Estimating Reef-Adjacent Tourism Value in the Caribbean

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Executive summary

The Caribbean is more dependent on the travel and tourism sector than any other region worldwide: it accounts for over 15% of GDP, and 13.2% of jobs in the region. Much of this sector is focused on coastal areas, notably through beach-based activities, cruise tourism and in-water activities including sailing, and diving.

An earlier study led by The Nature Conservancy showed the significance of coral reefs to the global travel and tourism sector. The current work improves a key component of that work for the Insular Caribbean[1] – reef-adjacent values – and hence revises our overall understanding of the value of coral reefs for this region.

Reef-adjacent tourism is the component of tourism that depends on coral reefs without making direct use of them for in-water activities such as diving and snorkelling. It is a term that includes values derived from views, calm waters, coastal protection, beach generation, and superlative seafood. The work uses three broad approaches to estimate the importance of reef-adjacent tourism. With revised numbers it then re-assesses total values of coral reefs in the Caribbean.

Three approaches to assess reef adjacent value

1. **Social media images.** Following the development of training layers we used machine learning to analyse over 86,000 images, and to generate 29,000 reef-adjacent images. Further controls enabled us to distil 2,659 "Photo User Day" locations giving us a model of the spread and intensity of reef-adjacent activities
2. **Social media texts.** A training set of over 5900 TripAdvisor posts pertaining to reef activities was used to train machine-learning algorithms to identify "on reef" or "reef adjacent" activities. These were then applied to a total of 6,691,162 posts in 866,858 threads pertaining to the Caribbean region. Some 3% of posts mention an on-reef activity and 10% mention a reef-adjacent activity such as beach-going
3. **National data.** On-line data searches were undertaken to locate available data from visitor surveys. Details on "activities undertaken" or "motivations for visits" were found for 22 jurisdictions (69%), and were combined with expert knowledge to generate estimates of reef adjacent importance for every jurisdiction.

Reef-adjacent values

Scores from the three approaches were standardised, spread across a range of 0-40% to represent the actual importance of reef-adjacent values per jurisdiction, and then averaged to obtain a single score. These data show a spread of averaged reef-adjacent values from 4% on Haiti to 36% for St Kitts and Nevis.

Correlation between the three approaches was relatively poor; however, this does not diminish the value of the study. While further work might lead to improvements, this is already a valuable finding, pointing to the risk in having an over-reliance on single metrics, and providing an important lens for interpreting studies which rely on one method only. It also indicates promise in using what are now emerging methods for harvesting social media data to examine these trends.

Reef value in the Caribbean

[1] In this report, Insular Caribbean includes all of the island nations and dependent territories of the Caribbean, with the addition of Belize, which, with its largely coastal economy, is regularly classed as a small island developing state.

- Reef-adjacent expenditure is estimated at $5.7 billion annually and drives some 7.4 million visitors.
- Total values for all reef-associated tourism (on-reef and reef-adjacent) are now estimated at over $7.9 billion of expenditure and over 11 million visitors, with average values of 660 visitors and $473,000 per square kilometre of reef per year.
- Puerto Rico and the Dominican Republic benefit from visitor expenditure of over a billion dollars per year directly linked to coral reefs.
- The Bahamas, Cayman Islands and Puerto Rico receive the equivalent of over a million visitor trips per year directly linked to coral reefs.
- The very highest value reefs (top 10%) generate values of over $5.7 million per km2 and over 7,000 visitors per km2 each year. These are scattered in almost every jurisdiction other than Haiti.
- Barbados, Puerto Rico and the US Virgin Islands have a very high proportion of high value reefs, each with an average expenditure value of over $3 million per km2 per year.
- The countries most dependent on reef-adjacent tourism include many small-island nations - Anguilla, Antigua and Barbuda, Bermuda, St Kitts and Nevis and St Martin – where there may be relatively few alternatives to reef adjacent tourism.
- Only 35% of reefs, in just seven jurisdictions, are not used by the travel and tourism sector, indicating that there is very little space for movement of activities to new areas.

This work provides a sharp focus on the value of coral reefs to a critically important industry in the Caribbean. Threats to coral reefs abound, but there is evidence that local management can improve their ability to survive or to recover from regional and global impacts.

Local management must thus be an imperative and the tourism sector needs to increase its engagement in support of sustainable coral reef management and coral reef restoration. Impactful activities, including unsustainable fishing and poorly planned coastal development can be driven by the tourism sector, but by the same token the sector can be a powerful voice to prevent such impacts.

Introduction

Tourism in the Caribbean Islands

Travel and tourism is already one of the world's largest economic sectors globally: in 2017 accounting for over 10% of GDP and 9.9% of jobs (331 million). The Caribbean is more dependent on this sector than any other region. Travel and tourism accounts for over 15% of GDP, and 13.2% of jobs in the Caribbean – the highest proportion in the world (WTTC 2018b). A very large proportion of this industry is focused on coastal tourism, including beach-based activities and cruise tourism. While some of this tourism is very clearly "nature-based" – snorkelling, diving, hiking – much more has a dependency on nature that is often poorly understood and overlooked. Spalding et al. (2017), undertook the first global study of the value of coral reefs to tourism and showed that reefs were highly significant world-wide, generating some $36 billion in expenditure and some 70 million visitor trips a year – in the Caribbean these initial estimates suggested that only around half of this value was derived from direct activities on coral reefs, the remainder coming from "reef-adjacent" benefits (see below).

This work takes the work Spalding et al. as a starting point, but attempts to more accurately define the role of reef adjacent activities in tourism visits and expenditure for the Caribbean. It focuses on 32 jurisdictions which together make up the insular Caribbean plus Belize. These jurisdictions include 14 fully independent nations and 18 territories with varying degrees of affiliation to France, the Netherlands, the UK or the USA.

Reef adjacent value

The earlier global evaluation of coral reefs in travel and tourism classified a series of reef benefits that did not involve direct "experience" of the reef as "reef adjacent". This term was broadly defined as recreation and tourism values derived from coral reefs, but not linked to activities taking place on the reefs themselves (Spalding et al. 2017). These include the values associated with beaches and coastal waters protected by offshore reefs – white sand, bright colourful vistas of nearshore waters, activities such as swimming or small boat activities which require tranquil waters, and reef-linked local seafood. Reef imagery, both underwater and above-water views, is also a central component of marketing for almost every destination in the Caribbean (Figure 1).

In the original study, a conservative approach was taken. Having apportioned values for on-reef tourism, 10% of remaining values (located within 30km of a coral reef) were assigned as reef-adjacent. Two priorities for future work were then to improve the estimate of such value and to seek to provide some spatial resolution and understand how that value might vary, at least from one jurisdiction to the next.

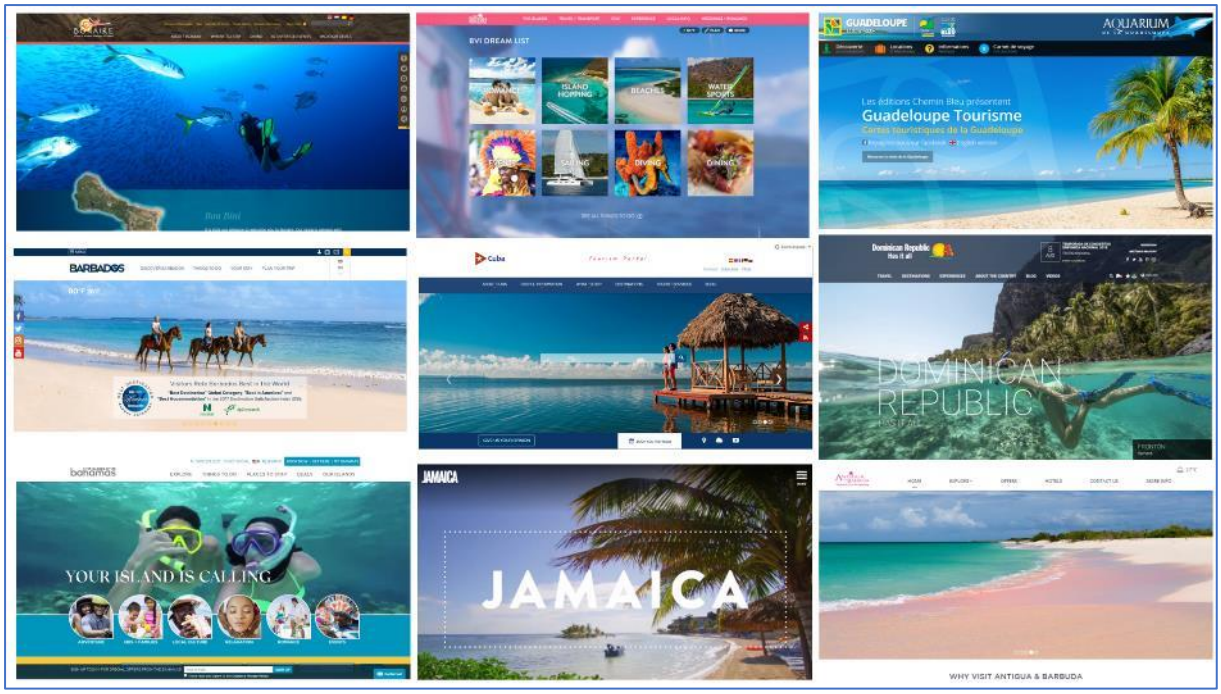


Figure 1: Home pages from official tourism sites for a selection of Caribbean islands nations. Coral reefs are a critical component of the marketing for every Caribbean destination, with images of tranquillity, beauty or the lure of underwater adventure all serving to attract visitors. (Sources: www.tourismbonaire.com, www.godominicanrepublic.com, www.bvitourism.com, www.visitbarbados.org, fr.guadeloupe-tourisme.com, www.cubatravel.cu/en, www.visitjamaica.com, www.antiguabarbudatourism.org, www.bahamas.com).

At the same time there are many other motivations for travel which have little or no reliance on reefs, even in the relatively small island nations of the Caribbean. Shopping, golf, carnivals, hiking and casinos are all regularly featured as motivations for travel or as activities undertaken. Damage to reefs is unlikely to harm such attractions directly, at least in the short-term, although it could reduce visitor numbers overall.

Although there are many components to reef-adjacent value, a key focus in the current work is on beach visitation. Beaches are a particularly key focus for tourism in the Insular Caribbean and the role of coral reefs in building white-sand beaches, and in protecting them from erosion is already well-documented in the scientific literature (de Alegria-Arzaburu et al. 2012, Ferrario et al. 2014, Perry et al. 2015, Beck et al. 2018).

Under the current work we have sought to re-evaluate the importance of coral reefs in tourism across the insular Caribbean and particularly to re-assess the reef-adjacent value. We believed that the generic application of 10% was an underestimate, particularly in a region where coastal and non-urban tourism was so dominant. We further have sought to understand how the relative importance of reef-adjacent tourism might vary geographically. Given the challenges of quantifying non-use or indirect use values we have taken a multifaceted approach to derive a better understanding of such values from three distinct and un-connected sources.

Methods

This work sought to explore and evaluate novel approaches to value reef adjacent tourism in the Caribbean, and then to use these values to re-draft the maps of coral reef tourism values originally developed by Spalding et al. (2017).

Traditionally, knowledge of tourist activities and preferences have been studied through survey methods such as exit surveys, often carried out in airports; or through questionnaire-based sampling during visits. More recently, there has been growing success in the utilisation of social media to understand tourist activities and movements (Lu and Stepchenkova 2015, Spalding et al. 2017, Tenkanen et al. 2017). For the current work it was decided to explore three broad approaches to develop numerical values for reef-adjacent tourism, one being a meta-analysis of jurisdictional level data from traditional published and grey literature sources, and the others focusing on diverse social media based assessments. In each case the aim was to obtain an average value for each jurisdiction (country or territory[2]). During the process it was hoped to develop and refine methods, to assess their validity, and, if possible to use the combined findings to "triangulate" on a best-estimate for reef-adjacent value in each jurisdiction.

An initial step involved developing terminology to describe reef adjacent in terms that might be "seen" either by researchers, or indeed from a machine learning platform using either words or images to identify data around such values. These terms were refined through expert review and a final set were developed (Table 1) to inform the research process.

Table 1: Descriptors of the guidelines used to inform identification of training datasets for machine-learning processes both for image-based and text-based analyses

Value class	Image identifiers	Text identifiers
Beach-going	White beaches with adjacent reef	White sand, fine sand, wide beach, clear water, clean water, calm water
Eating seafood	Reef fish on dinner plates or in market (spiny lobster, parrotfish, grouper, jacks, snapper)	"Local" seafood, or fish markets, named reef fish species (spiny lobster, parrotfish, grouper, jacks, snapper)
Scenic beauty	Turquoise water, "reef" identifiers (e.g. strong dappling of blues with turquoise; or line of breakers offshore with turquoise), palm-fringe and beach; key combinations of turquoise water, white sand and green vegetation	Turquoise water, reefs, nature, aesthetic beauty of beaches or islands
Biodiversity	Crabs, turtles, seabirds seashells (on beach only) or other reef-dependent species	Reef-dependent species (ghost crab, turtle, seabirds, finding seashells (on beach), coral, fish (eg "visible from the beach"), marine park/reserve/protected areas, conservation, reef habitats, environmental protection
Water-sports	Paddle-boarding, kayaking	Paddle-boarding, kayaking

As beaches are a key component of reef-associated tourism a further input layer was developed to inform the reef-dependency of beaches. A detailed map of Caribbean island beaches was combined with the global reef map, and beaches with high reef association were defined as beach <5km from a reef.

1 Image analysis

Our first approach involved attempts to use image-based social media to identify locations and patterns of geographic intensity in reef-adjacent activities. For this we used a custom implementation of the Microsoft Cognitive Services Computer Vision API. Computer vision, in its most basic definition, involves a computer trying to match the shapes, colours, and patterns it sees

[2] The geographic focus was on the insular Caribbean, but expanded to include the Bahamas, Bermuda and Belize. These were 34 jurisdictions in total.

in an image with images it has been trained to recognize, in an attempt to mimic the way the human brain performs the same task. The Custom Vision API allows users to simply and quickly create and train their own computer vision models by uploading tagged images either programmatically or through a graphical web interface. Each time a model is trained, whether images were added or removed from the training set or re-tagged, the Custom Vision API calculates the model's overall performance as well as the probability of each image belonging to any of the categories within the model, using a leave-one-out cross validation method. The model can then be refined and retrained, as patterns of false positives and false negatives emerge, and overall model performance is evaluated. Once a model is trained and ready for implementation, it can be accessed programmatically through the API to rapidly classify images with a level of statistical certainty. For the current work, training layers were hand-selected from a set of geotagged Flickr photos that were less than 30 km from a coral reef and not more than 2 km inland.

A key part of this work was the process of developing a workable methodology, and some initial exploratory work was undertaken prior to the selection of a final approach. This work is briefly described below.

Initially we explored the possibility of developing training layers to identify reef-adjacent images using the full range of identifiers described in Table 1. It was, however, quickly apparent that the level of complexity expressed across these elements was too large. For the purpose of this project, it was decided to focus on one key element: beaches. Developing separate models for individual elements of additional reef-adjacent activities (e.g. kayaking in reef adjacent waters, reef seafood in restaurants) is something that could be explored during future iterations of the work.

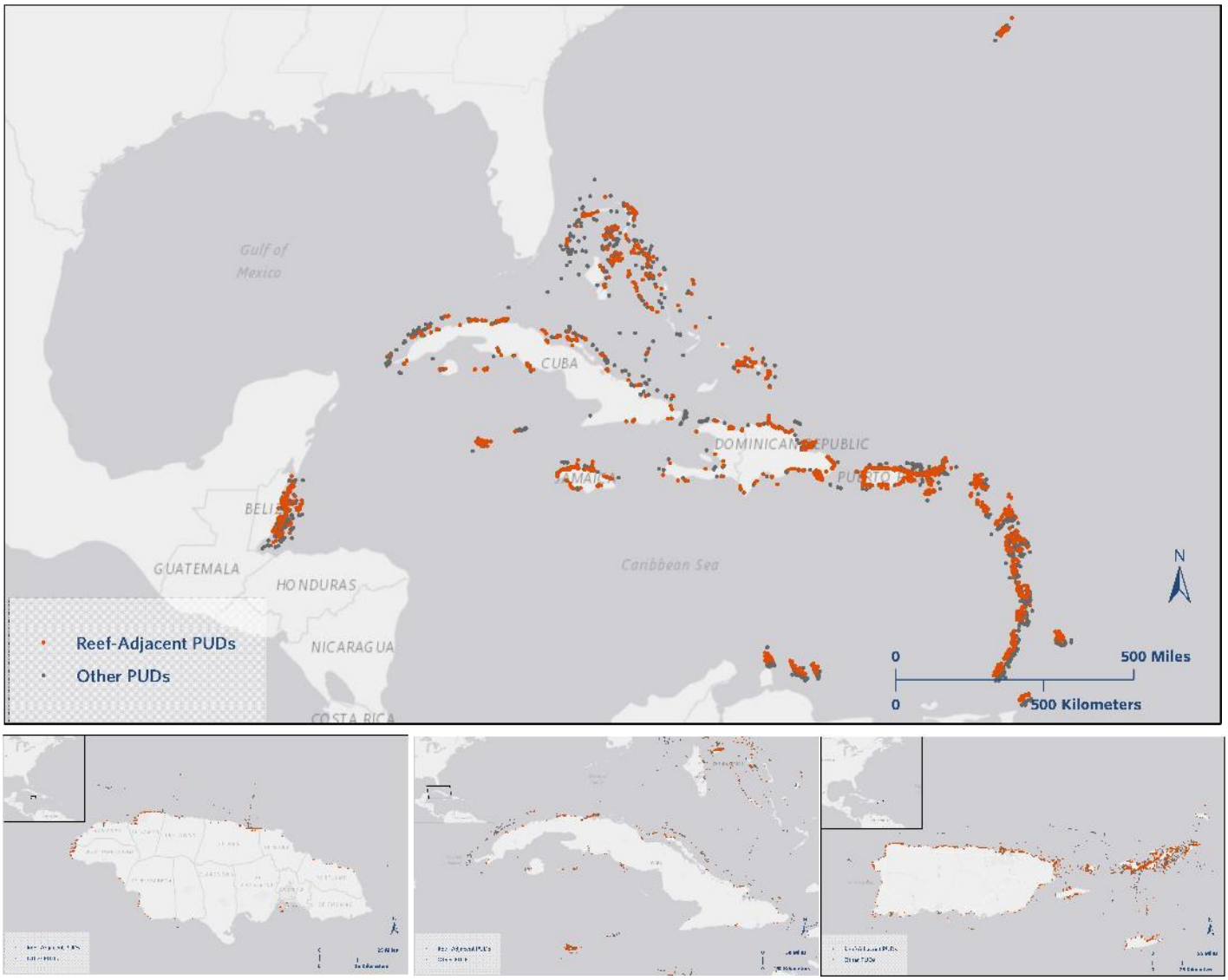
Following some initial success in a separate project to identify photos taken underwater, we first attempted a binary approach, identifying several hundred photos which included both "reef-adjacent" beach images (scenes with turquoise-coloured water and white sands often associated with reef-adjacent beaches) and "non reef-adjacent" images (focused on activities not tied to the presence of the reef: large hotel complexes, pools, interiors of restaurants, beachside shops and bars, or open expanses of water with no visible shoreline). We intentionally excluded images that were heavily altered through filters, took place at or around sunset, or were otherwise blurred or altered in such a way that prominent beach features were not clearly visible, to reduce the risk of false positives and negatives in the model. Unfortunately, even with this approach, the variability among the photos classified as reef-adjacent (e.g., scale, subject, number and type of objects in the photo, presence/absence of people, etc.) combined with some of the similarities between the reef-adjacent and non-reef adjacent photos (e.g., ocean, beaches, palm trees, near-shore vegetation, etc.), confounded the model, yielding a high rate of both false positives and false negatives in each category.

We then attempted to refine and simplify our approach by only choosing photos that showed both a clear sandy shoreline, and the presence of water extending to a visible ocean horizon. The binary classifier approach was also dropped, and we focused on developing a training layer of "idealized" type of images that we wanted to identify, without providing counter-factual non reef-adjacent images. This approach was acceptable because we were not trying to identify every image that qualifies as "reef-adjacent", but rather to obtain a reliable and representative sample that would enable differentiation of relative variation in importance over geographic space. We thus sub-selected from the earlier training layers a small array of just 78 images that displayed a visible expanse of beach next to an ocean, ideally with turquoise-coloured water which is often associated with coral reef ecosystems. Many of these photos also featured palm trees, white sands, and other coastline features often associated with Caribbean beaches (Figure 2).

Figure 2: Top row: images showing the array of images that might inform all elements of reef adjacent tourism. Middle row: Images showing positive and negative (red "x") images used in initial trials for training APIs. Bottom row: selection of "idealised" images used in the final training process.

These photos were used to train a final computer vision model classifier. The classifier was then used against all photos from Flickr that were within 30 km of a coral reef and not more than 2 km inland, to identify photos of reef-adjacent beaches that were similar to the photos in the training set. We found this simplified model to perform much better than previous versions and used it to analyze over 86,000 images. Of those images analyzed, nearly 29,000 had a probability of greater than 70% of belonging to the reef-adjacent category.

The final step was to normalize these data to create Photo User Days (PUDs) as a means to prevent potential bias introduced by one person taking many photographs in the same location over the course of a day. 1 km grid cells are applied across the study area, and the photographs are aggregated such that each 1 km grid cell has a value representing the total number of days, across all users, that at least one photograph was taken in an area. The photos identified by the model were processed to produce 2,659 PUDs for the insular Caribbean (Map 1).



Map 1: Reef-adjacent imagery: PUDs identified as being reef-adjacent are marked in orange against the full array of coastal, near-reef PUDs (in grey).

These were then compared to total numbers of PUDs by jurisdiction to generate an initial metric of relative importance of reef-adjacent tourism by jurisdiction (Table 2). The same PUDs also provide the only detailed spatial metric from which it might be possible to see variation in the importance of reef-adjacent tourism within a country, and so sample maps were also prepared to show intensity of reef adjacent beach use for a number of larger jurisdictions.

Table 2: The numbers of PUDS and reef associated PUDs across the Caribbean.

Jurisdiction	Total PUDs	Total reef-adjacent PUDs	Proportion of PUDs reef adjacent
Anguilla	15	26	58%
Antigua & Barbuda	87	136	64%
Aruba	55	101	54%
Bahamas	215	597	36%
Barbados	71	126	56%
Belize	167	439	38%

Bermuda	64	123	52%
Bonaire	64	212	30%
British Virgin Islands	29	61	48%
Cayman Islands	136	341	40%
Cuba	231	580	40%
Curaçao	169	335	50%
Dominica	51	107	48%
Dominican Republic	44	71	62%
Grenada	206	367	56%
Guadeloupe	64	103	62%
Haiti	30	72	42%
Jamaica	93	181	51%
Martinique	87	149	58%
Montserrat	12	20	60%
Puerto Rico	10	17	59%
Saba	168	462	36%
Sint Maarten	260	468	56%
St. Barth's	4	11	35%
St. Eustasius	2	5	40%
St. Kitts & Nevis	25	37	67%
St. Lucia	14	25	57%
St. Martin	39	59	66%
St. Vincent & the Grenadines	72	137	53%
Trinidad and Tobago	35	66	53%
Turks & Caicos	82	160	51%
US Virgin Islands	58	101	57%

2 Text analysis

Our second attempt to track and map reef-adjacent values involved the exploration of text-based social media. This component, led by the Natural Capital Project, used TripAdvisor's online discussion forum (https://www.tripadvisor.com/ForumHome) where travellers discuss vacations to countries worldwide. Online, users can either create a new discussion (called a "thread") or follow-up posts to existing threads. After approximately two days of inactivity, a thread is closed to further posts. The forum has been active since 2004. In March-April 2018, we pulled every thread created about a Caribbean country from TripAdvisor's online forum.

For the modelling process we used support vector machines (SVMs), as a means of supervised machine learning. SVMs are trained from pre-classified documents. For each training document, a vector is derived which contains a score for every word that is contained in that document derived from its frequency of use within the document and the wider family of documents in the training set.

An initial training set of 3,860 TripAdvisor posts pertaining to the Bahamas were identified, and following initial trials, an additional random sample of 2,101 documents were added from across the Caribbean. Each was associated with "on reef" or "reef adjacent" activities (guided by the language outlined in Table 1). Posts not obviously classifying in either were classified as "Irrelevant".

The performance of the SVM binary classifiers for each reef-related category was estimated using five-fold cross-validation: accuracy, precision, recall, and F-1 score for each model were determined by using 80% of the training data as a model to predict the remaining 20%, and repeating this process for the remaining four partitions of the training data. For reef-adjacent posts the accuracy was measured at 0.91 (the number of correct predictions as a proportion of all predictions attempted), however this can be a poor measure for comparing results, and the F-1 score, which combines metrics for precision and recall was 0.61. This indicates that we were achieving reasonable

levels of reliability and most likely considerably better than we would achieve from a simple keyword search.

Following this model-building we applied the model to the full range of TripAdvisor texts. Our analysis of www.tripadvisor.com/ForumHome returned a total of 6,691,162 posts in 866,858 threads pertaining to the Caribbean region. 19,775 of the total posts were not assigned to a specific country and were ignored in further analyses.

The initial results from this work are presented in Table 3. According to our analysis, 11% of posts to TripAdvisor's online forum for Caribbean nations mention a reef-related activity. Of these, 3% mention an on-reef activity and 10% mention a reef-adjacent activity such as beach-going.

Table 3: Summary data on the number of TripAdvisor posts and threads that have on-reef or reef-adjacent relevance. The dataset used to derive overall reef-adjacent value by jurisdiction for comparison with other approaches was the proportion of posts that were reef-adjacent (column 4)

Country	Posts	On-reef Posts	Reef-adjacent Posts	Threads	On-reef Threads	Reef-adjacent Threads
Anguilla	114,279	2%	15%	12,770	46%	46%
Antigua and Barbuda	82,228	4%	15%	15,252	40%	40%
Aruba	276,066	3%	10%	37,012	35%	35%
Bahamas	259,889	5%	13%	45,060	35%	35%
Barbados	306,369	2%	11%	34,011	39%	39%
Bermuda	60,322	4%	18%	8,944	49%	49%
Bonaire	11,892	25%	15%	2,147	37%	37%
British Virgin Islands	50,183	8%	16%	8,780	41%	41%
Cayman Islands	130,574	10%	16%	17,813	48%	48%
Cuba	1,396,613	1%	6%	164,020	24%	24%
Curacao	47,539	9%	16%	8,161	40%	40%
Dominica	6,200	9%	12%	1,379	29%	29%
Dominican Republic	1,531,059	1%	8%	195,819	30%	30%
Grenada	30,856	4%	15%	4,889	41%	41%
Guadeloupe	6,162	5%	13%	1,273	31%	31%
Haiti	3,076	1%	5%	638	15%	15%
Jamaica	1,092,942	2%	9%	127,135	33%	33%
Martinique	3,303	5%	15%	901	31%	31%
Montserrat	1,086	5%	11%	224	30%	30%
Puerto Rico	221,229	4%	13%	38,818	37%	37%
Saba	841	12%	10%	177	25%	25%
St Martin / St Maarten	126,324	3%	16%	20,450	43%	43%
St. Barthelemy	13,691	2%	17%	2,053	46%	46%
St. Eustatius	179	16%	10%	44	20%	20%
St. Kitts and Nevis	24,431	5%	19%	4,893	42%	42%
St. Lucia	142,380	5%	12%	23,543	35%	35%
St. Vincent and the Grenadines	31,912	3%	10%	4,287	33%	33%
Trinidad and Tobago	19,599	3%	9%	3,089	29%	29%
Turks and Caicos	342,594	5%	15%	39,597	51%	51%
U.S. Virgin Islands	337,569	7%	14%	43,779	43%	43%

The fraction of on-reef and reef-adjacent posts varies by country. Discussion of on-reef activities is highest amongst travellers to Bonaire (25%) and lowest for travellers to Haiti (1%). Reef-adjacent

activities were mentioned most often in posts about travel to Bermuda and St. Barthelemy (17%) and least often in posts for travel to Haiti (5%).

3 National data

Traditional approaches to understanding tourism movements and activities have relied on observations, surveying tourists, travel-associated businesses and relevant agencies such as park visitor centres, and using economic tourism data from the country's national accounting system. Such approaches have been particularly useful at local to national scales and have generated much of our knowledge about tourist activities and preferences in a number of coral reef countries.

This work used a comprehensive internet search to locate published and grey literature as well as statistical data on activities or motivations for tourism in the coral reef jurisdictions and to generate summary data comparative at a regional scale.

Following the initial review, it was clear that for majority of jurisdictions there were summaries of "activities undertaken" by visitors, typically derived from exit polls. A small number of jurisdictions provided similar information based on questions around "motivations" for visiting, often derived from entry polls or surveys conducted during vacations. Although not following a standardised methodology, similar classes of activities or motivations were found in most surveys. These data, typically reported as percentages (x% went diving…), were extracted into a spreadsheet, alongside notes on the sources, and on any interpretations of classes (e.g. "jet-skiing classified as 'other motor boating'"). The classes used in this first tabulation are laid out in Table 4.

Table 4: Classes of activities undertaken (exit surveys) or motivations for travel, used to populate tables of visitor activities. Reef associated activities are indicated.

Activities undertaken	
Visiting beaches	Reef adjacent
On-reef (undifferentiated)	On-reef
Snorkelling	On-reef
Diving	On-reef
Fishing	Reef adjacent (50%)
Sailing	Reef adjacent
Canoe/kayak/SUP	Reef adjacent
Watersports (undifferentiated)	Reef adjacent (50%)
Other motor boating/waterskiing	
Carnival	
Parks and aquariums	
Cultural sites/museums	
Outdoor terrestrial: mountaineering/jungle/hiking/birdwatching/ecotourism	
Nightclub/dancing	
Shopping	
Carnival/music/concert/festival	
Eating out/Bars/cafes	
Golf	
Spas and relaxing at resort	
Other	

Motivations	
Beach	Reef adjacent
Diving/other on-reef	On-reef
Sailing	Reef adjacent
Fishing	Reef adjacent (50%)
Water sports (undifferentiated)	
Climate	
Sightseeing	

Visiting nature areas
Culture
People
Friends and Relations
Business
Nightlife/casinos
Shopping
Eating/drinking
Low prices
Golf
Tranquillity/R&R
Other

Details on activities were found for 18 of the 32 jurisdictions (56%), while motivation data were found for ten (31%). Given overlap, a total of 22 jurisdictions (69%) had survey-derived data.

Within the input data a number of classes were designated as reef-adjacent or on-reef. The former included all beach activities, as well as non-powered small-boat use (which benefits from the shelter of reefs). Fifty percent of fishing scores were also included: some fishing was recorded as deep-water fishing, but most cases did not specify and it is worth noting that that even offshore fish species often have a notable degree of reef dependence. Where watersports were undifferentiated we took 50% of the value, while we did not include any value for motorised watersports as these are less likely to benefit greatly from the presence of reefs. These values were then summed and expressed as a percentage of all values for each jurisdiction.

Alongside variability of methods, the number of classes in each study was also highly variable. Some only asked for main motivation or most important activity, others scored all activities or motivations. Large numbers of classes in one sector would also dilute the apparent importance of others. It was thus not possible to utilise these numbers directly.

The summarised data were thus reviewed both by the original collator (MAM) and by a second independent reviewer (MDS) with a view to understanding the reliability and compatibility of scores. Both reviewers had a good knowledge of Caribbean countries. From this both reviewers assessed and recommended a score for reef-adjacent value based on the summary data, giving short notes for their reasons. In a Delphi-like process the reviewers assessed the reasoning of the other and scores were refined based on their combined expert input.

In the insular Caribbean countries reefs are widespread, however they are not ubiquitous and some countries have coastal tourism in areas away from reefs, or beaches that are not reef-derived. For this reason, a further modifier was developed. Using a regional database of Caribbean beaches we developed a metric, by jurisdiction, for the proportion of beaches close to (less than 5km from) coral reefs and used this as a multiplier to modify the reef-adjacent value where appropriate.

For the 12 jurisdictions for which no activity or motivation data were available, the reviewers felt that they had sufficient knowledge to categorise them into simple classifications of low medium and high. These were then converted to percentages based on the range observed in the other countries, and again informed by expert knowledge (low – 10%, medium – 20%, and high – 25%).

These final assessments are presented in Table 5, along with indications of the source of the final estimates for reef-adjacent value.

Table 5: Final reef-associated values derived from the national data sources and expert opinion inputs, together with brief notes on sources. Activity surveys are in large part derived from exit polls

undertaken by or for governmental purposes. Motivation surveys are mostly those conducted during the period of individual visits.

Jurisdiction	Final reef-associated value	Source of final number
Turks and Caicos Islands	35%	Motivation survey - modified
Anguilla	31%	Activity survey
Barbados	31%	Activity survey - modified
Bermuda	28%	Activity survey
Cayman Islands	28%	Activity survey
Sint Maarten	27%	Activity survey
St Kitts and Nevis	27%	Activity survey - modified
Curacao	26%	Activity survey - modified
Dominican Republic	26%	Motivation survey
Jamaica	26%	Motivation survey
Antigua and Barbuda	25%	Expert opinion
Aruba	25%	Activity survey
British Virgin Islands	25%	Expert opinion
U.S. Virgin Islands	25%	Expert opinion
Bahamas	24%	Activity survey
Cuba	20%	Expert opinion
Grenada	20%	Motivation survey
Guadeloupe	20%	Activity survey - modified
Puerto Rico	20%	Expert opinion
Saint Barthélemy	20%	Expert opinion
St Martin	20%	Expert opinion
St. Vincent & the Grenadines	20%	Expert opinion
Trinidad & Tobago	20%	Expert opinion
Belize	18%	Activity survey - exclude beach modifier
Martinique	18%	Motivation survey
Bonaire	17%	Activity survey + Motivation survey, expert modified
St. Eustatius	12%	Activity survey - modified
Montserrat	10%	Expert opinion
St Lucia	10%	Expert opinion
Haiti	6%	Motivation survey
Dominica	5%	Expert opinion
Saba	0%	Activity survey - modified

From these numbers it is apparent that three jurisdictions have very low reef-adjacent values – Dominica, Haiti, and Saba. Interestingly both Dominica and Saba are still highly tourism dependent, but with a strong focus on inland (Dominica) or on-reef (Saba) activities. The former has beaches, but these are mostly black-sand and not as great an attraction as many other locations (and are not reef dependent), while Saba has renowned diving, but no significant area of accessible beach. At the other end of the spectrum, Anguilla, Barbados and the Turks and Caicos Islands all have very high reef-adjacent scores. All are known for their beaches and unlike some of the larger islands in the region, they perhaps have fewer urban or non-coastal attractions to offer.

Combining results

The findings from the three approaches described above each give values that point to the relative importance of reef-adjacent tourism in each jurisdiction. Each approach has its strengths and weaknesses. Each is difficult to assess for validity, and that validity is likely to be variable between jurisdictions, which means that it is not possible to make any generic decisions about reliability of sources.

In exploring the relations between the three approaches, we standardised the values (Figure 3). An overall comparison of these, using a matched (repeated measures) 1-way ANOVA showed what was already readily apparent from visual inspection, that there is no strong trend between datasets ($P=0.26$, assuming sphericity): this is discussed later. Pairwise correlations suggest that there may be weak correlation in both images-national data ($r = 0.348$, $P=0.055$; $n=31$) and text-national data ($r = 0.391$, $P=0.030$; $n=31$), but no correlation between image and text data ($r = 0.203$, $P=0.281$; $n=30$).

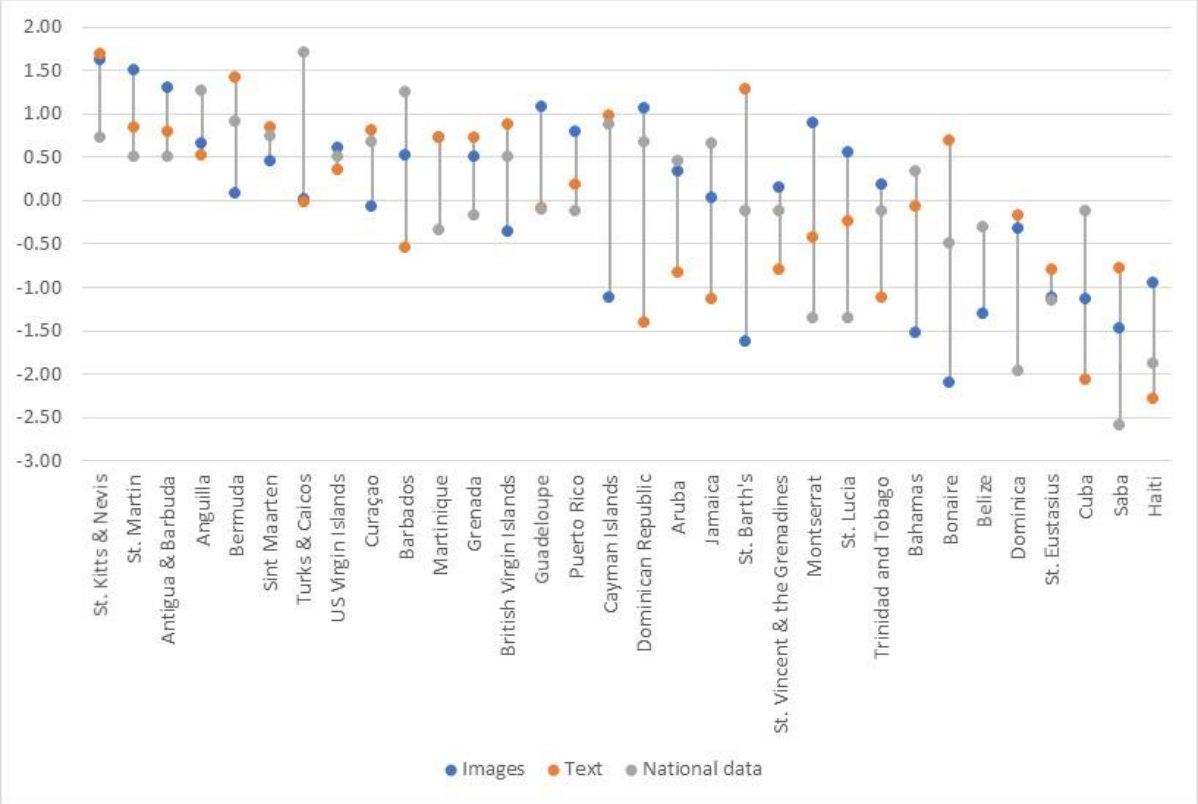


Figure 3: Standardised scores for all three metrics, plotted in order of decreasing average reef adjacent value estimates. Given the lack of clear 3-way correlations and only very weak pairwise correlations (see text) it is important not to read this as a clear ranking.

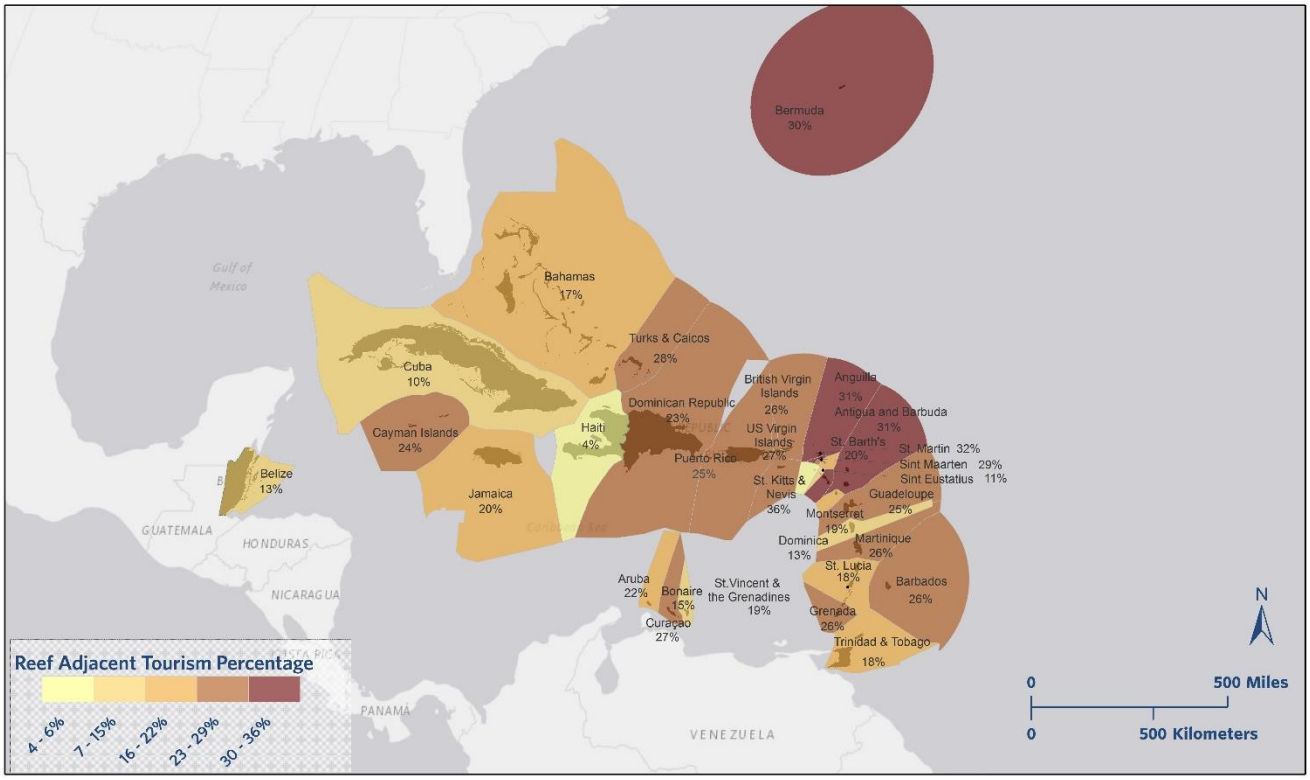
Finally, these standardised scores were spread across a range of 0-40% to represent the actual importance of reef-adjacent values per jurisdiction from each scoring method. Without further knowledge of the individual input data it was not possible to assess the reliability of individual measures from specific jurisdictions and so for each, an average value from the available scores was determined for use in the model. These numbers are presented in Table 6 and in Map 2.

These data show a spread of averaged reef-adjacent values from 4% on Haiti to 36% for St Kitts and Nevis.

Table 6: Final estimates of reef-adjacent values for 32 Caribbean jurisdictions. All results were first standardised and then normalised between 0-40%. Blank cells indicate no data. Average results are those used in the final mapping.

Jurisdiction	PUD ratio	TA posts	Exit polls	AVERAGE
Anguilla	30%	27%	35%	31%
Antigua & Barbuda	36%	30%	27%	31%
Aruba	26%	13%	26%	22%
Bahamas	6%	21%	25%	17%
Barbados	28%	16%	35%	26%
Belize	8%		18%	13%
Bermuda	23%	37%	31%	30%
Bonaire	0%	29%	16%	15%
British Virgin Islands	18%	31%	27%	26%
Cayman Islands	10%	32%	31%	24%
Cuba	10%	0%	20%	10%

Curaçao	22%	30%	29%	27%
Dominica	19%	20%	0%	13%
Dominican Republic	34%	7%	29%	23%
Grenada	28%	29%	20%	26%
Guadeloupe	34%	21%	20%	25%
Haiti	12%	0%	1%	4%
Jamaica	23%	9%	29%	20%
Martinique	30%	30%	18%	26%
Montserrat	32%	17%	7%	19%
Puerto Rico	31%	24%	20%	25%
Saba	6%	13%	0%	6%
Sint Maarten	27%	31%	30%	29%
St. Barth's	5%	35%	20%	20%
St. Eustasius	10%	13%	9%	11%
St. Kitts & Nevis	40%	40%	29%	36%
St. Lucia	28%	19%	7%	18%
St. Martin	39%	31%	27%	32%
St. Vincent & the Grenadines	24%	13%	20%	19%
Trinidad and Tobago	24%	10%	20%	18%
Turks & Caicos	23%	21%	40%	28%
US Virgin Islands	29%	26%	27%	27%



Map 2: Caribbean jurisdictions with adjacent EEZs coloured to show their average reef-adjacent importance (from Table 6).

Overall valuation results

The final results from the application of the mean reef adjacent scores by jurisdiction into the former global model are presented in Table 7 and in Maps 1-6.

The revised numbers suggest values of reef-adjacent expenditure of $5.7 billion annually and of 7.4 million visitors. Total values for all reef-associated tourism are now estimated at over $7.9 billion of expenditure and over 11 million visitors that can be directly related to the presence of coral reefs. These numbers put coral reefs right at the core of this industry and the entire economy of the region – the dollar terms represent 23% of all tourism expenditure and are equivalent to over 10% of GDP.

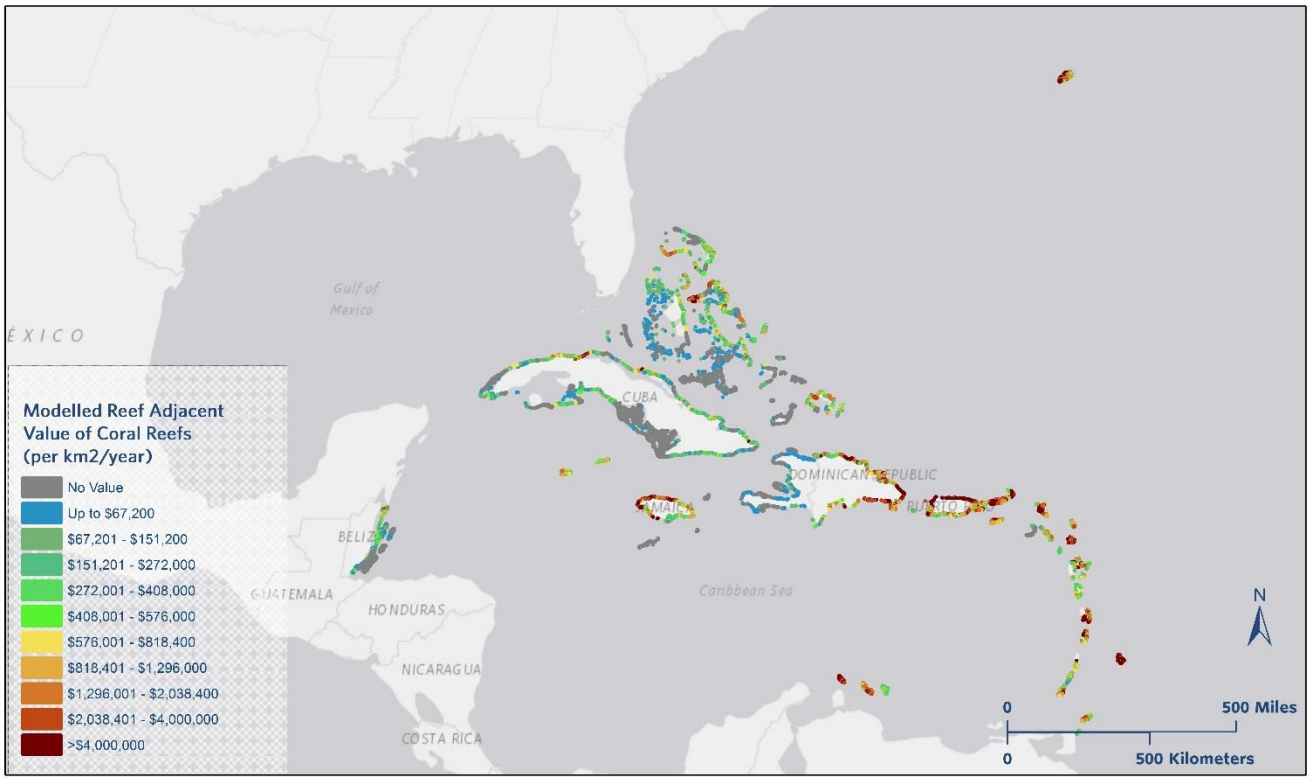
Table 7: Results from the final models. The reef adjacent values (visitation and expenditure) have been re-calculated from the work described above and have been combined with the former on-reef values to give new total values.

Jurisdiction	Reef adjacent visitors	On-reef visitors	Total visitors	Reef adjacent expenditure ($k)	On-reef expenditure ($k)	Total reef expenditure ($k)
Anguilla	18,480	4,293	22,773	35,479	8,240	43,719
Antigua and Barbuda	233,540	40,680	274,220	132,943	23,158	156,101
Aruba	297,790	73,093	370,883	311,750	76,521	388,271
Bahamas, The	606,630	545,971	1,152,601	353,478	318,130	671,608
Barbados	253,960	61,537	315,497	287,247	69,602	356,849
Belize	79,090	147,839	226,929	30,552	57,109	87,661
Bermuda	171,800	128,846	300,646	206,436	154,827	388,787
Bonaire	38,750	162,742	201,492	18,534	77,844	96,378
British Virgin Islands	212,310	176,383	388,693	160,896	133,667	294,563
Cayman Islands	421,740	869,849	1,291,589	118,102	243,585	361,687
Cuba	98,810	53,360	152,170	183,955	99,335	283,290
Curaçao	196,750	104,934	301,684	128,548	68,559	197,107
Dominica	41,330	65,809	107,139	9,686	15,423	25,109
Dominican Republic	692,200	108,345	800,545	865,321	135,442	1,000,763
Grenada	97,590	43,916	141,506	27,738	12,482	40,220
Guadeloupe	105,980	26,708	132,688	138,748	34,964	173,712
Haiti	8,160	9,182	17,342	4,195	4,719	8,914
Jamaica	453,310	122,394	575,704	432,969	116,902	549,871
Martinique	129,510	26,897	156,407	150,829	31,326	182,155
Montserrat	690	729	1,419	775	821	1,596
Puerto Rico	962,540	103,954	1,066,494	1,277,297	137,948	1,415,245
Saba	940	7,343	8,283	272	2,122	2,394
Sint Eustatius	3,100	17,741	20,841	735	4,210	4,945
Sint Maarten	556,300	138,117	694,417	196,822	48,866	245,688
St. Barth's	57,680	6,199	63,879	10,216	8,190	18,406
St. Kitts And Nevis	176,410	30,872	207,282	35,866	6,277	42,143
St. Lucia	146,210	58,485	204,695	59,205	23,682	82,887
St. Martin	442,530	8,837	451,367	57,079	11,608	68,687
St. Vincent and the Grenadines	35,000	29,840	64,840	17,868	15,235	33,103
Trinidad and Tobago	28,680	21,507	50,187	34,436	25,827	60,263
Turks and Caicos Islands	227,680	182,957	410,637	84,074	67,560	151,634
Virgin Islands	623,500	270,183	893,683	343,480	148,841	492,321
TOTAL	7,418,990	3,649,542	11,068,532	5,715,531	2,183,022	7,926,077

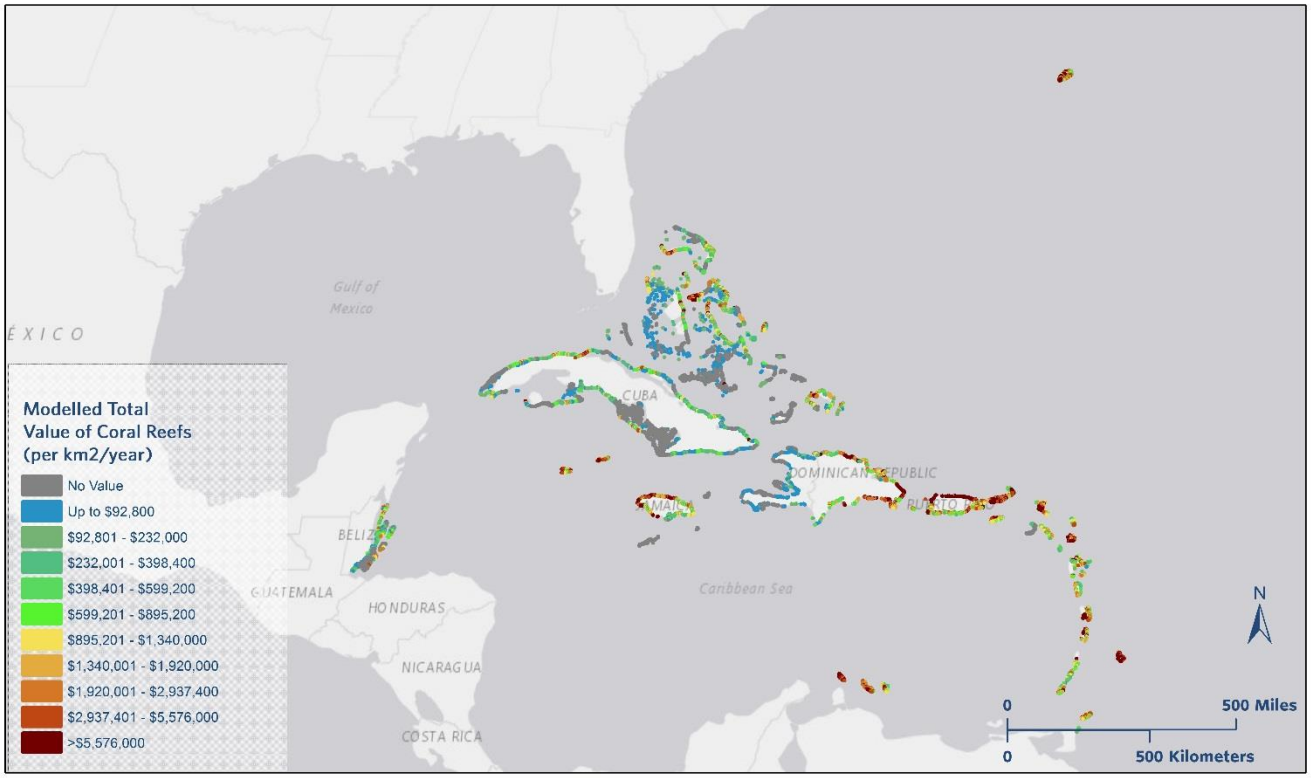
From these tables it is clear that reefs are of considerable value right across the region. The average values from the entire insular Caribbean are 660 visitors and $473,000 per square kilometre of reef per year. Puerto Rico and the Dominican Republic generating the highest values in terms of

expenditure – both having values of more than a billion dollars per year directly linked to coral reefs. Two other countries – The Bahamas and the Cayman Islands – stand alongside Puerto Rico in terms of the visitation statistics: all three countries are receiving the equivalent of over a million visitor trips per year directly linked to coral reefs.

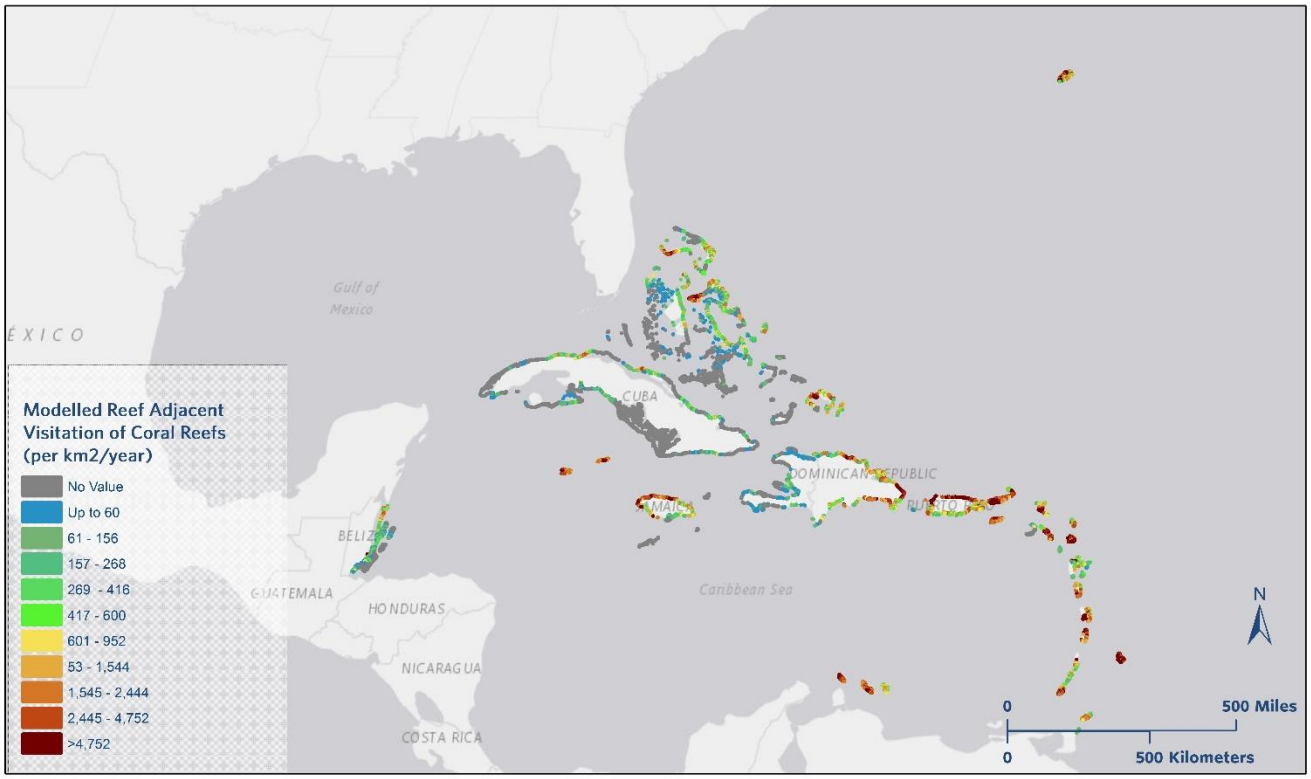
The maps show that the geographic spread of these values is considerable. Almost every country, with the exception of Haiti has at least some very high value reefs (from the top decile, or 10% by area). In these areas, reef-adjacent tourism alone is generating over $4 million per km2 in expenditure, and over 4,700 visitors per km2, each year, while total values for all coral reef tourism stand at over $5.7 million per km2 and over 7,000 visitors per km2 each year. By contrast, only seven countries (Bahamas, Belize, Cuba, Haiti, Jamaica, Saba and Turks and Caicos) have reefs with no tourism value. This are mostly far offshore, or far from any populated areas.



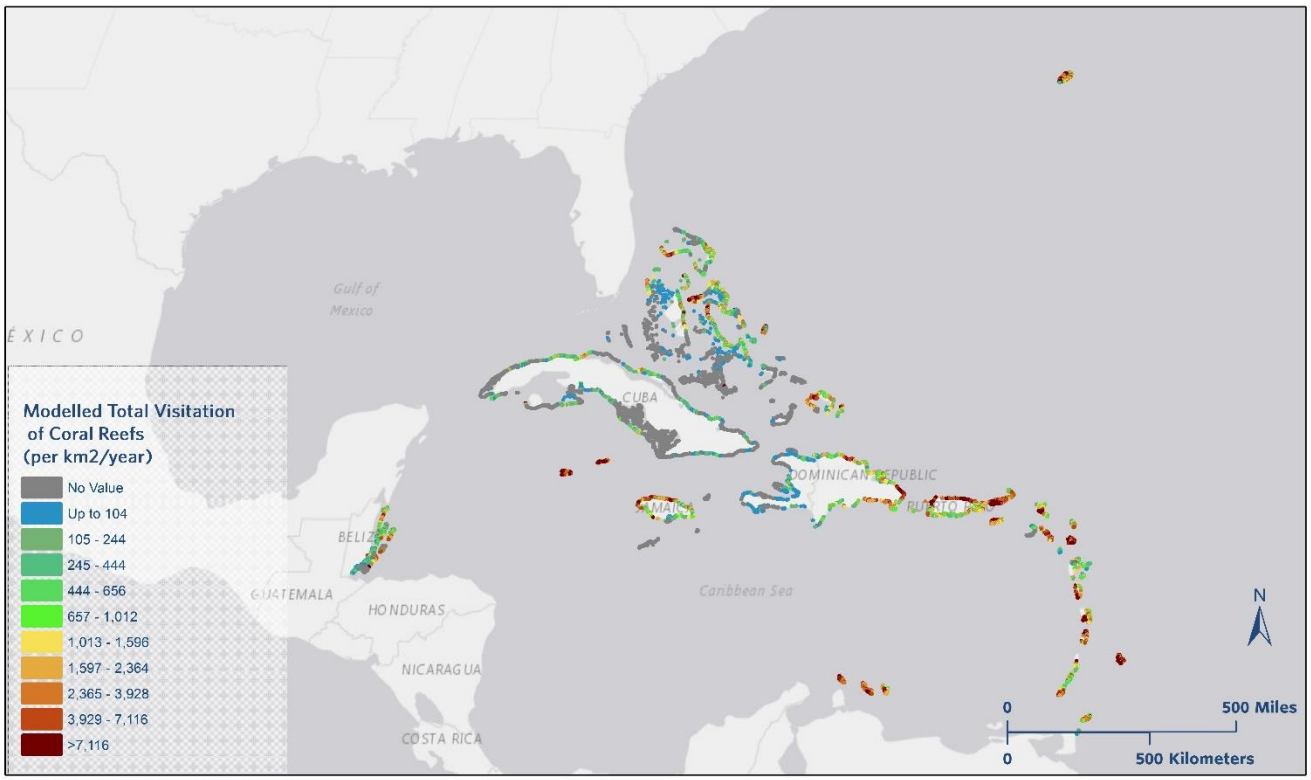
Map 3: Reef adjacent expenditure (UD$ per km2 of reef) with values classified into deciles



Map 4: All reef associated expenditure (US$ per km2 of reef) with values classified into deciles.



Map 5: Reef adjacent visitation (visitor trip equivalent per km2 of reef) with values classified into deciles.



Map 6: Total reef visitation (visitor trip equivalent per km2 of reef) with values classified into deciles.

The value of reefs by jurisdiction can also be weighted by the total area of reefs under the control of those jurisdictions. In this case three jurisdictions in particular – Barbados, Puerto Rico and the US Virgin Islands – have a very high proportion of high value reefs, giving an average value in all cases of over $3 million per km2 per year.

Conclusions

This work sought to improve our ability to understand the spatial distribution of nature-dependent tourism, notably on elements of indirect use that remain a challenge to quantify and map. The work focused on coral reef-dependent tourism in the island Caribbean.

Methodological approaches

A key part of this work was the exploration of potential approaches to model and map reef-adjacent tourism. Traditional studies of tourism activities and preferences have relied on visitor surveys, which have, in turn, informed governments and industry. This is witnessed by the provenance of almost all of our sources for this element of the work: government web-sites and reports, including future planning documents (Annex 2). While these studies are clearly very useful, the variation between survey methods makes direct comparison between jurisdictions somewhat challenging.

A small number of more recent studies have utilised social media sampling approaches to look at these same issues, but in this study we developed novel angles to such work with the more systematic incorporation of machine-learning into both image and text-based assessments. Both elements show promising results.

With more time we expect that the image-based analyses could be improved, both around the focus on beaches, but also to develop multiple, separate image recognition models to identify other

components of reef-dependent activities such as kayaking, sailing, stand-up paddleboards etc. There may also be some opportunity to develop more complex models that consider colour and shade more comprehensively, for example picking out the often highly specific colouration of reefs in shallow water. Sample size would also be greatly improved by utilising other image-based platforms beyond Flickr.

The text-based analyses equally showed considerable promise and with more investment would be considerably improved. The focus of the initial training layer only on the Bahamas may have introduced bias. Future studies will further need to consider language. While the searches were conducted on English posts the very low scores for both Cuba and Dominican Republic may reflect some bias against Spanish. Most important, however would be an ability to move from the spatially blunt and topically broad nature of generic postings to try to assess individual locations within sites such as TripAdvisor (Attractions, Hotels and Restaurants).

The lack of any strong correlations between our findings using different approaches is in some ways disappointing, however we believe it also provides an important lens through which to view past and future work, as it points to the need to look to multiple sources to determine value Clearly the lack of consistency between approaches may raise concerns about the accuracy of previous assessments which have assumed a single approach was delivering valid results. Variability based on sampling populations is a continual challenge in any research of this nature and the shift towards online sources is unlikely to change this (Tenkanen et al. 2017), and so we might expect demographic, linguistic or other differences between the users of, for example, Flickr versus TripAdvisor. While we cannot be certain, it may be hoped that by combining these disparate sources, a mean value may, at least in a majority of cases, tend towards a more balanced assessment.

Patterns of reef tourism value

The values for reef tourism are very high in the insular Caribbean. In multiple countries, coral reefs are generating a third or more of all tourism expenditures[3], and over 10% of net GDP. While this importance has been called out before now, the detail arising from the current study makes a powerful case. Some 65% of all the region's reefs have a value for tourism. Those that have no significant tourism value are mostly remote and located in only seven jurisdictions (22%) have reefs that are not generating and supporting tourism.

The decision in this study to increase the spread of values for reef-adjacent tourism has inevitably resulted in net increases in overall estimates for reef-adjacent and net tourism values across the region compared to the original reef tourism study. This decision was appropriate given both the conservative nature of the original scoring and the particular dependence on reef-adjacent coastal tourism in the island Caribbean.

Looking particularly at the reef-adjacent values calculated here, clear patterns emerge. The countries most dependent on reef-adjacent tourism include many small-island nations - Anguilla, Antigua and Barbuda, Bermuda, St Kitts and Nevis and St Martin – where there may be relatively few alternatives to reef adjacent tourism. Other jurisdictions have a more diversified tourism sector, including on-reef activities (Cayman Islands, Bonaire, Saba), inland nature-based tourism (Dominica,

[3] The results of this analysis suggest that Bonaire, St. Eustatius, Cayman Islands, Bermuda, Saba, the British Virgin Islands, Turks and Caicos, Curaçao, the U.S. Virgin Islands, Anguilla, Sint Maarten, and St. Kitts and Nevis are jurisdictions where coral reefs (through both on-reef and reef-adjacent tourism) are generating a third or more of all tourism expenditures. However, it should be noted that Saba and Sint Eustatius have, overall, low tourism spending compared to other Caribbean jurisdictions (<$10 million), which may partially account for the high values.

Montserrat and Belize) or a range including cultural and nature-based activities (Cuba, Jamaica, Trinidad and Tobago).

The maps presented give considerable resolution to the patterns of value even within jurisdictions. Thus, while only our image-based analysis gave sub-jurisdictional detail (Map 1), our approach to spreading values out to reefs using tourism density and proximity to reefs helps to focus our value estimates (Maps 3 and 5) in a manner that appears to closely mirror the apparent use intensity shown by the reef-adjacent images.

Alongside the upward revisions in value are the important levels of geographic variance provided by this study. Our overall spread for the data shows an average 1.7-fold upwards estimate in both total visitors and expenditure compared to the 2017 study, but for several jurisdictions (Anguilla, Antigua and Barbuda, Martinique, Puerto Rico, Sint Maarten, and St. Kitts and Nevis) overall values are more than double the previous estimates while for others, values are unchanged or slightly decreased (notably Haiti and Saba).

Linkages to Other Studies

The contribution of coral reefs to tourism value through factors such as beach quality, calm water, storm protection, vistas, seafood and so forth is of course difficult to determine. Broadly there are two variables – the first is the simple value of these particular components (e.g. the importance of beaches or vistas) to particular destinations, and the second is the importance of coral reefs as contributors to those values (e.g. reefs are often, but not always, the main supplier of beach material). The computation of even the first numbers is already challenging and efforts to quantify indirect use and non-use values often show highly divergent findings (Marre et al. 2015, Schuhmann and Mahon 2015).

In the academic literature a number of authors have attempted to value coral reefs, but their value attribution to these indirect values has been highly variable. (Sarkis et al. 2013) suggested that any beach related activity on Bermuda could be considered reef related, while (Cooper et al. 2009) suggest that any time spent in the coastal areas of Belize to be reef- or mangrove-associated.

This study also builds on previous approaches to link tourist perceptions to habitat characteristics. In terms of tourism value, beach width has been shown to be directly correlated with value perceptions (Schuhmann et al. 2017). (Wielgus et al. 2010) used hedonic pricing to show a clear link between room pricing and beach width in the Dominican Republic, and (WRI 2011) used similar work to explore the impacts on tourist spending linked to coral death and increased beach erosion.

Implications and applications

These results point to a considerable dependence on coral reefs across the insular Caribbean, and the near ubiquitous use of all reefs in the region also points to a fragility in the industry. There is no slack: impacts or declines to coral reefs will not be easily offset by transferring to other locations.

Tourism is a high-value industry, and a critical pillar of the economies of every island nation in the Caribbean. At the same time, it is a volatile industry, with rapid changes in value linked both to natural events such as hurricanes (WTTC 2018a), and more particularly to changes in social, economic and market settings. Tourism can also be a threat to itself, as suggested in the many

discussions around the "tourism life cycle" (Butler 2006) and around more recent concerns on over-tourism (Goodwin 2017). This may be played out particularly around coral reefs which are highly sensitive to physical or chemical impacts associated with dredging, pollution, anchor-damage, or even sun-tan lotion in the water (Gil et al. 2015, Corinaldesi et al. 2018, Schaap and Slijkerman 2018).

The thinking behind Mapping Ocean Wealth (www.oceanwealth.org) has always been that if accurate and spatially explicit metrics of the value of nature could be made available they could provide a critical tool in encouraging efforts to use nature sustainably, and work towards its protection, maintenance or restoration.

Awareness of the value of reefs does not, in itself, promote change, but by sharing those values with industry and government it may provide a critical motivator. The statistics here point to a very real dependence on coral reefs and the maps point to locations where such importance is located. In some cases that dependence is territory-wide, but elsewhere it is also possible to pinpoint locations where reefs are particularly critical: the northern and western coasts of Jamaica, the northern coast of Puerto Rico, and north-central Cuba, for example.

Pascal et al. (2012) look at several economic valuation studies in the Pacific and suggested that their "effect on policy decisions was varied and, in general, lower than expected". More specifically Waite et al. (2014) point out that "the number of success stories is low relative to the overall number of coastal valuation studies conducted in the [Caribbean] region to date". Changing this situation requires a flexible approach, adapted to local settings, but they point out the importance of "extensively engaging stakeholders (including close collaboration between valuation practitioners, key stakeholder groups, and decision makers), selecting the best available methods that can feasibly be applied, and executing a targeted outreach strategy". The same study does provide details of success stories and the need for engagement is further promoted in other work (Arkema et al. 2015).

The work presented here is a beginning. Being regional in scope and somewhat broad-brush in its detail, it needs to be used to raise general awareness, within industry, governmental, public and NGO sectors, but primarily as a lever to promote more targeted responses at national and local levels.

Coral reefs are known to be in a precarious state world-wide, afflicted by multiple threats ranging from natural perturbations such as hurricanes to the growing global trauma of climate change (Spalding and Brown 2015). In reality, many issues can be dealt with at local scales, and, in tackling these more manageable issues, many reefs would appear to be more resilient to cope with, or recover from, some of the threats that exists at global scales (Mumby et al. 2014, Aswani et al. 2015). But even at local scales we often fail. Wear (2016), for example, has pointed out that while considerable funds have been made available to control fishing, the widespread threats to coral reefs from coastal development have received far too little attention. Coastal tourism is clearly part of the problem of coastal development, but it can also play a critical role in the solution, tackling issues of pollution head-on (Wear and Thurber 2015), restoring damage, and setting back buildings and other development from coastlines to allow coastal vegetation to defend shorelines.

Efforts are growing to co-ordinate the multi-faceted pressures on coastal and near-shore space from social and industrial uses and this is leading to increasing levels marine spatial planning. It is our hope that this work will support such efforts, giving a clear and strident call for coral reef conservation and rehabilitation in the future. Such a call will help secure the long-term future for

people and industries that are often not fully aware of their dependence on nature. We hope that both governments and the travel industry will work together in such efforts.

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