Assessing Species Habitat Using Google Street Vi
Cliff-Nesting Vultures

Pedro P. Olea , Patricia Mateo-Tomás

Abstract

The assessment of a species' habitat is a crucial issue in ecology and conservation. While the collection of
sensing technologies, certain habitat types have yet to be collected through costly, on-ground surveys, limiti
provide habitat for a rich biodiversity, especially raptors. Because of their principally vertical structure, howe
technologies, posing a challenge for many researches and managers working with cliff-related biodiversity.
available on-line tool, to remotely identify and assess the nesting habitat of two cliff-nesting vultures (the gri
in northwestern Spain. Two main usefulness of Google Street View to ecologists and conservation biologist
habitat and ii) extracting fine-scale habitat information. Google Street View imagery covered 49% (1,907 km
visibility covered by on-ground surveys was significantly greater (mean: 97.4%) than that of Google Street
the vulture's habitat survey would save, on average, 36% in time and 49.5% in funds with respect to the on-
identify cliffs (overall accuracy = 100%) outperformed the classification maps derived from digital elevation
DEM maps may be useful to compensate Google Street View coverage limitations. Through Google Street
existing in the study area (*n* = 148): 64% from griffon vultures and 65% from Egyptian vultures. It also allow
World Wide Web-based methodology may be a useful, complementary tool to remotely map and assess the
geographic areas, saving survey-related costs.

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Introduction

Habitat – any part of the biosphere where a particular species can live [1]– determines the occurrence, abur
measuring and monitoring habitat of organisms is a crucial task in ecology, management and conservation
the most serious drivers of extinction of species worldwide [3]. Consequently, the assessment of habitat acr
biodiversity conservation [e.g. [4].

The measurement of the quantity and quality of a species' habitat is often a costly and time-consuming labo
field-based surveys over large spatial extents [5]. Fortunately, recent advances in remotely sensed imagery
geographic information systems (GIS), have reduced costs and limitations associated with the collection an
by remote sensing include the characterization of habitat and biodiversity over large spatial extents in a con
these advances, some habitat types or habitat features have yet to be partially or completely collected on g
study over large areas.

Cliffs are steep faces that create abrupt discontinuities in the landscape, shaping inaccessible habitats and
biodiversity (from ancient communities of plants to threatened raptors; [9], [10], [11]). For example, 20 (44%
cliffs for nesting obligatorily (17.7%) or facultatively (26.7%) (authors' unpublished data; [12]). Because of th
identify and assess by remote sensing technologies, which are based on a bird-eye perspective (Figure 1, s
drawback has posed a challenge to adequately deal with cliff habitat for many researches and managers w
recently launched could however assist in remotely collecting cliff habitat information, reducing survey-relat
methods for biodiversity monitoring and conservation is necessary, as funds available for these activities ar

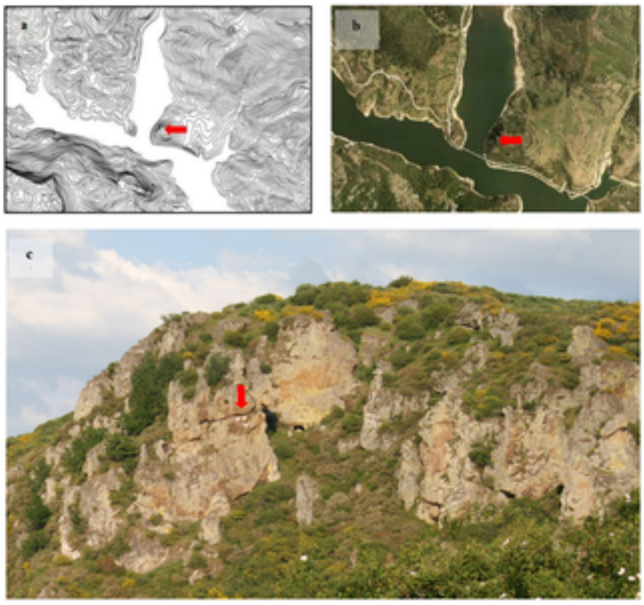

Figure 1. Illustrative examples of a same cliff viewed from different sources.
(a) a topographical map (data source: Instituto Geográfico Nacional de España), (b) an aerial photograp
España), and (c) a picture taken *in situ* (Autor: PMT). Red arrows indicate the location of the cliff. Simila
Maps™ (http://goo.gl/maps/xQ4e8; Accessed: 2012-11-29), and Google Street View (Google Maps™, ©
2012-11-29).
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Google Street View is a freely available tool incorporated in Google Maps and Google Earth® that provides
world (http://en.wikipedia.org/wiki/Google_Street_View). It was launched in May 2007 in the United States a
cover a wide net of cities and rural areas worldwide. This application allows users free viewing of georeferen
along most of the roads from a pedestrian level. Accordingly, it may be a useful tool to remotely identify and
that shown so far (Figure 1). Despite its potential for the evaluation of diverse environments, as far as we kr
research. Most works so far using Google Street View have been developed in the categories of health scie

has been conducted in life sciences (as assessed from a search on Scopus from 1960 to 21st February 201
"abstracts, titles and keywords").

In this paper we explore the feasibility of Google Street View as a useful tool to identify and assess the nest
vulture *Gyps fulvus* and the globally endangered Egyptian vulture *Neophron pernocpterus*. We evaluated tw
and conservation biologists: i) remotely identifying a species' potential habitat to assist in the subsequent sa
habitat data for potential use in habitat selection studies (or species' distribution models, SDMs). Both tasks
researchers and managers.

Methods

Study Area

The study area covers 7,000 km^2 on the south slope of the Cantabrian Mountains, in north-western Spain (
covered by 3,905 km of paved roads and has a complex topography, with elevations ranging between 340–
are abundant all over the study area [14].

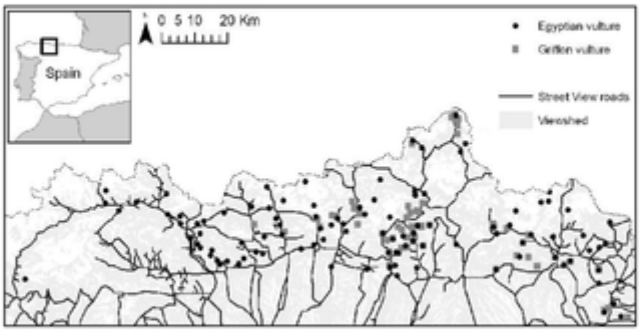

Figure 2. Location of the study area in north-western Spain.
Sixty five percent of the study area was potentially visible (bright grey) from the paved roads covered by
cliffs used by griffon and Egyptian vultures for nesting is also shown. The dotted line indicates the northe
inset).
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Study Species

The two study species are obligated cliff-nesters. The Egyptian vulture is a medium-sized territorial scaveng
and South Africa. This species is classified as *Endangered* by the IUCN [15]. Spain holds the most importar
breeding population [15], [16]. In Spain, the species occupy very different habitats, from plains to middle anc
winter grounds in Africa in early March and remain in the territories until mid-September. Nesting cliffs are g
usually built in caves, and more rarely on ledges or crevices. In the study area, Egyptian vultures prefer to n

The griffon vulture is a colonial cliff-nesting scavenging raptor widely distributed from the Mediterranean cou
Africa [20]. The species is classified as of *Least Concern* by the IUCN [20], but it is locally threatened in son
[21]. The species use caves, ledges and crevices to install their nests. Nests can be close to each other (i.e
that range from a few to hundreds of pairs [17]. In our study area, colony size ranged from 2 to 20 breeding
taken into account.

Procedure

In Google Maps or Google Earth an orange “pegman” icon appears (Figure 3). By dragging it onto a locatio
imagery using the Street View feature (see http://maps.google.es/support/bin/answer.py?answer=144358 fo
Google Street View imagery searching for cliffs. Dates of the imagery provided by Google Street View were

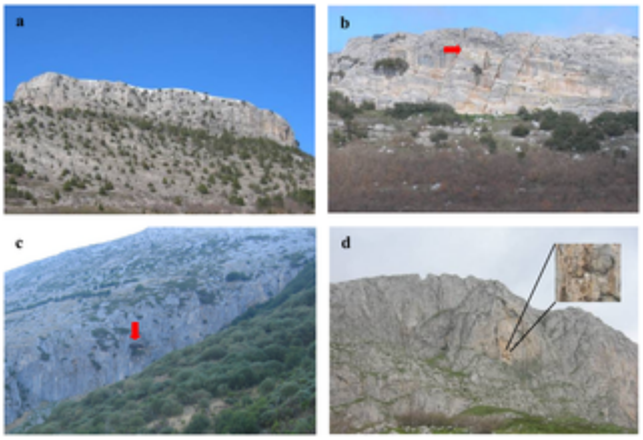


Figure 3. Nesting cliffs used by the griffon and the Egyptian vultures in the study area.
Caves and white drops are highlighted with red arrows or expanded by zooming. All the four images are
can be remotely observed by using Google Street View (Google Maps™, © Google) [Figure 3a: http://go
Figure 3c: http://goo.gl/maps/b3ROu; Figure 3d: http://goo.gl/maps/bKNZT; All the images accessed: 20
doi:10.1371/journal.pone.0054582.g003

Remote identification of potential habitat.

To assess the usefulness of Google Street View to assist in the initial design of species censuses (usefulne
10×10-km UTM squares entirely located within the study area. Four observers inspected each of these seve
and noted the time spent on this task for each square. The four observers were: one expert on vulture cens
raptors but not familiar with the study area; and two non-experts in censusing vultures also unfamiliar with t
from roads covered by Google Street View within each 10×10-km UTM square by using the Viewshed utility
Inc., Redlands, California, US). The distribution of paved roads covered by Google Street View was obtaine
streetview/learn/where-is-street-view.html and implemented in a GIS.

At the same time, we estimated the virtual time spent looking for cliff habitat in the same seven squares stu
entirely performed by car. On-ground survey by car would cover all the paved and unpaved roads in each s
calculated the final area surveyed by using the Viewshed utility described above. The distribution of paved
(©Instituto Geográfico Nacional de España) and aerial photographs, and implemented in a GIS. Monetary c
assuming a mean consumption of 0.19 euro km^{-1} (Real Decreto 462/2002) [22]. We compared the time spe
Google Street View by applying pair-wise comparisons of Wilcoxon signed rank paired tests; we used the sa
cliffs using Google Street View and virtual on-ground surveys.

Digital Elevation Model (DEM) vs Google Street View.

Cliffs can be located through the conventional analysis of the slope of the terrain in GIS (Figure 1) [14]. We
that of Google Street View. We used a high resolution (i.e. 5 m pixel) DEM to obtain the slope values for the
above which classify a location as a cliff, we considered the slope of all the vulture breeding cliffs recorded i
[14]. On this distribution of slopes, we selected three different thresholds [14]: the minimum slope value (0.3
values were used to obtain maps (i.e. Smin, S25th and S50th, respectively) of potential cliffs.

To assess accuracy in the identification of cliffs, we randomly assigned a total of 100 points (i.e. field test sa
10×10-km UTM squares previously selected (see above; 14–15 points per square). These points were locat

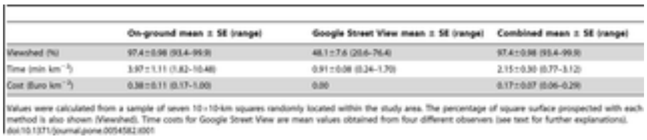
View (see above). This allowed a better comparison between methods (i.e. DEM maps and Google Street V field surveys. Overall accuracy, producer and user accuracy, omission and commission error rates, and Coh i.e. DEM maps (Smin, S25th and S50th) and Google Street View. Overall accuracy is the division of the tota of points; producer's accuracy is the percentage of field points of a category which are correctly classified a accuracy is the percentage of points of a category derived from the method (or map) which are really in that predictions, while commission errors are false positive predictions. The Cohen's Kappa coefficient indicates and the on-ground (reference) points. Cohen's Kappa coefficients were performed with the *irr* package [24]

Obtaining fine-scale habitat characteristics.

In order to assess the usefulness of Google Street View to obtain fine-scale habitat characteristics (usefulne percentage of nesting cliffs known to be used by griffon and Egyptian vultures that we were able to unequivo known to be used by griffon and Egyptian vultures were available from previous studies [14], [16], [19], [20], detailed description of the census methodology of both species, see, for example, [34] for the Egyptian vultu vulture nesting cliffs, one observer experienced in censusing vultures and knowledgeable of the study area searched for these cliffs using Google Street View and assessed whether or not he/she was able to unequiv clearly see at least 80% of the cliff previously identified through field surveys; see Figure 3 for examples). If visual inspection, the observer noted whether or not he/she could also see caves, vegetation (i.e. shrubs an These characteristics, which can indicate a higher probability of occupancy of those cliffs by the study speci extract fine-scale habitat information (Figure 3). The observer also noted the type of substrate (i.e. limeston from Google Street View. Distances from nesting cliffs to the nearest road covered by Street View were calc

Results

Of the 3,905 km of paved roads existing in the study area, 49% (i.e. 1,907 km) were covered by Google Str Viewshed utility in ArcGIS 10; see above) covered by Google Street View was 65% (4,550 km^2) of the whol visibility ranged between 20.6 and 76.4% per 10×10-km square with a mean of 48.1±7.6% (SE) (Table 1). A the potential visibility covered by car was significantly greater (mean: 97.4±0.98% per 10×10-km square, ra t-test, $t = -6.30$, $p = 0.0007$). Time spent looking for cliffs using Google Street View was not significantly diff signed rank paired test, $V = 12–18$, $p = 0.21–0.94$). Time spent looking for cliffs was significantly lower usin 0.91±0.08 min km^{-2} of surveyed area, range: 0.24–1.70 min km^{-2}) than using on-ground surveys by car (m Wilcoxon signed rank paired test, $V = 0$, $p = 0.016$). The cost of looking for cliffs on-ground was of 0.38±0.1 The surveyed area using Google Street View encompassed 49.5±7.8% (range: 21–76%) of that covered by both methods could be covered by Google Street View instead of by on-ground survey by car, it would save that is, 12,262±6726 min (204.4 hours) and 1,447±657 euro for the whole study area, saving 36.1±7.9% in t surveys by car only.



	On-ground mean ± SE (range)	Google Street View mean ± SE (range)	Combined mean ± SE (range)
Viewshed (%)	97.4±0.98 (93.4–99.9)	48.1±7.6 (20.6–76.4)	97.4±0.98 (93.4–99.9)
Time (min km^{-2})	3.97±1.11 (1.82–10.48)	0.91±0.08 (0.24–1.70)	2.15±0.30 (0.77–3.12)
Cost (Euro km^{-2})	0.38±0.11 (0.17–1.00)	0.00	0.17±0.07 (0.06–0.29)

Values were calculated from a sample of seven 10×10-km squares randomly located within the study area. The percentage of square surface prospected with each method is also shown (Viewshed). Time costs for Google Street View are mean values obtained from four different observers (see text for further explanations).
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Table 1. Mean time and monetary cost per km^{-2} of surveyed area (viewshed) looking for suitable methods.
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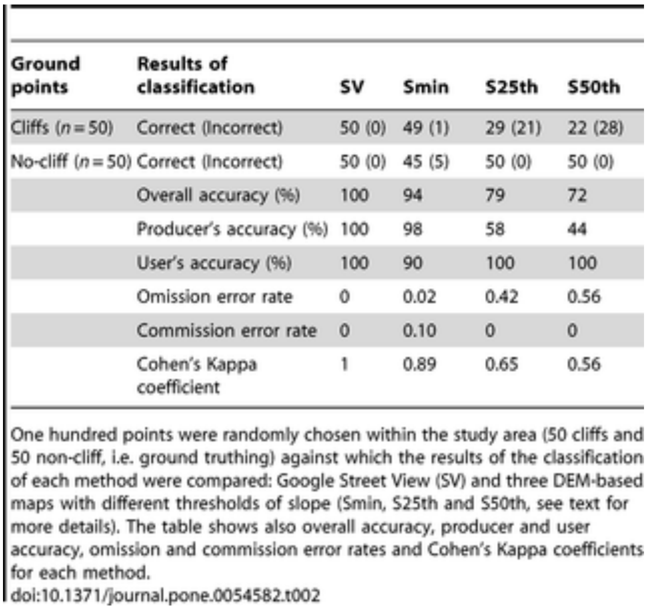
Google Street View had an overall accuracy in classifying cliffs of 100% (Cohen's Kappa = 1) (Table 2). For Kappa = 0.89) of the ground points, S25th correctly classified 79% (Cohen's Kappa = 0.65), and overall acc 2).



Ground points	Results of classification	SV	Smin	S25th	S50th
Cliffs (*n* = 50)	Correct (Incorrect)	50 (0)	49 (1)	29 (21)	22 (28)
No-cliff (*n* = 50)	Correct (Incorrect)	50 (0)	45 (5)	50 (0)	50 (0)
	Overall accuracy (%)	100	94	79	72
	Producer's accuracy (%)	100	98	58	44
	User's accuracy (%)	100	90	100	100
	Omission error rate	0	0.02	0.42	0.56
	Commission error rate	0	0.10	0	0
	Cohen's Kappa coefficient	1	0.89	0.65	0.56

One hundred points were randomly chosen within the study area (50 cliffs and 50 non-cliff, i.e. ground truthing) against which the results of the classification of each method were compared: Google Street View (SV) and three DEM-based maps with different thresholds of slope (Smin, S25th and S50th, see text for more details). The table shows also overall accuracy, producer and user accuracy, omission and commission error rates and Cohen's Kappa coefficients for each method.

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Table 2. Results of the accuracy assessment of different methods.

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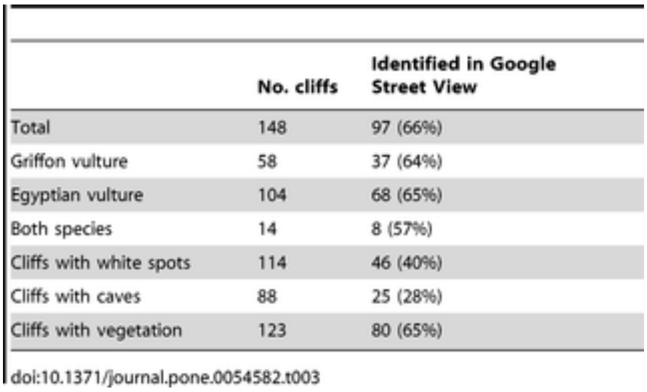
In the study area there are 148 nesting cliffs known to be occupied by vultures: 58 (39%) by griffon and 104 both species. From these 148 nesting cliffs, we observed 97 (66%) cliffs through the Google Street View im 68 (65%) out of 104 of Egyptian vulture (the between-species difference in the number of detected cliffs wa



	No. cliffs	Identified in Google Street View
Total	148	97 (66%)
Griffon vulture	58	37 (64%)
Egyptian vulture	104	68 (65%)
Both species	14	8 (57%)
Cliffs with white spots	114	46 (40%)
Cliffs with caves	88	25 (28%)
Cliffs with vegetation	123	80 (65%)

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Table 3. Number of cliffs used for breeding by griffon and Egyptian vultures which were identifie

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The nesting cliffs observed through Google Street View laid to a significantly shorter mean distance to the n 955±67 m, range: 43–3,729 m, *n* = 97) than that of the unobserved cliffs (2,170±210 m, range: 310–8,782 vulture identified with Google Street View were observed at a larger average distance from the nearest road those of the Egyptian vulture (839±86 m, *n* = 60; although non-significant: *t* = 1.87, *P* = 0.065; same cliffs us between-species difference in cliff identification was not due to the cliffs used by griffon vulture being farther

Egyptian vulture (mean for griffon vulture cliffs: 1,432±141 m, *n* = 44 *vs* Egyptian vulture: 1,336±140 m, *n* = were excluded from the analysis).

We determined correctly the type of substrate in 100% (*n* = 97) of the nesting cliffs detected via Google Stre = 46), caves in 26% (*n* = 25) and vegetation in 65% (*n* = 80). Field surveys showed that white spots were ob vegetation in 76% (*n* = 123) of the nesting cliffs. Therefore, using Google Street View we detected white spo respectively, of the subset of cliffs with caves, white spots and vegetation registered in the field surveys (Tat

Discussion

Ecosystem study and management require the collection of spatially-explicit detailed information for mappin but this information is usually difficult and costly to gather through field-based techniques [35], [36]. Remote contributed to addressing this need [35]. Yet, certain attributes of the landscape and fine-scale habitat eleme largely dependent on field-based data for their characterization and thus greatly limiting the spatial extent to [10], whose identification and assessment in a landscape through remote sensing or DEM maps is not straig studying cliff biota has had to be generally conducted by costly on-ground surveys (e.g. [9], [10], [11], [14], [that a considerable portion (65%) of the area prospected to locate suitable habitat for two cliff-nesting vultur important percentage of their nesting cliffs could be observed (66%) and evaluated for features (28–100%) l although the conventional method which used digital elevation models (DEMs) provided good results regarc cliffs), Google Street View outperformed the DEMs in accuracy (Table 2). All of this suggests that Google St and census of cliff-related biodiversity, reducing also survey-related costs (e.g. transportation time and milea associated with (habitat) data collection is essential in the worldwide context of limited resources for biodive web-based tool can be quite useful on a landscape scale. It would enable the design of more efficient fieldw the study by focusing and prioritizing on more suitable areas and/or cliffs or in remote areas away from pave without cliffs), thus saving both time and money. In our study, Google Street View only allowed covering betv it obligated combining the use of this web-based tool with other method(s) to completely survey the square. conjunction with high-performance DEMs (e.g. Smin) could be highly useful as a first coarse-scale approach Nonetheless, on-ground data (e.g. surveys by car) should be collected in the area uncovered by Google Str variable percentage of locations (Table 2). The incorporation of Google Street View to this study would save the car on-ground survey only. Note that we did not take into account costs of travel from the point of origin View would be greater. Although these particular figures are site-specific, they illustrate the usefulness of thi

Once the nesting sites are known –which can only be reliably attained by on-ground surveys in our study sp researchers and managers who can also remotely obtain fine-scale features of used and available cliffs to ir added advantage of Google Street View that is not currently provided by other remote-sensing techniques. I occurrence data with georeferencing records in digital databases (e.g. Global Biodiversity Information Facilit used in habitat selection models or SDMs [38], [39] for which Google Street View may aid to remotely extrac occurrence sites (Figure 3). Our study adds to the small but increasing body of evidence proving the usefuln surveys on species ecology and conservation (e.g. [40], [41], [42], [43]). Google Street View offers an inexpe information for large geographic areas, and allows similar advantages to those provided by others remote se ([7], [8]).

Nonetheless, neither all the study area could be surveyed (65%) nor all the nesting cliffs known to be occup (i.e. 66%). This spatially uneven coverage establishes a difference between Google Street View and other r spatially complete manner ([7], [8]). Moreover, only a fraction of the nesting-cliffs could be evaluated for som bird depositions, 40%; vegetation, 65%). Therefore, Google Street View is not currently a substitute for cliff l to them (see above). It is expected, however, that the usefulness of this tool will increase in the future if the increases (e.g. only the 48.8% of the paved roads in our study area is currently covered), and especially if it http://maps.google.com/intl/en/help/maps/streetview/technology/cars-trikes.html). This expansion into dirt ro work: i.e. the impossibility of assessing those cliffs located far away from the paved roads. In fact, our result from the roads covered by Street View was a limiting factor to study cliffs with this technology, as these dista

In our study area, this distance limit to which cliffs become unidentifiable could be around 1 km from the roa
most of the identified cliffs lay within around that distance; median: 800 m; 75th percentile = 1,173 m). Althou
affect variation in the distance within which the cliffs can be identified with Street View (e.g. vegetation struc
important. This idea is supported by our results showing that the species that use larger nesting cliffs (i.e. th
registered a greater mean distance from the road to the identified cliff. Other limitations of this method were
fog, cloudy, backlighting) under which Street View imagery were taken, which prevented us from adequately
imposes restrictions on the use of Street View images (http://support.google.com/maps/bin/static.py?hl=en8
shared in publications via direct links (see Fig. 1 and 3) or through an application programming interface (AI
Therefore, Google Street View images that are shared via direct links in published studies may not be perm
by Google or subject to change in the access site).

We have tried to keep the assessment of cliff features simple, but other cliff features can also be assessed
crevices). In fact, we think that measures of height and width as well as surface of the cliffs or parts of them
the recent development of techniques for measuring objects such as building facades from Street View ima
provide a valuable tool to the standard assessment of cliff size, as it is currently a very difficult and inaccura
increase the quality of the information on cliff habitat improving the studies on selection of habitat for cliff-de

Cliffs are expected to change little over time and so they are a type of habitat adequate to study with online
updated as other remote sensing technologies (e.g. airborne and satellite imagery) [5]. This web tool has th
elements of cliff ecosystems such as plants or ancient trees, [9], [10], [11] as well as other types and feature
structure and composition of the vegetation along the roads, detection of nesting sites occupied by conspicu
the rook *Corvus frugilegus;* authors, pers. obs.). It could also have potential to be applied in other fields suc
[46], or in environmentally friendly cliff road construction [47].

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manuscript. Editors of PLoS ONE for assistance about copyright permissions.

Author Contributions

Conceived and designed the experiments: PPO. Performed the experiments: PPO PMT. Analyzed the data:
PPO PMT. Wrote the paper: PPO PMT.

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