A REVIEW OF GLOBAL LAND COVER MAPS IN TERMS OF THEIR POTENTIAL USE FOR HABITAT SUITABILITY MODELLING

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ABSTRACT

Recently, there has been a significant increase in number of land cover maps available to researchers and they are now more commonly used. The broad variety requires some system for determining the differences between maps and for estimating their applicability for specific research purposes. We focused on comparing land cover maps from the point of view of how the land cover categories used characterize potentially suitable habitats for species. This comparison includes only freely available global land cover projects with resolutions from 1 km to 10 m. The criteria chosen were temporal and spatial resolution, number of classes and map precision. To demonstrate the differences, two areas of different sizes were always chosen. Our results reveal that maps can significantly vary in their estimates of different types of land cover, even at the same spatial resolution. Results also revealed that one type of vegetation in this area is poorly recorded in all land cover maps. Copernicus CGLS-LC100 and ESA CCI-LC maps appear to be the most suitable for evaluating potentially suitable habitats.

Keywords: comparison; Copernicus; ESA; FAO; habitat connectivity; habitat suitability

Introduction

The number of land cover maps and their use by researchers is greatly increasing. Earth observation satellites, such as Sentinel missions, Landsat missions, Terra and others provide data for these maps. Researchers can gain access to satellite imagery data with various levels of processing, such as an image of the Earth's surface with several bands, or an already processed map that is ready for analysis. Acquiring unprocessed satellite images could be a better option for a relatively small area, especially if it consists of a few images. Land cover maps can be created from satellite images in free open-source programs (Manton et al. 2005; Ndegwa Mundia and Murayama 2009; Barik et al. 2021). Precision of such maps depends not only on the quality of satellite imagery (Manton et al. 2005), but also on the classification approach (Li et al. 2017) and on type of data used (Novillo et al. 2018). However, for a global scale study, creating land cover maps from individual satellite images is extremely time consuming and this process will often exceed storage memory and processing capacities of a personal computer. Proper measuring of the precision of the final world map is an impossible task for an ordinary researcher. An average researcher, who is not specialized in processing remote sensing data, would be unable to correctly measure the precision of the final world map. Therefore, only land cover maps that do not require further processing were included in this comparative study. Some of these maps were created using data from several satellite sensors and replicating this method on a personal computer is unrealistic.

Land cover maps can be used in various fields of study: habitat connectivity (Ciudad et al. 2021), effect of changes in land use (Barik et al. 2021), conservation planning (Falcucci et al. 2007), climate change (McMenamin et al. 2008) and forest monitoring (Rawat and Kumar 2015). Here we consider using land cover maps for estimating land cover of habitats that are potentially suitable for species on a global scale. For example, for epiphytic orchids, tropical forest is one of its suitable habitats. Evaluation of habitat suitability should be based on multiple sources of information (Manton et al. 2005; Hirzel and le Lay 2008). Nevertheless, land cover maps can be used to estimate, e.g., habitat connectivity (Cisneros-Araujo et al. 2021). Here we concentrate on usefulness of such maps for estimating site connectivity (e.g. that of an island or protected area) and habitat suitability for a species.

For the purpose of this study, maps should have certain characteristics. In order to correctly determine potentially suitable habitat, the map should temporally match that at the time the occurrence records were collected. It is worth considering using a series of land cover maps to determine changes over time, such as population dynamics (Ndegwa Mundia and Murayama 2009), the effect of changes in land cover on a species' habitat (Breininger et al. 2006), etc. Obtaining a time series of maps for a single project might minimize the bias in the resulting estimates of potentially suitable habitat, particularly if the maps were developed using the same algorithms and data from the same satellites. The map should have an appropriate spatial resolution. Choosing the appropriate spatial resolution is crucial for evaluating the pattern of potentially suitable habitat, since the final estimate of the extent of suitable habitat is highly dependent on the resolution of the land cover map (Rondinini et al. 2011; Ciudad et al. 2021). This decision is primarily based on the ecology of the species studied and purpose of the research. Overall, a too coarse resolution can omit habitat

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fragmentation, resulting in an inaccurate estimate of the extent of suitable habitat. Displaying interactive maps in online map viewer, for example on the FAO GeoNetwork, should be treated with caution, as it tends to inflate the real resolution of the map. Number of classes needed for evaluating suitable habitat also depends on the aim of the study. A map with fewer classes, but higher resolution, would better reflect the average distribution of these classes than a coarser map with the same classification. However, for types of vegetation (forests, shrubs, etc.) it is important to provide multiple subcategories, since such categories have critical details for evaluating habitat suitability. E.g., category "Mosaic tree and shrub (> 50%) / herbaceous cover (< 50%)" in CCI-LC map (ESA 2017) provides more information than "Shrub Covered Areas" in GLC-SHARE map (Latham et al. 2014).

Materials and Methods

Maps were obtained from a variety of sources, the NASA Earthdata Search, ArcGIS, Zenodo and FAO GeoNetwork. 254 maps were found using NASA Earthdata Search using the keywords "Land use/Land cover" and "Global." The majority were individual satellite images or specific small areas, which often included other categories of maps besides land cover maps (normalized difference vegetation index (NDVI), snow-free albedo, etc.). The names of projects and platforms (satellites or sensors) used in the development of global cover maps were the main results of this search. The agencies that provide final land cover maps, such as ESA, Copernicus and FAO, were discovered after searching individual projects and sensor names. GLOBCOVER and GLC-SHARE maps were found in the FAO GeoNetwork. The ArcGIS online Map Viewer was used to visually inspect some of the projects (MODIS, ESA). Maps GLC_FCS30, FROM-GLC10 were downloaded from Zenodo service. ESA and Copernicus maps were obtained directly from the respective agencies.

The final selection of land cover maps is listed in Table 1. All the maps listed are free to download and links to websites are given at the end of this paper. The maps were selected using the criteria outlined below. Two different sized areas were chosen to illustrate the variations in detail captured by each map. The large area is 60 × 115 km in size. It includes part of Croatia and nearby small islands: Čiovo (28.8 km²), Drvenik veli (12.07 km²), Drvenik mali (3.43 km²), Šolta (58.98 km²), Brač (396 km²), Hvar (297.4 km²), Paklinski islands (7.165 km²), Šćedro (8.36 km²). Small area is approximately 4 × 4 km in size. It includes a part of Čiovo island, which has a mosaic of forests, shrubs and open areas, and quite a large amount of urban areas along the coast and there does not seem to be any crops, only orchards, but definitely open herbaceous vegetation. Such a small area was chosen to demonstrate the accuracy of each map. For the smaller area, map classification was compared with Google Earth satellite imagery (Gorelick et al. 2017).

The following criteria for selecting maps were determined based on their potential use in evaluating habitat connectivity or habitat suitability:

Matching time periods

Some projects include land cover maps for earlier periods (ESA CCI-LC map is available from the year 1992), while others are for a specific short period of time (ESA GLOBCOVER map). There are projects that predict historical land use changes, such as ISLSCP II data collection (International Satellite Land-Surface Climatology Project, Initiative II), which includes 50 global time series data sets from 1986 to 1995 and describes historical changes in land use over a period of 300 years (1700–1990) (Goldewijk et al. 2007). Or, for example, a project from the United States Geological Survey (USGS), which is only for the years 1992–1993, but contains more data for this period of time. It provides not only a map of land cover, but also a global ecosystems map, simple biosphere model, biosphere–atmosphere transfer scheme, and vegeta-

Table 1 Final map selection.

Data provided by	Map name	Resolution	Number of classes	Approximate file size	Overall mapping accuracy	Temporal coverage
Copernicus	CGLS-LC100	100 m	23	53 GB	80.6% in 2015 80.3% in 2019	2015–2019
Food and Agriculture Organization of the United Nations (FAO)	GLC-SHARE	1000 m	11	35.2 MB	80.2%	1998–2012
European Space Agency (ESA)	CCI-LC	300 m	37	258 MB /2.3 GB	75.4%	1992 – present with one year delay
European Space Agency (ESA)	GLOBCOVER	300 m	22	374 MB	67.10%	12.2004 – 06.2006 01.2009 – 12.2009
Liangyun et al. 2020 (open access)	GLC_FCS30	30 m	9/16/24	21 GB	82.5%/71.4% /68.7%	2015, 2020
Gong et al. 2019 (open access)	FROM-GLC10	10 m	27 (2015) 11 (2017)	unknown	72.76%	2015, 2017

tion lifeform map. Monthly NDVI composites, however, are only available on the continent-scale map (GLCC).

Temporal resolution

The majority of the final products have the same temporal resolution (one year), which may be insufficient for analyses requiring a finer temporal resolution (Ciudad et al. 2021). Unfortunately, there is no global land cover map with a lower temporal resolution. Indexes, characterizing vegetation, such as normalized difference water index or normalized difference vegetation index are produced monthly and can be used as substitution for a land cover map (Teng et al. 2021). If a land cover map is needed for a particular time period, for a smaller area it can be created using satellite imagery (Pennington et al. 2008; Li et al. 2017).

Spatial resolution

Maps with resolutions greater than 1 km were excluded from the comparison due to the loss of landscape features (islands, water bodies, etc.) at such resolutions.

Highest global land cover map resolution that is currently available is 30 m (considering only publicly available projects from major agencies, for which this precision was thoroughly evaluated). There are companies that provide higher-resolution maps, for example, 10 m BaseVue maps from 2005 to the present time (MAXAR 2021). However, these maps have to be purchased and are provided on request, for a user-defined area. Alternatively, such maps can be obtained from open projects, such as FROM-GLC10 with a resolution of 10 m (Gong et al. 2019).

File size

Since this is primarily determined by map resolution, a direct comparison would be unreasonable. Even so, due to the difference in raster compression methods, the size of the final product will vary between maps with a similar resolution. Distributors provide well-compressed maps, but it should be mentioned that file size can drastically change after re-saving, for example, after exporting categories into separate files. This may present a problem, es-

Table 2 Land cover classes included on CGLS-LC100 map, taken from Buchhorn et al. (2020). Corresponding land cover map is shown in Fig. 1.

Land cover class	Definition
Closed forest, evergreen needles	Tree canopy > 70%, almost all trees with needles remain green all year. Canopy is never without green foliage.
Closed forest, evergreen, broad leaf	Tree canopy > 70%, almost all trees are broadleaved and remain green all year. Canopy is never without green foliage.
Closed forest, deciduous needles	Tree canopy > 70%, almost all trees bear needles and are deciduous.
Closed forest, deciduous broad leaf	Tree canopy > 70%, almost all trees are broadleaved and deciduous.
Open forest, evergreen needles	Top layer: trees 15–70% and second layer: mixed of shrubs and grassland, almost all the trees bear needles and are evergreen. Canopy is never without green foliage.
Open forest, evergreen broad leaf	Top layer: trees 15–70% and second layer: mixed of shrubs and grassland, almost all the trees are broadleaved and evergreen. Canopy is never without green foliage.
Open forest, deciduous needles	Top layer: trees 15–70% and second layer: mixed of shrubs and grassland, all the trees bear needles and are deciduous.
Open forest, deciduous broad leaf	Top layer: trees 15–70% and second layer: mixed of shrubs and grassland, all the trees are broadleaved and deciduous.
Shrubs	These are woody perennial plants with persistent woody stems and no main stem and are less than 5 m tall the foliage of which can be either evergreen or deciduous
Herbaceous vegetation	Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10%.
Cultivated and managed vegetation/agriculture (cropland)	Land covered with temporary crops followed by harvest and a bare soil (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate type of forest or shrub land cover.
Urban / built up	Land covered by buildings and other man-made structures.
Bare / sparse vegetation	Lands with exposed soil, sand, or rocks with never more than 10% covered with vegetation.
Snow and ice	Lands under snow or ice throughout the year.
Permanent water bodies	Lakes, reservoirs, and rivers. Can be either fresh or salt-water.
Temporary water bodies	
Herbaceous wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.
Open sea	Oceans, seas. Can be either fresh or salt-water bodies.

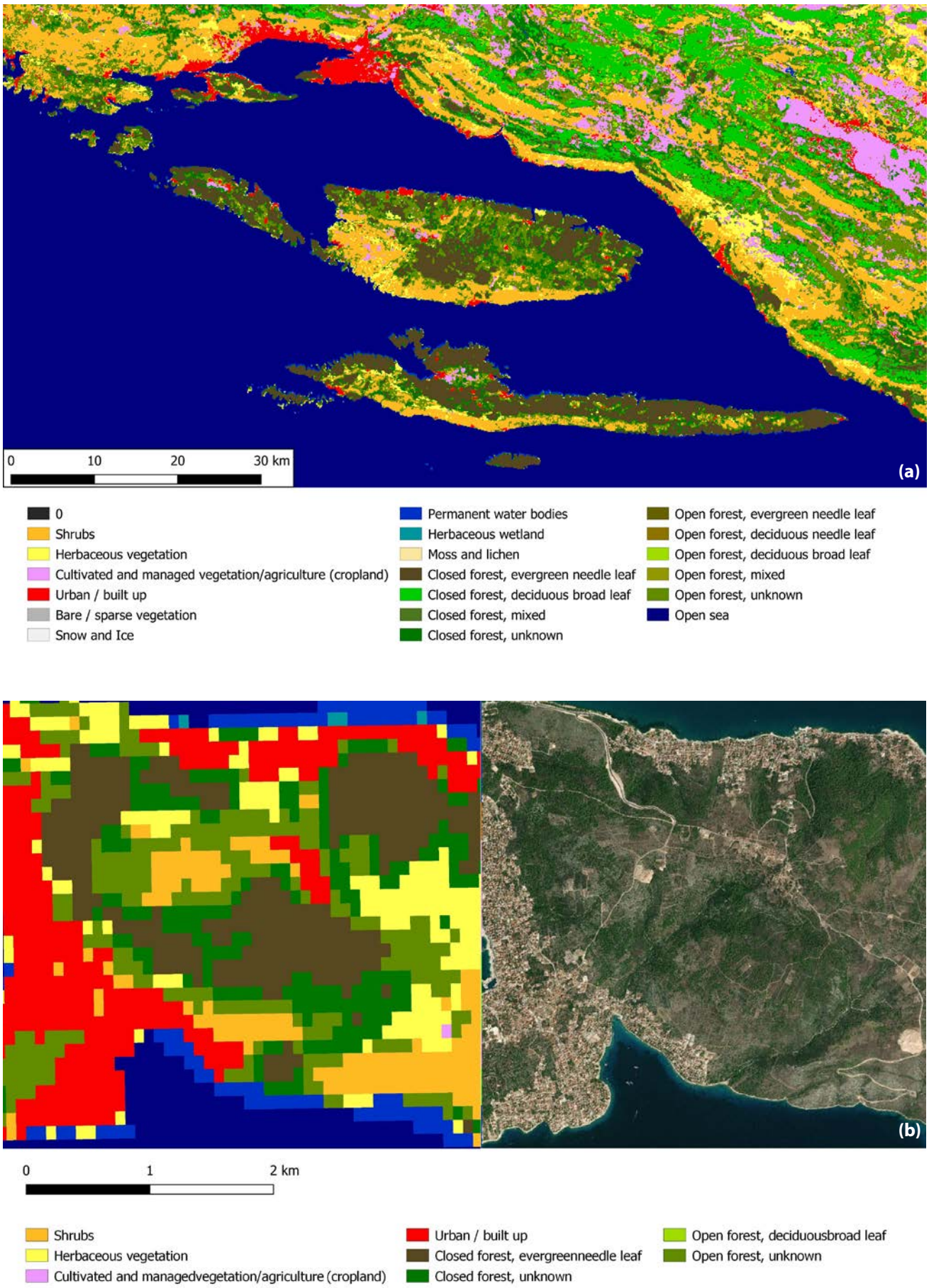


Fig. 1 Land cover map CGLS-LC100, (a) less detailed, legend includes all map classes; (b) more detailed, only the map classes present in the area are shown.

pecially with maps with high spatial resolution and large compressed file sizes.

Number of classes

Some projects provide comparison of maps classification system with the Land Cover Classification System (LCCS). FAO created this method to provide a standardized structure for land cover classification and mapping. As a result, such projects are easier to compare.

Map precision

Due to the global scale of the data, the most reliable information on the precision of the final map can be obtained from the map's provider. The precision of a map may vary depending on the number of classes (for example, in the GLC FCS30 map), so the accuracy of same map depends on the number of classes used. Furthermore, the precision of a project's estimate of a specific land cover category can vary; this information is usually given in validation reports.

Results

Copernicus global land service: land cover 100 m (Buchhorn et al. 2020)

This project provides a comparison of map land cover classes with definition from LCCS classification system (Table 2). In addition to a map with 18 land cover classes, Copernicus provides layers that describe probability and quality of classification for each pixel. This map is also accompanied by cover layers, which define the percentage of pixels covered by a particular class pixel (forest, herbaceous vegetation, shrub, and bare soil) (Buchhorn et al. 2021).

Fig. 1a shows that the map not only depicts a high overall diversity of different types of land cover, but also a diversity on small islands and even the smallest island. Fig. 1b gives a clear indication of the level of detail recorded. There are clear similarities in the detail in satellite imagery and a map characterization of land cover, even the shapes of urban areas are accurate. The only inaccu-

Table 3 CCI-LC map categories, adapted from ESA (2017). Corresponding land cover map is shown in Fig. 2.

Global scale class	Regional scale class
Cropland, rainfed	Cropland, rainfed, herbaceous cover
	Cropland, rainfed, tree or shrub cover
Cropland, irrigated or post-flooding	
Mosaic cropland (> 50%) / natural vegetation (tree, shrub, herbaceous cover) (< 50%)	
Mosaic natural vegetation (tree, shrub, herbaceous cover) (> 50%) / cropland (< 50%)	
Tree cover, broadleaved, evergreen, closed to open (> 15%)	
Tree cover, broadleaved, deciduous, closed to open (> 15%)	Tree cover, broadleaved, deciduous, closed (> 40%)
	Tree cover, broadleaved, deciduous, open (15–40%)
Tree cover, coniferous, evergreen, closed to open (> 15%)	Tree cover, coniferous, evergreen, closed (> 40%)
	Tree cover, coniferous, evergreen, open (15–40%)
Tree cover, coniferous, deciduous, closed to open (> 15%)	Tree cover, coniferous, deciduous, closed (> 40%)
	Tree cover, coniferous, deciduous, open (15–40%)
Tree cover, mixed leaf type (broadleaved and coniferous)	
Mosaic tree and shrub (> 50%) / herbaceous cover (< 50%)	
Mosaic herbaceous cover (> 50%) / tree and shrub (< 50%)	
Shrubland	Evergreen shrubland
	Deciduous shrubland
Grassland	
Lichens and mosses	
Sparse vegetation (tree, shrub, herbaceous cover) (< 15%)	Sparse tree cover (< 15%)
	Sparse shrub cover (< 15%)
	Sparse herbaceous cover (< 15%)
Tree cover, flooded, fresh or brackish water	
Tree cover, flooded, saline water	
Shrub or herbaceous cover, flooded, fresh/saline/brackish water	
Urban areas	
Bare areas	Consolidated bare areas
	Unconsolidated bare areas
Water bodies	
Permanent snow and ice	

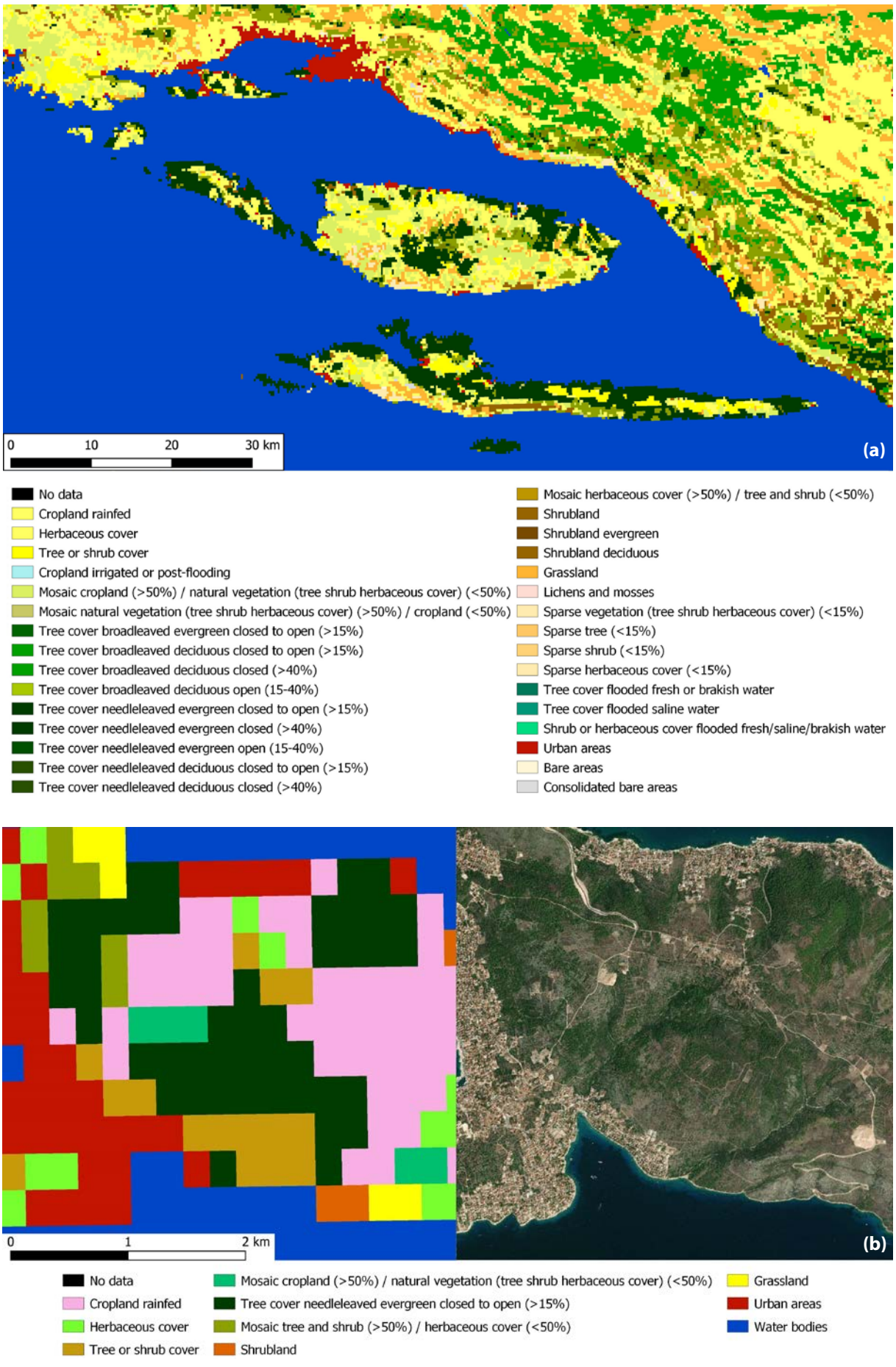


Fig. 2 Land cover map CCI-LC, (a) less detailed, legend includes all map classes; (b) more detailed, only map classes present in the area are shown.

racy is that bare soil is categorized as cropland (one pink pixel bottom right). However, due to the small size of this patch, this misclassification is negligible, as it indicates there is a difference in the landscape.

European Space Agency: Climate Change Initiative Land Cover map (CCI-LC) (ESA 2017)

CCI-LC map categories are compatible with the LCCS coding. This map has two scales of categories (Table 3), in some areas, where certain types cannot be defined, global scale classes are substituted for regional scale classes.

CCI-LC correctly indicates the uneven distribution of different types of land cover, as shown in Fig. 2a, and it also includes the smallest islands. Visual estimates of overall diversity is difficult due to the similar colouration of categories (in Fig. 2a categories have the colours in ESA). This is not a problem if the map has already been downloaded. The disadvantage is that due to the higher spatial resolution, the majority of online map viewers will display this map in a very misleading manner (the map can be "upscaled" to a higher spatial resolution for a faster display). It is impossible to determine whether the area of interest is classified on a regional or global scale (all cropland and needle leaved forest classes are indistinguishable in terms of colour). In Fig. 2b, similar colours were changed. Fig. 2b reveals that the map provides significantly less detail than Copernicus, but overall it is similar. Orchards were identified as rain fed croplands, which are categorized as cropland in this map.

Food and agriculture organization of the United Nations: Global land cover SHARE (GLC-SHARE) (Latham et al. 2014)

This project's map has only 11 classes, which are not compatible with the LCCS classification system, but in-

Table 4 Map categories with descriptions, taken from Latham et al. 2014.

Land Cover	Description
Artificial Surfaces	This category includes any type of area with a predominantly artificial surface. Any urban or related feature is included, for example urban parks (parks, parkland, sport facilities). It also includes industrial areas, waste dumps and extraction sites.
Cropland	Herbaceous crops: includes cultivated herbaceous plants (graminoids or herbaceous plants) and crops used for hay. All the non-perennial crops that do not last for more than two growing seasons and crops like sugar cane where the upper part of the plant is regularly harvested while the root system can remain for more than one year in the field are included.
	Woody crops: includes permanent crops (trees and/or shrub crops) and includes all types of orchards and plantations (fruit trees, coffee and tea plantation, oil palm, rubber plantation, Christmas trees etc.).
	Multiple or layered crops: includes different land cover situations: – Two layers of different crops (woody + herbaceous): A common case is the presence of woody crops (trees or shrubs) and herbaceous crops, such as, wheat fields with olive trees in the Mediterranean area and intense horticulture, oasis or typical coastal African agriculture where the cover for herbaceous fields is provided by palm trees, etc. – Presence of one important layer of natural vegetation (mainly trees) that cover one layer of cultivated crops: a typical example are coffee plantations shadowed by natural trees in the equatorial area of Africa.
Grassland	Includes any geographic area dominated by natural herbaceous plants (grasslands, prairies, steppes, and savannahs) with a cover of 10% or more, irrespective of different human and/or animal activities, such as: grazing, selective fire management etc. Woody plants (trees and/or shrubs) can be present providing their cover is less than 10%.
Tree covered areas	Includes any geographic area dominated by trees with a cover of 10% or more. Other types of plants (shrubs and/or herbaceous) can be present, even at a density greater than the trees. Areas planted with trees for afforestation purposes and forest plantations are included in this category, which also includes areas seasonally or permanently flooded with fresh water, but not coastal mangroves.
Shrubs covered areas	Includes any geographic area dominated by shrubs with a cover of 10% or more. Other types of plants (herbaceous) can be present, even at a density greater than shrubs.
Herbaceous vegetation, aquatic or regularly flooded	Includes any geographic area dominated by natural herbaceous vegetation (cover of 10% or more) that is permanently or regularly flooded by fresh or brackish water (swamps, marsh areas etc.). Flooding must persist for at least 2 months per year to be considered regular. Woody vegetation (trees and/or shrubs) can be present if their cover is less than 10%.
Mangroves	Includes any geographical area dominated by woody vegetation (trees or shrubs) with a cover of 10% or more that is permanently or regularly flooded by salt and/or brackish water located in coastal areas or in river deltas.
Sparse vegetation	Includes any geographic areas where the cover of natural vegetation is between 2% and 10%. This includes permanently or regularly flooded areas.
Bare soil	Includes any geographic area dominated by natural abiotic surfaces (bare soil, sand, rocks, etc.) where the natural vegetation is absent or almost absent (covers less than 2%) and areas regularly flooded by inland water (lake shores, river banks, salt flats etc.), but not coastal areas affected by the tidal movement of salt water.
Snow, glaciers	Includes any geographic area covered by snow or glaciers persistently for 10 months or more.
Waterbodies	Includes any geographic area covered for most of the year by inland water bodies. In some cases the water can be frozen for part of the year (less than 10 months). Because the geographic extent of water bodies can change, boundaries must be consistent with class 11 according to the dominant situation during a year and/or many years.

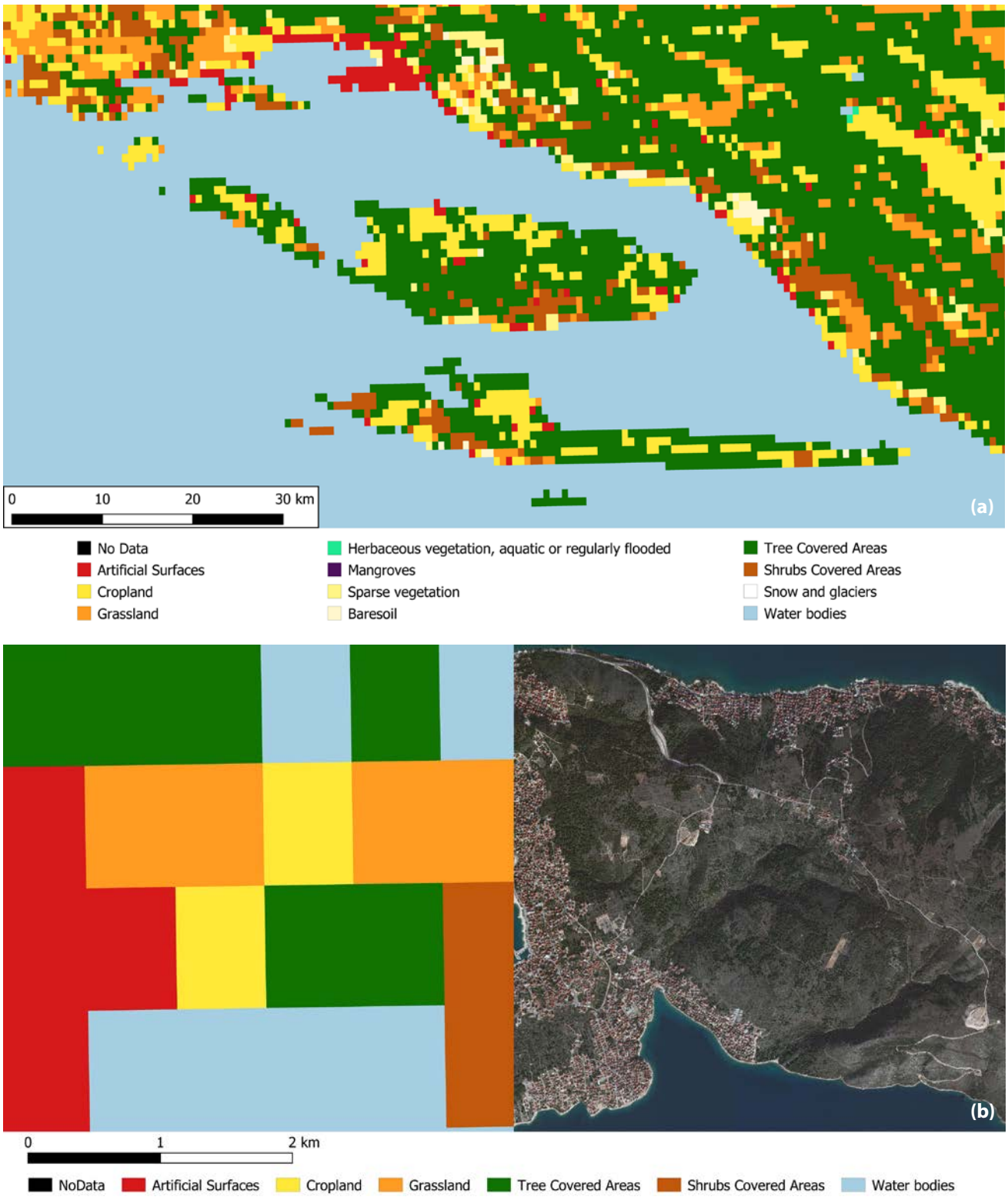


Fig. 3 Land cover map GLC-SHARE, (a) less detailed, legend includes all map classes; (b) more detailed, only map classes present in the area.

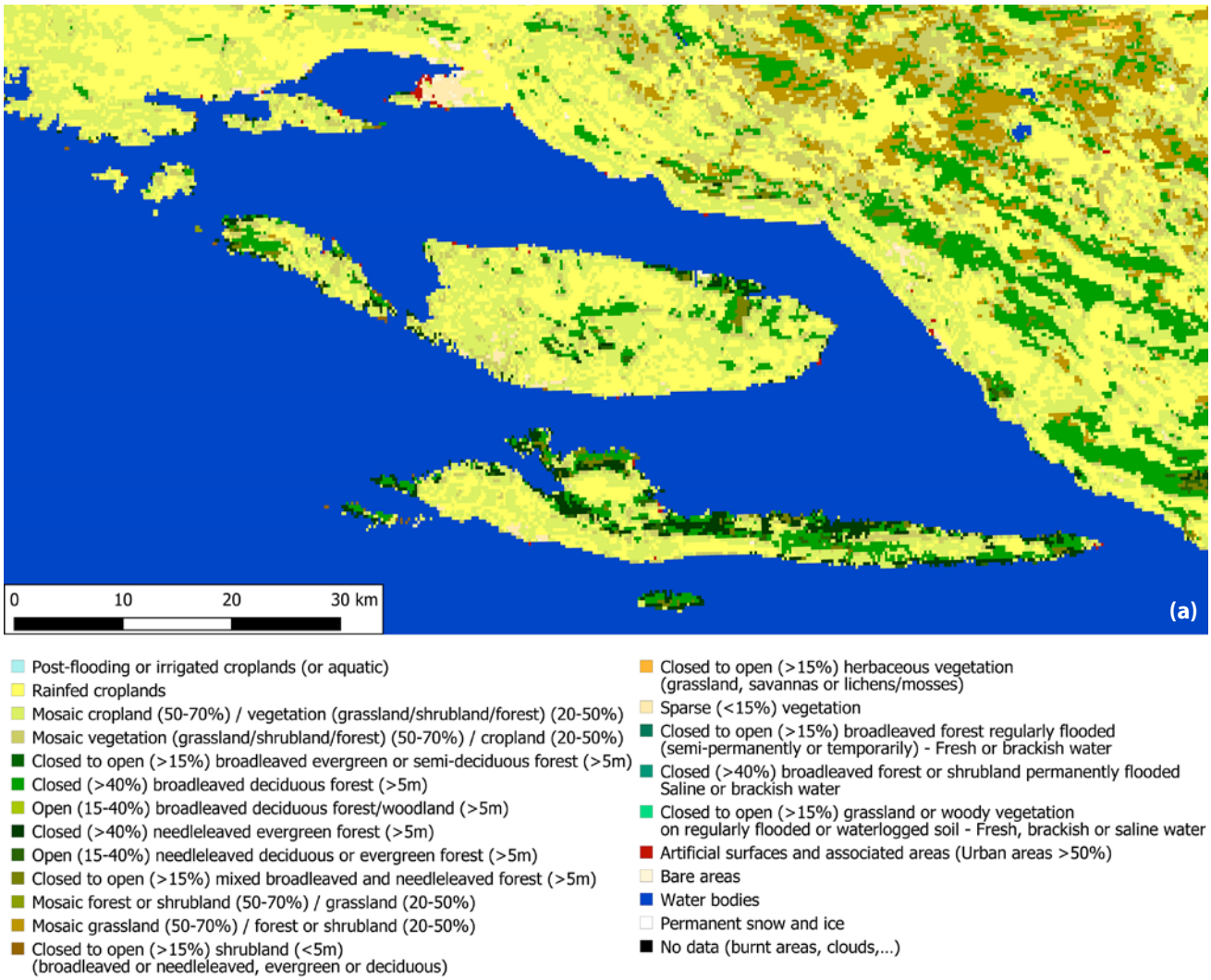
cludes a detailed description of each class (Table 4). This map not only doesn't accurately capture landscape features because of its resolution and number of classes, but it also omits several important details: distribution of urban areas, smaller islands, shape of coast line and so on (Fig. 3). Such resolution is hardly suitable for modelling species habitats.

European Space Agency: GlobCover (Arino et al. 2012)

Classification of GlobCover (Table 5) is compatible with the LCCS system. Fig. 4a shows that the map of this region does not truly represent urban areas (there should be more red colour along the coast, as in Fig. 2a, at a similar resolution). Fig. 4b reveals another misclassification: forest was not identified.

Table 5 Land cover classes of GLOBCOVER map, adapted from Arino et al. (2012).

Land cover classes	Land cover classes
Post–flooding or irrigated cropland (or aquatic)	Closed to open (> 15%) (broadleaved or coniferous, evergreen or deciduous) shrubland (< 5 m)
Rainfed cropland	Closed to open (> 15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
Mosaic cropland (50–70%) / vegetation (grassland/shrubland/forest) (20–50%)	Sparse (< 15%) vegetation
Mosaic vegetation (grassland/shrubland/forest) (50–70%) / cropland (20–50%)	Closed to open (> 15%) broadleaved forest regularly flooded (semi–permanently or temporarily) – Fresh or brackish water
Closed to open (> 15%) broadleaved evergreen or semi-deciduous forest (> 5 m)	Closed (> 40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water
Closed (> 40%) broadleaved deciduous forest (> 5 m)	Closed to open (> 15%) grassland or woody vegetation on regularly flooded or waterlogged soil – Fresh, brackish or saline water
Open (15–40%) broadleaved deciduous forest/woodland (> 5 m)	Artificial surfaces and associated areas (Urban areas> 50%)
Closed (> 40%) coniferous evergreen forest (> 5 m)	Bare areas
Open (15–40%) coniferous deciduous or evergreen forest (> 5m)	Water bodies
Closed to open (> 15%) mixed broadleaved and coniferous forest (> 5 m)	Permanent snow and ice
Mosaic forest or shrubland (50–70%) / grassland (20–50%)	No data (burnt areas, clouds…)
Mosaic grassland (50–70%) / forest or shrubland (20–50%)	



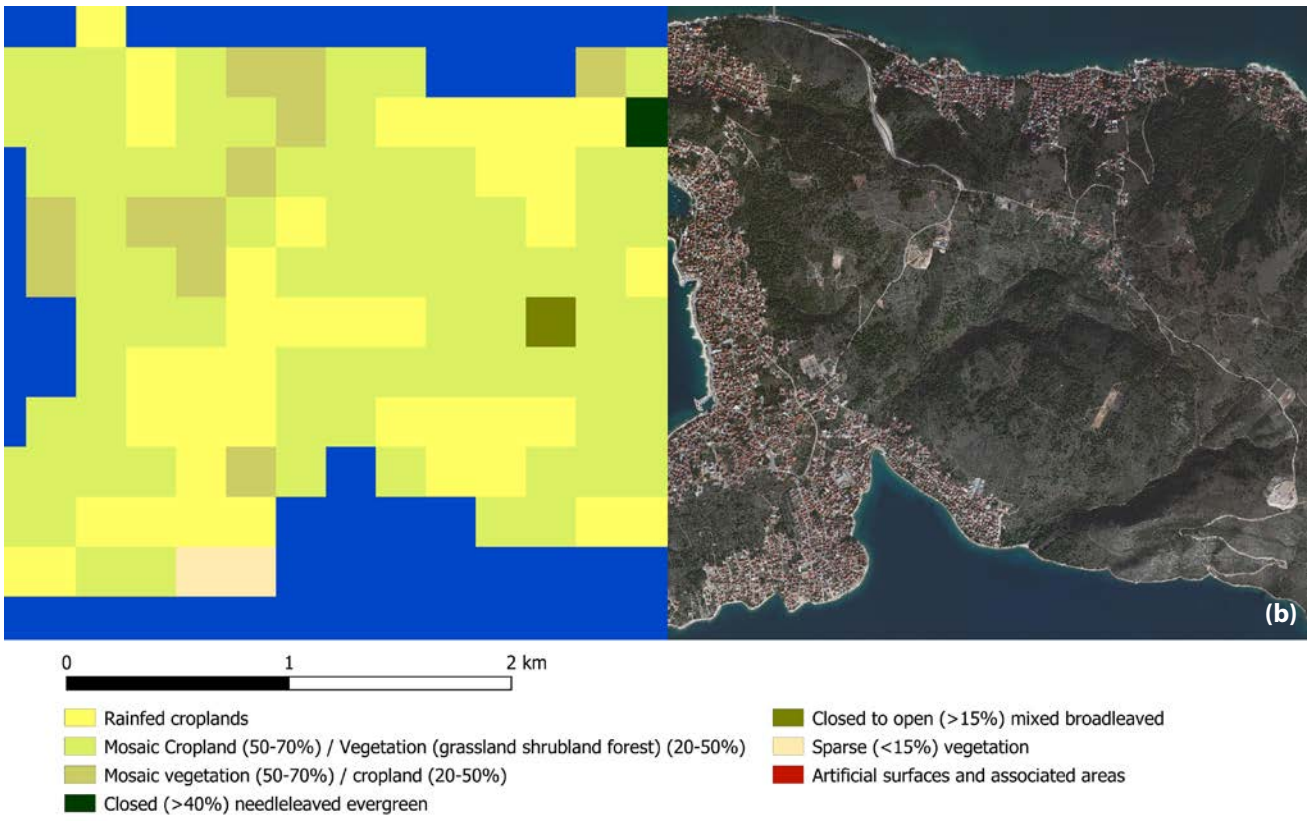


Fig. 4 Land cover map GlobCover: (a) less detailed, legend includes all map classes; (b) more detailed, only map classes present in the area.

GLC_FCS30 map, open access (Liangyun et al. 2020)

This map has 24 classes (Table 6), but is not compatible with the LCCS classification system. There are some misclassifications in this map along the coastline, but because of its resolution, it captures the finer details (Fig. 5). It also has some minor artefacts, such as: "orchards" along roads; small patches of "shrubland" within "closed forest", despite the fact that in the various satellite images forest appears to be homogeneous at such locations; occasionally roads are classified as "herbaceous cover". These minor misclassifications are correctable. However, this map has a more serious problem. Since sections of these maps overlap (Fig. 6a) and classification in the overlapping sections differs (Fig. 6b), these maps must be processed before they can be used for analysis. In contrast, the Copernicus (CGLS-LC100 map) map does not have such a

Table 6 Land cover classes GLC_FCS30 map, adapted from Liangyun et al. (2020). Classes with (*) are not present in map legend, these classes were added to categorize the legend.

Land cover classes		**Land cover classes**	
Cropland classes*	Rainfed cropland	Shrubland	Evergreen shrubland
	Orchard		Deciduous shrubland
	Irrigated cropland	Herbaceous cover	
Evergreen forest types*	Open evergreen broadleaved forest	Tree or shrub cover	
	Open evergreen broadleaved forest	Grassland	
	Open evergreen needle-leaved forest	Sparse vegetation	Sparse shrubland
	Closed evergreen needle-leaved forest		Sparse herbaceous vegetation
Deciduous forest types*	Open deciduous broadleaved forest	Lichens and mosses	
	Closed deciduous broadleaved forest	Wetlands	
	Closed deciduous needle-leaved forest	Impervious surfaces	
	Open deciduous needle-leaved forest	Bare areas	Unconsolidated bare areas
Mixed leaf forest types*	Open mixed broadleaved and needle-leaved forest		Consolidated bare areas
	Closed mixed broadleaved and needle-leaved forest	Water body	
		Permanent ice and snow	

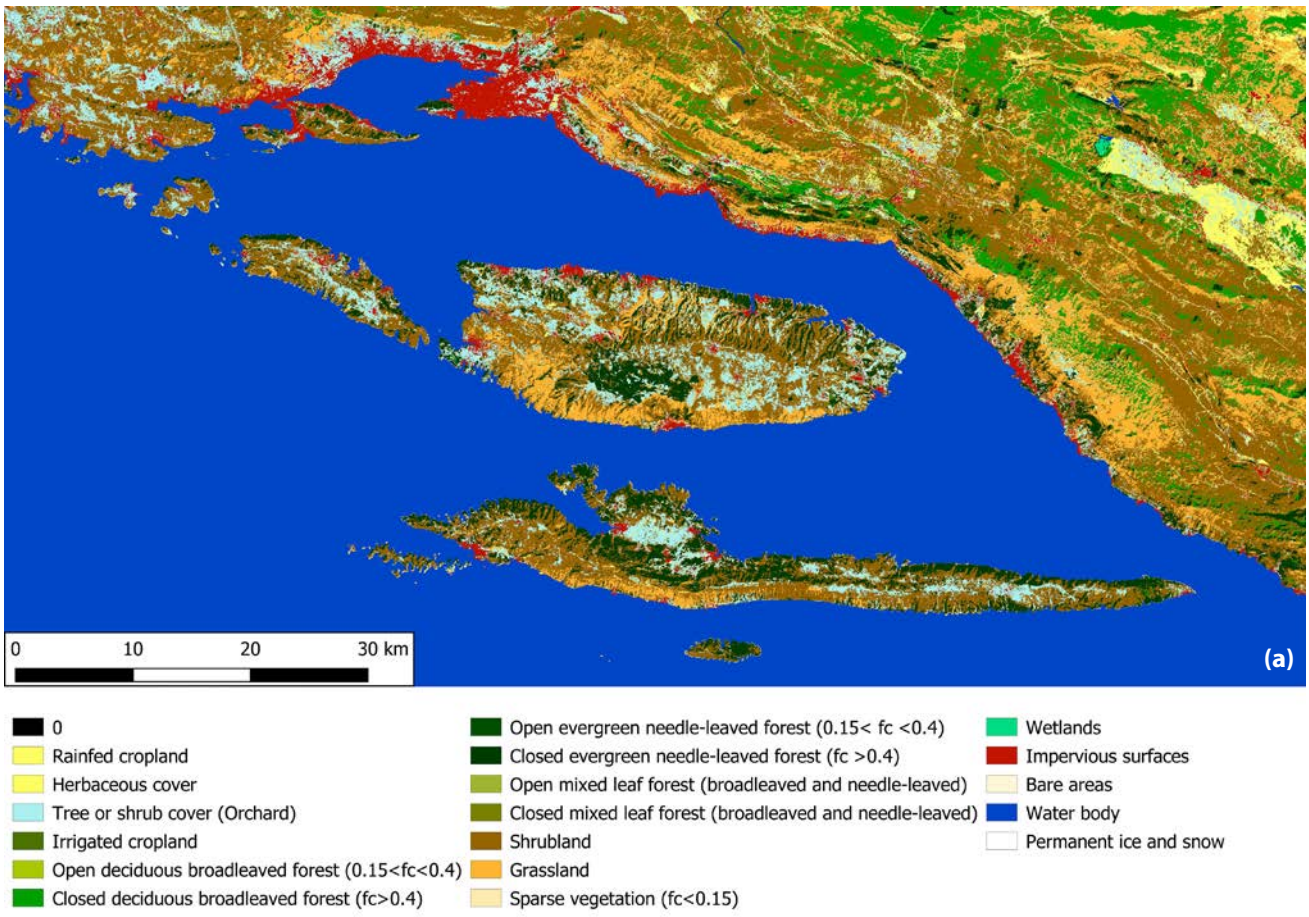
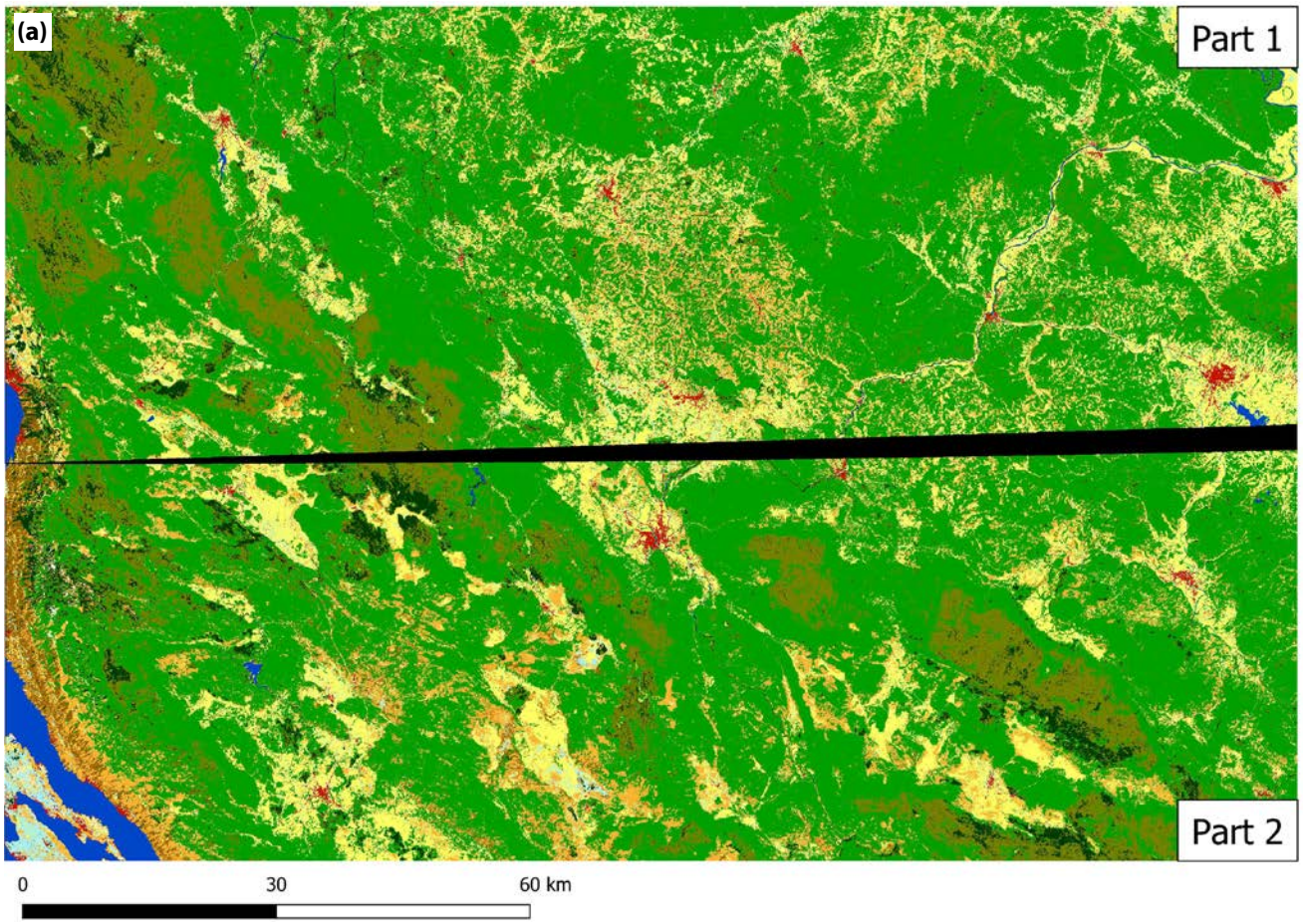


Fig. 5 Land cover map GLC_FCS30, (a) less detailed, legend includes all map classes; (b) more detailed, only includes classes present in the area.



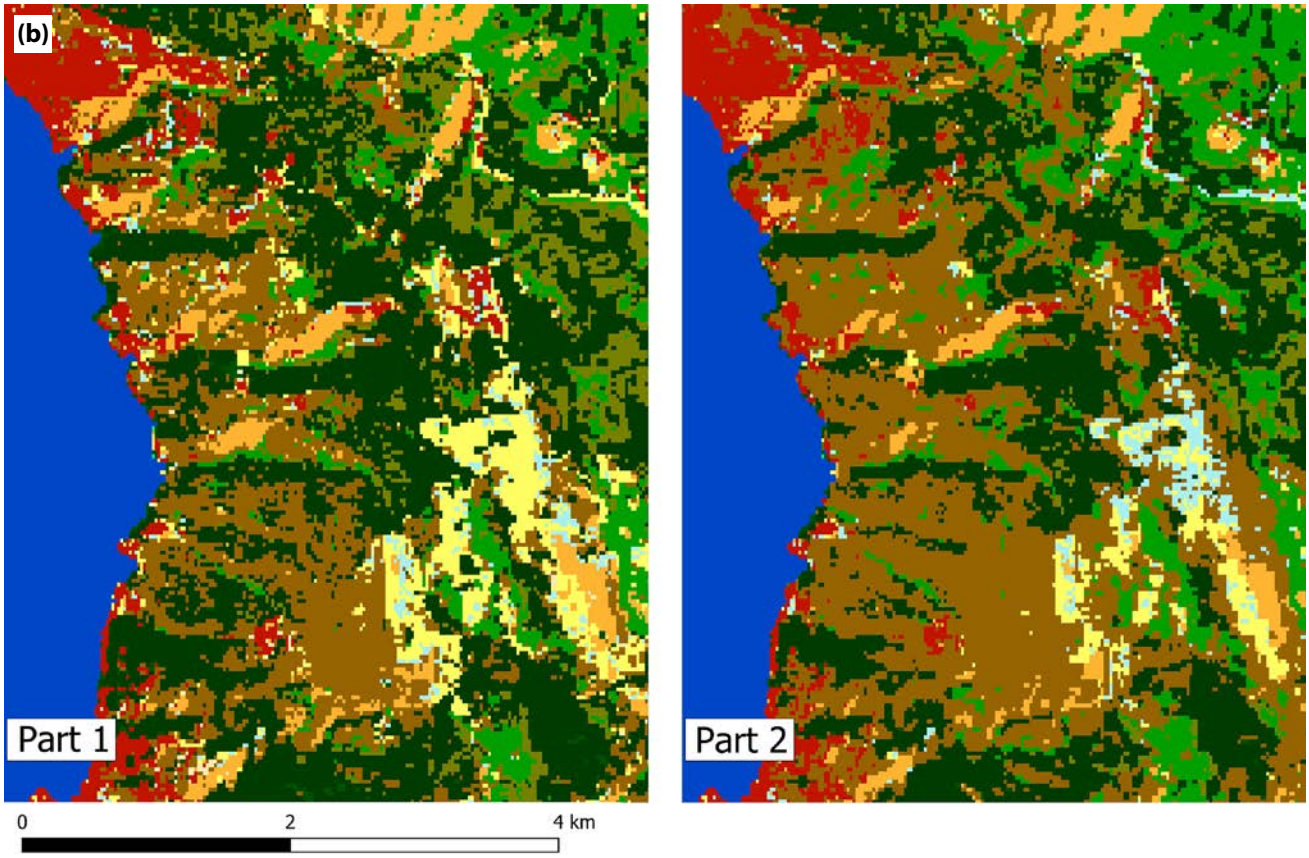


Fig. 6 Land cover map GLC_FCS30, (a) alignment between part 1 (E15N50) and part 2 (E15N45), extent of the area: 45.38, 14.9; 44.48, 16.82; (b) differences between overlapping sections, and the extent of the area: 44.98, 14.91, 44.93, 14.98. Parts' codes are section designations of GLC FCS30.

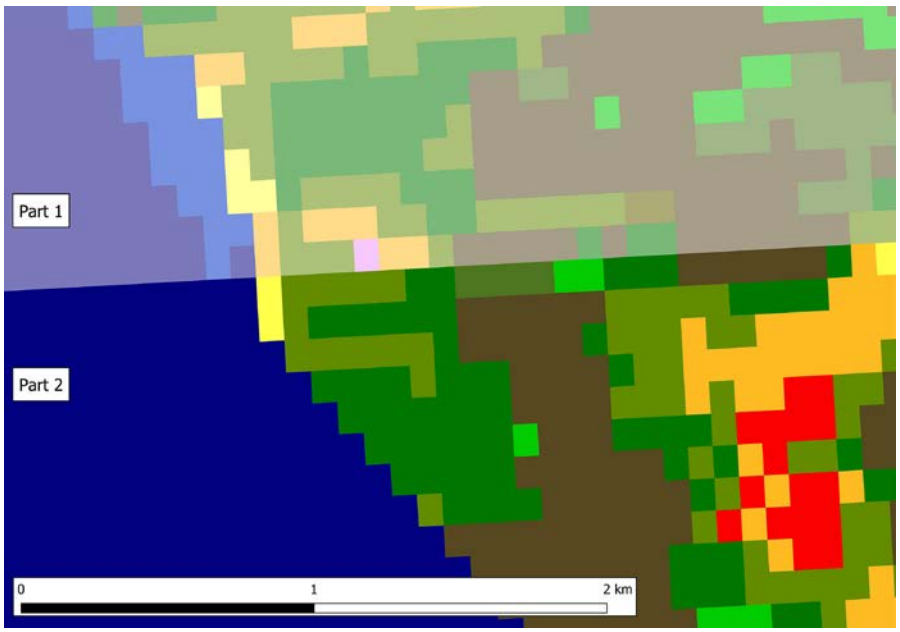


Fig. 7 CGLS-LC100 map's section alignment.

problem (Fig. 7), despite the fact that this map was also downloaded in the same way, by individual sections. On such a small scale (30 m), these differences are significant and will affect the results of the analysis.

FROM-GLC10 map (Gong et al. 2019)

This map is the first freely available global land cover map with a resolution of 10 m. Map for 2015 has regional level classification, map for 2017 only global classification (Table 7). This map's sections are well aligned, with only one pixel separating them. The colouring of the FROM-GLC10 map is the same as that of the ESA CCI-LC map and some regional level groups have the same colour as the global level class (Fig. 8a), making it difficult to estimate the level of detail of this map online. In this particular area this map tends to classify sparse herbaceous vegetation or shrubland as "Natural grassland". As there is no explanation of classification parameters or comparison with the LCCS system, it is difficult to determine whether this map classifies this type of vegetation correctly.

Conclusions

At a global scale, study maps should be compared for several parts of the main target area of a study. For correct comparison, these maps should be downloaded and then carefully investigated. Some maps may provide a better representation of particular classes than others. Note that the ideal classification of a large number of classes at a small resolution is almost unachievable, but such minor misclassifications can be easily fixed.

During this investigation it was observed that for the particular area studied, most maps appear to misclassify sparse mosaic shrub and herbaceous vegetation (prob-

Table 7 Regional and global classification for the FROM-GLC10 map, adapted from Gong et al. (2019).

Map land cover class	
Global level classification	**Regional level classification**
Cropland	Rice paddy
	Greenhouse
	Orchard
	Bare farmland
	Other
Forest	Broadleaved-on
	Broadleaved-off
	Needles-on
	Needles-off
	Mixed leaved-on
	Mixed leaved-off
Grassland	Natural grassland
	Desiccated
	Pasture
Shrubland	Shrubland, leaves-on
	Shrubland, leaves-off
Wetland	Marshland
	Marshland, leaves-off
	Mudflat
Tundra	Shrub and brush tundra
	Herbaceous tundra
Snow/Ice	Snow
	Ice
Water	
Impervious surface	
Bare land	
Cloud	

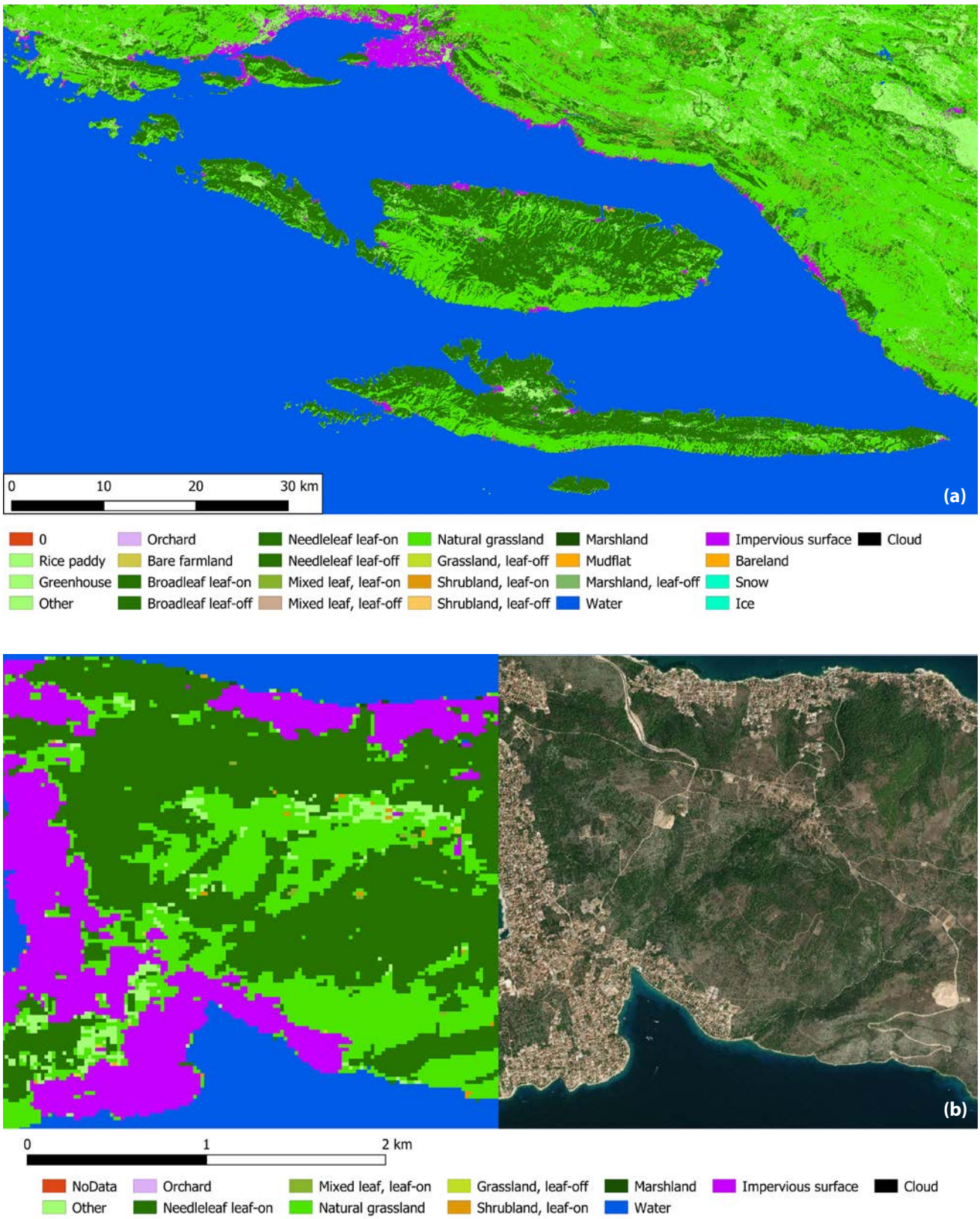


Fig. 8 FROM-GLC10 map, (a) less detailed, legend includes all map classes; (b) more detailed, only those classes present in area are shown.

ably perennial) mixed with bare soil (rocks), visible on satellite imagery. The Copernicus CGLS-LC map tends to indicate that this area is covered by crops or cultivated and managed vegetation, despite the fact that it has more suitable classes. The ESA CCI-LC map, on the other hand, classifies these areas as "Cropland rainfed", which is mostly correct; or incorrect as "Tree cover broadleaved deciduous closed to open (> 15%)". However, this could be a problem unique to this area that requires further investigation. The GLOBCOVER map provides a mislead-

ing classification of particular types of vegetation (forest) and incorrect classification of urban areas, which make this map unsuitable for use for studying this area. The resolution of map GLC-SHARE from FAO is too coarse for evaluating habitat suitability as it does not describe the pattern of vegetation or even the shape of the mainland. There may be another version of the GLC_FCS30 map (Liangyun et al. 2020) that is properly aligned and has averaged classification for overlapping parts, which is more accurate. FROM-GLC10 map (Gong et al. 2019) is the first global map that is freely available with such small resolution. This map has some noticeable artefacts due to its resolution, 10 m, however, such minor artefacts can be removed. ESA CCI-LC and Copernicus CGLS-LC100 maps provide the most accurate estimates for the area studied. Incorrect position of classes CCI-LC map against satellite imagery (Gorelick et al. 2017) may be due to the level of resolution. Both maps sometimes misclassify certain types of vegetation (sparse vegetation on bare soil), but if this is consistent and exclusive to this region, it can be manually corrected.

This comparison indicates that the Copernicus CGLS-LC100 and ESA CCI-LC maps seem to be the most universal maps for determining potentially suitable habitats. They have a wide range of land cover groups that can be compared (using LCCS classification system), making it easier to decide which spatial resolution to use.

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