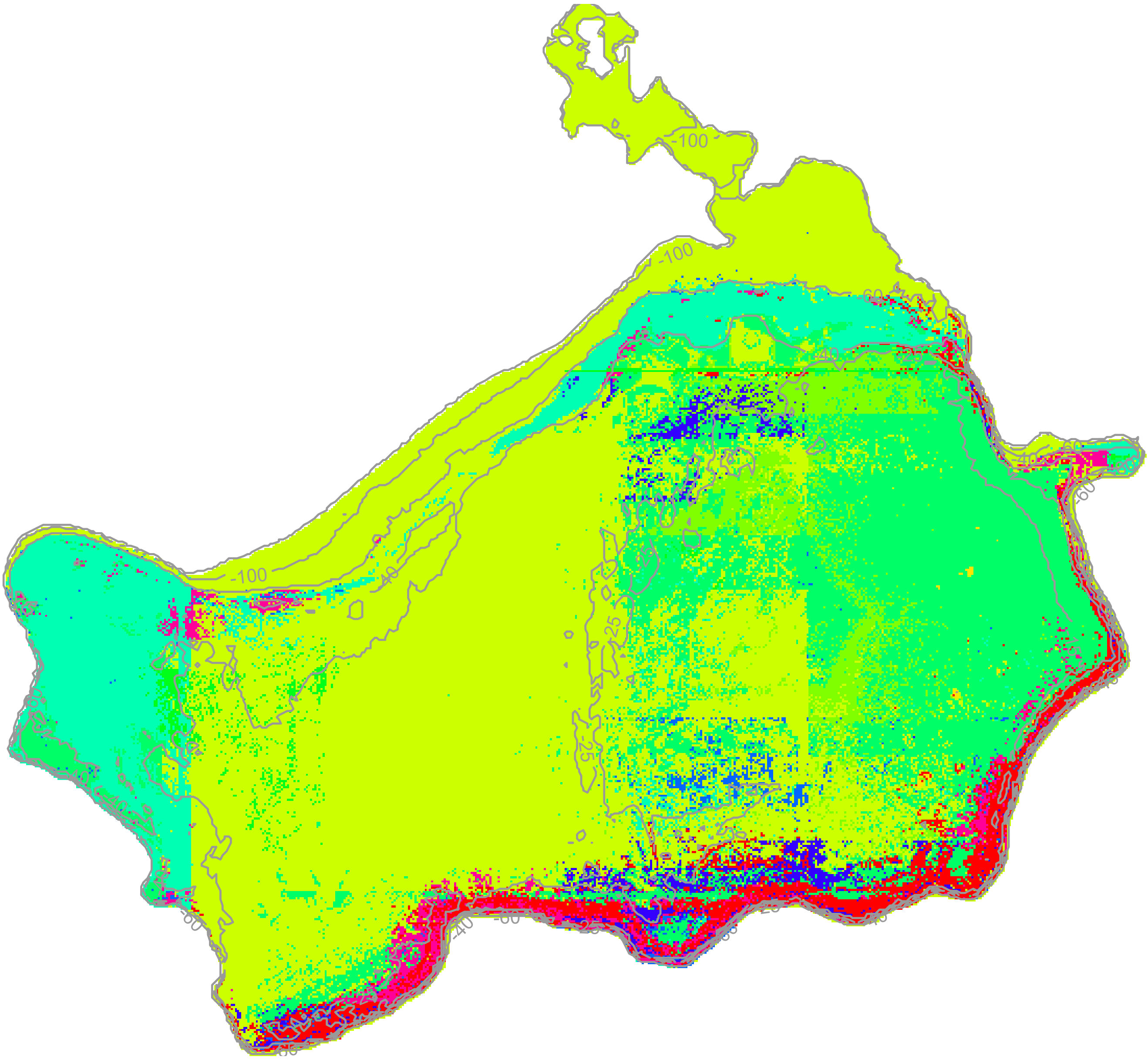

Benthic habitats of the Saba Bank

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Wageningen University & Research report:C098/23

WAGENINGEN UNIVERSITY & RESEARCH

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Wageningen Marine Research
Report C098/23

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Photo cover: Figure 29. Gradient boosting predicted habitat types.

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Contents

Summary

Habitat mapping is crucial for understanding habitat connectivity and for spatial planning, environmental management, conservation, and targeted research, including long-term change monitoring. However, such information has been lacking for many Dutch Caribbean islands, especially regarding marine habitats. This study used 2144 georeferenced images from different surveys to develop habitat models predicting the distribution of habitat types within the Saba Bank National Park. The habitat models link environmental factors to species or habitat occurrence, enabling predictions in unsurveyed areas with known covariates. Machine learning techniques (Random Forests, Gradient Boosting, and weighted K Nearest Neighbor) were applied to interpret and predict ten habitat types over the Bank. Three models were created for each technique: 1) utilizing only geographic coordinates; 2) incorporating covariables such as depth, distance to the edge of the Bank, Topographic Position Index (TPI), and Terrain Ruggedness index (TRI); 3) a combination of the previous two models. All models performed well, accurately predicting habitat types between 67 and 74% of the georeferenced images. However, the most natural representation occurred with models combining geographic and covariate variables. Predicted habitats include coral reef, patch reef, gorgonian reef, sargassum fields, cyanobacteria-dominated fields, *Lobophora* fields, Neogoniolithon-Lyngbya habitat, other macroalgae fields, sand with a mix of species, and bare sand. Habitat distribution appears to be related to the main currents in the area and depth, with coral reefs occurring mainly along the southern and eastern edge of the Bank, with gorgonians and other soft corals dominating there the shallow areas. Macroalgae, including fields of Sargassum, dominate the back-reef area. Extensive sand plains dominate the center of the Bank, and along the north-western and northern edge of the Bank, between 40 and 60m depth *Lobophora* fields can occur. In the south-eastern back reef area a number of mounds built up by the coralline alga *Neogoniolithon* occur. The Luymes Bank, the northeastern part of the Saba Bank, was the only area that was not correctly predicted, indicating that additional field-based observations are needed to refine results in this area.

1 Introduction

Quantitative habitat mapping and description form the basis for understanding the provisioning of ecosystem services and habitat connectivity, provide an essential underpinning for spatial planning, management and conservation, as well as for efficient targeting of scientific research, among which the monitoring of long-term change. Such background information has either been outdated or lacking for most of the Dutch Caribbean islands, particularly with respect to marine habitats (Debrot & Sybesma, 2000). Considering the rapid pace of urbanization and development of infrastructure on several of these islands, the need for baseline descriptive ecosystem assessment and mapping has been acute and recognized as a priority within the Exclusive Economic Zone (EEZ) management plan for the Caribbean Netherlands (Meesters et al. 2010). It has also been incorporated as a key action point in the nature and environmental policy plans for the Caribbean Netherlands (Min. EZ, 2013; Min. LNV et al., 2020). Several studies that map habitat diversity and biodiversity throughout the Dutch Caribbean have been done, including in Lac Bay, Bonaire (Davaasuren & Meesters, 2012; Debrot et al., 2019), Saba (Kuramae & van Rouendal, 2013; de Freitas et al., 2020), St. Eustatius (Debrot et al., 2014; de Freitas et al., 2014), and St. Maarten (de Freitas et al., 2020).

One key area that remains to be properly mapped is the Saba Bank, which is located approximately 5 km southwest of Saba Island and 25 km west of St. Eustatius (Fig. 1) and possesses a rich marine biodiversity, including a wealth of sponges, marine algae, corals and reef fish species (Hoetjes & Carpenter, 2010; Littler et al., 2010; McKenna & Etnoyer, 2010; Thacker et al., 2010; Toller et al., 2010; Hoeksema et al., 2018). The Saba Bank is a refuge for coral reef organisms and a potentially important source of replenishment of biodiversity and fish stocks throughout the northeastern Caribbean (Glynn, 1996; De Bakker et al., 2017; Truelove et al., 2017).

Since 2010 the Saba Bank has attained a successively higher and more extensive conservation status (2010: "Nature Park" by the Netherlands; 2012: "National Park" by the

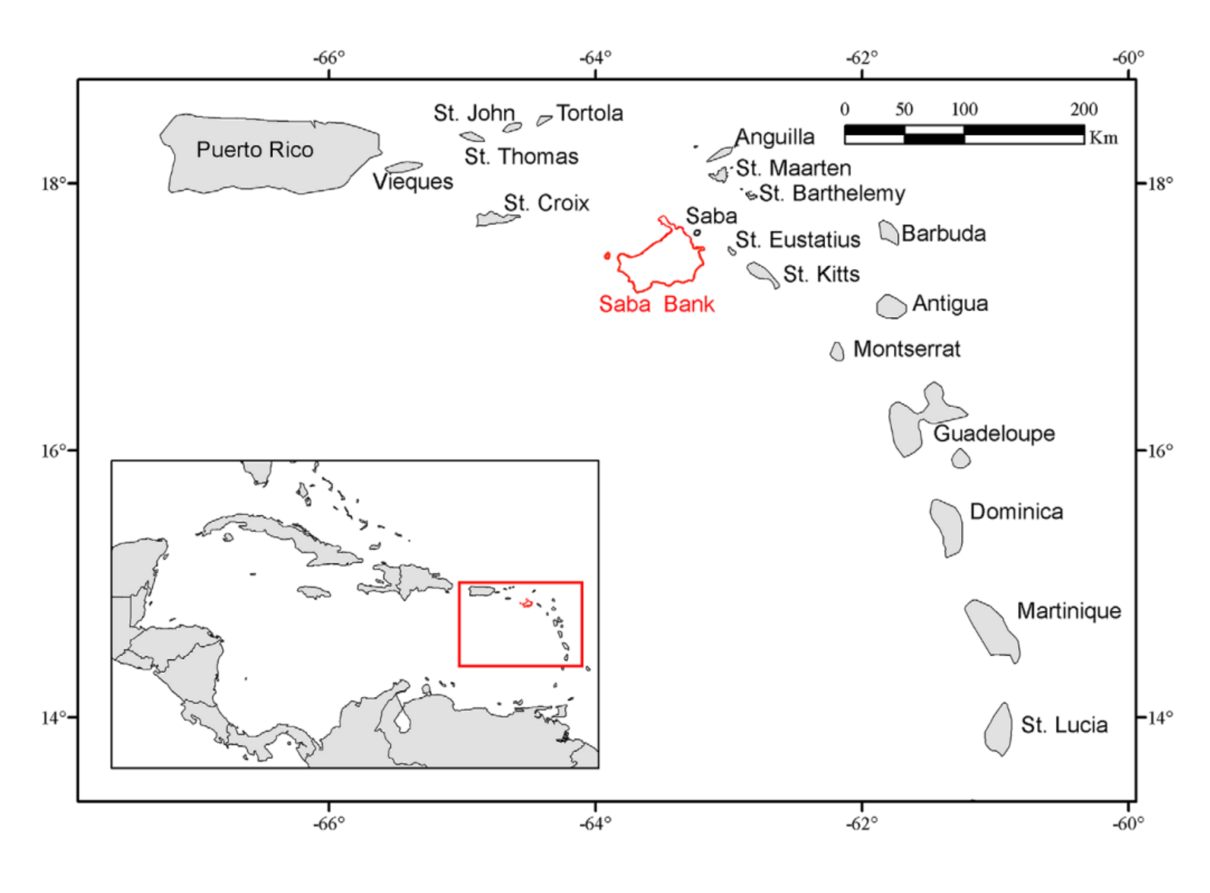

Figure 1. Location of the Saba Bank (source: Hoetjes & Carpenter, 2010).

Netherlands, “Particularly Sensitive Sea Area” by the International Maritime Organization, “Specially Protected Areas and Wildlife (SPAW)” status within the SPAW Protocol, “Ecologically or Biologically Significant Marine Area (EBSA)” within the Convention on Biological Diversity; 2015: part of the “Yarari Marine Mammal and Shark Sanctuary” status by the Netherlands) (Van Beek & Meesters, 2014; Debrot et al., 2017).

The Saba Bank National Park covers an area of 2680 km^2 and is the largest national park within the Kingdom of the Netherlands. In addition, the Bank also represents one of the richest and most important fishing grounds in the Caribbean Netherlands (de Graaf et al., 2017, Brunel et al., 2021). The fisheries of the Saba Bank were estimated to contribute approximately 1.38 million US$ annually to the economy of Saba (Van der Lely et al., 2014). In comparison, the key sector of Saba, nature tourism, yields about 7.5 million US$ annually (Van de Kerkhof et al., 2014). In 2015, the total landings of fisheries amounted to 135.2 tons, with 60% of the annual commercial effort (in terms of fishing trips) focused on the Caribbean spiny lobster (*Panulirus argus*) and 40% on deep-water snappers (redfish, De Graaf et al., 2017). As a basis for sustainable fisheries management, more insight into different uses of specific habitats by commercial fish stocks is critical (habitat use may vary during a species’ life cycle). This requires a good understanding of the distribution and characteristics of these habitats on the Saba Bank, which has been lacking till this study.

Habitat mapping and community description can take place at several geographic levels of detail, depending on its intended purpose and the possibilities of the method used. For example, in mapping the reefs of Curaçao and Bonaire to depths of 20 m (Van Duyl, 1985), the use of aerial photographs and SCUBA diver vehicle-assisted propulsion provided a coarse-grained quantitative community assessment of the leeward fringing reefs of these islands. The belt-transect method was used for a detailed community description of the macrobenthic seagrass communities of the Spaanse Water, Curaçao and Lac Bay, Bonaire (Kuenen & Debrot, 1995; Debrot et al., 2019). Underwater camera images were used to map benthic habitats for St. Eustatius (Debrot et al., 2014). Satellite imagery was successfully used to quantitatively assess mangrove coverage and principal species composition for mangrove stands in Bonaire (Davaasuren & Meesters, 2012). Finally, Toller et al. (2010) also used satellite imagery for coarse mapping of 5 different habitat zones across a 40 km section of the Saba Bank, combined with a more detailed community description at eight locations in each zone based on SCUBA and belt transects.

1.1 Research objectives

The benthic communities on the Saba Bank are distributed over a wide depth range. Most of the Bank lies within euphotic depths, meaning that light can still penetrate deep enough for photosynthesis (approximately 100m). Only a small fraction of the Bank (<10%) lies between 10 to 20 m, generally along the southern and eastern edges of the Bank. Currently, the available data on benthic community distribution at the Saba Bank consists of underwater towed video transects, baited remote underwater videos (BRUVs), and several extensive underwater photographic surveys from other studies conducted at the Bank in recent years. Depth data have been provided by the Hydrographic Service of the Royal Netherlands Navy. These point data were converted into a raster with a resolution of 5m.

The objectives of this study were:

- to provide a preliminary semi-quantitative assessment of the range of benthic habitat types present on the Saba Bank and their spatial distribution based on a set of geopositioned images of the benthic communities of the Saba Bank;
- predict the distribution of the distinguished habitat types on the Saba Bank using machine learning techniques;
- to discuss the distribution of these habitats and communities in relation to patterns in physical regimes of waves, currents, substrate, sedimentation, and depth.

2 Study area and approach

2.1 Saba Bank

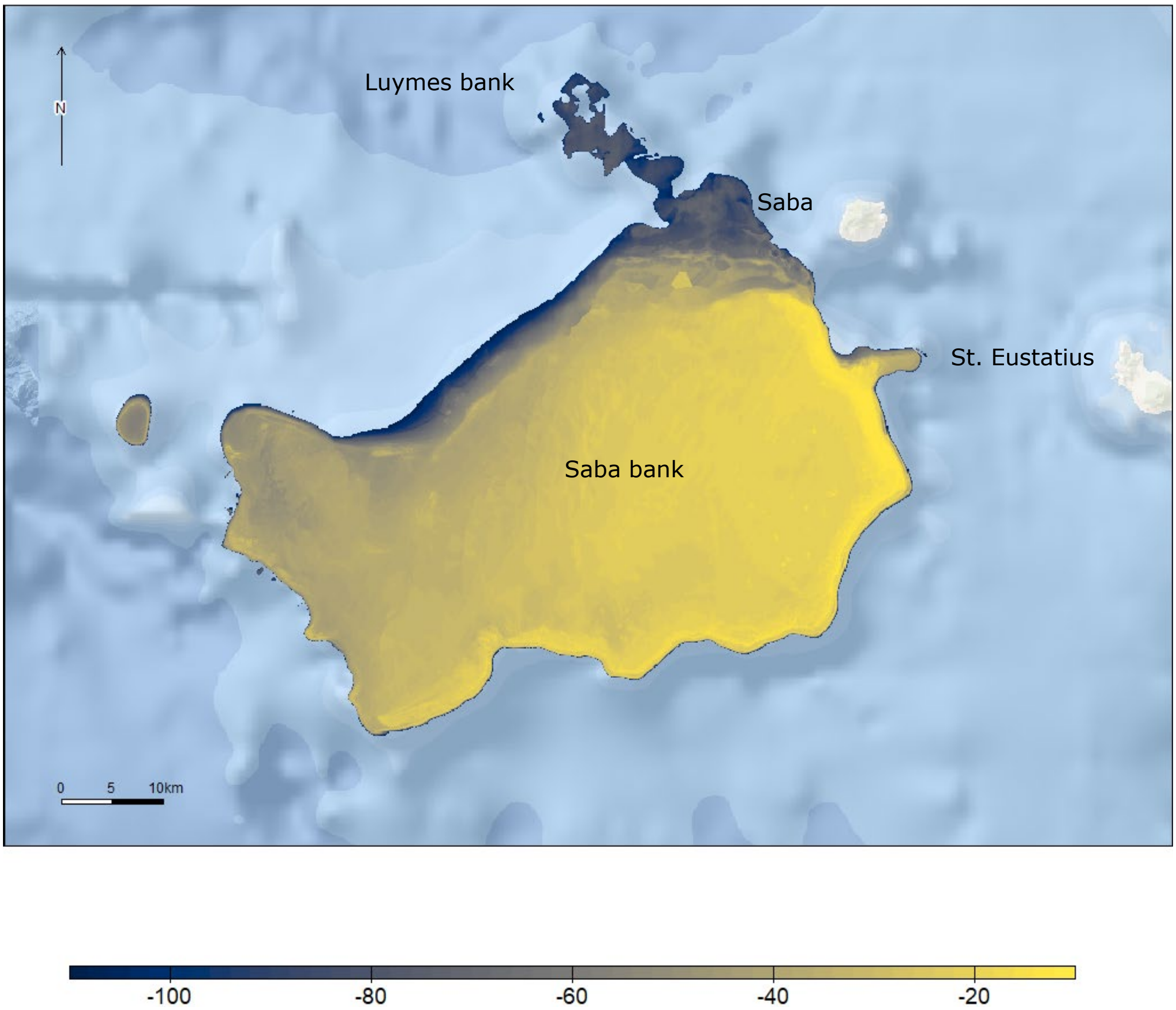

Figure 2. The Saba Bank is close to the islands of Saba and St. Eustatius. Background from ESRI; bathymetric data Saba Bank from Hydrographic Service. Depth in meters.

The Saba Bank is an isolated submerged carbonate platform situated in the north-eastern Caribbean Sea (17°25′ N, 63°30′ W) (Fig. 2; Macintyre et al., 1975; Droxler & Jorry, 2020) and has a total surface area of roughly 2,200 km^2 (60-65 km long, 30-40 km wide; Meesters et al., 1996). The Bank has a flat top but is somewhat tilted, with water depths ranging from 50 m on the deeper north-western edge to 7-15 m on the shallower south-eastern edge (Macintyre et al., 1975). Roughly 225 km^2 has a depth of 10 to 20 m (Macintyre et al., 1975; Van der Land, 1977), and the general depth of most of the Bank ranges between 20 and 50 m, making it an upper-mesophotic reef system that is deeper than most studied reefs in the Caribbean (Thacker et al., 2010). In the north-north-eastern corner, the Saba Bank extends into a carbonate peninsula that reaches not shallower than ca. 80-100m of depth called the Luymes Bank (Fig. 2) and which is connected to the Saba Bank by a ridge with a minimum depth of ca. 90 m (Van der Land, 1977). The Luymes Bank harbours multiple sinkholes that can vary in diameter from 70-1100 m and have depths ranging from 10-300 m (Humphreys et al., 2022).

Van der Land (1977) constructed an early structural map based on echo-soundings and visual observations. At the broadest spatial scale, he separated the shallow platform area into a peripheral reef zone surrounding a large "central

Table 1. *Overview of the number of geo-referenced images used to construct the database. 15 images were not used because they showed too little detail of the benthic community.*

Method	**Number of images**	**Survey time**	**Source**
Towed video transect	190	Jun-Nov 2014	Boman et al. (2016)
BRUV surveys	163	Oct 2012 & Feb 2014	See comment below
Photographic surveys	1805	Aug- Sept 2016	De Nooijer & van Heuven, 2016
Total	2158		
Total used for analysis	2144		

lagoon" zone. In contrast, he described seven discrete reef structures at a smaller spatial scale that showed a spatial gradient in habitat type extending from the Saba Bank's rim to the Bank's center. More recently, the total area of coral reef habitat based on Van der Land's survey (1977) was estimated at 255 km^2, accounting for 92% of the coral reefs in the Caribbean Netherlands (Verweij and Mücher, 2018). Another habitat type that has been described is the extensive macroalgae fields with an estimated diversity of 150-200 species, including green (e.g. *Halimeda* sp.), brown (e.g. *Dictyota* sp., *Lobophora* sp., *Sargassum* sp.), and red (e.g. *Jania capillacea*) macroalgae fields (Littler et al., 2010). So far, no seagrasses have been documented on the Saba Bank (Henkens et al., 2018).

2.2 Methodological approach

In a three-step approach, this study created habitat maps that predict the occurrence and location of the different habitats on the Saba Bank. Briefly, the first step (I) was the construction of a database including all available images of the Saba Bank that included geographic coordinates. This was followed by (II) an extensive analysis of the images, to determine the different habitat types on the Saba Bank. Lastly, (III) habitat maps were constructed following analysis of data on the location of each image, the main habitat type, and abiotic data with different machine-learning techniques. The steps are described in more detail below.

2.2.1 Constructing image database

As many as possible georeferenced images of the Saba Bank surface were collected from various expeditions and surveys of the Bank carried out from 2012 to 2016, including transects collected by a towed video method, baited remote underwater stereo-videos, and a photographic survey of the benthic communities executed by the Royal Netherlands Institute for Sea Research (NIOZ) and Wageningen Marine Research (WMR). The images were inspected for usability (e.g. was there a large amount of bottom in the image, could the main community be judged from the image, could percentage cover be estimated) and consequently characterized (Table 1). More details on the image sources can be found in Appendix 1. Image sources.

Baited Remote Underwater Videos (BRUV) were shot between October 2012 and February 2014 partly by Jelmer Pander and partly by Twan Stoffers (Stoffers, 2014). The transects collected by the Towed Video Method (TVM) were collected between June and November 2014 by Boman et al. (2016) to study Queen conch (*Lobatus gigas*) populations (Boman, 2019). The third dataset based on photographic surveys of the benthic communities on the Saba Bank was collected by Meesters and De Bakker as part of an expedition on the research vessel Pelagia organised by NIOZ that took place from 19th August to 8th of September 2016 (De Nooijer & Van Heuven, 2016).

2.2.2 Analyzing image database

Habitat characteristics on each image were scored based on (1) determination and quantification of main substrate and benthos types and (2) quantification of habitat complexity. Next, the obtained information on habitat characteristics was used to assign a habitat type to each image.

2.2.3 Substrate type and benthos

Substrate type, either rock, sand, or rubble, was estimated as a percentage of the bottom type in each image. Sand posed the greatest challenge as it was often present as a thin layer on top of a hard substrate, just as described in Toller et al. (2010). If the sand layer was judged as thin (less than a few cm), it was scored as rock. A mixture of sand, rock, and rubble is possible, but the total of the three substrate types was always 100%.

Benthos categories were (1) corals (inc. Millepora), (2) seagrass, (3) coralline algae, (4) sponges, (5) cyanobacteria, (6) Sargassum, (7) Halimeda, (8) Lobophora, or (9) other algae including turf algae. We also marked the number of soft corals, *Xestospongia muta* sponges, seastars, and the number of queen conch, but these were not included in the further analysis.

The cover of substrate type was estimated to the nearest percentage, while cover of the most benthic category was done in categories (Table 2), because images differed in orientation and it was impossible to estimate the percentage cover exactly. The categorization started at 1% because a benthos cover of less than 1% was too small to distinguish. Also, categories were not evenly distributed as an initial exploration of the data showed a large variation in the coverage percentage of benthos below 30% and less above. Among gorgonians, a distinction was made between sea fans, black corals, and other gorgonians (e.g. sea whip, sea rod, sea plume). Gorgonian colonies were counted, while the rest of the categories were given a numerical category based on the estimated percentage cover (Table 2). It is important to note that each image can be scored in different categories. For example, an image can score a 1 on 'sponges' and a 6 on '*Sargassum* sp.'.

Table 2. Numerical categories of the estimated percentage of benthos cover

Category	Percentage cover (%)
1	1-5
2	6-10
3	11-20
4	21-30
5	31-50
6	51-70
7	71-100

2.2.4 Habitat types

Several habitat types were considered, but because machine learning techniques require a substantial amount of images, we ultimately decided on the following habitat types:

2.2.4.1 Bare sand

The habitat 'bare sand' consists generally only of bare sand (>90%); however, it can also have some very sparse algae. Occasionally, a sea star, sea urchin, or queen conch can be encountered in this habitat.

2.2.4.2 Bare mixed

The 'Bare mixed' habitat type consists of mostly sand (between 30 and 80%) with a small percentage of a mix of other (mostly algal) species.

2.2.4.3 Coral reef

The coral reef habitat consists of a habitat that is dominated by living hard corals (>10%). The amount of sand is low and the habitat contains many structures originating from coral colonies.

2.2.4.4 Patch reef

Patch reef habitat consists of a clearly structured area with coral colonies that appear to be separated by patches of sand. The amount of sand is between 20 and 50%. Coral colonies look like islands in a sandy area. This area is often mingled with the coral reef area and the gorgonian reef and together they can be considered as reef area.

2.2.4.5 Gorgonian reef

This habitat is dominated by soft corals. Generally, it borders the coral reef area but is situated in the most shallow zone where wave action is high.

2.2.4.6 Neogoniolithon-Lyngbya habitat

Neogoniolithon is a genus of coralline algae. The species on the Bank has a bushy appearance characterized by many small branches. Within the fields of Neogoniolithon, there are often small patches of Lyngbya, a species of cyanobacteria, that is quite common on coral reefs. Neogoniolithon can be locally so abundant that has formed mounds hundreds of meters wide and a maximum height of 5m. The community is also characterized by many different sponge species.

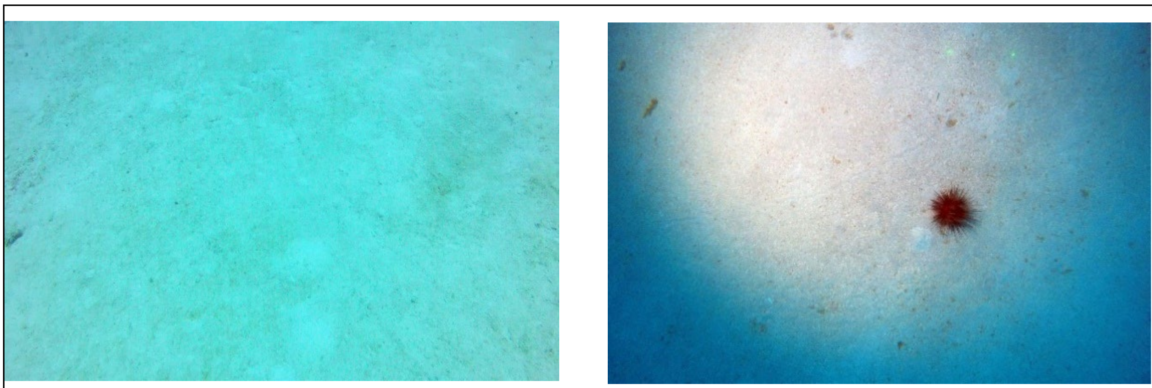

Figure 3. Bare sand with only sand (left) and a single sea urchin (right).

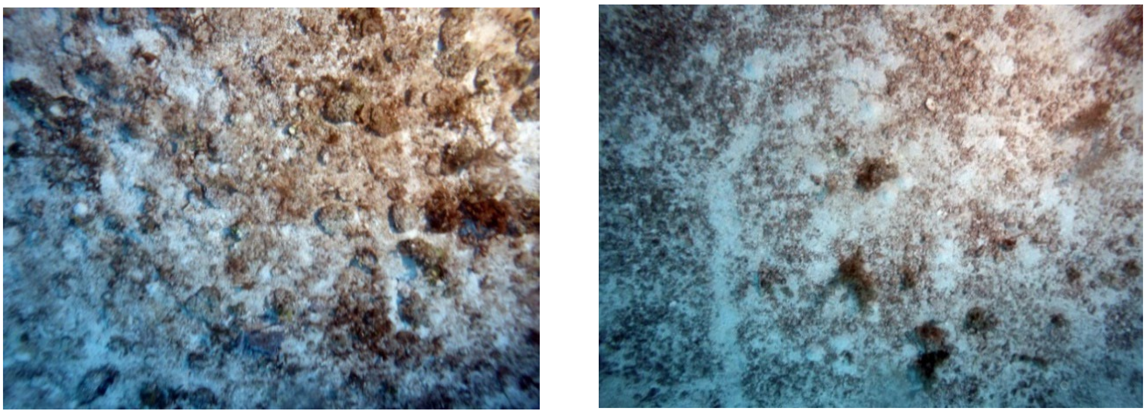

Figure 4. Two examples of the 'Bare mixed' habitat.

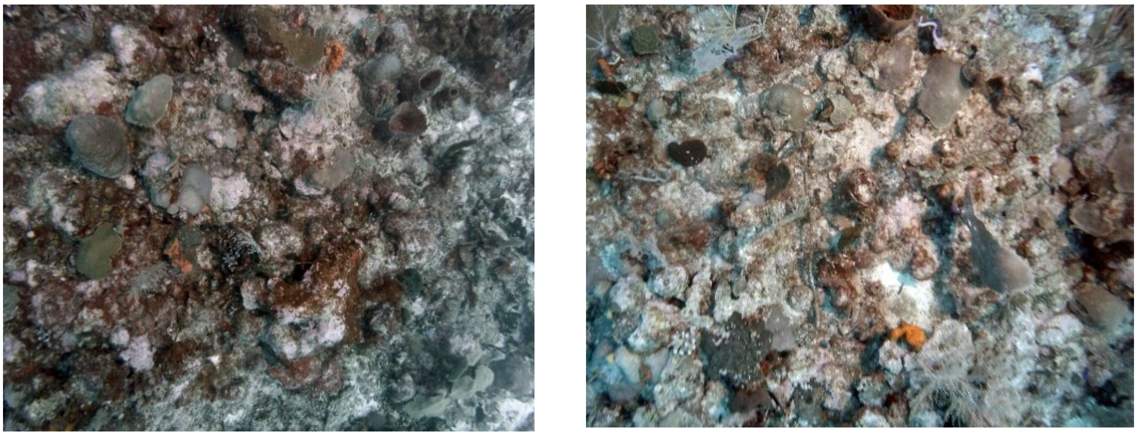

Figure 5. Two examples of the coral reef habitat.

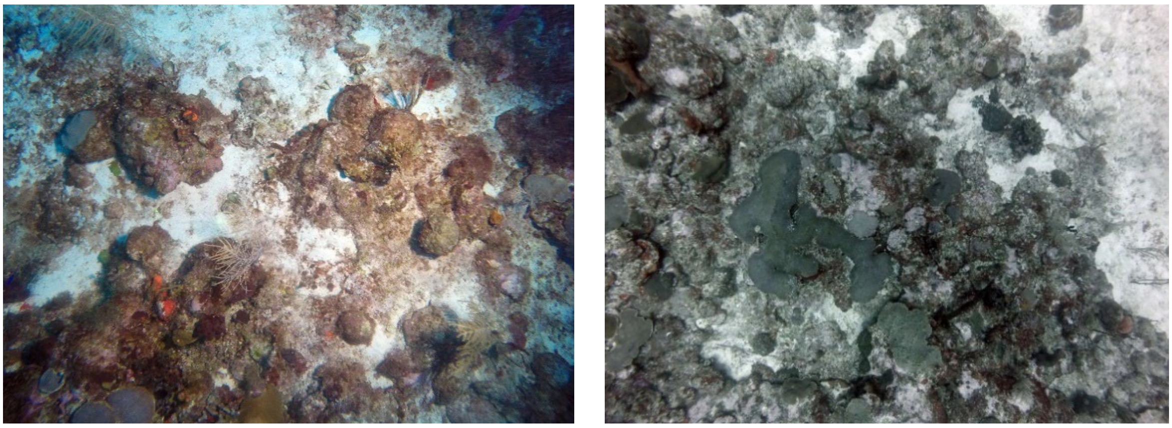

Figure 6. Two examples of patch reef habitat.

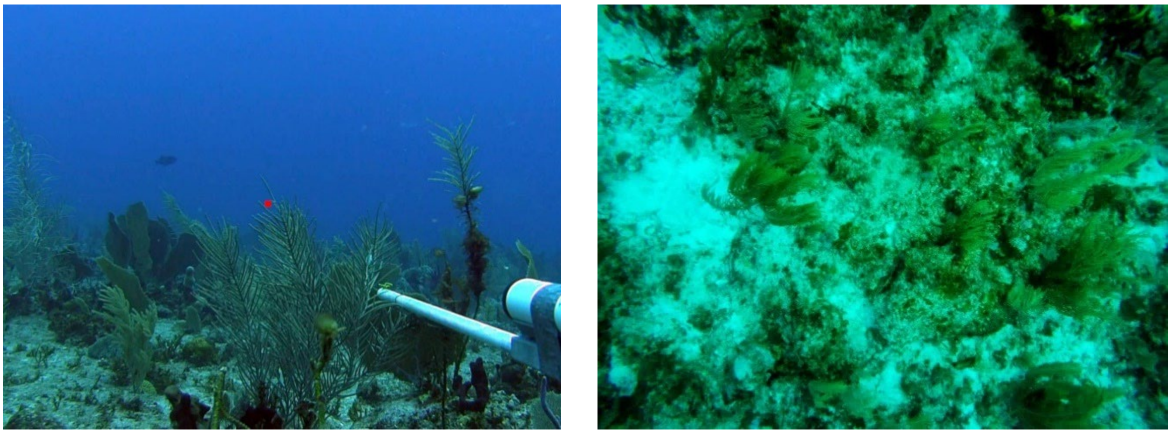

Figure 7. Two examples of the gorgonian reef habitat.

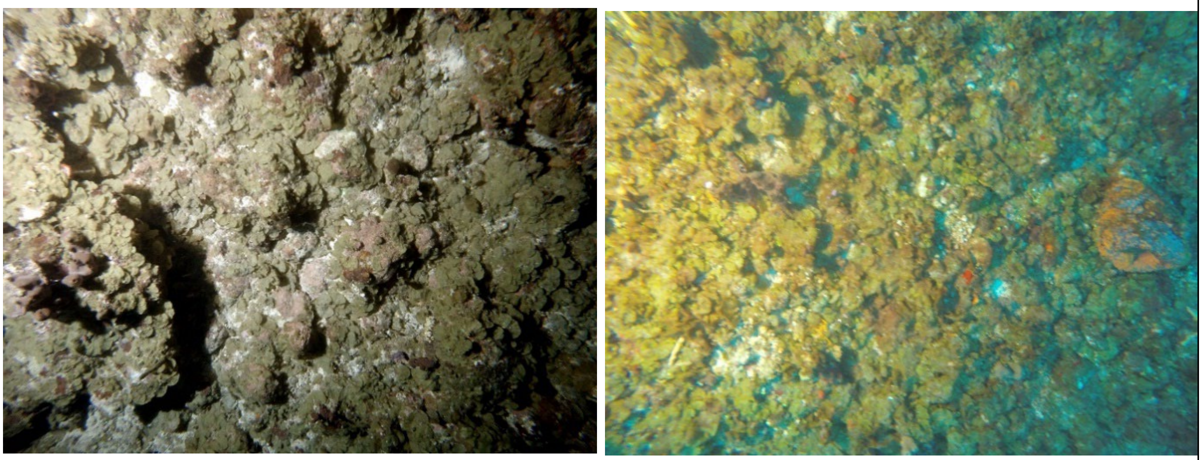

Figure 8. Two examples of the Lobophora habitat.

Figure 9. Two examples of the Sargassum habitat.

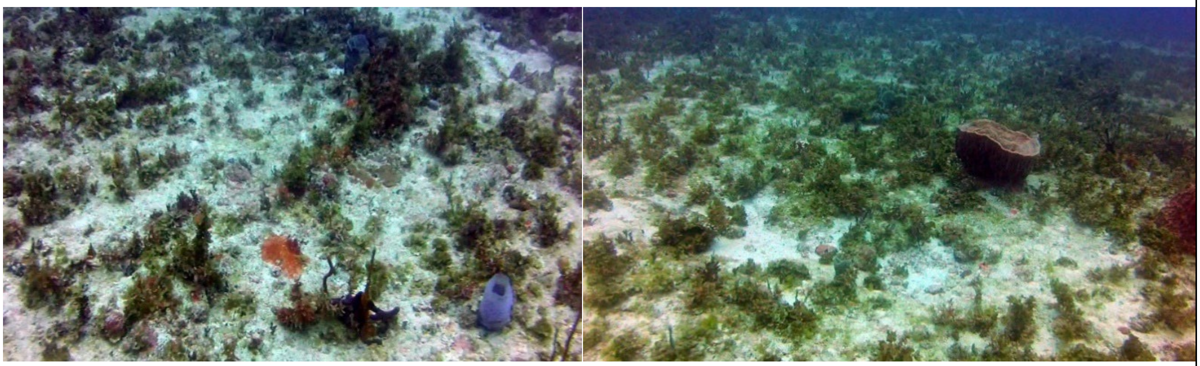

Figure 9. Two examples of the macro-algae habitat.

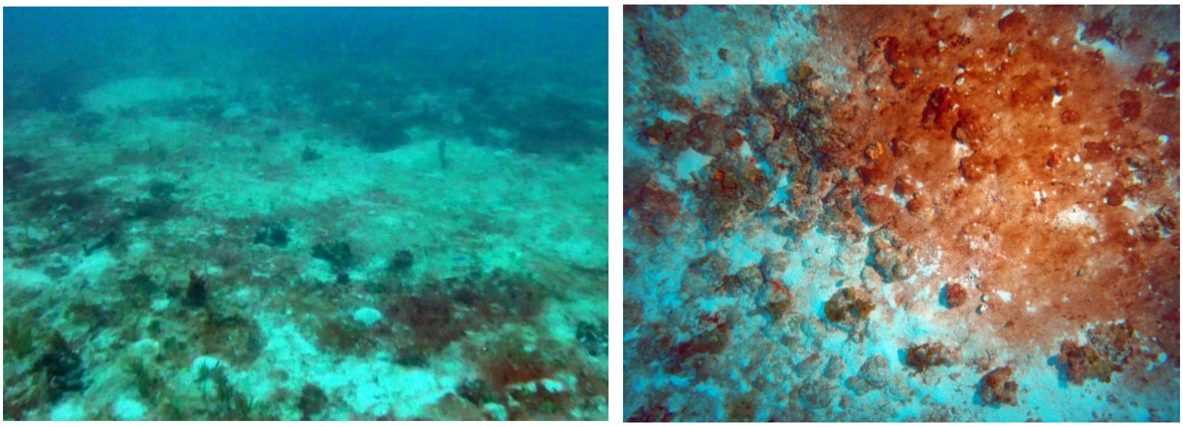

Figure 10. Two examples of habitats dominated by cyanobacteria.

2.2.4.7 Lobophora fields

Lobophora is a brown seaweed genus that occurs naturally on coral reefs. Lobophora is known to be capable of overgrowing large reef stretches if environmental conditions are detrimental to corals. Bottom cover by Lobophora may hinder coral recruitment. There are approximately 18 species in the Caribbean. The Lobophora habitat appears to be mostly on old coral colonies. Thus, this habitat used to be coral reef habitat, and some coral colonies may still be present between the sea weed leaves.

2.2.4.8 Sargassum fields

Sargassum not only occurs as a floating species (2 species) that creates problems on Caribbean beaches, but the rest of the 360 species of Sargassum grow attached to the bottom. On the Sababank, there are areas dominated by

Sargassum bushes that can grow up to about 1m in height.

2.2.4.9 Other Macro-algae fields

The main macro algae on the Saba Bank that can dominate large areas are Sargassum and Lobophora. There are, however, other algae that may form dense fields and often these are mixed assemblages. When it was neither a clear Sargassum or Lobophora dominated community, the habitat was classified as macro-algae field.

2.2.4.10 Cyanobacteria fields

Sometimes, benthic cyanobacteria can cover large parts of the bottom. The reasons for these blooms of cyanobacteria are not yet understood. The blooms can sometimes be related to eutrophication, but at other times there is no clear reason, and it is hypothesized that input of organic matter through sedimentation or upwelling may cause these blooms to appear.

2.2.5 Variables and covariates in habitat modeling.

In this study we used the assigned habitat type of each geo-referenced image together with Saba Bank wide environmental data to predict the occurrence of the different habitat types over the whole Saba Bank.

For the whole Saba Bank there are only a limited number of environmental covariates available, generally derived from depth data that were mainly collected by the Dutch Royal Hydrography. These covariates include the x and y coordinates of each pixel (resolution of 100 x 100m), depth, Topographic Position Index (TPI), Terrain Ruggedness index (TRI), Roughness, and distance to the edge of the Bank. Roughness was highly correlated to TRI and was therefore excluded.

The Topographic Position Index (TPI) is defined as the difference between a central pixel and the mean of its 8 surrounding cells (Wilson et al. 2007). TPI is a measure of relative elevation. It is calculated by comparing the elevation of each pixel to its surrounding neighbors. The number of neighbors (i.e. the size of the neighborhood) impacts the characterization of features. A small and large neighborhood size is defined to characterize the small-scale and large-scale features. Combining parameters from two neighborhood sizes enables the identification of complex landscape features, thus, provides more topography information (Weiss 2001). A zero/near-zero TPI value equals a flat or a near continuous slope. Large positive values mean the central pixel is much higher than the surrounding areas, and equal ridges or hill tops. Large negative values mean lower central pixels and indicate the bottom of a valley or gulley.

The terrain Ruggedness Index is similar to TPI, except that the depth of a particular cell location on the grid is compared to the directly adjacent cells. The topographic or terrain ruggedness index (TRI) was developed by Riley et al. (1999) to express the amount of elevation difference between adjacent cells of a Digitial Elevation Model. TRI is the mean of the absolute differences between a cell's value and its 8 surrounding cells.

Distance to the edge of the Saba Bank is the shortest distance from any grid cell to the nearest edge point of the Saba Bank. The edge of the Saba Bank is physically relevant, as there is a sudden and large increase in depth. This may influence how material (such as nutrients and organic material) travels over the Saba Bank. The distance to the nearest edge was calculated for both the observed data and the grid data. The Bank's edge was defined as the 150m depth contour. TRI, TPI, and distance to the edge were calculated from depth values from a grid with a 5m resolution and then averaged to a resolution of 100m. The resolution of 100m was chosen because this meant the focus was more on larger areas, but it was also necessary for computational reasons.

2.2.6 Habitat modeling

Habitat models are commonly used in biodiversity and conservation studies and can quantitatively link a set of relevant environmental covariates (inputs) and a habitat’s occurrence, or species’ occurrence, abundance, or biomass. Based on such links, a distribution prediction (probability of a habitat or species occurring at a certain place) can be made for unsurveyed areas, provided the environmental covariates cover the whole area.

Machine Learning techniques have recently become an important tool for creating spatial prediction maps because they often show superior prediction capabilities (Elith et al. 2006, 2008). We used three machine learning techniques suited for modelling the Saba Bank habitats, namely Random forests (RF), Gradient Boosting (GB, Breiman et al. 1984, Hastie et al. 2001), and weighted K Nearest Neighbor (wKNN, Fix &

Hodges 1951, Cover et al. 1967). Gradient Boosting and Random forests are based on decision trees, whereas Nearest Neighbor is an interpolation technique.

Overall, RF and GB can be used for explaining and prediction, whereas wKNN can only be used to predict the occurrence of habitat types. The use of all three machine learning techniques is recommended as all may give good results, but each has specific advantages and disadvantages (see Beguin et al. 2017 for more details).

RF consists of a randomly built large number of decision trees to make predictions (Breiman 2001). The trees are independent and should be less prone to overfitting (i.e. becoming too specific for the data the tree is based upon). Gradient boosting combines many regression or classification trees, resulting in a single regression model with the most optimal (and smooth) predictions. The main difference between random forests and gradient boosting is how the decision trees are created and aggregated. Unlike random forests, the decision trees in gradient boosting are built additively; in other words, each decision tree is built one after another. Each new tree is built to improve the deficiencies of the previous trees, and this concept is called boosting. wKNN is a non-parametric supervised machine learning algorithm for classification. Here, a training dataset is first created using locations with known habitat types and covariates, and a test set is used where the covariates were known, but the habitat types were unknown, for which habitat types are predicted by taking the habitat type of the most similar data point in the training dataset. Data points are weighted by the distance to the target point. Weighted K Nearest Neighbour (wKNN) analysis was performed using the kknn package (Schliep & Hechenbichler 2016).

The three model-building techniques were tested with environmental covariates, spatial coordinates, and a combination of both. We used repeated 10-fold cross-validation with 5 repeats per fold. This means that 50 models were evaluated for each combination of techniques and variables.

All analyses were performed using R version 3.6.3 64-bit (R Core Team, 2020) and Tinn-R version 8.02.02.01 (Tinn-R Team, 2023). Library *randomForest* (Liaw & Wiener 2002) was used to calculate RF classification trees. wKNN analysis was performed using the kknn package (Schliep & Hechenbichler 2016). Gradient Boosting was performed using the *caret* package (Kuhn 2008). The sf R-package (Pebesma, 2018) was used to calculate the distance to the nearest edge for both the observed data and the grid data.

3 Results

3.1 Constructing image database

The combined photographs resulted in a set of 2443 geo-referenced images (Figure 12), collected by Baited Remote Underwater Videos (BRUV), Towed Video Method (TVM), and NIOZ-WMR expeditions, respectively, with 163, 190, and 1791 images. This included many sampling points in the east at the shallowest part of the Bank, where most habitat variety can be expected because depth changes quickly over a short distance. The Luymes Bank (the north-eastern part of the Bank) and deeper parts in the west were also sampled. The depths of the images varied from approximately 11 to 126 m.

3.2 Habitat type and benthos

The dominant benthos species were: crustose coralline algae (*Neogoniolithon* sp.), cyanobacteria (*Lyngbya* sp.), *Sargassum* sp., *Halimeda* sp., *Lobophora* sp., other algae (including turfs), corals, sponges, gorgonians and black corals.

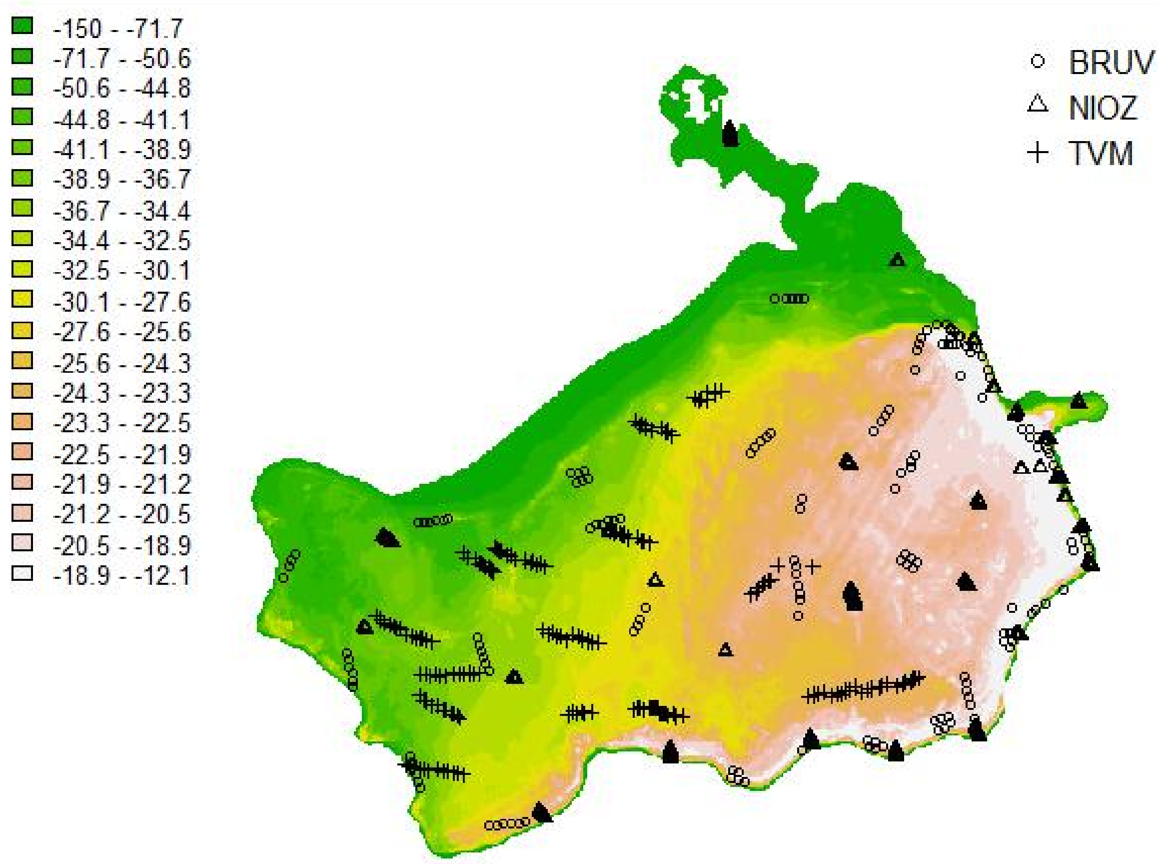

Figure 11. Sample locations of the combined image database, with TVM being towed video method images; BRUV, Baited Remote Underwater Video stills (n = 163), and NIOZ, expedition images from NIOZ expeditions. The background color is depth in meters based in 5% quantile intervals (see legend). Depth is restricted to a maximum of 150m. Note that due to the close distance between points not all points are visible.

Table 3. Different habitat types and the number and percentage of images in the database per habitat type.

Habitat type	Number of images	Percentage of all images
Bare sand	676	32
Bare mixed	97	5
Coral reef	343	16
Patch reef	352	17
Gorgonian reef	41	2
Lyngbya / Neogoniolithon field	84	4
Lobophora field	126	6
Sargassum field	90	4
Macro algae field	276	13
Cyanobacteria field	34	2

3.3 Geographical distribution of the different habitat types

Table 3 shows the image classification into the distinguished habitat types. Initially, there were many more habitats, but because machine-learning classification techniques need a reasonable amount of training data, the habitats used for the modelling were limited to 10. The habitat classification used in this study is mainly based on the Caribbean classification of habitats by Mumby and Harborne (1999) and Debrot et al. (2014) but has been expanded because of the new habitat types determined in
this study. Since the image collection is not random, the distribution cannot be used to estimate the distribution of habitats over the whole Bank. For instance, the classification of 16% of the images as coral reef areas reflects concentrated survey efforts along the Bank's edge. However, this does not necessarily imply that 16% of the Bank constitutes coral reef habitat. See Van Leijsen (2021) for more detailed descriptions of the different habitat types.

3.3.1 Bare sand

Bare sand appears everywhere on the Bank, but especially in the deeper western part of the Bank. In total, 676 images (32%) where classified as 'Bare sand'. Large sea stars, queen conch, or a sea urchin were sometimes present on top of the sand.

3.3.2 Bare mixed

Bare mixed habitat can occur everywhere on the Bank, except in the north-west. Five percent of all images (n = 97) were classified as mostly bare, with multiple species taking up some cover. It appears to be generally absent in the sandiest parts (see "Bare sand" habitat).

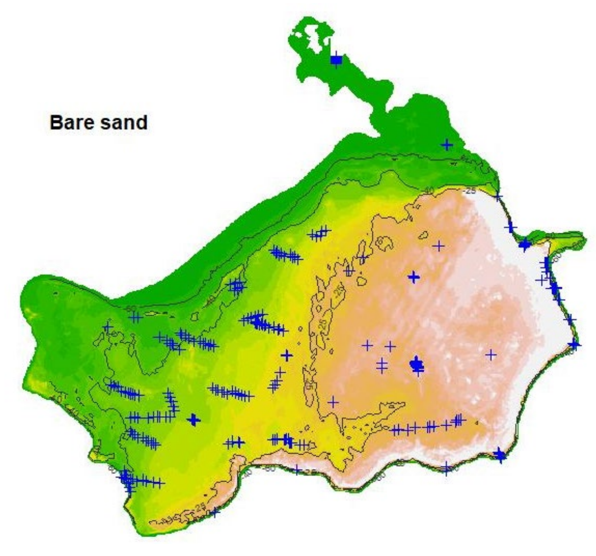

Figure 12. Distribution of images (indicated by "+" signs) that were classified as "Bare sand" habitat across the Saba Bank. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

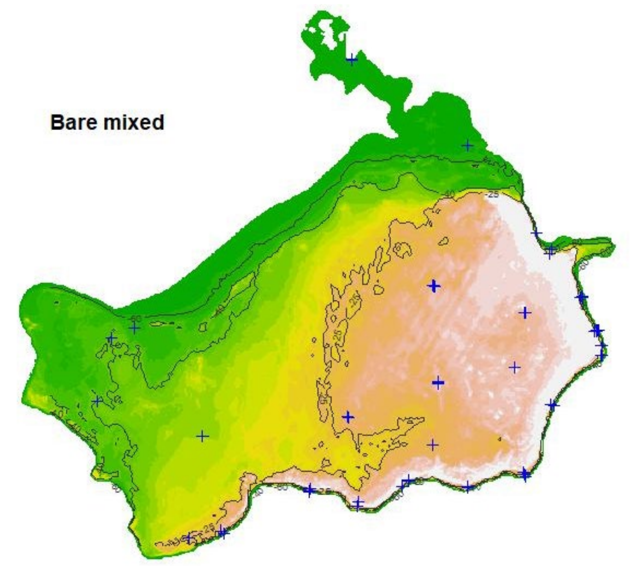

Figure 13. Distribution of images ("+" signs) that were classified as 'Bare mixed habitat across the Saba Bank. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

3.3.3 Coral reef

The coral reef area occurs mostly along the Bank's southern and eastern edge; however, this habitat also occurs unexpectedly in the north-western part of the Bank at a depth of around 40m.

The coral reef habitat appears to have suffered from massive coral mortality in the past as there still is a lot of structure, but the bottom is covered largely by macroalgae such as Lobophora (Fig. 16) and many images in this newly discovered deep coral reef area where also classified as

Lobophora habitat. Of all images, 16 % (n = 343) were classified as coral reef area. The top of the Luymes Bank, in the northeast, is also covered with vast coral communities mixed with sponges and calcareous algae (Fig. 17).

3.3.4 Patch reef

Patch reef habitat is generally part of the reef area and intermingled with coral reefs and gorgonian reefs. Therefore, it is situated along the eastern and southern edge of the Bank. In total, 352 images (17%) were classified as patch reef areas.

3.3.5 Gorgonian reef

This habitat is generally in the shallowest parts of the Bank, between 25 and 15m depth. Because of the strong wave action between these depths, hard coral colonies here are generally small, flat, or absent, and only soft corals can survive. Because of the depth of the Saba Bank, most habitat of this type is along the edge of the Bank where coral growth has been highest, and the reef may have grown to a depth of 12m from the surface at some places. Soft corals can sometimes dominate deeper areas, but these are then surrounded by sand and probably consist of different species than in the shallow areas.

3.3.6 Neogoniolithon- Lyngbya habitat

This habitat is very specific and appears to be restricted to several mounds in the shallow areas of the Bank. These mounds appear to be formed by a species of *Neogoniolithon*. All 84 images were taken on one mound, but similar structures can be found in the same area.

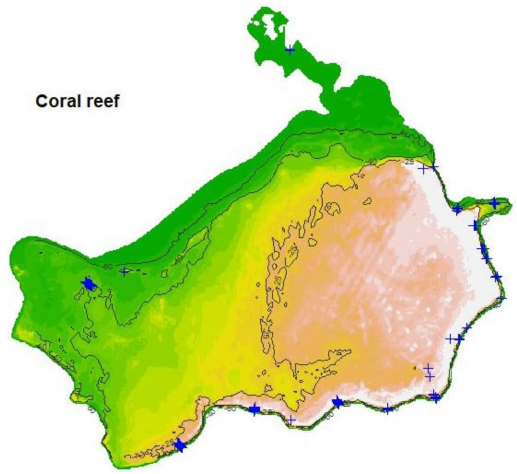

Figure 14. Distribution of images ("+" signs) that were classified as "Coral reef" across the Saba Bank. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

Figure 15. Close-up image of an area in the north-west of the Bank where a coral reef was discovered. Much of the picture is taken up by the macro-alga Lobophora.

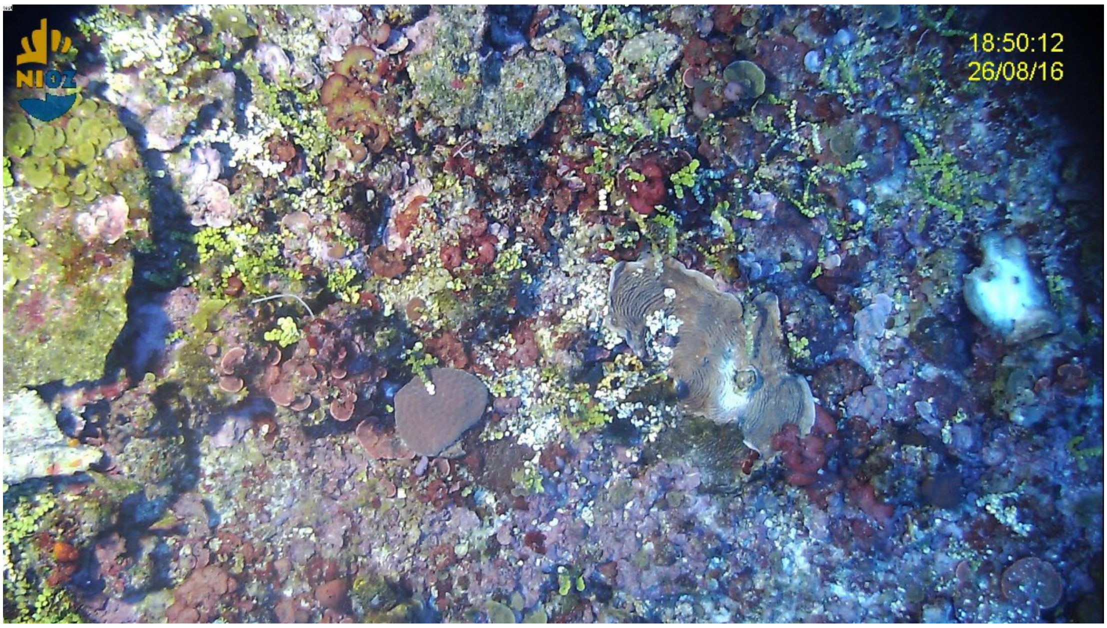

Figure 16. Top of the Luymes bank with many coral colonies, macroalgae (i.e Halimeda spec.) and calcareous algae.

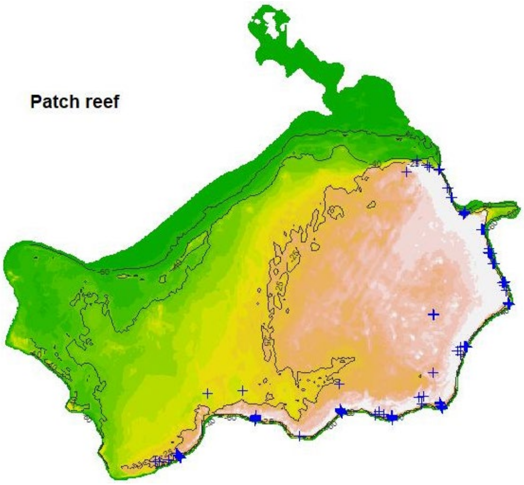

Figure 17. Distribution of images ("+" signs) that were classified as patch reef area. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

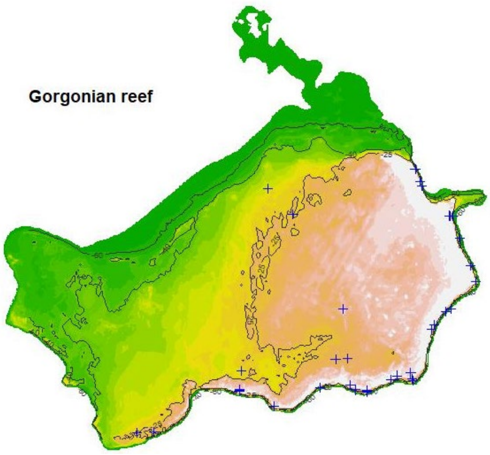

Figure 18. Distribution of images ("+" signs) that were classified as Gorgonian reef habitat. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

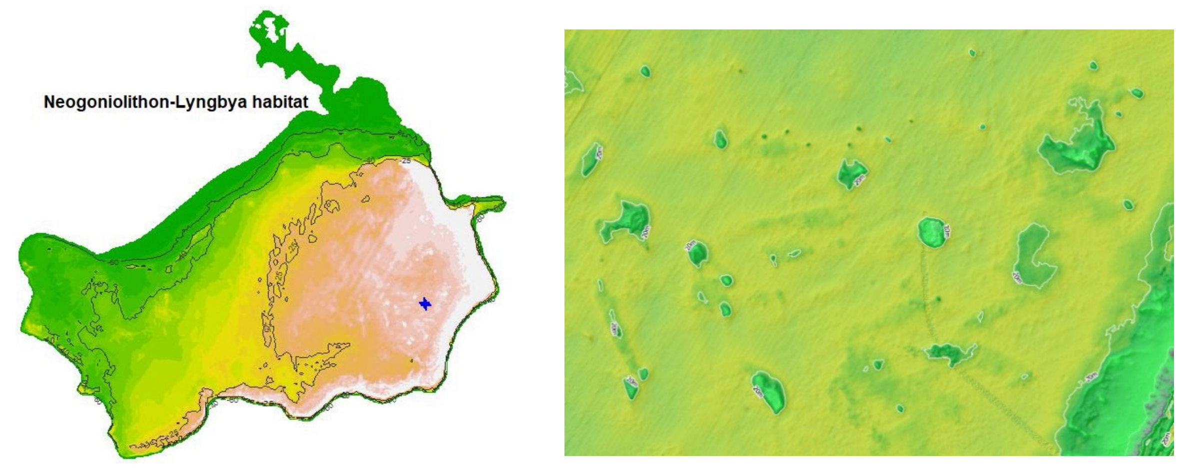

Figure 19. Location of the mound where the Neogoniolithon-Lyngbya habitat was found indicated by the "+" sign (left) and similar mound-like structures in the same area (right).

3.3.7 Lobophora fields

126 images were classified as *Lobophora* habitat. It appears to be particularly abundant in the north-western corner of the Bank. This area lies between 40 and 60m depth, which includes depths around which *Lobophora* frequently can be found on Caribbean coral reefs.

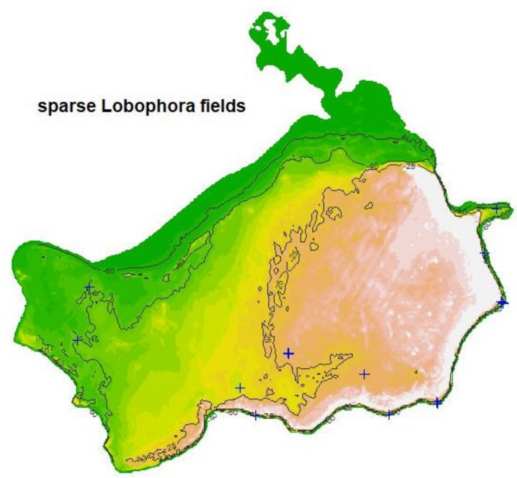

Figure 20. Distribution of images ("+" signs) that were classified as Lobophora habitat. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

3.3.8 Sargassum fields

Sargassum fields are limited to the well-lit part of the Bank and behind the edge of the Bank in water between 20 and 30m depth. This habitat is also the area where fields of other macroalgae can be found.

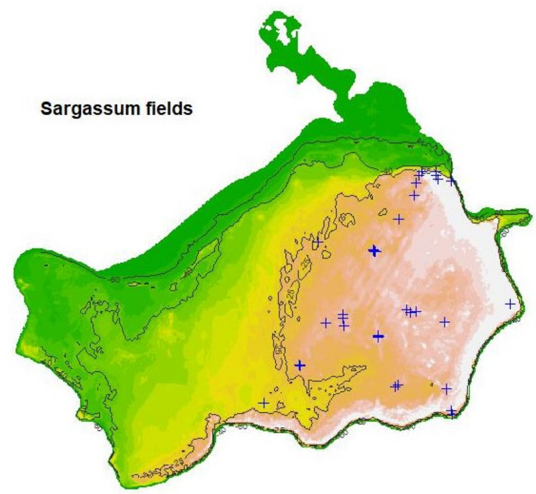

Figure 21. Distribution of images ("+" signs) classified as Sargassum fields, which occur within the macro-algae field habitat. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

3.3.9 Other macroalgae fields

Macroalgae are a dominant feature of the Bank, and they can occur virtually anywhere except maybe in the deeper parts, below 40m., where light becomes limiting. Both *Lobophora* and *Sargassum* are the main macro-algae types on the bank, but within this specific habitat type there is usually a mix of different species of macroalgae. These fields are very common in the eastern part of the Bank within the 25m depth contour. In total, 276 images (13%) were classified into this habitat.

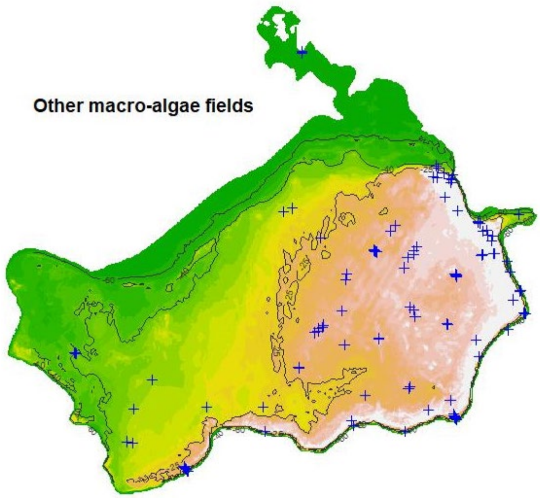

Figure 23. Distribution of images ("+" signs) classified as macro-algae fields that were not dominated by Sargassum or Lobophora. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

3.3.10 Cyanobacteria fields

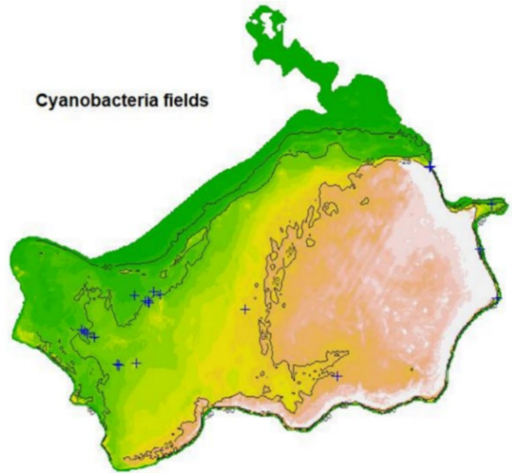

Figure 22. Distribution of images ("+" signs) classified as Cyanobacteria dominated habitat. Background colors reflect various depths (m) as in Fig. 12. Contour lines at 150, 60, 40, 25, and 8 m. depth.

In certain areas, the sand can be covered with cyanobacteria. Generally, these areas are not very large, but cyanobacteria can be the dominant bottom cover. Occasionally, cyanobacteria can become a dominant feature within the coral reef habitat. In total, 34 images (2% of all images) were classified as cyanobacteria fields. The habitat appears to occur between 30 and 40m depth.

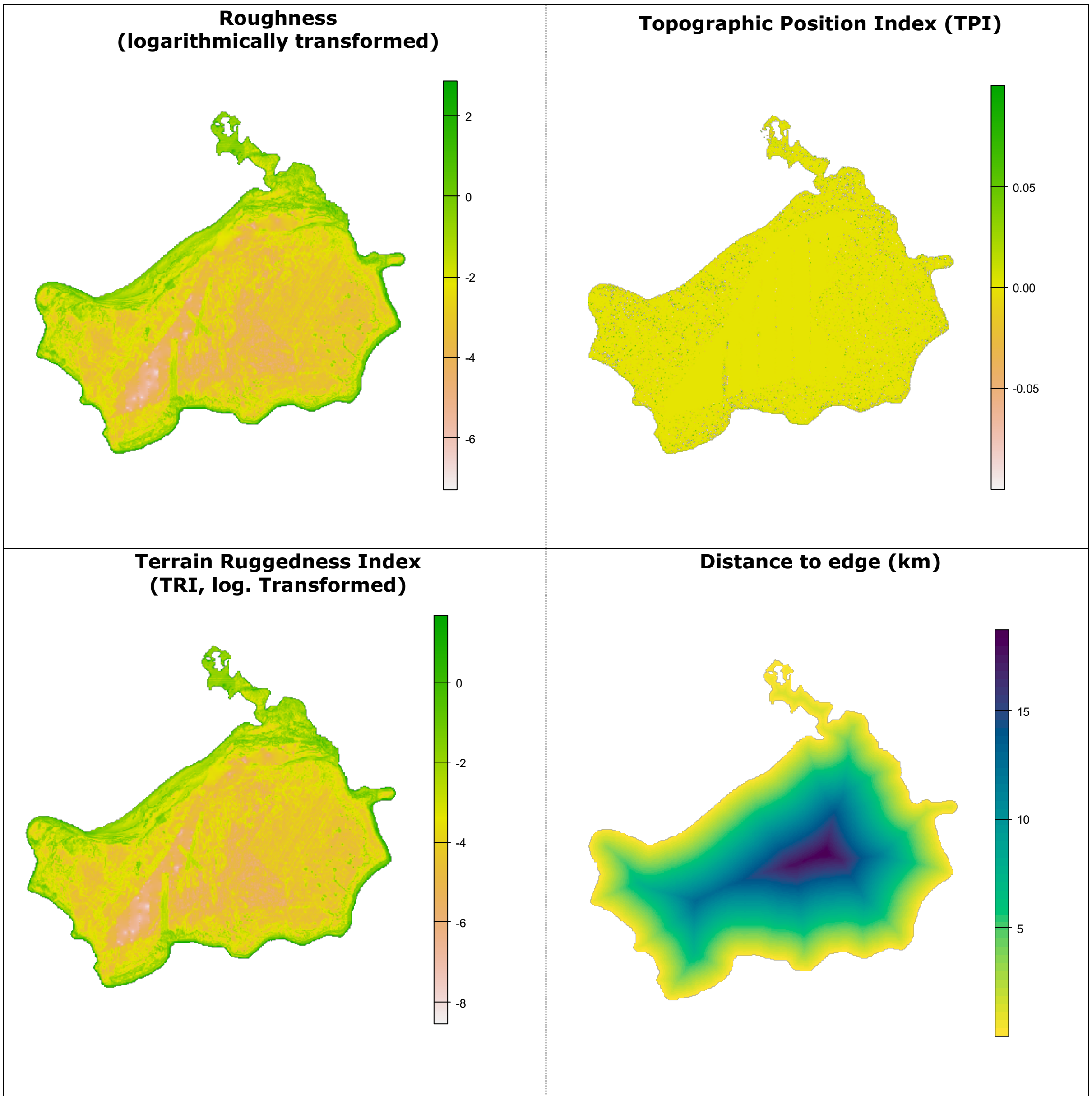

Figure 24. Images of covariates of the Saba Bank.

3.4 Habitat modeling

Habitat maps that predict the occurrence of a certain habitat type at non-surveyed locations are based on the relationship between the probability of the presence of each habitat type and the available environmental covariates. The covariates that ultimately were used in the modeling are depth (Fig. 12), the coordinates (x,y) of each image, roughness, Terrain Ruggedness Index (TRI, both logarithmically transformed), Topographic Position Index (TPI), and distance to the edge of the Bank (Fig. 25). Roughness however was highly correlated to TRI and excluded as a covariate.

3.4.1 Statistical models

For all modeling techniques the overall accuracy was on average between 67 and 74% (Table 3). It can be concluded that in terms of accuracy, how well the models predict the data, there is not much difference between the different techniques. For all techniques, however, the covariates only option has the lowest score. For Random forests and weighted K Nearest Neighbour "spatial-only" gives the highest accuracy, while for gradient boosting, the combination of covariates and spatial coordinates gives the highest accuracy. Not all habitat types are predicted equally well. Habitats with only a limited number of observations are generally less well predicted than habitats that appear on many images.

Next the models were used to predict the occurrence of the different habitat types over the Bank. The output consists of probability maps and prediction maps depicting the occurrence of the different habitat types, with probability maps showing the probability that a habitat type is present at a certain location, and prediction maps showing the habitat type most likely to occur at a certain location. Thus, a location can have multiple probabilities, one for each habitat type, but the prediction only contains one habitat type, namely the one with the highest probability. In this report, we present only the prediction maps. These maps indicate that even though the accuracy of the models in Table 3 is very similar, the predicted maps can be very different (Fig. 26). With spatial covariates (s), the models can only predict along x or y lines. Therefore, the occurrences of the habitats appear unnatural, with the different habitats delineated along straight lines, even though the accuracies of the s-models are among the highest. The other models appear to give a more natural distribution of the different habitats. However, the covariates-only models (c) seem to create an artefact whose origin seems to be the distance to the edge grid, as this shows a similar pattern. The combination of spatial and other covariates gives the most natural feeling distribution of the different habitats. Therefore, the following section concentrates on these model predictions. In Appendix 2, the location of all predicted habitat types is shown separately.

Table 3. The median, 2.5 and 97.5 percentile for the accuracy of the nine different model types (150 models per method-mode type combination). Methods: wKNN, weighted K Nearest Neighbour; GB, Gradient Boosting; RF, Random Forests. Covariates: c, co-variates only; s, spatial variables only; cs, the combination of the covariates and spatial coordinates.

Method	2.5% percentile	50% percentile	97.5% percentile
RFc	0.699	0.705	0.714
RFs	0.719	0.731	0.746
RFcs	0.707	0.722	0.734
GBc	0.636	0.668	0.677
GBs	0.659	0.676	0.692
GBcs	0.665	0.692	0.705
wKNNc	0.675	0.686	0.698
wKNNs	0.724	0.744	0.748
wKNNcs	0.702	0.705	0.711

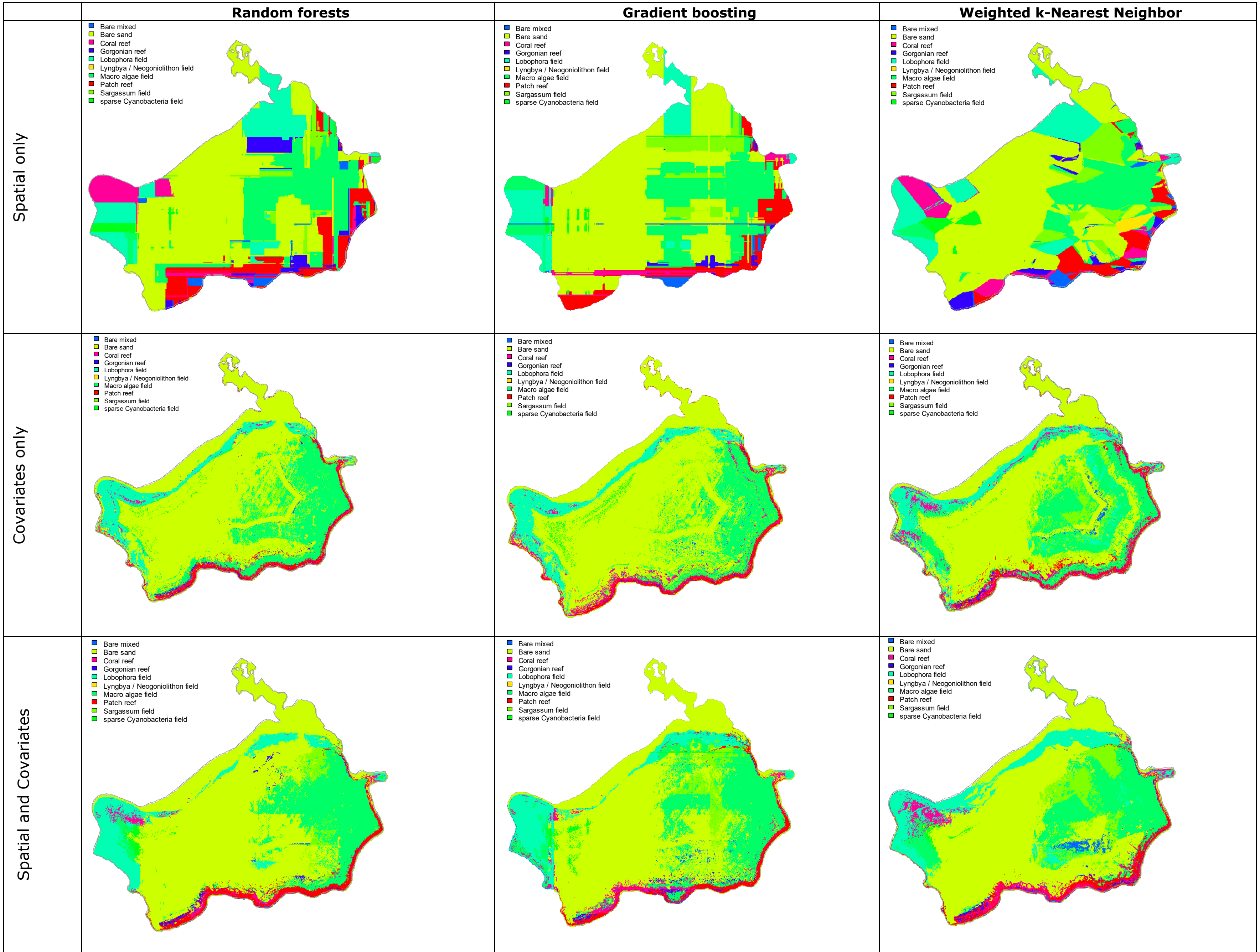

Figure 25. Resulting prediction map for each combination of a modeling technique and variables.

3.4.2 Prediction with spatial and covariates

For each pixel of 100 by 100 square meter between the shallowest locations and 150m depth the habitat type is predicted by three different models with spatial variables and covariates. The total surface area per habitat type can be compared (Table 4). The results for each machine learning technique are clearly similar indicating that most of the area of the Saba Bank is taken up by sand, and the smallest area is the *Neogoniolithon- Lyngbya* habitat

Table 4. Predicted areas (km^2) of the different habitats on the Saba Bank for each of the 3 machine learning modelling techniques using both covariates and spatial coordinates.

Habitat	RFcs	GBcs	wKNNcs
Bare mixed	5.83	19.67	26.65
Bare sand	1315.94	1104.14	1108.19
Total sand	**1322**	**1124**	**1135**
Coral reef	34.74	47.73	84.89
Gorgonian reef	14.47	41.48	14.79
Patch reef	93.15	97.35	86.18
Total reef	**142**	**187**	**186**
Lobophora fields	194.65	220.86	240.94
Macro algae fields	405.62	479.48	412.51
Sargassum fields	55.29	106.47	150.77
Total algae	**656**	**807**	**804**
Neogoniolithon-Lyngbya habitat	2.24	1.14	3.17
Cyanobacteria fields	19.47	23.08	13.31

3.4.2.1 Random forests

The random forests model (Fig. 27) has the overall highest accuracy of the combined models (Table 3). The coral reef area may appear a little underestimated (Table 4). If it is combined with the patch reef and the gorgonian reef area and viewed as a combined reef area it seems to give a good indication of the main areas where reef habitat can be found. The sand area appears to be quite large and the Luymes bank in the northeast has been misclassified. The *Lobophora* habitat appears well defined, as are the other macro-algae and the cyanobacteria. Sometimes the boundary between two habitats appears too sharp. For example, between the sand and the *Lobophora* habitat in the west or between the Macro-algae and the sand in the east.

3.4.2.2 Weighted K Nearest Neighbor analysis

This technique estimates slightly larger surface areas for each habitat type (Fig. 29, Table 4). The geographic position of the different habitats, however, is very similar to those from the random forests analysis. Macro-algal habitats, such as Sargassum, Macro-algae field, and Bare mixed may be better classified as an area or habitat with a mixture of macro-algae.

3.4.2.3 Gradient boosting

This technique gave similar results as the other two when both spatial and depth-derived variables were included, but the boundaries of some habitats, such as the Sargassum and the *Lobophora* habitat, appear rather sharply defined at places (Fig. 29).

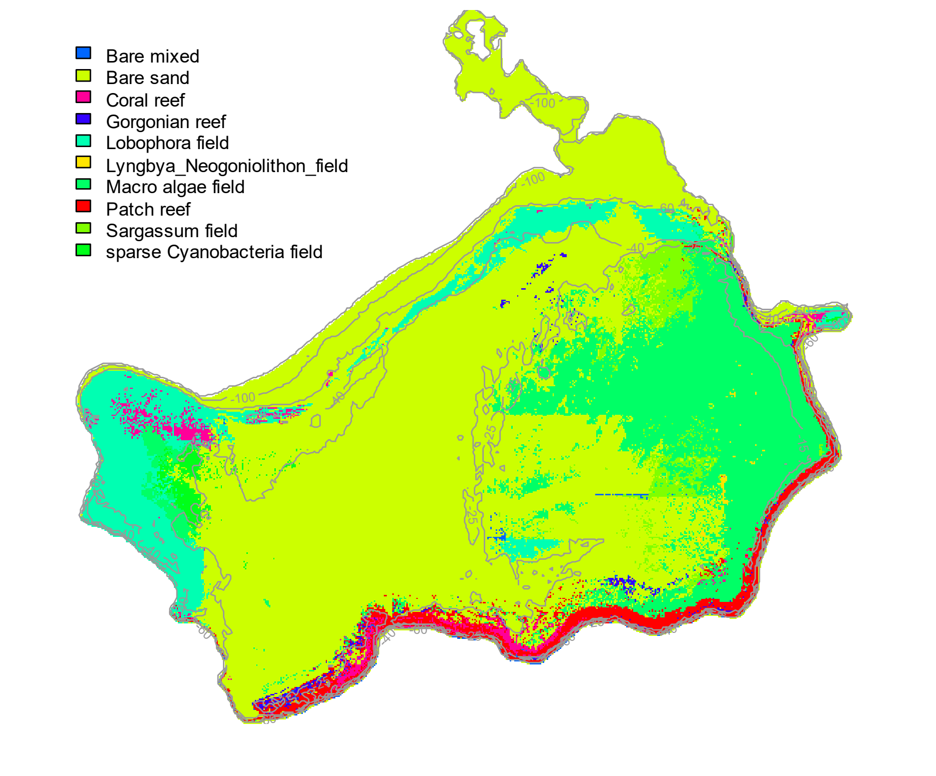

Figure 26. Random forests prediction for the 10 habitat types.

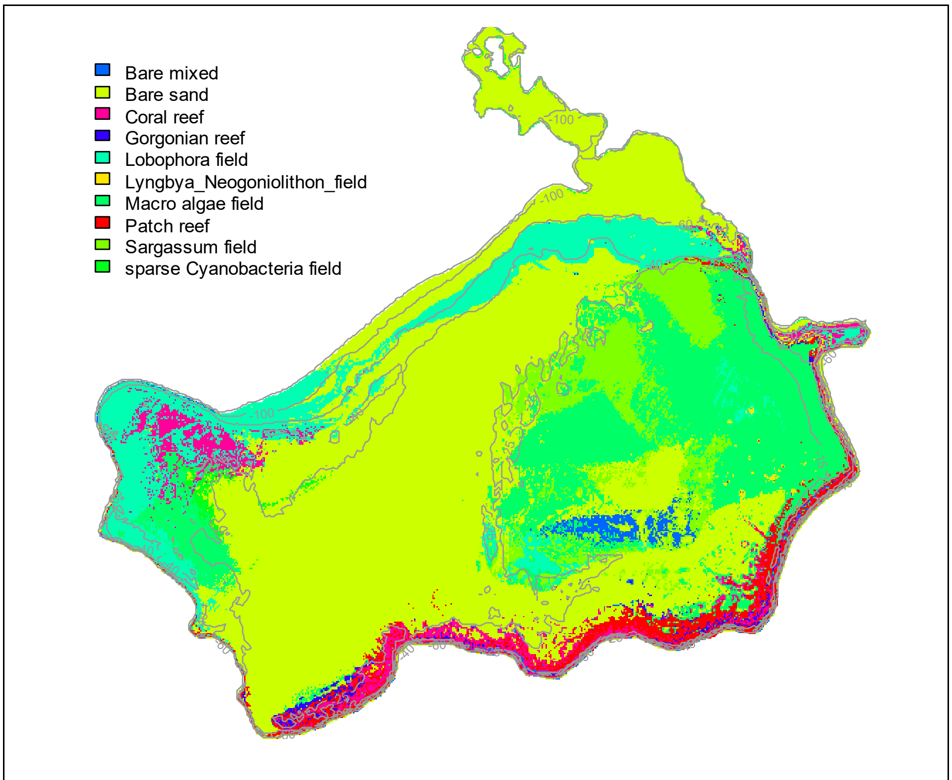

Figure 27. Habitat prediction of the weighted K Nearest Neighbor analysis.

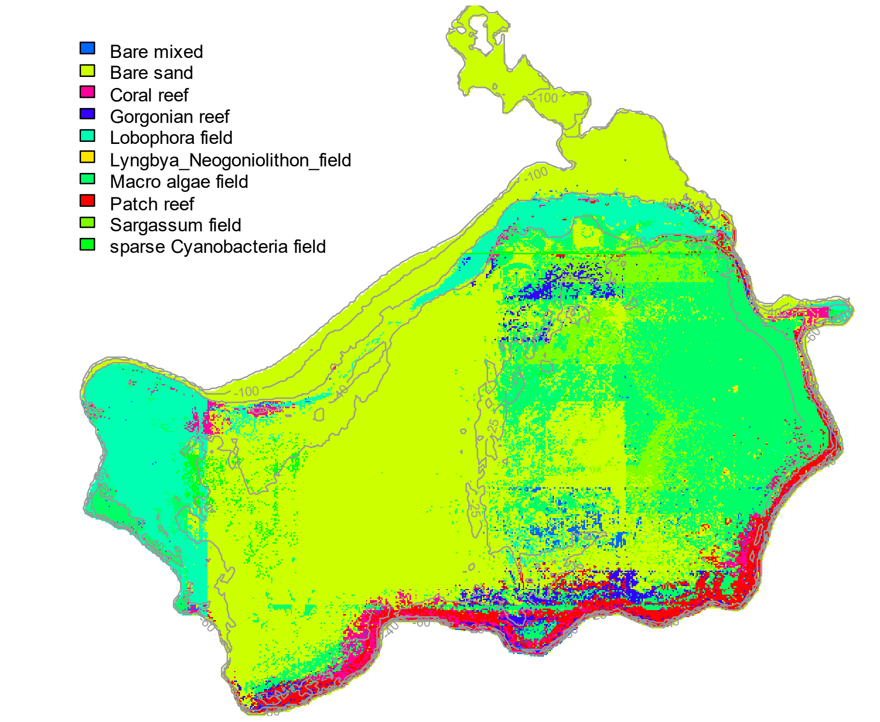

Figure 28. Gradient boosting predicted habitat types.

4 Discussion

The different techniques that were used to predict the distribution of habitats on the Saba Bank give comparable results with regard to the position of the distinguished habitat types (Fig. 26) and their total surface area (Table 4). It is also quite clear that the distribution of the habitats is related to depth. For example, *Lobophora*-dominated habitat is generally restricted to depths between 40 and 60m along the north-western to north-eastern part of the Bank. The coral reef area, which should be viewed as the co-occurring of coral reef, gorgonian, and patch reef habitats, is situated mostly along the relatively shallow southern edge of the bank, and to a lesser extent along its eastern edge, starting at the shallowest parts of approximately 10m depth and extending into the deeper water south and eastwards down to more than 40m. The predicted distribution of coral communities agrees largely with that of Van der Land (1977) who also indicated reef structures in the south, southeast and east based on bathymetric surveys. The predicted distribution of corals also coincides with the coral communities described by Toller et al. (2010), in which a fore reef was described, dominated by hard substrate with macroalgae, corals, and gorgonians, resulting in high vertical relief. Remarkable is a deeper area in the north-west where coral reefs also appear to occur. The sand-dominated area is mostly in the Bank's middle, between 25 and 40m depth. Covering the eastern half of the Bank, behind the coral reef along the Bank's edge, a back reef area down to 25m depth is dominated by macro-algae, dominated by *Sargassum*. *Sargassum* sp. fields were mainly predicted to occur in the eastern part of the Bank, thereby concurring with the distribution of *Sargassum* as described by Toller et al. (2010) and Littler et al. (2010), who distinguished an inner reef flat with low relief and dominant macroalgae such as *Sargassum* and *Dictyopteris*. Here, the depth of the Bank (15-35 m) is not too deep for *Sargassum* to occur (Van den Hoek et al., 1978; Engelen et al., 2005).
Furthermore, *Sargassum* sp. is a filamentous macroalgae that can grow relatively long thalli that might break under strong water movements, which would exclude the fringe of the Bank as suitable habitat for this macroalgae. The large areas of macroalgal cover on the Bank may explain its value as a productive lobster fishing ground. Many lobster species, including the spiny lobster, show large ontogenetic changes in habitat use. Lobsters typically settle from the plankton in areas of seagrass or

macroalgal dominance and use such areas as their principal nursery habitat. As they grow and mature, they typically migrate towards reef-dominated habitats where the adults will concentrate (Behringer et al. 2009). The same applies to many coral reef-associated snapper and grunt species (Nagelkerken et al. 2015; de la Moriniere et al. 2003). Several large and commercially valuable reef- and deep-water fish species of the Saba Bank (Williams et al. 2010), like the Snowy grouper (*Epinephelus niveatus*), Black-finned snapper(*Lutjanus buccanella*), and Lane snapper (*Lutjanus synagris*), are known to use shallow vegetated (i.e. seagrass and algae) habitats as nursery areas (Arena et al. 2004; Pimentel and Joyeux 2010). This includes the IUCN vulnerably-listed Rainbow parrotfish(*Scarus guacamaia*) (Dorenbosch et al., 2006). For most species, their use of different habitats in the Saba Bank seascape remains unknown.

The mounds of *Neogoniolithon sp.*, a small branching coralline alga, seem to be restricted to a smaller shallow area behind the reef (Fig. 20). This habitat appears somewhat similar to Maerl or Rhodolith beds (Barbera et al. 2003) and are likely places of elevated biodiversity. These coralline algae constitute an important part of the reef environment. In an extensive study of the Albrolhos bank off the coast of Brasil Brasileiro et al. (2015) found 14 different rhodolith forming taxa among which the genus *Neogoniolithon* at comparable depths as in this study. Whether the dominant genus is actually *Neogoniolithon* (with more than 60 species) or some other genus (e.g. *Lithothamnion* with 80 different species) within the extremely diverse order of the Corallinales still needs to be determined as no samples have been taken for verification.

The only area not predicted correctly is the coral reef area on the Luymes bank, the north-eastern tip of the Bank between 80 to 100m. Probably, too few observations were available in this area. As most corals rely on phototrophic symbionts, coral communities are generally bound to shallow waters where the distribution of the corals is dictated by light penetration and the availability of hard substratum that facilitates coral recruitment. The coral communities on the Luymes Bank are remarkable, though not predicted by the models; here, corals appear down to 100 m depth. We assume that the absence of sand and the local topography is responsible for the favorable conditions for coral growth. The area is extremely sensitive and deserves special protection as the cover of corals can be very high (Van Duyl & Meesters 2019). Because of the depth the coral blades are extremely thin and fragile. Likely they grow slowly and may be very old. Furthermore, this area also harbors special communities of crustose coralline algal pillars within a number of sinkholes that belong to the deepest sinkholes on Earth (Van Duyl & Meesters 2020). One of these sinkholes is more than 300m deep and has an acidic lake of dense water at the bottom produced by the expulsion of gases from cracks in the bottom of the sinkhole (Humphreys et al. 2022).

The coral reef is best developed along the southern and south-eastern edges of the Bank. This shows that Holocene coral reef development is most likely related to the prevailing wind and currents favoring this area's highest coral reef growth rates (Macintyre et al. 1975). The sediment produced here is then transported in a north-western direction, leading to a more sand-dominated habitat in that same direction. Because the sand layer is very thin in the eastern backreef part, macroalgae attached to the underlying hard bottom can occur here. Where the sandy layer becomes too thick, macroalgae disappear.

The habitat maps in this report provide an assessment of the distribution of the main benthic habitat types of the Saba Bank. Species−habitat relationships are affected by biotic and abiotic processes that occur on various spatial and temporal scales. The main abiotic variables that generally influence the distribution of marine habitats include depth, sedimentation, turbidity, nutrient availability, and exposure. Only depth and related variables were used in this study, indicating that there is still room for improvement. Also good satellite imagery may improve the classification.

Overall, spatial information about habitat distribution is crucial for the management and maintenance of these habitats. The mapping of habitat types can give valuable insights into species distributions, ecosystem services, and habitat use. The quantitative description of the habitats on the Saba Bank as presented in this study, provides a baseline for environmental legislation and management and can support sustainable fishery management and biodiversity conservation.

The atoll question Macintyre et al. (1975) noted that two types of sediment could be found on the Saba Bank that indicated sediment transport to be controlled largely by the amount of agitation of the sea floor, meaning it is related to depth, wind and currents. Van der Land led an expedition to the Saba bank in 1972 with the Royal Navy. He was the first to give a distribution map of the reefs of the Saba Bank (his Figure 2, Van der Land 1977). Of the different reef structures he identified, the patch reefs he described are probably the same as the *Neogoniolithon* reefs described here. Van der Land (1977) was the first to name the Luymes Bank. He proposed that the Saba Bank was an old atoll *sensu* Darwin, however, nowadays Darwin's theory has been adjusted, and the Saba Bank probably formed because of karst dissolution during glacial lowstands of the sea and new reef growth along its margins during deglacial reflooding of the glacial karstic morphologies during the last 5 million years (Droxler et al. 2021). This is visible in the up to 7 coral ridges in many places at different depths. In some places these ridges look the same as the coral terraces that can be found on dry land on Curacao and Bonaire. Where the southern islands of the Dutch Caribbean are slowly being uplifted, the islands in the north are subducting. When sea level rises, the weathered islands are reflooded, and coral growth reinitiates with maximum values along the edge of flat-topped banks. Depending on currents, exposure, reef growth, plate tectonics, and sea level rates these coral reef rims may form atolls, barrier reefs, or simply lose the race between sea level rise and reef growth and become drowned reefs. If during the last 10k years coral growth on the Saba Bank would have been higher, or at least been able to keep up with sea level rise, the Bank would probably have been a clear atoll, like those found in the Maldives. Clear reef structures can be seen in many parts along the edges of the Bank (e.g. north-east, north-west, and also on the western promontories), and at some time in the past the Saba Bank may have been a clear atoll, but it has not been able to keep up with the rising sea level during the Holocene. The areas in the west and north were least able to keep up with sea level rise and are now situated in waters between 40 and 50m depth, while some of the vigorously growing parts in the eastern and southern side appear to have been able to keep up with sea level rise longer as they are in some places around 15 m. of water.

Another possibility is that the Bank is subsiding asymmetrically, and the north-western part is sinking faster than the south-eastern part. There is one isolated reef area that appears to represent a true (drowned) atoll. This is the area in the southwest. Figure (Fig. 30) shows a 3D representation based on the bathymetric data of this area. We named it Small Saba Bank Atoll, located in water 100 - 35m deep. As seen from the 3D image below, this island is still surrounded by a full ring of probably old reefs. Up to now, we have not been able to collect images here.

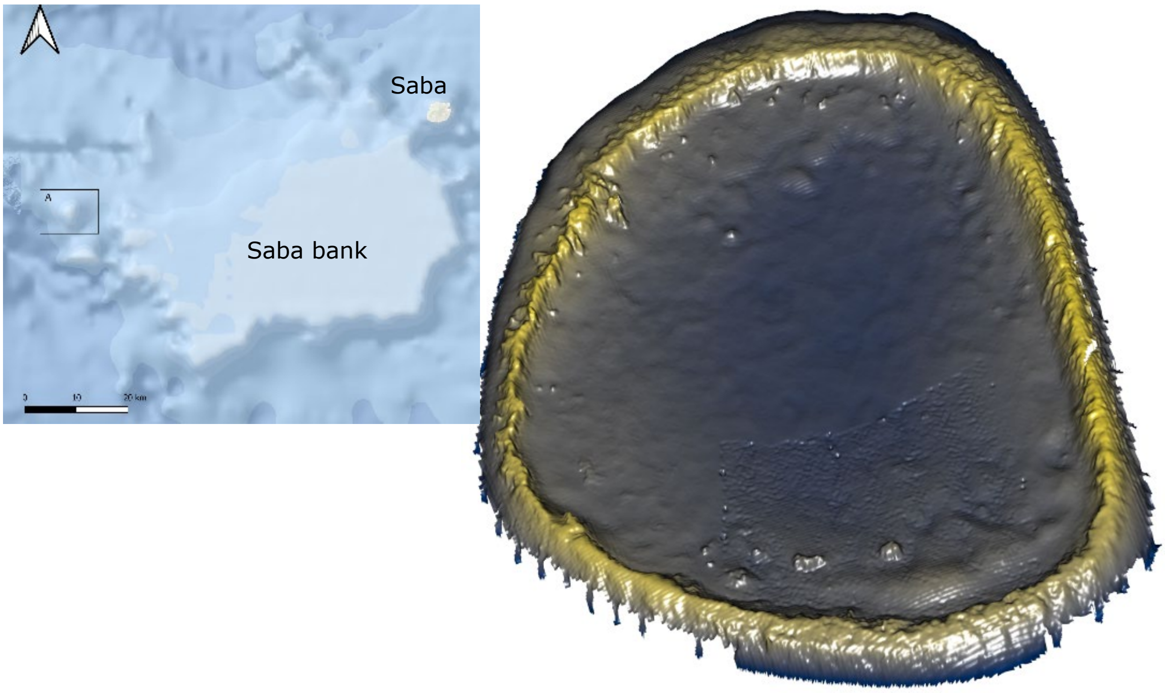

Figure 29. Inset the Saba Bank with the island of Saba in the east and the drowned atoll, Small Saba Bank Atoll, approximately 72km west, and shown in full here. The part shown lies between 65 and 40m depth. The height of the rim is between 10 and 20 m, the width and length are 3.2 and 4.9 km, and the total area is approximately 12 km^2. The surrounding seafloor lies at 300m depth.

Methodological discussion, limitations and recommendations The three model types gave similar results (Table 3). Remarkably, the models with only coordinates fitted the data best for two of the three techniques. This may indicate that the covariates are not sufficient to predict habitat occurrence well enough. On the other hand, the coordinates correlate highly with depth; thus, including one group may be sufficient to obtain a good model fit. Bathymetry is linked to many marine ecological processes. Depending on bathymetric information, species-specific affinity to certain depths and topography can be linked to characterizing biological processes. Hence, bathymetry is one of the most useful data layers for marine geospatial mapping. For prediction, however, it is necessary to include covariables as well, because spatial coordinates only will result in habitats along straight lines (Fig. 26, first row of figures). The habitat prediction using both covariables and coordinates appears to give a more natural impression of the position of the different habitats. Still, we think that the habitat prediction can be improved by using additional data, such as satellite data in the blue range of the light spectrum and by including more ground-truthing data, such as available for the Luymes Bank (Van Duyl & Meesters, 2020).

Survey data used in this report are opportunistically collected and provide only a snapshot. The largest survey (NIOZ) studied an area of 40 km^2, representing only 1.8% of Saba Bank's total area. Thus, a more complete coverage collection of data, including more covariates. may provide a better prediction of the distribution of the different habitats. Biological variables can also be integrated into habitat predictions. Surveys could include, for example, variables such as chlorophyll-a or concentrations or zooplankton. High biological productivity can be linked to the occurrence of large megafauna or fish diversity (e.g. Sandin et al. 2008). Thus, measuring chlorophyll-a concentration in surveys by, for example, ROVs or satellites next to temperature might provide valuable data. The survey method can be very influential on the model predictions and the importance of covariates. For future studies, we recommend the application of underwater drones that can reach multiple depths and more easily explore complex habitat structures.

We recommend to:

- Combine the present results with satellite data of the Saba Bank in order to be able to discern patterns of distribution of the various habitat classes;
- More precisely determine coverage and spatial extent of the important habitats;
- Conduct quantitative in situ community assessments in the distinguished habitats in order to have more complete descriptions of the benthic diversity they represent;
- Determine the habitat function (or lack thereof) in the ontogenetic stages of different mobile species of interest.

5 Conclusion and policy advice

A first habitat map for the Saba Bank area has been constructed, which has provided new insights. Extensive coral reef areas were found along the edge of the Bank. Most reef growth occurs along the southern and eastern edges of the Bank. Algae and deeper sand dominate the central area. New discovered habitats include mounds of coralline algae (*Neogoniolithon*), an extensive reef in the north-western area, and an isolated drowned atoll, called the Small Sababank Atoll. The Luymes bank and the Small Sababank Atoll may deserve special protection. Our habitat predictions should be improved with additional (satellite-derived) environmental data and *in situ* quantitative assessments of the distribution of habitat types at the Saba Bank.

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Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

[If the report contains results from accredited laboratory (Chemisch en/of Benthos lab), include the following text, otherwise delete it entirely]
The Chemical and Benthos laboratory has an EN-ISO/IEC 17025:2017 accreditation for test laboratories with number L097. This accreditation has been granted by the Dutch Accreditation Council. As a result, the Chemical and Benthos laboratory has demonstrated its ability to provide valid results in a technically competent manner and to work in accordance with the ISO17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the original research results.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in proficiency tests.
In addition, a first-level control is performed for each series of measurements.

If desired, information regarding the performance characteristics of the analytical methods is available.

If the quality cannot be guaranteed, appropriate measures are taken.

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Justification

Report C098/23
Project Number: 4318100256

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Matthijs van der Geest
Researcher

Signature:

Date: 12 January 2024

Approved: name Management team member being responsible for the scientific content of this report
function

Signature:

Date: 12 January 2024

Appendix 1. Image sources

490 images came from the towed video method (TVM) used to study Queen conch (Lobatus gigas) populations living at depths deeper than 20 m collected by Boman et al. (2016). This method collected image data to count Queen Conch between June and November 2014.

The second dataset (162 images) were images collected using Baited Remote Underwater stereo-Videos (BRUV). This data was gathered between October 2012 and February 2014 to study reef fish assemblages, especially large predators (Langlois et al., 2010; Stoffers, 2014; Winter & de Graaf, 2019).
Thirdly, photographs (1791 images) of benthic communities used for the dataset were also collected by a photographic survey that was part of an expedition on the research vessel RVS *Pelagia,* by the Royal Netherlands Institute for Sea Research (NIOZ) and WMR that took place from 19 August to 8 September 2016 (De Nooijer & van Heuven, 2016). More details of each source are given below.

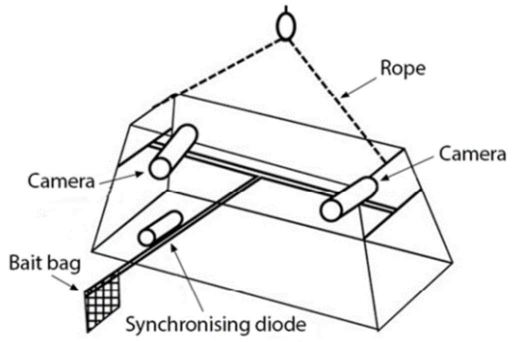
Towed video method

A PVC frame was used with a live view and transect camera. The live view camera was mounted on the frame in a forward and downward position of 30°, sending a live feed to the boat through a cable. The feed was continuously monitored to avoid collision with high-relief habitat and adjust for depth changes. The transect camera was mounted on the frame in a forward and downward position of 45°. The frame was placed approximately 1 m above the sea floor. The two green lasers indicated the 1 m width of the transect mounted parallel on a PVC bar on top of the frame at a fixed distance of 1 m apart. The two green lasers were placed in a forward and downward position of 45°, just like the transect camera. Each sampled transect ranged between 500-700 m. Boman et al. (2016) provide more information on towing and buoyancy.

The gathered video data was converted into stills by taking screenshots at the start of a video, after every 5 minutes, and at the end of the transect, resulting in 5-8 photos per transect. Based on the coordinates of the start and end positions of the transect, the locations of the intermediate screenshots on the transect were estimated under the assumptions that the transect was a straight line, and speed remained constant during the transect.

Baited Remote Underwater Videos (BRUV) data

Three stereo-BRUV systems were used to obtain video footage. Each BRUV system consisted of two video cameras (Canon Legria HFG10) mounted in high-density PVC housings. The cameras were attached to an aluminium frame, orientated along a horizontal plane relative to the seafloor. A mooring rope was attached to the BRUV system with, at the end, a buoy for retrieval. A bait bag containing ca. 800 grams of pilchards (*Sardinops* sp.) was mounted on a pole and placed at 1.5 m from the lens. The three BRUV units were used simultaneously at a minimum distance of 500 m apart to reduce overlap of bait odour plumes (Willis et al., 2000; Heagney et al., 2007). One-hour recordings were made per location.



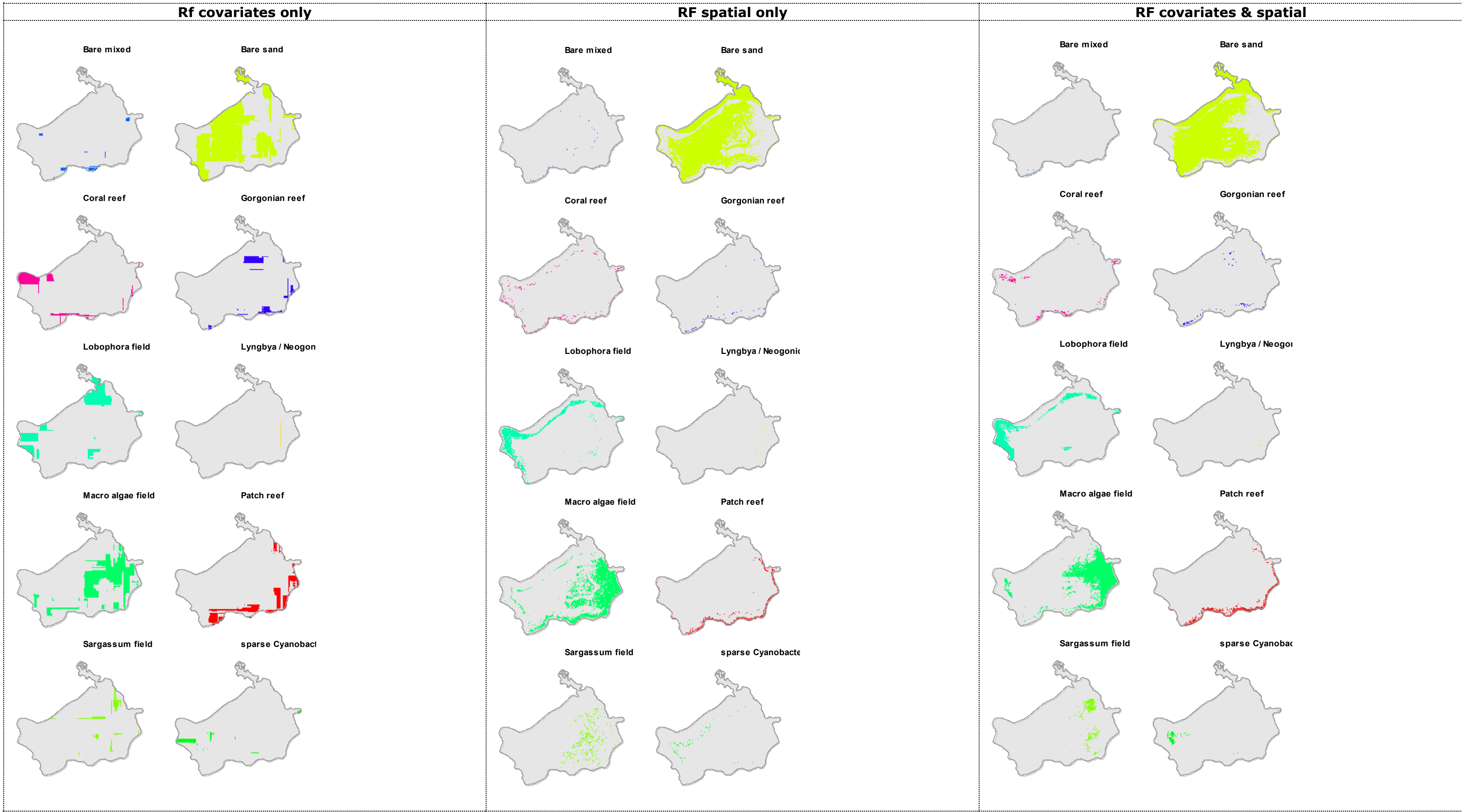
Setup of baited remote underwater stereo-video (BRUV) (After Langlois et al., 2010; Stoffers, 2014)

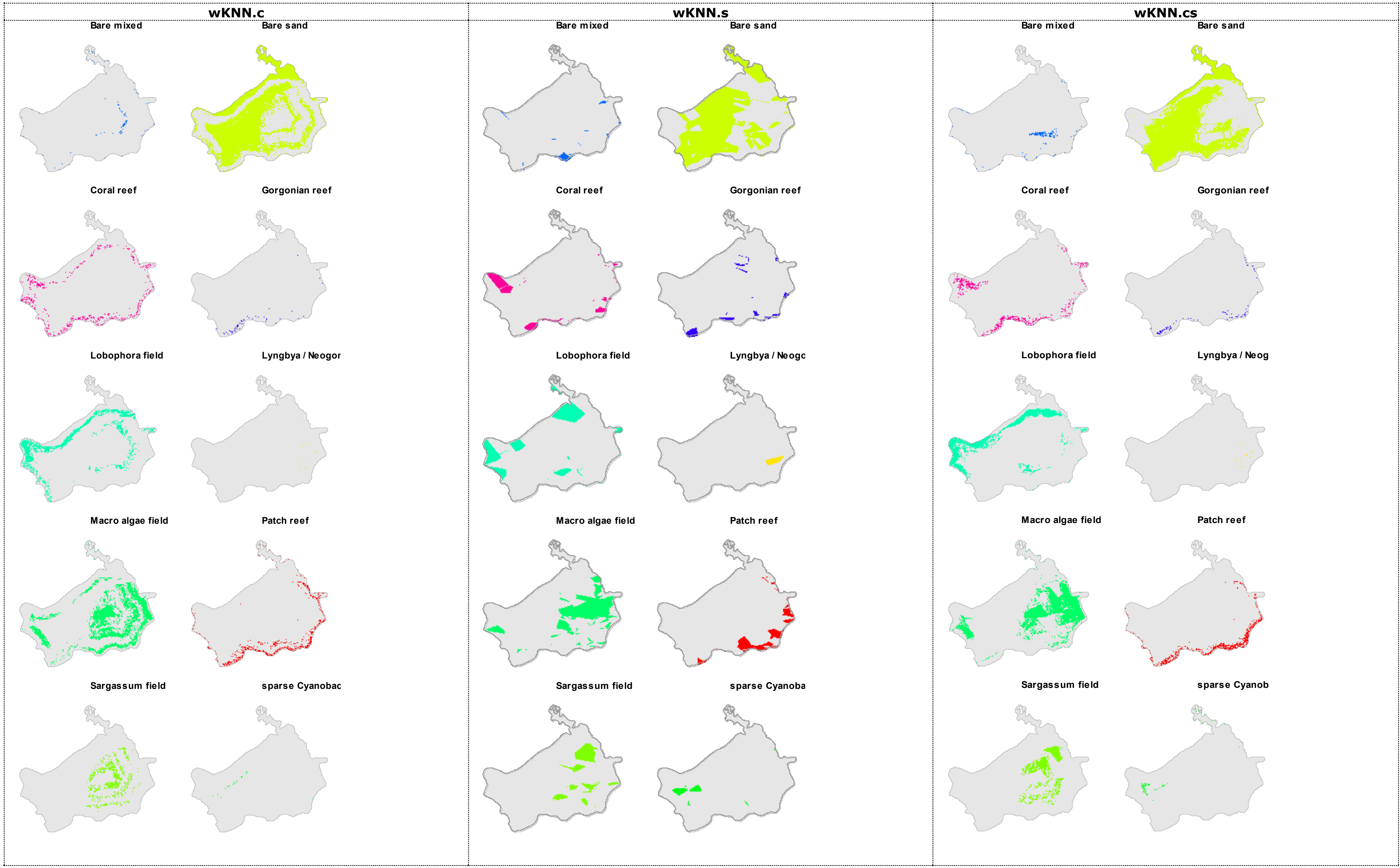
Sampling sites were distributed along three different depths (i.e. 15, 25 and 40 m) to conduct a comprehensive baseline survey of the Saba Bank and its habitats. Due to time restrictions, relatively more samples were taken in the shallow areas (<20 m) of the Bank (East and South), where the range of different habitat types that can be encountered is widest (Toller et al., 2010).
For the study in this report, one video image was used per hour of recording time to determine the habitat at that location.

Photographic survey of the benthic community (NIOZ data)

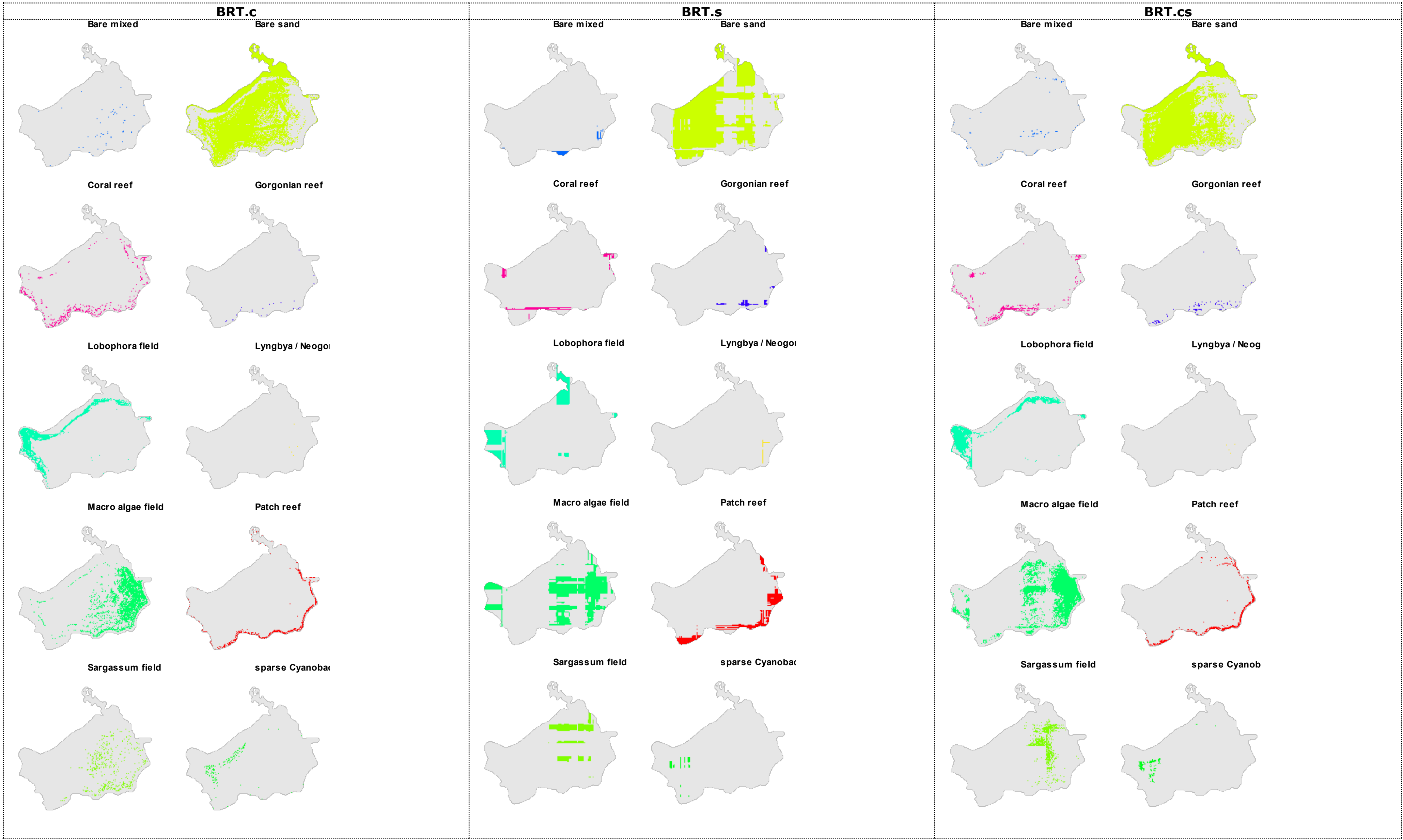
Image data of benthic communities was gathered via a steel frame equipped with two downward-facing cameras, a forward-facing camera, and lights. The lights also include two lasers placed 30 cm apart to help estimate sizes. One of the two downward-facing cameras and the forward-facing camera were connected to the vessel via cable, allowing real-time control of the cameras. The hopper frame was lowered to 1-2 m above the bottom. The cameras took pictures at an interval of five seconds and were linked to GPS time to determine the exact position of each picture. More information about camera specifications and boat speed can be found in De Nooijer and van Heuven (2016). In total, 32,000 images were collected on 31 transects. For the analysis in this paper, images were selected based on a minimum distance of 10 m.

Appendix 2. Model predictions by habitat type





wKNN.c
wKNN.s
wKNN.cs
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neogor
Macro algae field
Patch reef
Sargassum field
sparse Cyanobac
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neogc
Macro algae field
Patch reef
Sargassum field
sparse Cyanoba
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neog
Macro algae field
Patch reef
Sargassum field
sparse Cyanob


BRT.c
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neogo
Macro algae field
Patch reef
Sargassum field
sparse Cyanoba
BRT.s
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neogo
Macro algae field
Patch reef
Sargassum field
sparse Cyanoba
BRT.cs
Bare mixed
Bare sand
Coral reef
Gorgonian reef
Lobophora field
Lyngbya / Neog
Macro algae field
Patch reef
Sargassum field
sparse Cyanob

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