rapid indicator of cultural ecosystem service usage at a fine spatial scale: content analysis of social media photographs. Ecol Indic 53: 187-195.

RICHARDS DR & TUNÇER B. 2018. Using image recognition to automate assessment of cultural ecosystem services from social media photographs. Ecosyst Serv 31: 318-325.

SHERREN K, SMIT M, HOLMLUND M, PARKINS JR & CHEN Y. 2017. Conservation culturomics should include images and a wider range of scholars. Front Ecol Environ 15(6): 289-290.

SOARES MO, TEIXEIRA CEP, BEZERRA LEA, ROSSI S, TAVARES T & CAVALCANTE RM. 2020. Brazil oil spill response: Time for coordination. Science 367(6474): 155 LP-155. https://doi.org/10.1126/science.aaz9993.

SOUZA CA, RODRIGUES AC, CORREIA RA, NORMANDE IC, COSTA HCM, GUEDES-SANTOS J, MALHADO ACM, CARVALHO AR & LADLE RJ. 2021. No visit, no interest: How COVID-19 has affected public interest in world's national parks. Biol Conserv 256. https://doi.org/10.1016/j.biocon.2021.109015.

TELES DA MOTA V & PICKERING C. 2020. Using social media to assess nature-based tourism: Current research and future trends. J Outdoor Rec Tour ISSN: 2213-0780. https://doi.org/10.1016/j.jort.2020.100295.

TOIVONEN T, HEIKINHEIMO V, FINK C, HAUSMANN A, HIIPPALA T, JÄRV O & DI MININ E. 2019. Social media data for conservation science: A methodological overview. Biol Conserv 233: 298-315.

VAN ZANTEN BT, VAN BERKEL DB, MEENTEMEYER RK, SMITH JW, TIESKENS KF & VERBURG PH. 2016. Continental-scale quantification of landscape values using social media data. Proc Natl Acad Sci 113(46): 12974-12979.

VIEIRA FAS, BRAGAGNOLO C, CORREIA RA, MALHADO ACM & LADLE RJ. 2018. A salience index for integrating multiple user perspectives in cultural ecosystem service assessments. Ecosyst Serv 32: 182-192.

ZACHARIAS DC, GAMA CM & FORNARO A. 2021. Mysterious oil spill on Brazilian coast: Analysis and estimates. Mar Pollut Bull 165:112125. https://doi.org/10.1016/j.marpolbul.2021.112125.

How to cite

AZEVEDO AK, VIEIRA FAS, GUEDES-SANTOS J, GAIA JA, PINHEIRO BR, BRAGAGNOLO C, CORREIA RA, LADLE RJ & MALHADO ACM. 2022. A big data approach to identify the loss of coastal cultural ecosystem services caused by the 2019 Brazilian oil spill disaster. An Acad Bras Cienc 94: e20210397. DOI 10.1590/0001-3765202220210397.

Manuscript received on March 15, 2021;
accepted for publication on July 2, 2021

ANNA KAROLINE AZEVEDO[1]
https://orcid.org/0000-0002-6302-4187

FELIPE A.S. VIEIRA[1]
https://orcid.org/0000-0001-5517-8955

JHONATAN GUEDES-SANTOS[1]
https://orcid.org/0000-0003-3177-6496

JOÃO ARTHUR GAIA[1]
https://orcid.org/0000-0003-0847-3833

BARBARA R. PINHEIRO[1]
https://orcid.org/0000-0001-5032-8547

CHIARA BRAGAGNOLO[1]
https://orcid.org/0000-0002-9571-0026

RICARDO A. CORREIA[2,3,4]
https://orcid.org/0000-0001-7359-9091

RICHARD J. LADLE[1,5]
https://orcid.org/0000-0003-3200-3946

ANA C.M. MALHADO[1,5]
http://orcid.org/0000-0003-3621-779X

[1]Federal University of Alagoas, Institute of Biological and Health Sciences, Av. Lourival Melo Mota, s/n, Tabuleiro do Martins, 57072-900 Maceió, AL, Brazil

[2]University of Helsinki, Helsinki Lab of Interdisciplinary Conservation Science (HELICS), Department of Geosciences and Geography, 00014, Helsinki, Finland

[3]University of Helsinki, Helsinki Institute of Sustainability Science (HELSUS), 00014, Helsinki, Finland

[4]University of Aveiro, DBIO & CESAM – Centre for Environmental and Marine Studies, 3810-193, Aveiro, Portugal

[5]University of Porto, CIBIO - Research Center in Biodiversity and Genetic Resources, Vairão Campus, Rua Padre Armando Quintas, nº 7, 4485-661, Vairão, Portugal

Correspondence to: **Anna Karoline Azevedo**
E-mail: karolineakaf@gmail.com

Author contributions

Anna Karoline Azevedo: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Software. Felipe Vieira: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Software. Jhonatan Guedes: Investigation. João Arthur Gaia: Investigation. Bárbara Pinheiro: Investigation. Chiara Bragagnolo: Conceptualization, Writing – original draft, Writing – review & editing. Ricardo Aleixo Correia: Investigation Writing – review & editing. Richard J.Ladle: Writing – review & editing Ana Claudia Mendes Malhado: Conceptualization, Writing – review & editing.