Chapter 12. Marine spatial planning in data-poor contexts

To get the facts, reach for the sky

Adrien Brunel, Alessandre Giorgis, Noé Bente, Gilles Domalain and Sophie Lanco Bertrand

Introduction

1 The Paddle project ("Planning in a liquid world with tropical stakes") defines one of the objectives of marine spatial planning (MSP) as "reconciling human uses of the sea with conservation". A crucial starting point for this is to obtain information on these uses to inform future governance actions. One approach to this that partially overcomes possible data gaps on human activities is to extract spatially explicit information from satellite images available on Google Earth and process it using GIS (e.g. Quantum Geographic Information System software, QGIS). Currently, Google Earth is not widely used to inform MSP processes, yet it provides high-resolution optical satellite images (from Landsat) and aerial photographs that contain a wealth of information.

2 This chapter proposes a standardised methodology (for the purposes of sharing and reproducibility) for extracting data from this rich source of information. In concrete terms, this involves superimposing a discretisation grid on a background layer of Google Earth images and then manually pointing and clicking on each element of interest (fishing boats, seaside resorts, sun parasols, etc.) within each pixel of the grid. Then, an automatic count of these features can be performed by QGIS. The features counted per unit of space and their combination can be considered as relevant surrogates for fishing and tourism activities, for example, allowing density maps to be produced. Our case study for this approach is located on the coastline of Pernambuco, a state in northeast Brazil (the Nordeste region) on the Atlantic Ocean. The main activities on this tropical coastline are tourism and fishing.

Materials and methods

3 This section provides details for a standardised protocol for generating data based on a combination of Google Earth images and QGIS processing.

Tools

4 Google Earth (GE) and QGIS[1] are two free platforms available on all operating systems, allowing any user to access optical satellite and aerial images, with a resolution on the order of a metre. This data can then be manipulated to extract relevant information: for our purposes, concerning the spatial distribution of anthropogenic uses.

Google Earth

5 Google Earth is a software program that visualises the planet's surface through a combination of aerial and satellite photographs. The satellite images cover the entire surface of the Earth and currently come from Landsat 8 (launched by the National Aeronautics and Space Administration, NASA, in 2013). The program selects coverage dates that minimise cloud cover and guarantee a minimum resolution of 15 m at any point on the planet. The maximum resolution of geographical locations depends on their interest. For example, aerial photographs of urban areas can be observed with a sufficiently high resolution to be able to distinguish each individual building, house and even car (resolution on the order of a metre). In this case study, we used GE images as a background layer in QGIS to count objects of interest. In addition, Google Street Views were used to corroborate the nature of the counted objects: a closer view often helped to differentiate between types of boats or infrastructure.

QGIS

6 Quantum GIS (QGIS) is a widely used free GIS software. We used Madeira QGIS version 3.4 and installed the "Go2NextFeature3 2.00" extension. QGIS is a generic and user-friendly tool that overlays geographic layers and includes various useful features. It can be used, among other things, to view, browse, analyse, map, create, manage and export data. The relatively intuitive interface makes it easy to use even for a beginner, and the available extensions add even more functionality. The interest in using QGIS to collect and analyse data lies in its versatility (data collection and mapping), as well as in the fact that it allows working with different sources of information (satellite images, personal databases, data from agencies or institutes, etc.). In our case study, QGIS was a useful tool to conduct a count of features of interest in MSP: with the "Go2NextFeature" extension we were able to point and click on features in each pixel of the grid applied to the GE image backgrounds and thus semi-automate the count.

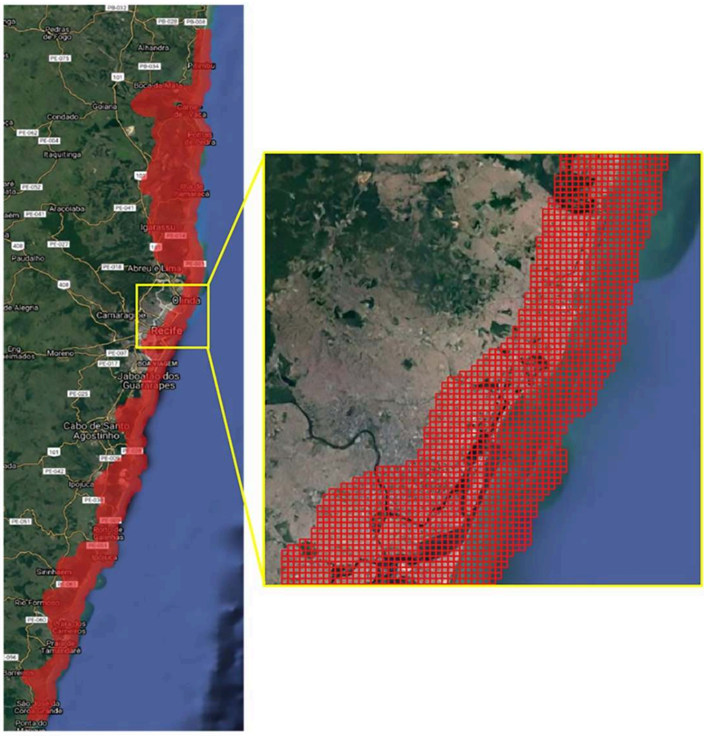
Method

7 Our method combined QGIS software with the GE image layer to extract a database of human uses. The overlay of a grid layer allows the discretisation of the study area and then automatically counts categorised features of interest within this grid that can then be treated as spatially explicit indicators of anthropogenic uses of coastal spaces.

Discretisation grid

8 The grid was constructed to cover the irregularly shaped coastline of Pernambuco (fig. 1), which extends approximately from longitudes 35.19° W to 34.79° W and latitudes 8.92° S to 7.39° S. The grid was composed of 29,295 cells of 220 m x 220 m, which corresponds to a coverage area of about 1400 km². The resolution was high enough to distinguish and count features of interest (boats, sun parasols, etc.).

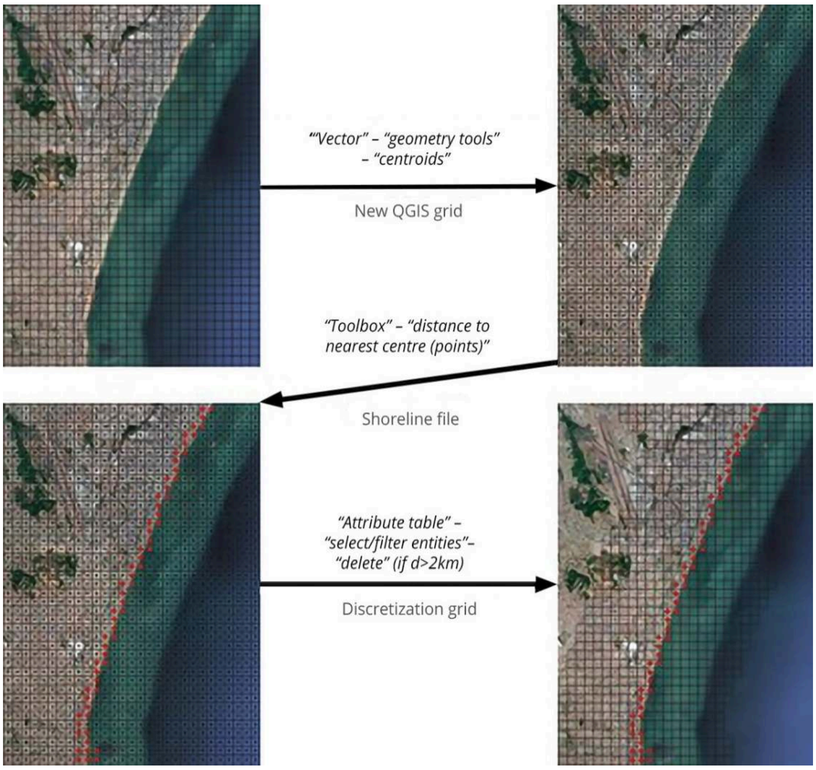
Figure 1. Discretisation grid (in red) of the Pernambuco study area and a zoom on Recife (yellow rectangle)



Source: Google Earth image processed with QGIS

9 The discretisation grid was generated using the dedicated QGIS function in the “Vector” tab. The default grid produced by QGIS is rectangular, which was not suitable to cover the latitudinally extended Pernambuco coastline. To remedy this, we created and positioned pixel centroids using the “Generate points (pixel centroids)” function in the “Vector” tab. Then, the “Distance to the nearest hub (points)” algorithm included in the QGIS toolbox was used between the pixel centroids and the file containing the shoreline coordinates. This procedure resulted in the final discretisation grid by deleting the pixels located more than 2 km from the shoreline (Fig. 2).

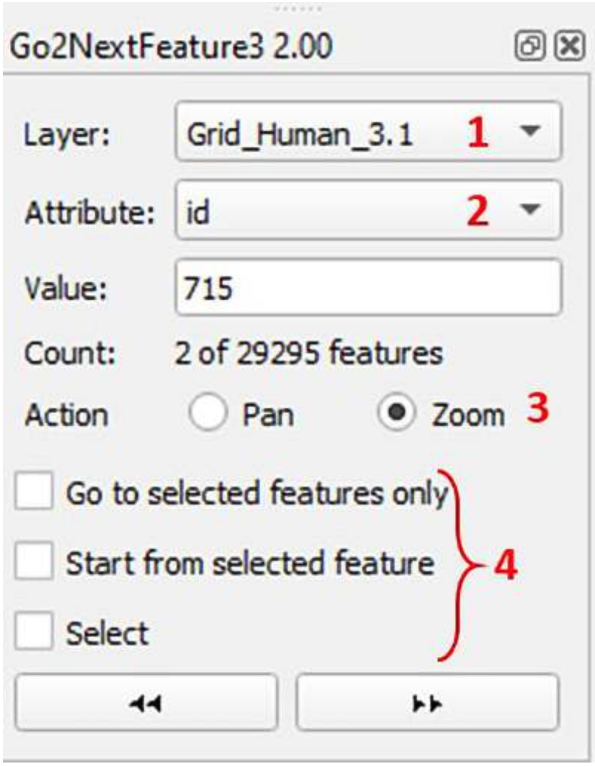
Figure 2. Workflow for developing the discretisation grid



In italics, path to desired commands in QGIS 3.4 Madeira
In bold, the files used
Source: Google Earth image processed with QGIS

10 Each pixel has an identification number and spatial coordinates. Once the grid is created and overlaid on the GE image background, it is possible to count the features of interest in each pixel and thus determine their spatial distribution. In practice, each pixel (identified by an ID number) is associated with a row in the QGIS attribute table, a spreadsheet used to retrieve the data. The QGIS "Go2NextFeature" extension allows the pixels to be listed (fig. 3) and the relevant information to be noted by point and click.

Figure 3. Go2NextFeature Extension Control Panel



This easy-to-use function allows you to choose the layer of the discretisation grid to be scrolled (1) according to the object considered (2), the action applied during scrolling (3), and the action applied on the object considered (4).
Source: QGIS

Categorisation

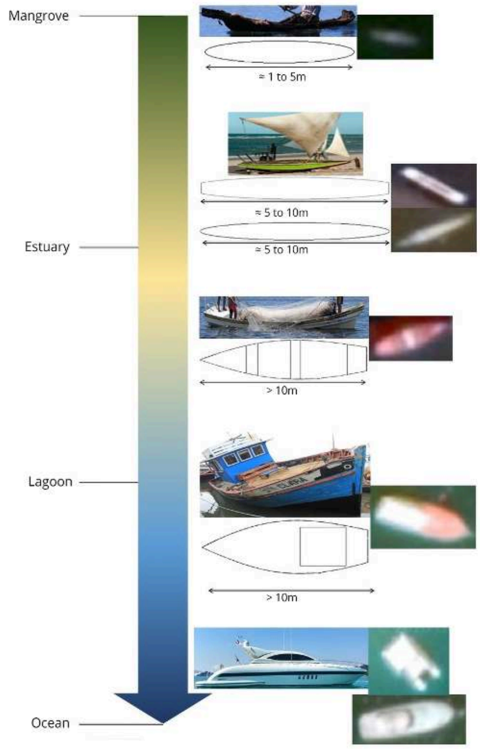
11 In this case study, we sought to identify objects that could be interpreted as indicators of human-induced pressures and that were identifiable in aerial views. In this area, where tourism and fishing activities are dominant, we counted the following objects: sun umbrellas, swimming pools, hotel infrastructure (four categories of hotel size: small, medium, large and very large), fishing gear (deployed nets and fish enclosures) and boats. Sun umbrellas, swimming pools and hotel infrastructure can be an indicator of tourism-induced anthropogenic pressure. Hotel infrastructure was subdivided into size categories to better describe the potential intensity of pressure created by tourism activity (fig. 4).

Figure 4. Size difference between two types of tourist infrastructure

The largest observed (left panel) and the smallest (right panel, circled in red).
Source: Google Earth

12 In terms of boats, a first category distinguished the use to which they are likely to be put (tourism or fishing) and a second category classified fishing boats according to their size: canoe-type fishing boat (*canoa*, non-motorised), raft-type fishing boat (*jangada*, possibly motorised, but low-powered and outboard), motorised fishing boat (inboard motor, with a deck or not), and finally boats for tourism. Each category of boat has a particular shape that can be recognised in aerial images (fig. 5). A *canoa* can be distinguished from a *jangada* by its size, the former being smaller. When there was doubt between two categories (between two types of engine, for example), the environment where the boat was located allowed us to determine its category. Motorised open boats are almost exclusively found in mangrove and estuary environments, whereas motorised boats with a deck are most often found in lagoons or at sea.

Figure 5. **Illustration of the five categories of boats and the environments where they are most often found**



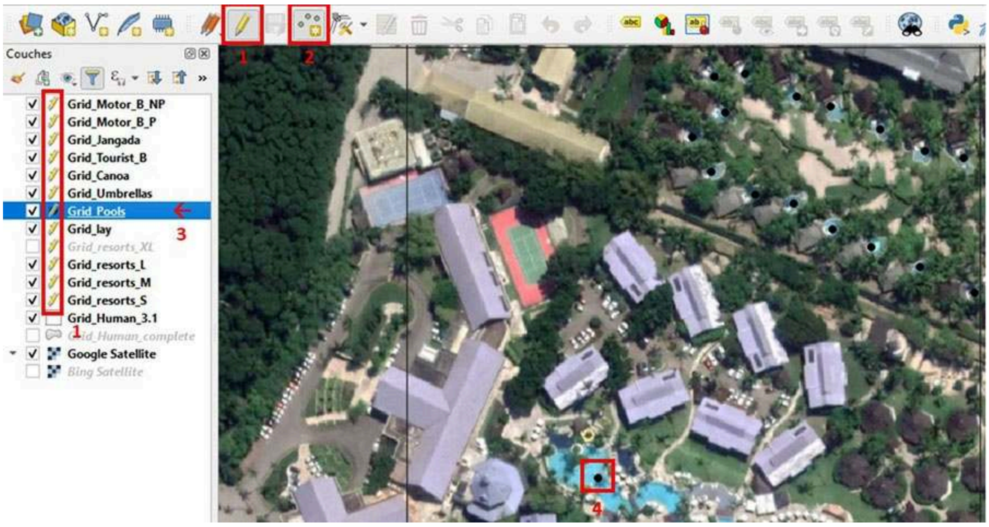
Each category includes a picture of the boat (top left), a schematic representation with the details important for its recognition (bottom left) and a screenshot of its appearance in GE images (right). From top to bottom: *canoa*, *jangada* (from the south of the state above, and from the north below), open motorised boat, motorised boat with deck, and tourist boat.
Source: A. Giorgis

Enumeration of the features

13 Once the features to be counted are identified, it is time for the most laborious part of the job, which is to point and click on each feature under consideration in each unit of the grid. QGIS automatically counts the selected features and provides a tabular output. This point-and-click approach allows for visual transparency and traceability, which hopefully allows for future improvements and possible corrections.

14 This method is made possible by two functions in QGIS. One allows the editing of several layers at the same time and the automation of an essential part of the count. This allows all layers to be put into edit mode at the same time (1 in fig. 6). To do this, the operator simply clicks on the "Add point feature" button (2 in fig. 6), selects the layer corresponding to the feature to be added and clicks on the feature in question (3 and 4 in fig. 6).

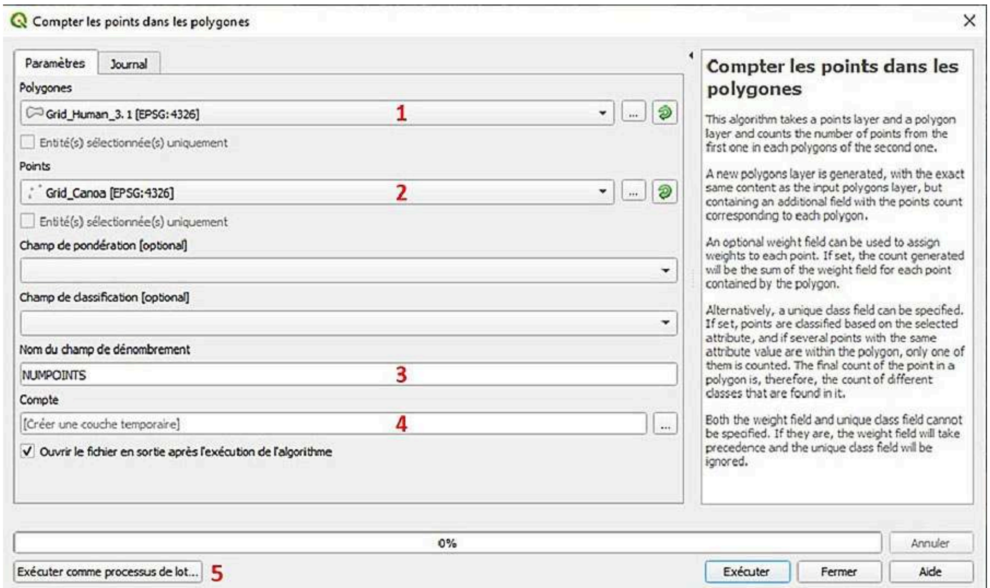
Figure 6. Screenshot of the counting area and application of the point-and-click method



(1) All layers are put in edit mode at the same time
(2) Click on the "Add point feature" button
(3) Select the layer corresponding to the feature to be added and (4) click on the feature.
Source: QGIS

15 Another function is based on the "Count points in polygons" function, which is a Python program, offered in the "Vector" tab of QGIS. This automates the counting of points resulting from the point-and-click process (fig. 7), which would otherwise be a very time-consuming task. This procedure depends on the creation of a layer for each category of anthropogenic pressure, detailed in the previous section.

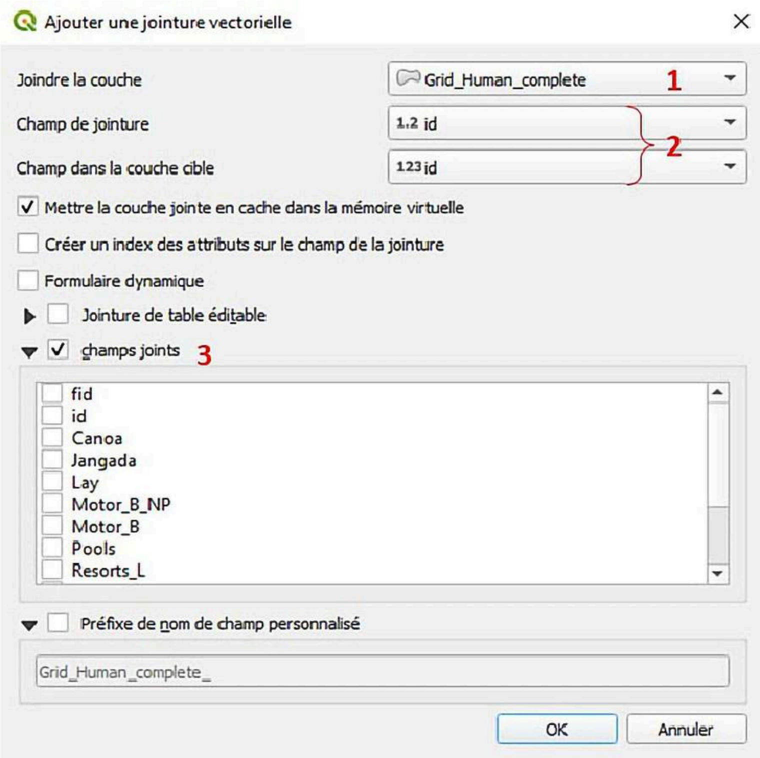
Figure 7. Control panel for the "Count points in polygons" functionality



(1) Layer containing the polygons
(2) Layer with features to be counted
(3) Name chosen from the attribute table field in the future layer
(4) Name of this new layer
If the count is to be performed on a large number of layers, it is possible to run the algorithm in "batch" mode (5).
Source: QGIS

16 As soon as each pixel of the discretisation grid has been scanned, the “Count points in polygons” program can be launched for each object layer. QGIS then adds a new column to its attribute table with the number of points in each pixel. Finally, to centralise all counts, each count column of each feature layer is included in the attribute table of the count grid using the “Merge vector layers” functionality of QGIS (fig. 8).

Figure 8. Control panel for the “Merge vector layers” functionality



Select the layer to be linked (1), fill in the linking field (2), which must contain the same data format (name, number, etc.) in both layers, but must not have the same field name. It is then possible to select the fields to be linked (3).
Source: QGIS

Indicators of anthropogenic pressures

17 This section presents how to calculate indices of anthropogenic pressures (in our case study, related to fishing and tourism pressure along the Pernambuco coastline) from counting features in aerial images.

General calculation

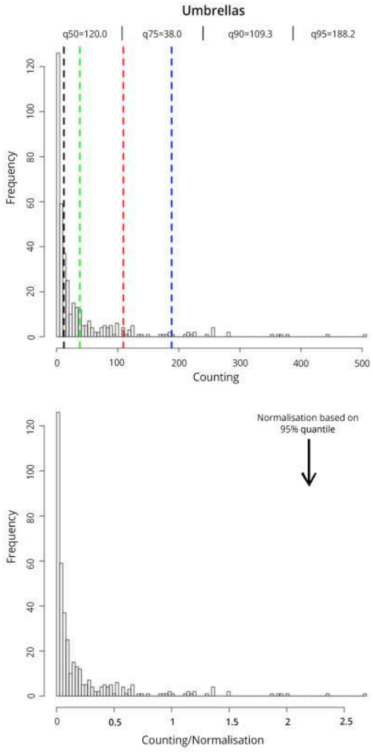
18 The main difficulty we encountered was the observable disparity between the count values obtained in each pixel for a given category and between the categories themselves. For example, in the “sun parasols” category, most of the values were less than 100 occurrences per pixel, while some reached 500 occurrences. The category “extra-large infrastructure” was far from this number of occurrences per pixel, representing only 48 objects in total. Such disparities prevent a normalisation with the maximum distribution value. We therefore decided to plot the distribution of the

histogram of each (non-spatialised) count to allow for further examination. In doing so, we determined that it made more sense to normalise the results based on the 95% quantile of non-zero values in each category (fig. 9). We removed the null values because they are the most represented value in the count, but are not meaningful in terms of occurrences of the category. After normalisation, each type of object counted became comparable and could be included in a weighted sum. It was then necessary to find a suitable formula, taking into account the fact that each category does not contribute equally to the anthropogenic pressure on the environment. In order to represent the unbalanced effects, adjustable relative weights were assigned to each category, which can be expressed as follows:

$$Index = \sum_{i=1}^{n} \omega_i \frac{x_i}{q_{95\%}(x)}$$

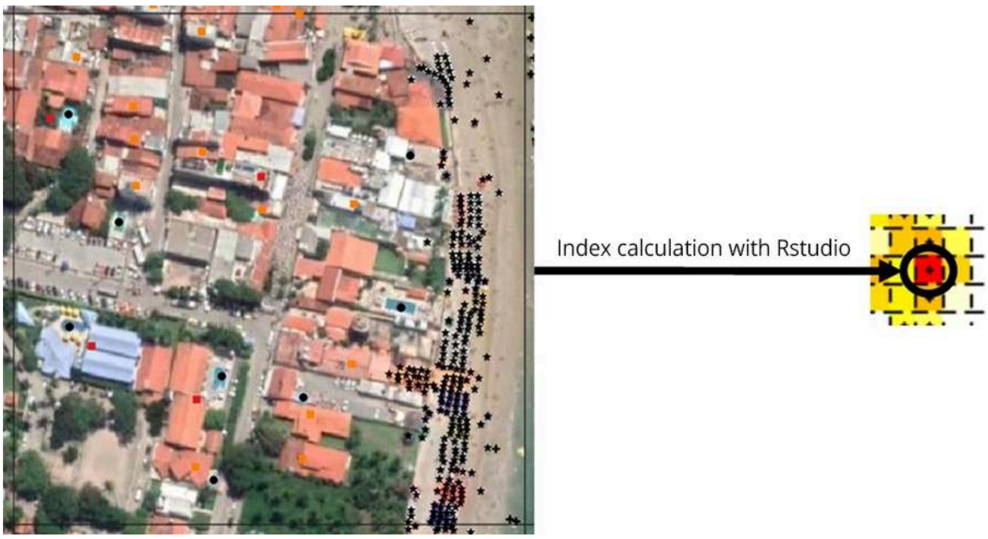
19 Using this calculation, we were able to provide an overall density map (fig. 10) of anthropogenic pressure. Its colours range from white (lowest density) to yellow, orange and red (highest density). The scale was calculated in relation to the pixel with the highest index value. In short, red represents maximum pressure, yellow/orange represents moderate pressure and white means that no pressure was identified.

Figure 9. Distributions of "sun parasol" histograms before (top) and after (bottom) the 95% quantile normalisation



The black, green, red and blue vertical lines represent a distribution of 50%, 75%, 90% and 95% quantiles of non-zero count histogram values respectively.
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Figure 10. An example of the conversion of raw count data (left) into coloured pixels based on the calculation of the tourism index (right)



In the left panel, each symbol (coloured square, star, circle, etc.) represents a feature belonging to the categories included in the calculation of the tourist pressure index. The right panel shows the density map of the surrounding pixels obtained by the calculation of our algorithm. It shows a pixel where tourist pressure is quite high, which can be explained by the large number of different features contributing to this.
Source: Google Earth

Fishing activity

20 A similar methodology can be applied to derive an index of fishing pressure based on counts of different types of boats (for an alternative source of data on boat monitoring, see Box 1). As an illustration, the following formula was applied successively to each pixel of the grid to calculate an overall index of fishing pressure per pixel:

$$0.3 \times \frac{Number\ of\ canoas}{Q95\ of\ canoas} + 0.7 \times \frac{Number\ of\ jangadas}{Q95\ of\ jangadas} + 0.05 \times \frac{Number\ of\ fishing\ boats}{Q95\ offishing\ boats}$$

$$+ \frac{Number\ of\ motorised\ boats\ with\ decks}{Q95\ of\ motorised\ boats\ with\ decks} + 0.7 \times \frac{Number\ of\ motorised\ boats\ without\ decks}{Q95\ of\ motorised\ boats\ without\ decks}$$

these different categories, we chose a weighting that simply optimises the graphic representation of the overall index. However, this pragmatic choice could easily be modified by a different balance of weights if objective criteria of other kinds are identified by experts in the field.

Box 1. How can automatic identification system (AIS) data be used for marine spatial planning?

Matthieu LE TIXERANT

While the value of MSP is now recognised and the legislative framework is being established, its operational implementation is sometimes tricky. One of the keys to success is the availability of evidence. The spatio-temporal development of maritime uses and conflicting or synergistic interactions between activities are essential information, but are particularly difficult to obtain in the marine environment. As a result, this type of data is often the weak link in information systems developed by maritime stakeholders.

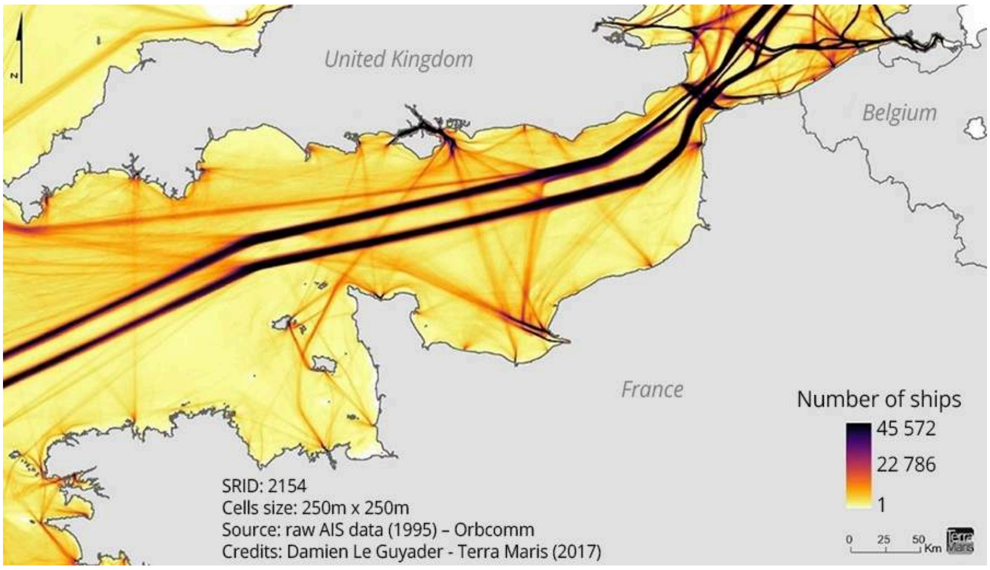
Since 2002, the use of the automatic identification system (AIS), essentially a tracking system used on ships, has been developing. Allowing real-time geolocation and identification of equipped vessels, the data from this system is a promising avenue for characterising certain human activities at sea. The relatively recent availability of archived data covering almost the entire coastal and offshore seas from the development of satellite AIS is a very useful resource in the field of operational oceanography. The analysis of AIS data can provide information on the spatial and temporal distribution of shipping and maritime fishing activities. This data is increasingly used for specific applications such as collision risk detection, real-time monitoring of ship behaviour, assistance with fisheries management and surveillance, risk assessment of infrastructure (submarine cables, ports, coastal nuclear power plants, etc.), estimation of marine currents, and measurement of chemical or noise pollution emissions generated by maritime traffic. This spatio-temporal information on maritime activities can also be associated with socio-

economic indicators that are of significant importance for MSP.
Within the framework of the Paddle project, studies have been carried out to evaluate the current uses of AIS for MSP at the European level and then to summarise a series of methods and results obtained in several operational research projects. The objective is to illustrate how the processing and analysis of AIS data can produce information suitable for MSP: maritime traffic density (fig. 11), shipping lanes and flows, hierarchical network of shipping routes, presumed fishing areas, spatio-temporal interactions between activities (conflicts of use or potential synergies between activities), etc. These studies have also examined the main legal issues relating to the use of AIS (access to non-anonymous data in principle reserved for public agencies for security, surveillance and monitoring purposes, use of personal data, commercial confidentiality, etc.).

For more information

LE TIXERANT M., LE GUYADER D., GOURMELON F., QUEFFELEC B., 2018
How can automatic identification system (AIS) data be used for maritime spatial planning? *Ocean & Coastal Management*, 166: 18-30.

Figure 11. Sample map showing the intensity of maritime traffic from AIS data in number of trajectories per pixel (2015, all types of vessels)



Source: Terra Maris/D. Le Guyader, 2017

Tourism

21 Similarly, we calculated an index of tourist pressure according to the following formula applied to each pixel of the Pernambuco coastline:

$$0.05 \times \frac{Number\ of\ swimming\ pools}{Q95\ of swimming\ pools} + \frac{Number\ of\ small\ hotels}{Q95\ of\ small\ hotels} + \frac{Number\ of\ medium\ hotels}{Q95\ of\ medium\ hotels}$$

$$+ \frac{Number\ of\ large\ hotels}{Q95\ of\ large\ hotels} + \frac{Number\ of\ very\ large\ hotels}{Q95\ of\ very\ large\ hotels}$$

$$+0.5 \times \frac{Number\ of\ tourist\ boats}{Q95\ of\ tourist\ boats} + 0.7 \times \frac{Number\ of\ sun\ parasols}{Q95\ of\ sun\ parasols}$$

22 Here again, the relative weights were chosen for illustrative purposes, to optimise the graphic representation of the overall index. This pragmatic choice can easily be modified by a different balance of weights if objective criteria of another nature are identified by experts in the field.

Results

23 The algorithm used for the calculation of pressure indices aimed to produce two types of files: a file containing raw counts per pixel and maps of pressure indices related to fishing and tourism.

Counts

24 The object tables for each count layer, as well as a summary layer, were exported in CSV format (comma-separated values, a text format with a comma or semicolon as separator), chosen because of its generic nature. This format facilitates sharing, storage and manipulation, both with Excel and with QGIS procedures. In addition, the procedure used to generate the anthropic pressure maps (in our case, related to fishing and tourism) can also create density maps of the raw count data. A total of 33,832 objects located along the Pernambuco coastline were counted and classified into the categories presented in Table 1.

Table 1. Objects counted by category

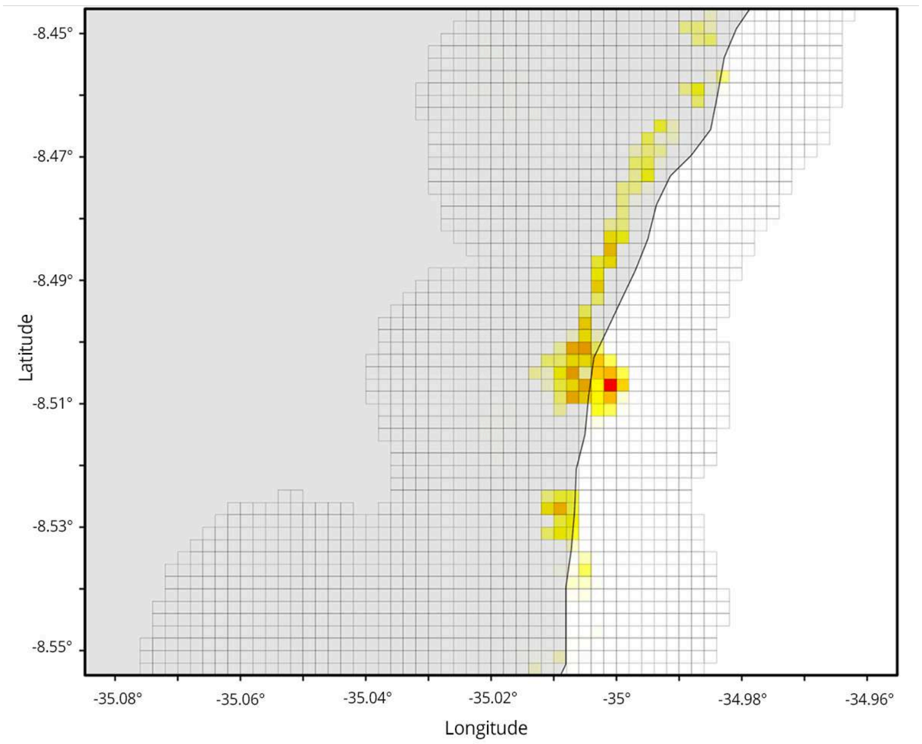
Category	**Total number of objects**
Tourism	**31,228**
Swimming pools	12,920
Small hotels	158
Medium hotels	802
Large hotels	243

Very large hotels	46
Tourist boats	1810
Sun parasols	15,249
Fishing	**2604**
Canoas	518
Jangadas	1199
Fishing boats	13
Motorised boats with decks	458
Motorised open boats	416

Pressure index maps

25 The resulting map of tourism-related pressures shows a linear and zonal distribution along the coastline in the south (fig. 12). The presence of many overlapping coloured pixels coincides with the location of the main cities of the state, such as its capital, Recife, or the seaside resort of Maracaípe. This indicates localised pressure, whose impacts are concentrated on a small area that can be identified by clusters of red or orange pixels surrounded by yellow pixels (fig. 12). The large white areas in the north overlap with those where mangroves are the dominant environment.

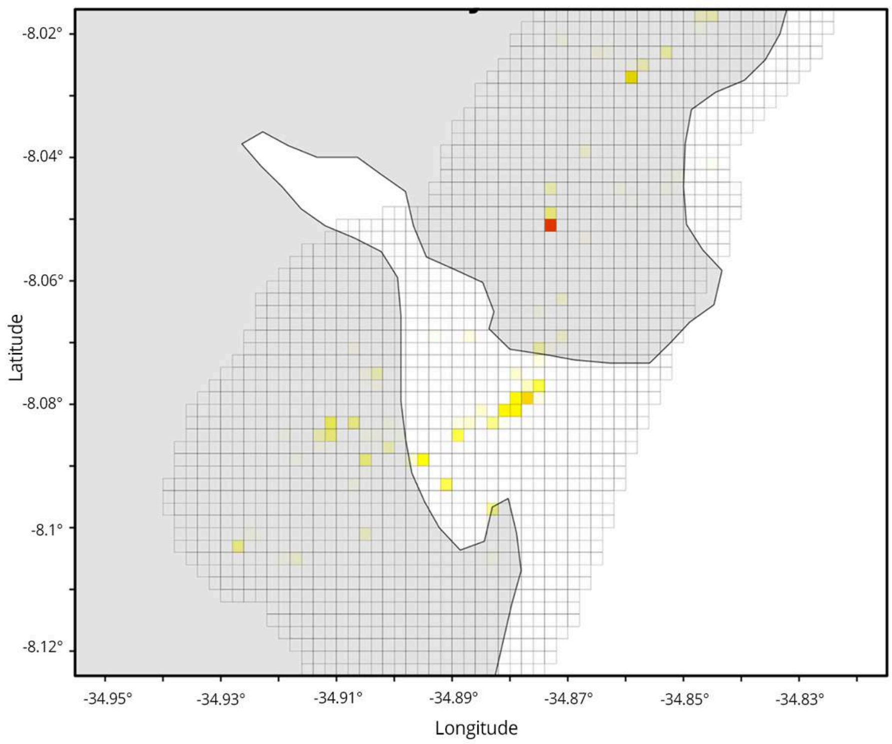
Figure 12. **Extract of map resulting from the calculation of the tourism pressure index**



The red pixel corresponds to the location of the city of Maracaípe. The yellow pixels are arranged concentrically around a red pixel, which shows high and localised pressure
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

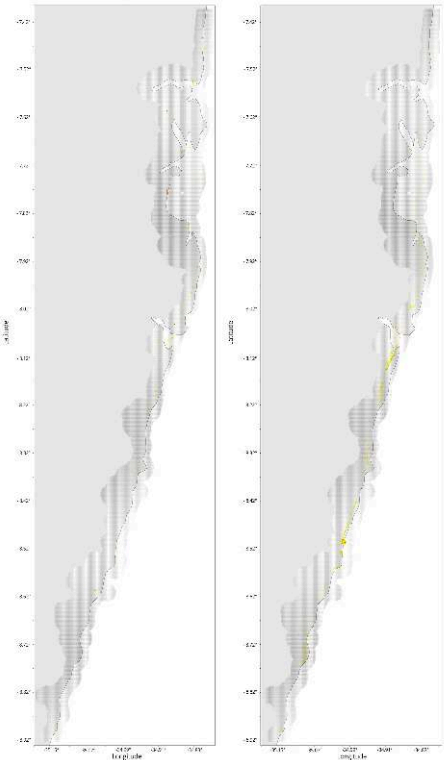
26 In the case of fishing, the trend is very different, indeed, the inverse. Fishing pressure is not concentrated around cities as in the case of tourism. Instead, yellow pixels are spread across all environments, from north to south (fig. 14). Although some impact zones are the same as those for tourism, the impact is much less significant. The pressure is more diffuse (fig. 13), i.e. exerted weakly to moderately on all environments, both in lagoon and mangrove ecosystems.

Figure 13. **Extract of map resulting from the calculation of the fishing pressure index**



The coloured pixels inland are due to the lack of coastline detail, which does not represent small estuaries.
Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Figure 14. Full maps of indices of fishing pressure (left) and tourism pressure (right)



Source: A. Brunel, A. Giorgis, N. Bente, G. Domalain, S. Lanco Bertrand

Discussion

27 This section discusses the limitations of the method, the key points to be retained and offers recommendations for possible future improvements.

Limitations of the approach

28 One limitation to take into account is that during the enumeration process, problems of temporality were observed. The satellite images are selected by the program to minimise cloud cover; a selection that is necessary, but creates areas where two nearby images may correspond to different seasons. This can introduce a significant bias in object counts: for example, in our case beach umbrellas are highly dependent on the season. To remedy this bias in the count data, one could consider assigning an internal weighting factor that reflects, for each image, the season in which it was taken.

29 Secondly, GE images record static objects, which are useful for assessing the spatial extent of infrastructure and features linked to human activities, but which only act as indicators of the presence of different activities that approximate the actual uses of marine areas. To deduce the use of areas from these indicators, it is necessary to formulate hypotheses based on other data: for example, what is the average range of a *canoa*, a *jangada* or different types of motorised craft? Which areas are most frequented by tourist boats and for which types of activity (walking, diving, recreational fishing, etc.)? What is the average occupancy rate of the different categories of hotels according to the season? What is the percentage of tourists who engage in activities at sea? These

hypotheses can then be used to estimate, at a lower resolution than that of the counts, but still spatially explicit, the areas where the various marine uses are carried out. For example, the intensity of anthropogenic impacts on the seascape can be estimated by adopting an approach based on centres of gravity that combines the objects counted with the accessibility of different areas at sea, as proposed by CINNER *et al.*

30 A further limitation is that in order to develop indicators of fishing or tourism pressures based on counting different objects, we had to "compare apples and oranges". To compensate in part for the variable effects of the various objects on the occupation of space at sea, we proposed introducing weighting when integrating them in the form of an overall indicator of fishing or tourism activity. Clearly, this weighting is not insignificant in the final result, and it should therefore be the subject of consultation between experts and users of marine areas in order to best represent the reality on the ground. Ideally, a sensitivity analysis of the pressure maps produced with these weighting factors should be systematically carried out and opened up for discussion.

Points to keep in mind

31 Our case study allows us to conclude that:

- The combination of QGIS and Google Earth can provide relevant information based on free data with global coverage, which is particularly valuable in a data-poor context.
- It is possible to create a spatially explicit database that is traceable, reproducible, easy to share and capable of feeding into MSP scenarios (and prospective impact assessments, see Box 2).
- The effectiveness of the approach is highly dependent on the resolution and temporality of the satellite images, as well as on the choice of objects to be counted, their respective weights, and the assumptions used to deduce the uses of marine areas.

Box 2. Impact assessments: a tool for taking the environment into account in MSP

Philippe FOTSO

In international environmental law, two concrete measures have gradually become established as transversal tools in the procedures of environmental protection: environmental impact assessment (EIA) and public participation in environmental matters. These create a procedural framework for environmental protection. An environmental impact assessment is an opportunity to verify the feasibility of an activity and to plan in advance how to avoid and reduce its impact on the environment. There are two forms of EIA: (1) a so-called "classic" or "operational" impact assessment, i.e. one that concerns specific development projects, and (2) a strategic environmental assessment (SEA), which relates to proposed policies and programmes. The latter involves a formalised, systematic and comprehensive process of identifying and assessing the environmental consequences of proposed policies, plans or programmes to ensure that these consequences are fully taken into account and appropriately addressed at the earliest possible stage of decision-making alongside the consideration of economic and social factors (SADLER, 1996).

The first legal recognition of EIA in international law entered into force in 1997,

with the Convention on Environmental Impact Assessment in a Transboundary Context (known as the Espoo Convention). The Protocol on Strategic Environmental Assessment (known as the Kiev Protocol), adopted in 2003, established a legal framework for SEA.
The signatories of these conventions are essentially European. In other countries, the legal framework for environmental impact assessments varies. In Brazil and Cabo Verde, there is currently no formal SEA instrument; "classic" EIA is a measure in framework laws on the environment and is enshrined in the Basic Law. In Senegal, the 2001 Environmental Code Act devotes a specific section to SEA in Chapter V on impact assessment. Like traditional EIA, the implementation of this measure falls within the regulatory domain, and the regulatory framework has not yet been adopted (FOTSO, 2019).

For more information

FOTSO P., 2019
Legal conditions for environmental integration in marine spatial planning (MSP). Opportunity analysis of the diffusion of a public process in the tropical Atlantic (Cape Verde, Senegal and Brazil), in the light of the experience of the European Union (EU). PhD thesis in law, Brest, University of Western Brittany, 424 p.

SADLER B., 1996
Environmental assessment in a changing world. Evaluating practice to improve performance – final report. Quebec, Canadian Environmental Assessment Agency, 248 p.

Recommendations for future use of the approach

32 The approach proposed in this chapter could be improved with one or more of these guidelines:

- Other databases could be used to describe anthropogenic pressure more precisely. For example, the Airbnb database could provide more detailed information on "tourism infrastructure" objects.
- New satellite images and improved image processing can provide better image resolution. For example, the Sentinel 1 satellite, using synthetic-aperture radar technology, offers the possibility of obtaining images, regardless of cloud cover, at a resolution of 10 m. This could limit temporal phase shifts between two neighbouring images.
- Deep learning artificial intelligence methods for image processing could be a relevant approach to automate the counting task. However, while this seems quite feasible for use at sea due to the uniform blue background, it seems more difficult for use on land.
- Maps obtained from images from other years could be compared to better understand the temporal variability of human activities.

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NOTES

1. QGIS: www.qgis.org/en/site/; GE: www.google.com/intl/en_uk/earth/

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