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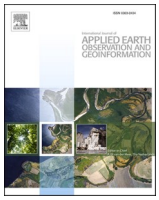

Detecting land use and land cover change on Barbuda before and after the Hurricane Irma with respect to potential land grabbing: A combined volunteered geographic information and multi sensor approach

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ABSTRACT

Two months after the hurricanes Irma and Maria hit Barbuda, the construction of a new international airport led to accusations of degrading the Codrington Lagoon National Park and contravening the conventions of the Ramsar Program. Scientists have analyzed the aftermath with respect to historical legacies, disaster capitalism, manifestation of climate injustices and green gentrification. The main objective of this study was to quantify and allocate land use and land cover change (LULCC) in Barbuda before and after the 2017 Hurricane disasters. Remote sensing data and volunteered geographic information were analyzed to detect the potential changes in natural LULC so that human activities and the emergence of artificial surfaces could be detected. Human-induced LULCC occurred at different sites on the island, with decreased activities in Codrington, but increased and continued activities at Coco and Palmetto Points. With an accuracy of 97.1 %, we estimated a total increase of vegetated areas by 6.56 km^2, and a simultaneous slight increase in roads and buildings with a total length of 249.67 km and a total area of 1.43 km^2. The vegetation condition itself depict a steady decrease since 2017. New hotspots of human activity emerged on the island in the Codrington Lagoon National Park.

1. Introduction

"Buy land, God doesn't create any more." This aphorism by Mark Twain can be considered as the guiding principle for humankind, evident from the steadily increasing global land consumption. Accordingly, the term "land grab" was coined and is related to the increased number of large-scale and commercial land deals by international actors (Wright et al., 2021). Pearce (2012) describes the various land transactions as a resource and their consequences. Although the focus of the study was agricultural land, the analysis also includes tourism and conservation or ecological land grabs, in which supposedly noble intentions ultimately lead to indigenous societies being excluded from their claimed land and losing their livelihoods. Starting on September 6, 2017, the 2-week long Hurricanes Irma and Maria (Category 5 storms) caused a total damage of US$120 billion, thousands of deaths, with > 70 % houses destroyed and damaged in the Caribbean islands. Barbuda was the first island to be hit by Hurricane Irma, which destroyed ~ 95 % of the environment and caused immense damage (up to US$222.2 million) to the small islands (Baptiste & Devonish, 2019, Boyd et al., 2021). Additionally, the storm also caused widespread destruction of vegetation through defoliation, saltwater flooding, and uprooting of crops; fortunately, only one death was recorded among the residents of Barbuda (Perdikaris et al., 2021). Of the 670 houses, 642 were either destroyed or damaged. As a safety measure, the Prime Minister of Antigua and Barbuda, Gaston Browne, ordered complete evacuation of Barbuda, temporarily housing 1,600 Barbudans on the sister island of Antigua. Even after two months from the Hurricane Irma, there was no energy supply in Barbuda and the hospitals or schools could also not begin to operate. However, in lieu of important reconstruction efforts on behalf of the still largely evacuated society, construction started for a new international airport. The construction project was already sanctioned, but it began without the necessary approval from the Barbudan Council (BC) and without an environmental impact assessment. This led to the impression that the government had utilized the crisis (Boyd et al., 2021), which was unlawful since the Barbuda Land Act 2007 states that all the land in Barbuda is owned by its citizens (Government of Antigua and Barbuda, 2008). In the aftermath of the 2017 hurricanes, the prime minister of Antigua and Barbuda had stated that "in terms of the legal ownership, Barbudans never had ownership, and up to this day do not have ownership. They occupy the land informally and unchallenged"

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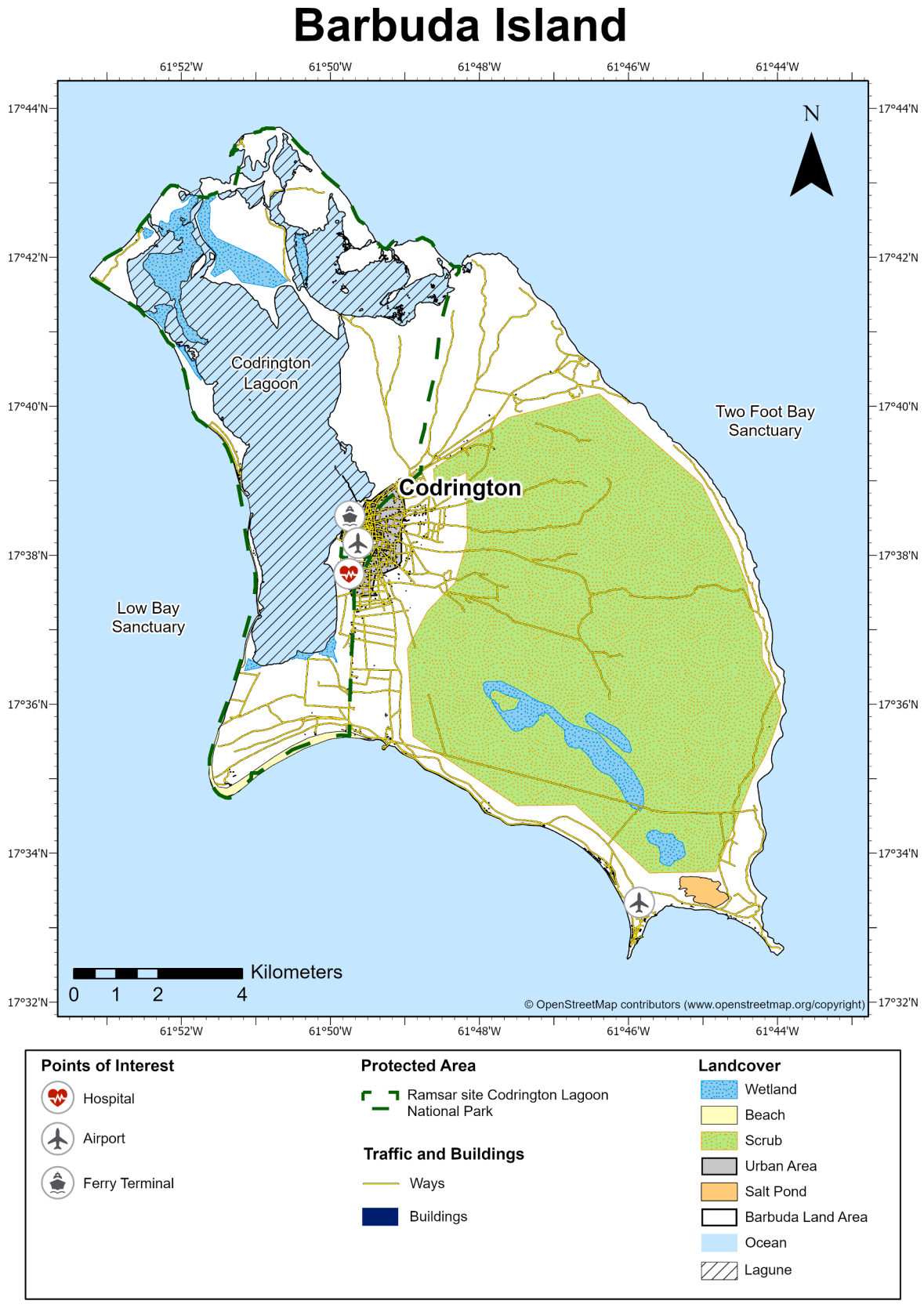

Fig. 1. Map of Barbuda island (modified, based on OSM). Note that the international airport construction site has not been mapped in OSM yet.

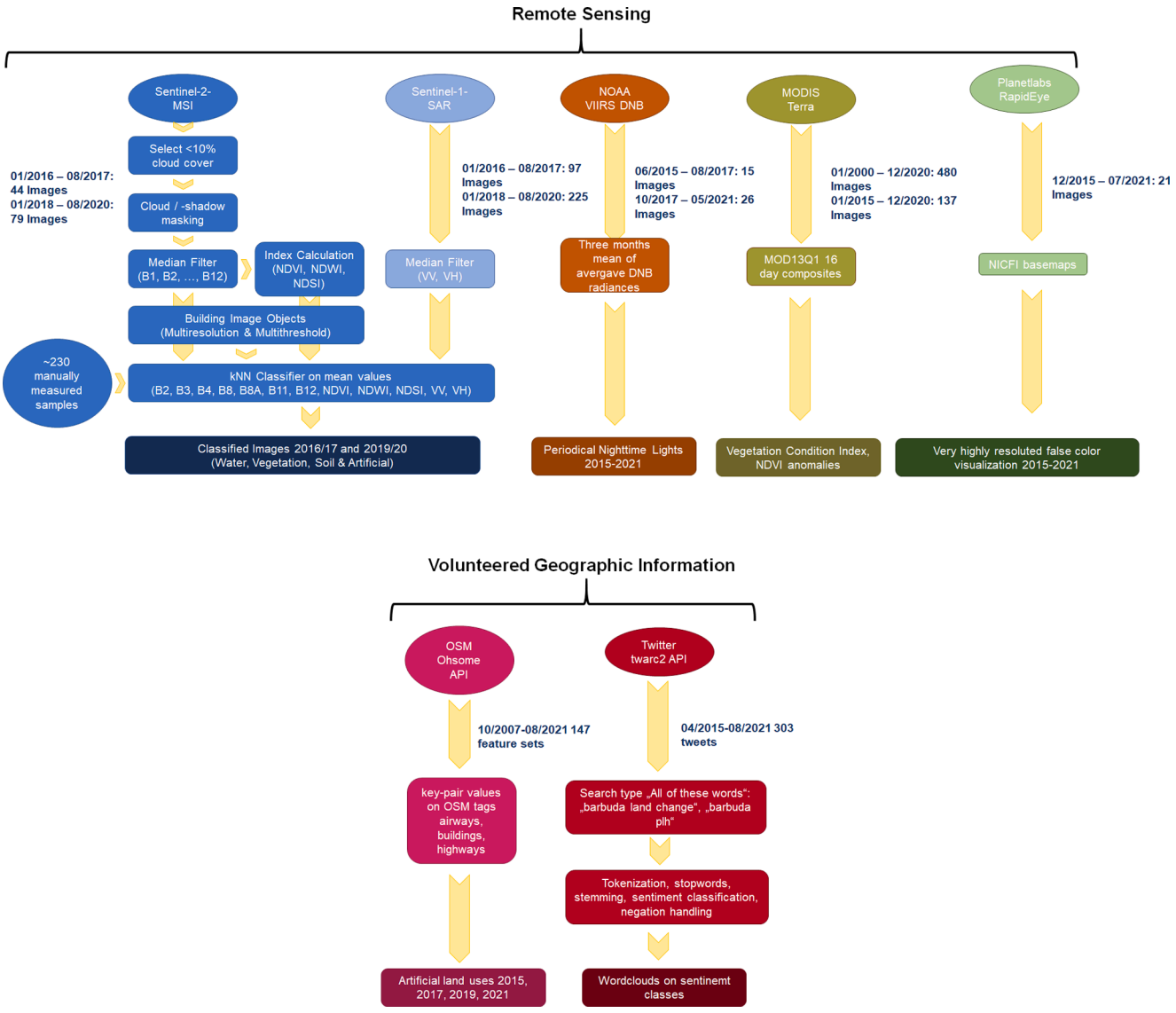

Fig. 2. Data and methods used in the study.

(Suliman, 2018). Accordingly, the government has subsidized project costs to implement tourism projects on the island (Boyd et al., 2021), which appear to be controversial. The projects called Peace, Love, and Happiness (PLH), the Barbudan Ocean Club, and Paradise Found (Nobu Beach Inn) were developed by John Paul DeJoria, co-founder of Patrón Spirits International AG, and actor Robert de Niro (Boyd et al., 2021, Gruenbaum, 2018). They are currently being scrutinized by the Global Legal Action Network of degrading Codrington Lagoon National Park and contravening conventions of the Ramsar Program for the Protection of Wetlands of the International Union for Conservation of Nature (Boyd et al., 2021). Ramsar has listed Codrington Lagoon as an internationally important wetland (Ramsar site no. 1488, since 2005, Fig. 1). Nevertheless, the PLH project of the U.S. tourism magnates is being advertised by the Prime Minister and Governor Rodney Williams against the resistance of the islanders, despite the threat of drastic ecological consequences and degradation of the lagoon (Boyd et al., 2021, Rhiney, 2020, Rodriguez-Garavtio & Donger, 2021). Following a representation to the UN from the people of Barbuda, the Office of the High Commissioner for Human Rights sent a letter to the central Government of Antigua and Barbuda, asking them to provide more information on the development of the luxury Barbuda Ocean Club and nearby runway that is currently abandoned (Boyd et al., 2021). Additionally, it addresses another amendment to the Land Act that was resolved in 2017 declaring, "all persons residing on the Island of Barbuda shall be and are hereby declared to be tenants of the Crown," which means an expropriation of the Barbudan citizens. The government response on this issue is still awaited.

Scientists have analyzed the effect of severe storms with respect to historical legacies and reconstruction politics (Bonilla, 2020, Popke & Rhiney, 2019), disaster capitalism (Boger & Perdikaris, 2019, Rhiney, 2020, Wright et al., 2021), manifestation of climate injustices and green gentrification (Gould & Lewis, 2018; Look et al., 2019; Rodriguez-Garavtio & Donger, 2021), disrupted identities (Perdikaris et al., 2021), and biopolitics of disaster management for a decolonial resilience (Cohle & Ortega, 2021; Juarez Cornelio et al., 2021; Popke & Rhiney, 2019). However, no attempt has been made to quantify and allocate land use and land cover change (LULCC) of Barbuda before and after the 2017 Hurricane disasters. Hence, the main objective of this study was to analyze different geodata from open sources to detect the potential changes in natural land use and land cover (LULC) in favor of developments that could provide a hint on human activities and the emergence of artificial surfaces. The main goal of the study was not to evaluate the potential land grabs in a qualitative, evaluating manner, but to examine the hypothesis that in the aftermath of Hurricane Irma,

the landscape of Barbuda changed rapidly, indicating an increase in human-induced LULCC by transforming natural habitats to artificial surfaces. This paper only aims to contribute to the debate of quantitative potential "neo-colonialism" and "disaster capitalism" from a geodata perspective.

This study addresses the following research questions:

1) Where is human-induced LULCC taking place on Barbuda and how accurate can it be allocated?
2) To what extent is LULCC occuring on Barbuda and how can it be quantified?
3) How does LULCC on Barbuda has changed before and after Hurricane Irma in terms of location and quantity?

This paper is structured as follows:

Section 2 discusses the historical role of land in defining the identity of the Barbudans. Section 3 presents the data and methods used in the study that are multispectral remote sensing-based LULCC classification, very high-resolution satellite imagery, nighttime lights, and volunteered geographic information gathered through Ohsome API and Twitters' Twarc 2 API. Section 4 presents the results of human-induced LULC regarding allocation, quantity, and dynamics before and after the severe Hurricanes 2017. A short conclusion and future research directions are presented in section 5.

2. Study site – Barbuda and the role of land to a distinctive identity

Barbuda is a Caribbean Island in the Lesser Antilles with an area of 161 km^2 and a population of 1,886 (projection based on Census 2011, https://statistics.gov.ag/) (Fig. 1). Compared to neighboring islands, including its sister island Antigua, Barbuda is considered unspoiled and remote (Potter & Sluyter, 2010).

The relationship of Barbuda with its larger sister island in the colonial nation state of Antigua and Barbuda, is characterized by a historically developed subordination of Barbuda to Antigua (Baptiste & Devonish, 2019). The tourism sector is responsible for 70 % of the gross domestic product and 85 % of the foreign exchange earnings, and 40 % of Antigua's population is employed in it (Boger et al., 2016). Development of the traditional tourism sector leads to the main social difference between the two islands, and determines self-perceptions and identities. Gould and Lewis (2018) have aptly formulated this as

> "Barbudans do not work as maids, bartenders, and landscapers, as do many of their counterparts in Antigua, nor do they seek such work."

Furthermore, specific farming techniques, an everyday life that was not exclusively sugar cane production-oriented, and the small continuous population were reasons for the distinctive cultural identity of Barbuda, which has been maintained after the emancipation of slaves and is present till date (Perdikaris & Hejtmanek, 2020). Barbuda struggles with problems that are symptomatic to the Caribbean, or islands in general, such as climate change impact and damage, unemployment and poverty, food and water scarcity, and social brain drain (Perdikaris & Hejtmanek, 2020).

3. Data and methods

For the assessment of artificial LULCC and human activity on the ground, we mainly utilized two data sources: 1) remotely sensed satellite data and 2) in situ mapped volunteered geographic information. We processed Sentinel-1 (S-1), Sentinel-2 (S-2), NOAA VIIRS data, MODIS Terra, and RapidEye data, and obtained data from the OSM archive via the Ohsome API and Twitter via twarc2 API (2). Thus, procured high-resolution (5–10 m scale) quantitative and regional information on LULCC before and after the Hurricane disasters in September 2017, and on-ground information on the artificial LULC. The nighttime light (NTL) imagery enabled the assessment of dynamic human activity (Fig. 2).

The LULCC analysis of Barbuda Island was performed using satellite imagery acquired from (S-2) and (S-1) data. Atmospherically corrected Level 2 data that had a cloud cover < 10 % were used. Subsequently, annual samples were created based on simple median filter methods for 2016–2017 (before September 5, 2017) and 2019–2020 (Fig. 3). The

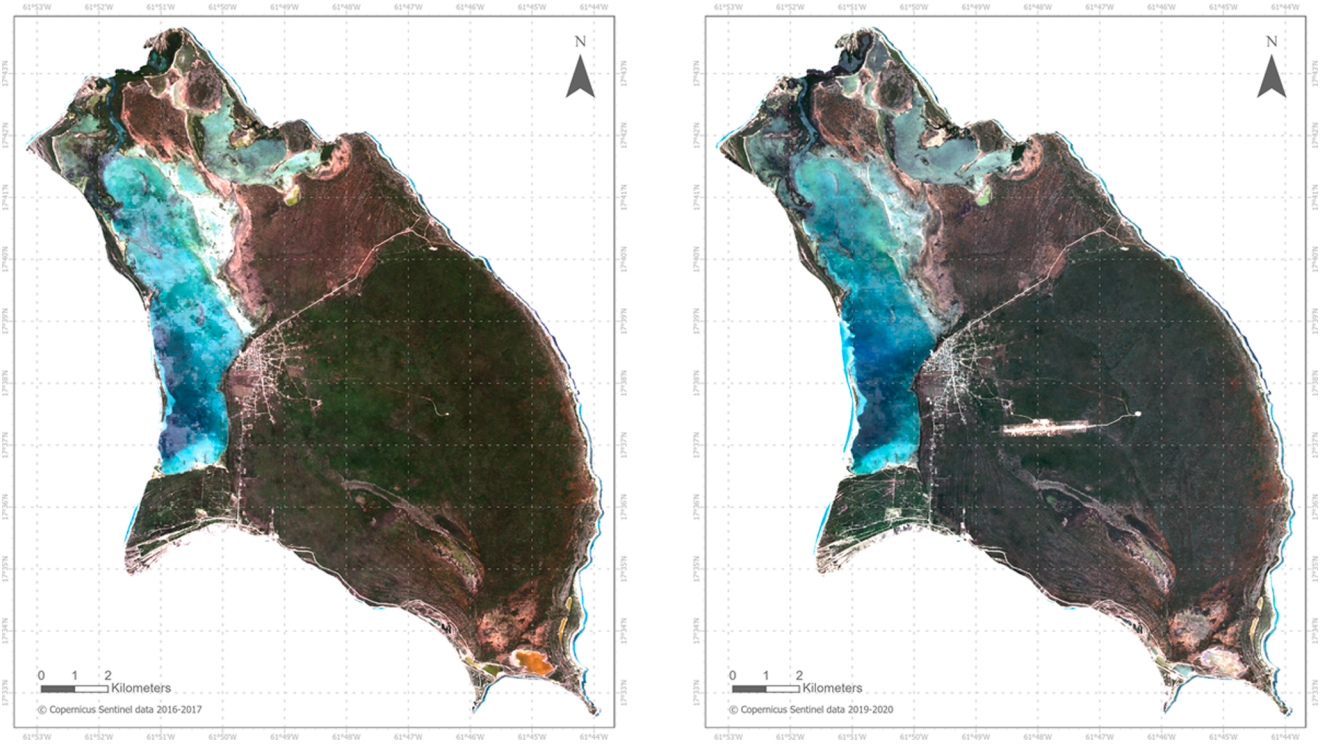

Fig. 3. Sentinel-2 cloud free median mosaics 2016–17 ((before September 5, 2017, left) and 2019–20 (right).

Table 1
Acquired and processed NTL data from the VIIRS.

Period	Scenes
Jun-Aug 2015	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20150601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20150701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20150801
Oct-Dec 2015	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20151001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20151101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20151201
Jun-Aug 2016	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20160601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20160701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20160801
Oct-Dec 2016	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20161001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20161101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20161201
Jun-Aug 2017	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20170601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20170701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20170801
Oct-Dec 2017	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20171001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20171101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20171201
Jun-Aug 2018	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20180601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20180701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20180801
Oct-Dec 2018	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20181001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20181101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20181201
Jun-Aug 2019	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20190601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20190701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20190801
Oct-Dec 2019	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20191001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20191101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20191201
Jun-Aug 2020	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20200601NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20200701NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20200801
Oct-Dec 2020	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20201001NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20201101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20201201
Jan-May 2021	NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20210101NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20210201NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20210301NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20210401NOAA/VIIRS/DNB/MONTHLY_V1/VCMCFG/20210501

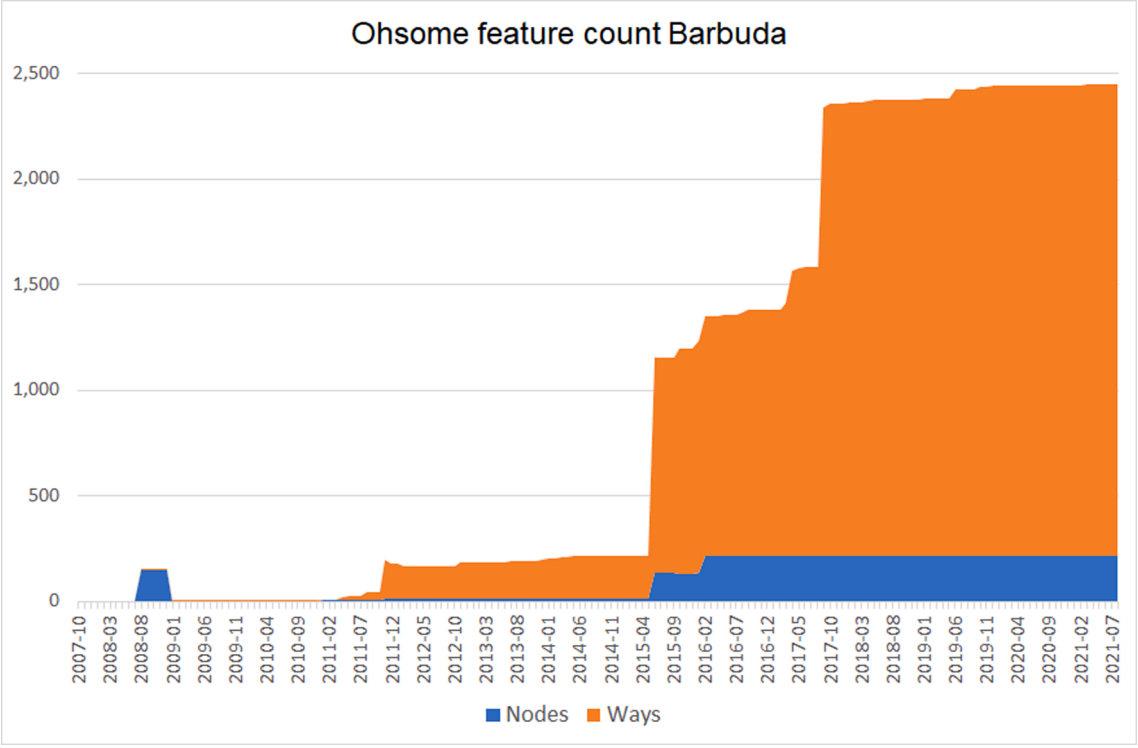

Fig. 4. Historic OSM mapping activities with most the frequent OSM types: nodes and ways (modified based on https://ohsome.org/apps/dashboard/).

object-based image analysis was conducted with a knn classifier to delineate three land cover classes: water, vegetation, soil/ artificial surfaces on a 10 m scale (Ghazaryan et al., 2021; Juergens et al., 2021). In order to derive more information on the vegetation condition, we have also acquired data of the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua Satellites (Moat et al., 2021) and calculated the Vegetation Condition Index (VCI) (Graw et al., 2020). According to Wilhilte (2000) the VCI is calculated as follows:

$$VCI = 100^{*}\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (1)$$

Considering a baseline between 2000 and 2020, MODIS Terra NDVI (MOD13Q1) 16-day composites at 250 m resolution were used to calculate the mean annual VCI for each year between 2015 and 2020.

Table 2
Utilized Ohsome API tags.

Land use	OSM Tags	OSM Types
Aerodromes	airways=*	ways
Buildings	building=*	ways
Roads	highway=*	ways

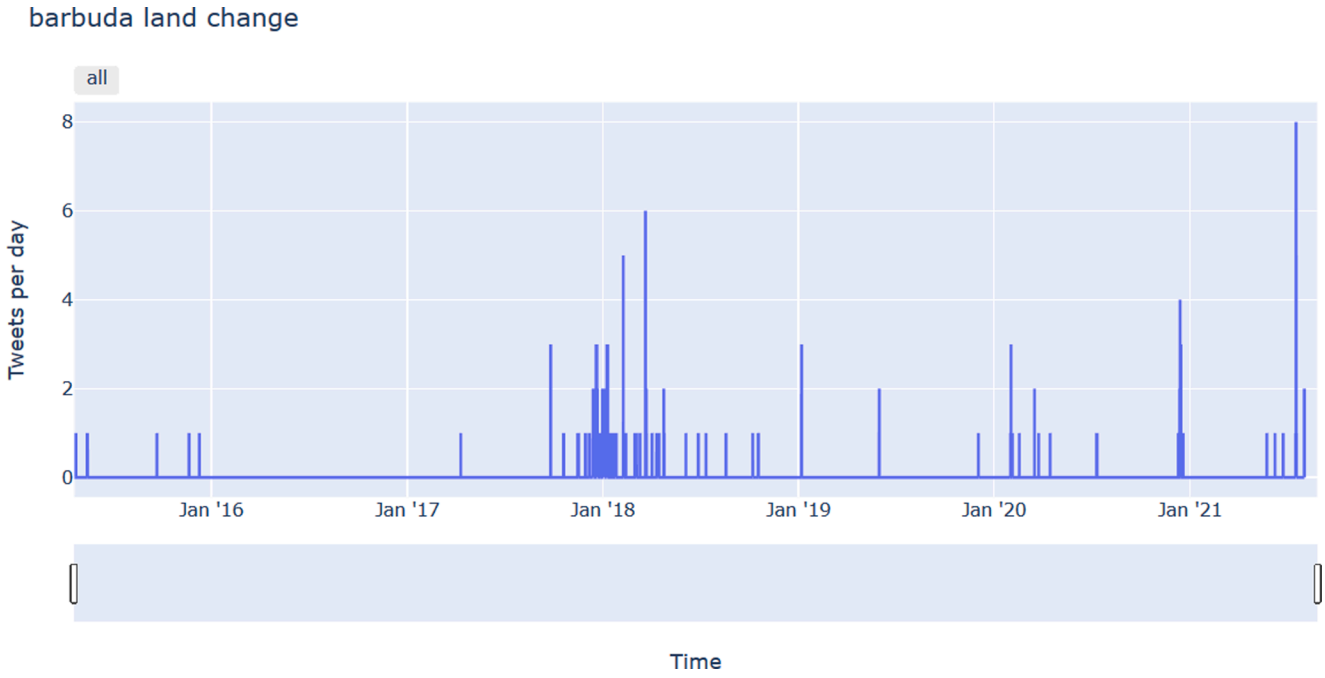

Fig. 5. Amount of tweets dealing with "barbuda land change" (found between March 2015 and August 2021).

To be able to visualize the potential hot spots of LULCC at a very high resolution (~5 m), we also acquired Planet Labs RapidEye data provided by Norway's International Climate & Forests Initiative (NICFI) (Planetlabs, 2021).

In order to remotely assess human activities, night light emissions are a simple and effective option (Levin et al., 2020). They are reliable in estimating the intensity of human activities on land and even interrogating the metanarratives of development (Bennett, 2020, Kyba et al., 2021). In this study, 41 scenes were acquired by VIIRS Day Night Band (DNB) from the Joint Polar-orbiting Satellite System (Elvidge et al., 2017). We used the available average DNB radiance values (nanoWatts/cm2/sr). Table 1 presents an overview of the acquired scenes and processed three months samples..

The utilized satellite data have spatial resolutions of 10 m and 5 m, which is still too coarse to detect smaller residential buildings in Codrington. We enhanced the satellite-based samples with Open Street Map (OSM) feature data to accurately differentiate between vegetated and non-vegetated and artificial and non-artificial areas. OSM is the most commonly used volunteered geographic information system in the world (Jokar Arsanjani et al., 2015). The Heidelberg Institute for Geoinformation Technology developed the Ohsome API as OpenStreetMap History Analyzer to access historical OSM data (Raifer et al., 2019). A beneficial side is the possibility to analyze the development of residential areas and certain amenities. Fig. 4 presents the historic OSM mapping activities mainly on nodes and ways in Barbuda during 2008–2021.

Note that the mapping activities enhanced in the aftermath of the 2017 Hurricanes (Fig. 4). We set up a Python script for the Jupyter Notebook accessing the Ohsome API and searched for relevant OSM tags to map the development of buildings, roads, and airways on Barbuda. Table 2 presents the key-value pairs and types used for mapping the artificial surfaces. We mainly focused on the two artificial LULC types: roads and buildings. We have added aerodromes for two reasons: first, their paved runways are artificial and controversial (Boger et al., 2016) and second, the construction of an airport shortly after the September 2017 hurricanes initiated researches in neocolonialism, land grab, and disrupted identities (cf. Section 1).

The study wants to contribute to the discourse of land grabbing, neocolonialism, and disaster capitalism by enriching spatially explicit geoinformation with impressions of Barbudan LULCC from the Twitter community. Although the most used social medium in Barbuda is Facebook, we have chosen Twitter since it reflects both: international news and official statements as well as local opinions on those. We set up a scientific developer account and accessed the full Twitter archive via the twarc2 API (Twarc-Project, 2021). We conducted an "all of these words" search for collecting tweets containing the words "barbuda land change" and "barbuda plh". We used the Natural Language Toolkit, comprising the Jupiter "vader" and "stopwords" lexicons, to build a Python program to analyze the collected tweets (Hutto & Gilbert, 2014, NLTK project, 2020). The text input was tokenized, filtered for stopwords, negation handled, stemmed, and classified in sentiments (Carvalho & Plastino, 2021).

4. Results and discussion

Progress in the development of the Barbudan Ocean Club has already been observed via Twitter. Fig. 5 depicts the number of tweets found using the search words "baburda land change." Fig. 6 reflects the remote observations that were shared via Twitter. Looking at the timeline of the catch phrases, one can see the trend intensity of LULCC in the public debate on Barbuda (Fig. 6). The period when the search phrase started

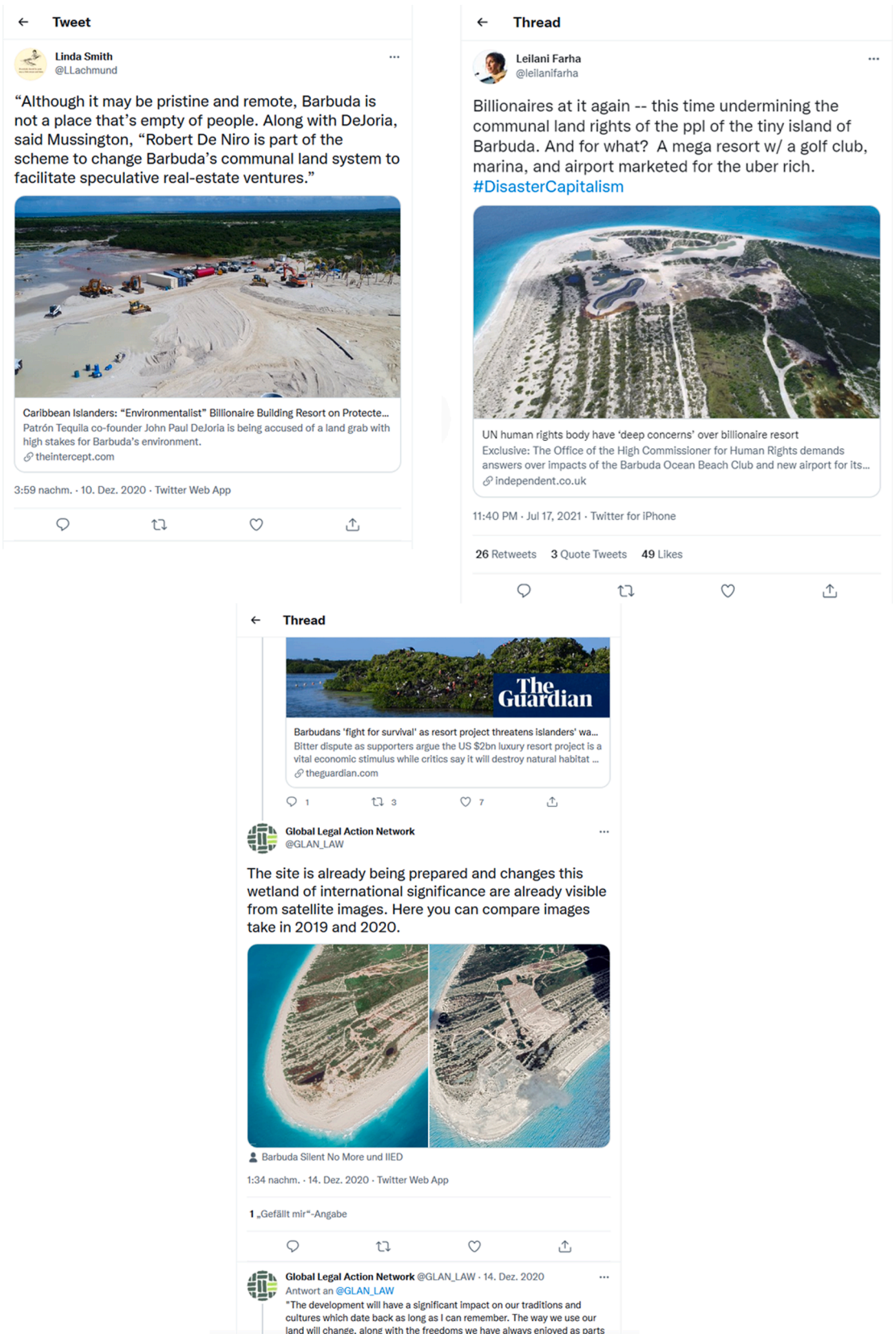

Fig. 6. Tweets picturing the Barduda Ocean Club construction site at Palmetto Point (Source: https://twitter.com/LLachmund/status/1337049299134410756, https://twitter.com/GLAN_LAW/status/1338462352002387973, https://twitter.com/leilanifarha/status/1416513225844305922).

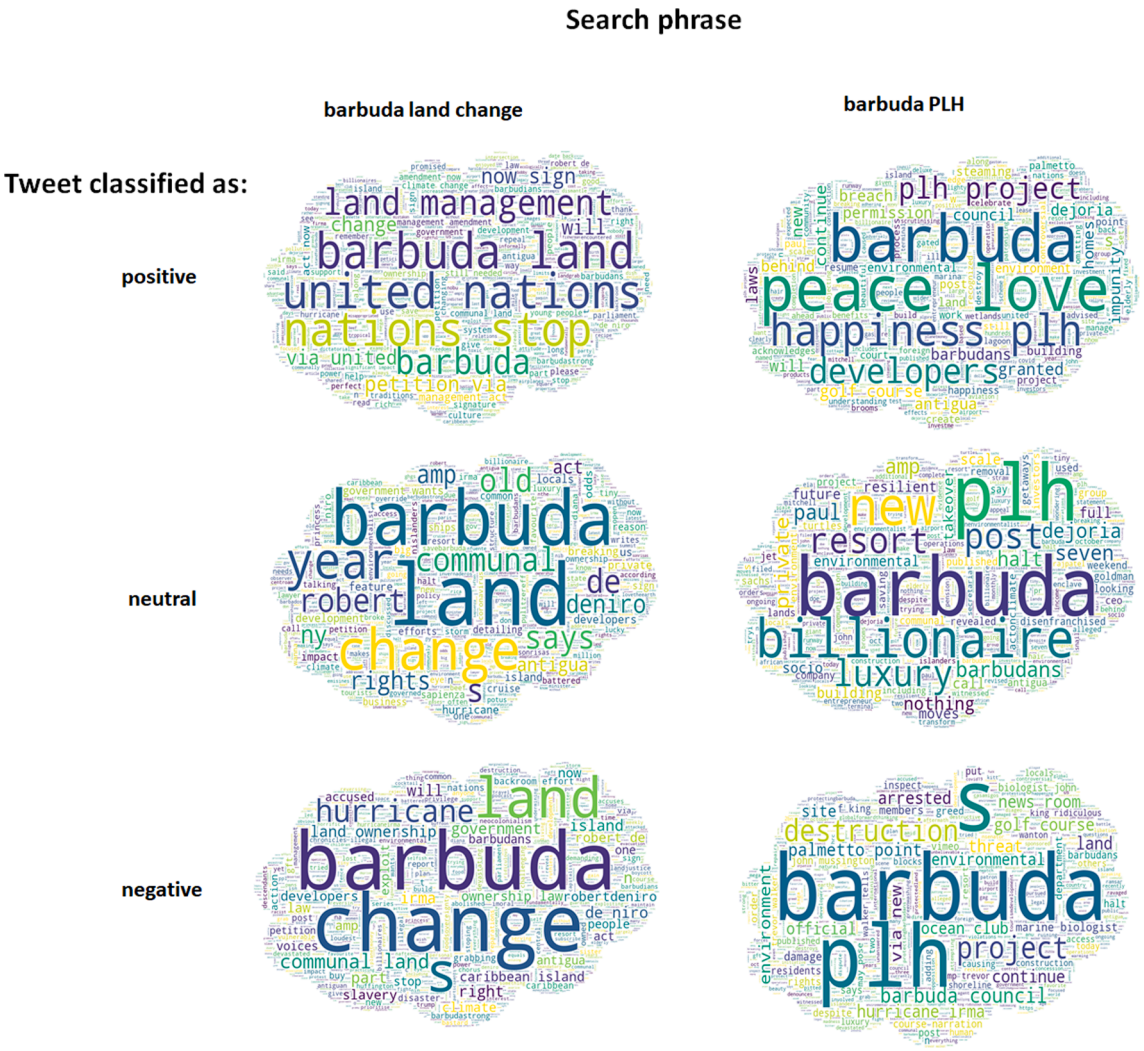

Fig. 7. Word clouds based on sentiment classification of tweets searched with "Barbuda land change" and "Barbuda plh."

Table 3
Classified data on land cover Barbuda Island (spatial resolution: 10 m).

Land cover class	Area 2016/17 (sq. km)	Area 2019/20 (sq. km)	Change (sq. km)
Water	39.20	37.96	−1.24
Vegetation	91.03	97.59	+6.56
Soil & Artificial surfaces	44.45	40.04	−4.41

Table 4
Accuracy assessment of LULC maps of Barbuda in 2016–2017 (before September 2017) and 2019–2020. Note that only those pixels have been used for validation that were part of the classification process and have not changed their LULC class between 2016 and 2017 and 2019–2020.

	2016/17 & 2019/20	Reference Water	Vegetation	Soil & Artificial surfaces	User's Accuracy
	Water	66	0	2	**0.97**
	Vegetation	0	70	0	**1.0**
	Soil & Artificial surfaces	4	0	68	**0.94**
	Producer's Accuracy	**0.94**	**1.0**	**0.97**	
	Overall Accuracy	**0.97**			
	Kappa	**0.95**			

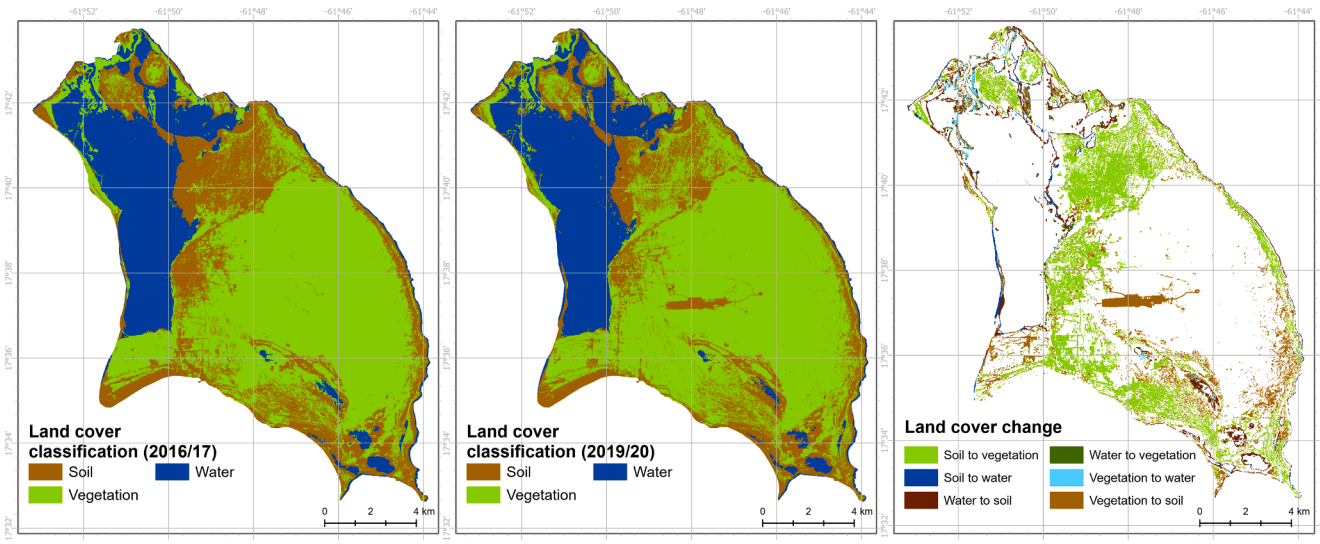

Fig. 8. LULC maps for 2016–2017 and 2019–2020; LULCC map for 2016–2020.

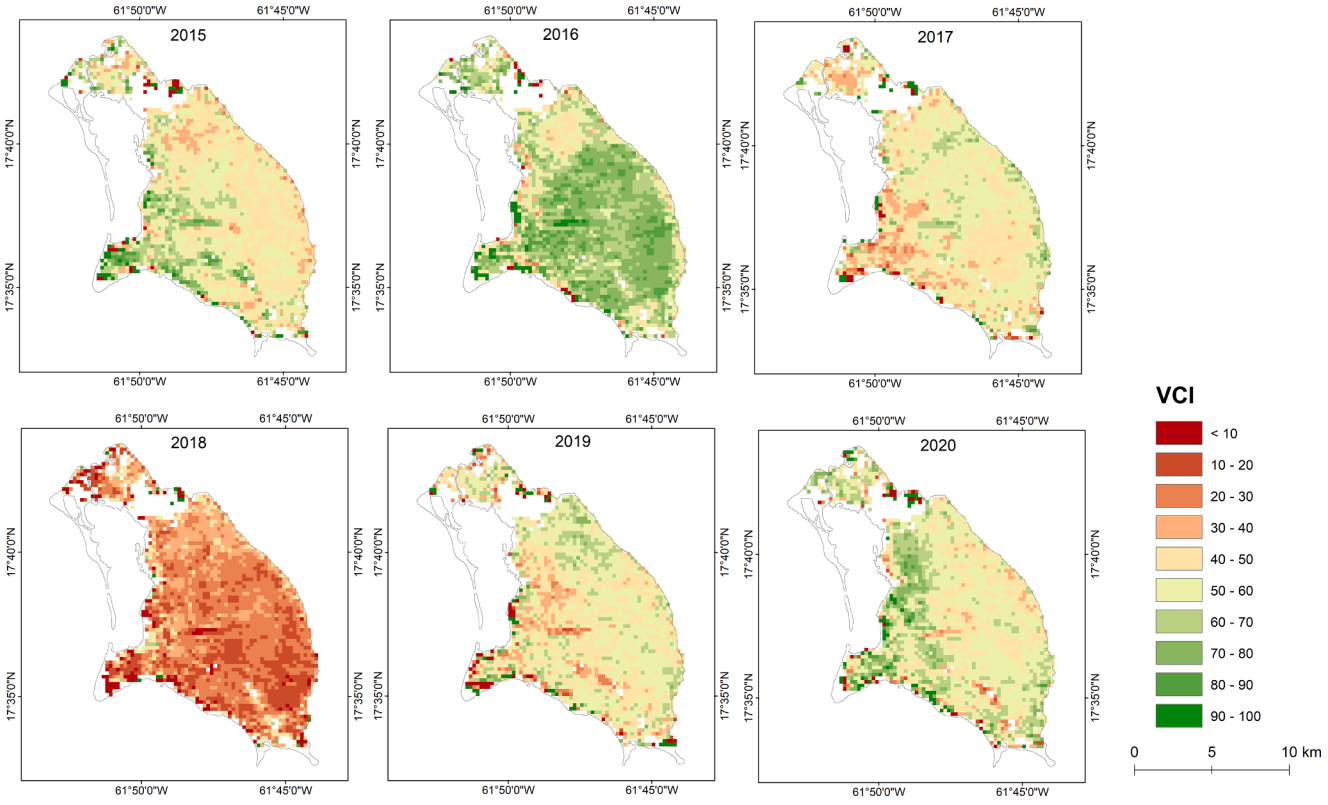

Fig. 9. Mean annual VCI values between 2015 and 2020.

trending was after the severe hurricanes in September 2017. The day with the most tweets on that topic, July 18, 2021, was right after the publication of an article in the Independent titled "Residents of hurricane-ravaged Barbuda hopeful as UN body signals 'deep concern' over resort for uber-rich" (Boyle, 2021). In total, 214 tweets on "barbuda land change" and 99 on "barbuda plh" were published by 186 users and can be found in the Twitter archive.

Fig. 7 depicts the word "clouds" with words that are most commonly used in tweets labeled as "positive sentiment" or "negative sentiment." The discourse reflected in the literature was also captured by Twitter users. Notably, the term "PLH," which is strongly intertwined to the land grab discourse (Rodriguez-Garavtio & Donger, 2021), cannot be found in any of the tweets with the words "land change". Furthermore, actor Robert de Niro, who will develop the Nuba Inn, is strongly reflected (29

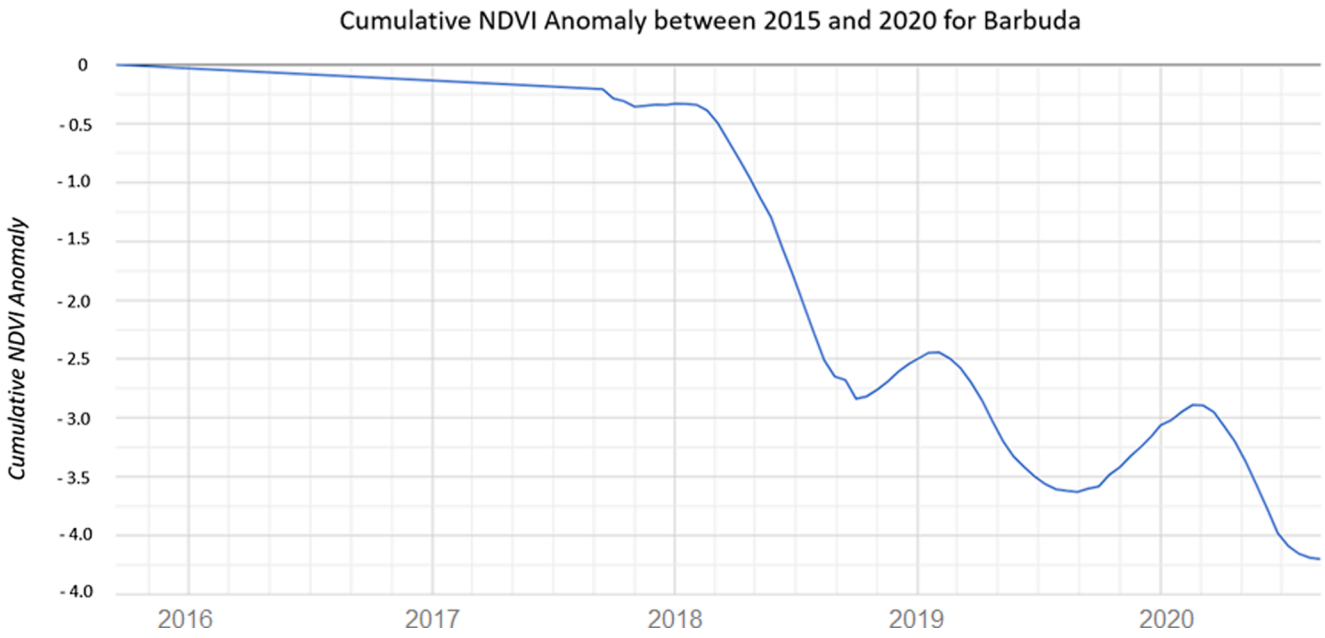

Fig. 10. Cumulative NDVI anomalies 2015 and 2020.

times) in tweets containing "land change", while de Joria, who is currently developing the two Barbuda Ocean Club sites that directly affect the Ramsar sites, is only mentioned 4 times when the search is conducted without the term "PLH" project. Unfortunately, none of the selected tweets contained geo tags, so it is not possible to know whether the Twitter users are Barbudan. Additionally, the hydration process of the sentiment analyses still has little flaws, such as in the counting of the word "amp" which is just the character reference of the ampersand.

The quantitative results of the classification based on S-1 and S-2 are presented in Table 3, with their accuracies listed in Table 4. The Barbudan architecture and the mixture of paved and unpaved surfaces within Codrington do not allow an accurate differentiation between artificial surfaces and bare soil/sand. However, a reliable estimation of vegetated and non-vegetated areas can be performed with perfect user and producer's accuracy. In general, vegetated areas grew in 2019–2020 by 6.56 km^2 compared to that in 2016–2017 (before September 2017). The pattern of changes could be derived (Fig. 8), where most of the newly vegetated areas were located in the northern part and in the neighborhood of Codrington, and the construction of the international airport that was being built in the aftermath of Hurricanes 2017 was clearly observed. Additionally, degraded land cover was observed in the southern and western parts of the island in Coco Point and Palmetto Point, respectively, where one of the Barbudan Ocean Club sites is located. In total, 2.97 km^2 of new areas that are covered by "bare soil and artificial surfaces" fell into the natural reserve of the Ramsar site of the Codrington Lagoon.

Fig. 9 shows the mean annual VCI values between 2015 and 2020 for Barbuda. While the island has experienced some variation in the VCI already before 2017, the impact of the hurricane but also the construction of the airport can be identified in the annual vegetation conditions. Furthermore, negative impacts in the Southern Ramsar side can be detected which also continues to occur in 2019 and slightly also in 2020. Lower VCI values are also visible around the urban area of Codrington, Pink Sand Beach and Coco Point in the South (these locations can be depicted in Fig. 13 for easier orientation). The NDVI Anomalies between 2015 and 2020 underline the findings of the VCI by also showing the sharp drop in NDVI due to the Hurricane in September 2017 but also indicating the decrease in VCI towards 2018 (Fig. 10). Improving conditions occur in 2019 as well as more intensively in 2020 which is also overlapping with the results of the annual VCI for the respective years. It is worth to be noted that the general NDVI anomaly trend is steadily decreasing since 2017.

The limitations of the remote sensing approach with MODIS or even Sentinel data is the resolution, which is too coarse for the detection of small Barbudan houses and the sampling methods. To overcome the problem of clouded imagery, we created annual median samples, which did not cover the seasonal effects. However, the quantification and allocation of vegetated and non-vegetated areas and their changes before and after the Hurricane can be carried out with an accuracy of 0.97. The kind of land use, i.e., housing, agricultural area, cannot be detected with the proposed approach.

Accordingly, we assessed the development of settlement structures using the Ohsome API (Fig. 11, Table 5).

Note that the unpaved under construction area of the international airport in the center of the island – the main reason for the letter of UN to the Government of Barbuda (Boyd et al., 2021) – has not been mapped by OSM volunteers so far. Based on the satellite classification, an area of ~ 1.09 km^2 can be measured, which is ten times the sum of all buildings in Barbuda. Additionally, it was observed that the number of mapped features as well as the total length of roads and total area of buildings and aerodromes increased between 2015 and 2021. It can be assumed that the enhanced mapping activities close to the aftermath of the 2017 Hurricanes led to an increase in the mapped features in Barbuda. Hence, the growth rates between 2017 and 2019 were higher than those between 2019 and 2021. Nevertheless, a recent increase in the length and area of artificial surfaces can be observed. The limitation of utilizing the Ohsome API to detect land use change is the assumption that a change in the feature set is related to a change in reality (Raifer et al., 2019). The omission of surface objects during volunteered mapping and the fact that some objects are no longer existent but still are a part of certain feature datasets need to be accounted. For positional and tag accuracy in OSM data, please refer to El-Ashmawy (2016) and Zheng & Zheng (2014). For example, a commission error can be observed at the Palmetto Point where the hurricane destroyed a property that was not

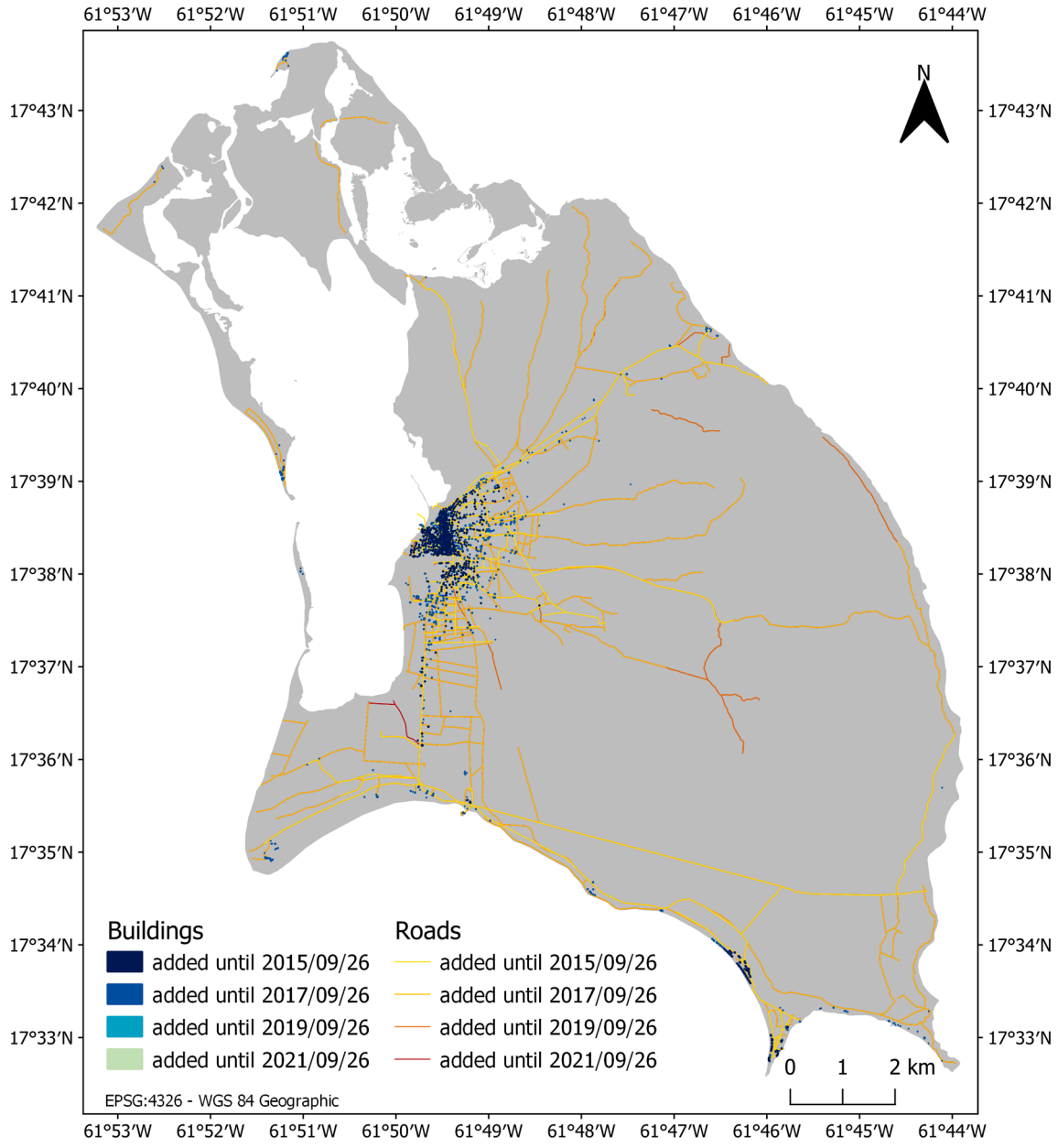

Fig. 11. Development of buildings and roads on Barbuda in 2015–2021 derived by the Ohsome API.

Table 5
Artificial OSM land uses.

Land use	Year (reference month August)	Area (km^2)/ Length (km^2)	Features (no.)	OSM mappers (no.)
Roads				
	2015	105.53	177	15
	2017	164.82	294	45
	2019	247.50	462	26
	2021	249.67	468	21
Buildings				
	2015	0.0954	812	15
	2017	0.1004	871	45
	2019	0.1004	1,460	26
	2021	0.1481	1,462	21
Aerodromes				
	2015	0.1232	4	15
	2017	0.1896	6	45
	2019	0.1902	8	26
	2021	0.1921	7	21

rebuilt until the development of the construction site of the Barbudan Ocean Club. However, the helipad is still a part of the feature dataset of 2021.

To add further value to the potential human-induced LULCC analyses based on remote sensing and OSM data, we analyzed the archive of the NOAA VIIRS DNB (Fig. 12). The spectral sensor product provides a coarse resolution of 440 m at the latitude of Barbuda. The intensity amplitude of NTL on Barbuda decreased from 7.21 to 4.84 nanoWatts/cm2/srbetween 2015 and 2021 due to a distinct disruption in 2017 (Fig. 12). Since the 2017 Hurricane, the maximum values of the NTL intensities depict a steady annual increase. The center of human activity observed at night is the area of Codrington. The LULCC detection (Figs. 8 and 9) and the NTL development (Fig. 13) signify that Codrington is still recovering from the impacts of the 2017 Hurricanes. The most interesting insight is the three-month mean of the monthly NTL DNB average radiances from October 2017 to December 2017. Although the island was evacuated, light was still detected (Fig. 13) in Codrington and in the center of the island. The construction site of the recently built airport

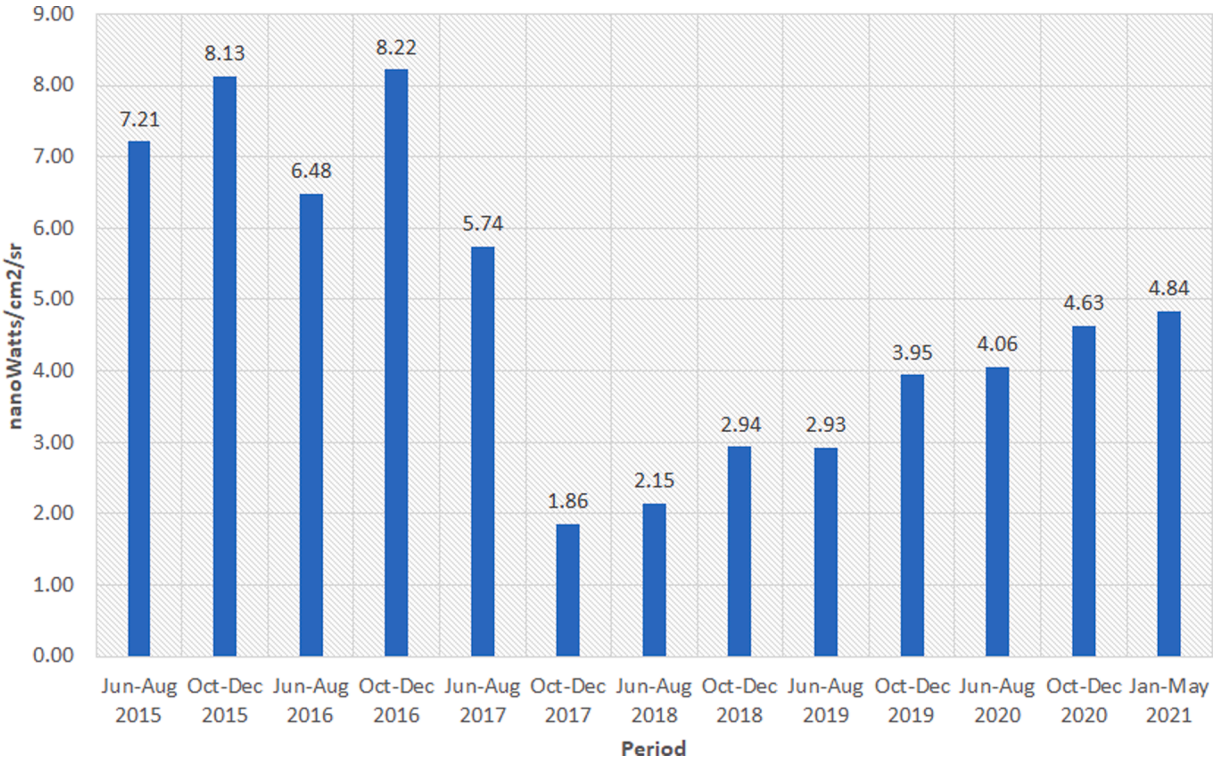

Fig. 12. Maximum values of three-month mean of average DNB radiances on Barbuda Island (nanoWatts/cm2/sr).

could be seen at night. The central NTL observations disappeared after clearing of the formerly vegetated area in 2018. The post-Hurricane period depicted three other smaller NTL radiance hotspots besides Codrington and the Lighthouse Bay Resort in the western peninsula. They occurred at Barbuda Pink Sand Beach, Coco Point, and Palmetto Point, of which the latter two are the sites of the Barbudan Ocean Club. One can disctinly observe the emerging construction sites and the resulting artificial areas in the NTL imagery.

Fig. 14 presents eight false color images from the NICFI program. Unfortunately, atmospheric disturbances, spectral artefacts, geometric distortions, missing data, cloud coverage, different resolutions in one product, and sharp lines in the mosaic pose problems when working with open access base maps provided by the Planet Labs NICFI program. Nevertheless, it is possible to derive visual impressions of regions of interest in the visible and near infrared spectrum. The very high-resolution satellite images showed the development of the golf course of Barbuda. While the unpaved pathways provided no evidence of a future golf club, the artificial lakes, which are not visible before the end of 2020, do.

5. Conclusion

The study was conducted to quantify the LULCC in Barbuda in the context of the ongoing debate on neocolonialism and land grabbing. Geospatial data, such as multispectral satellite images or voluntarily mapped OSM features provide an objective representation of the real world. Spectral, spatial, and temporal resolutions and different mapping intensities can be considered as the limitations to this approach. Therefore, we combined different types and strengths of geospatial data, such as the broad spectrum of remote sensing data that can visualize geospatial characteristics, which are invisible to the human eye, and in situ information derived by local mappers. We observed that human-induced LULCC is occurring on different sites on the island, with decreased activities in Codrington, but increased and ongoing activities leading to a LULCC in Coco Point and Palmetto Point. With an accuracy of 97.1 %, we estimated a total increase of vegetated areas by 6.56 km^2 and simultaneous increase in roads and buildings with a total length of 249.67 km and a total area of 1.43 km^2; this includes the area of the under construction central international airport. The satellite classification measures an area of ~ 1.09 km^2, which is ten times the combined sum of all the buildings mapped with the OSM. This and the fact that the vegetation condition itself depict a steady decrease since 2017 show the severe human-induced LULCC since the hurricanes Irma and Maria hit Barbuda and led to its temporary evacuation. While some places show a decrease in human activity, such as Codrington and the Lighthouse Bay Resort, other places experienced increased human activities. They became new NTL radiance hotspots on the island. Since these hotspots are the sites of the Barbudan Ocean Club, the dispute along the human-induced LULCC in the aftermath of the 2017 Hurricanes will and needs to be continued. It should be acknowledged that the Nobu Inn and the Palmetto Point site of the PLH are already under construction despite the international attention and applicable Barbudan land law. Hence, future work on geospatial analyses needs to focus on the connection between land rights and land development in Barbuda. While the Copernicus program does not provide data below 10 m spatial resolution, the base maps of the NICFI program could be an alternative; they are currently flawed by artifacts, geometric distortions, and atmospheric radiances. The OSM database needs to be updated so that the recently developed hotels and the international airport construction site can be found in the maps. Finally, landscape transformation needs to be analyzed with respect to the common wealth of the Barbudan citizens, and its impacts on the unique ecosystem of Barbuda.

CRediT authorship contribution statement

Andreas Rienow: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. **Jan Schweighöfer:** Writing – original draft. **Torben Dedring:** Software, Visualization. **Marcus Goebel:** Software, Visualization. **Valerie Graw:** Writing – original draft, Software, Visualization.

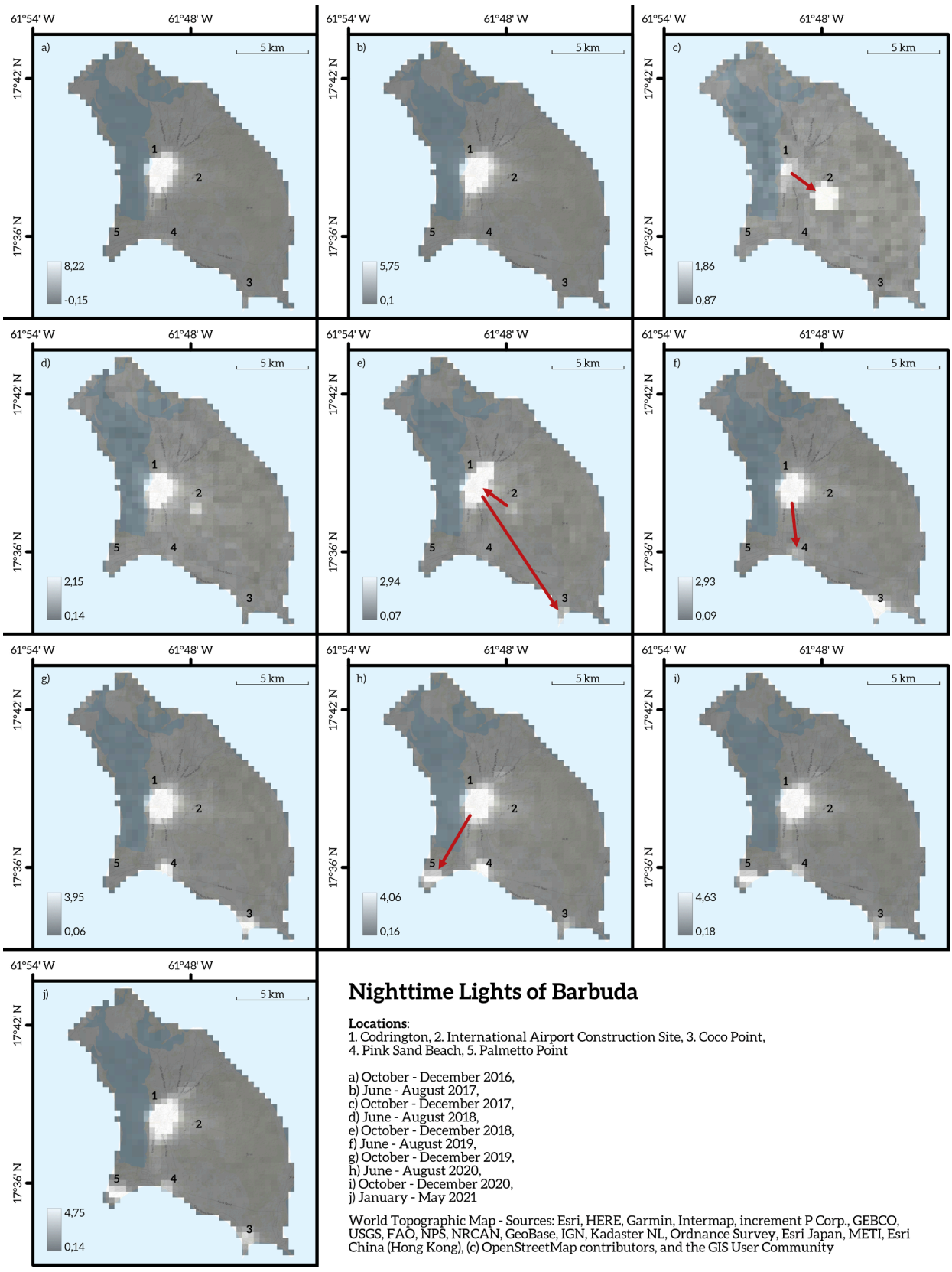

Fig. 13. Development of NTL on Barbuda in 2015–2021. The red arrows depict NTL intensity clusters besides Codrington (central cluster). Note the temporary shift of the central cluster from Codrington to the international airport construction site in 2017 (f) and back in 2018 (g). Additionally, one can see the emerging sites in Coco Point, Pink Sand Beach, and Palmetto Point. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

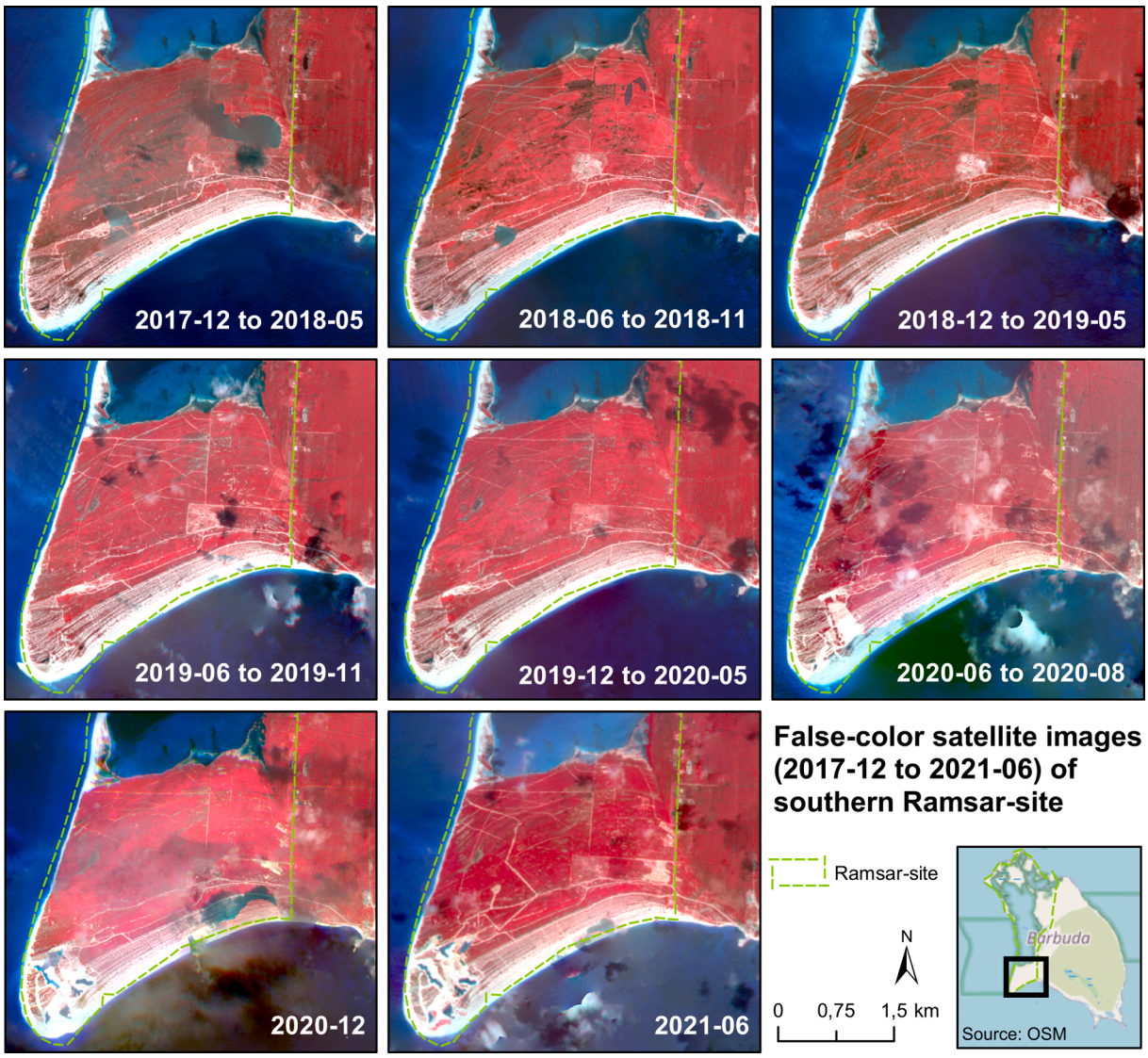

Fig. 14. Sampled very high-resolution false color images of Palmetto Point, south of the Ramsar site in 2017–2021 (RapidEye, NIR/R/G). The emerging golf course lakes are well depicted.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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