remote sensing

MDPI

Supplementary Materials:

An Analysis of the Early Regeneration of Mangrove Forests using Landsat Time Series in the Matang Mangrove Forest Reserve, Peninsular Malaysia

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Figure S1

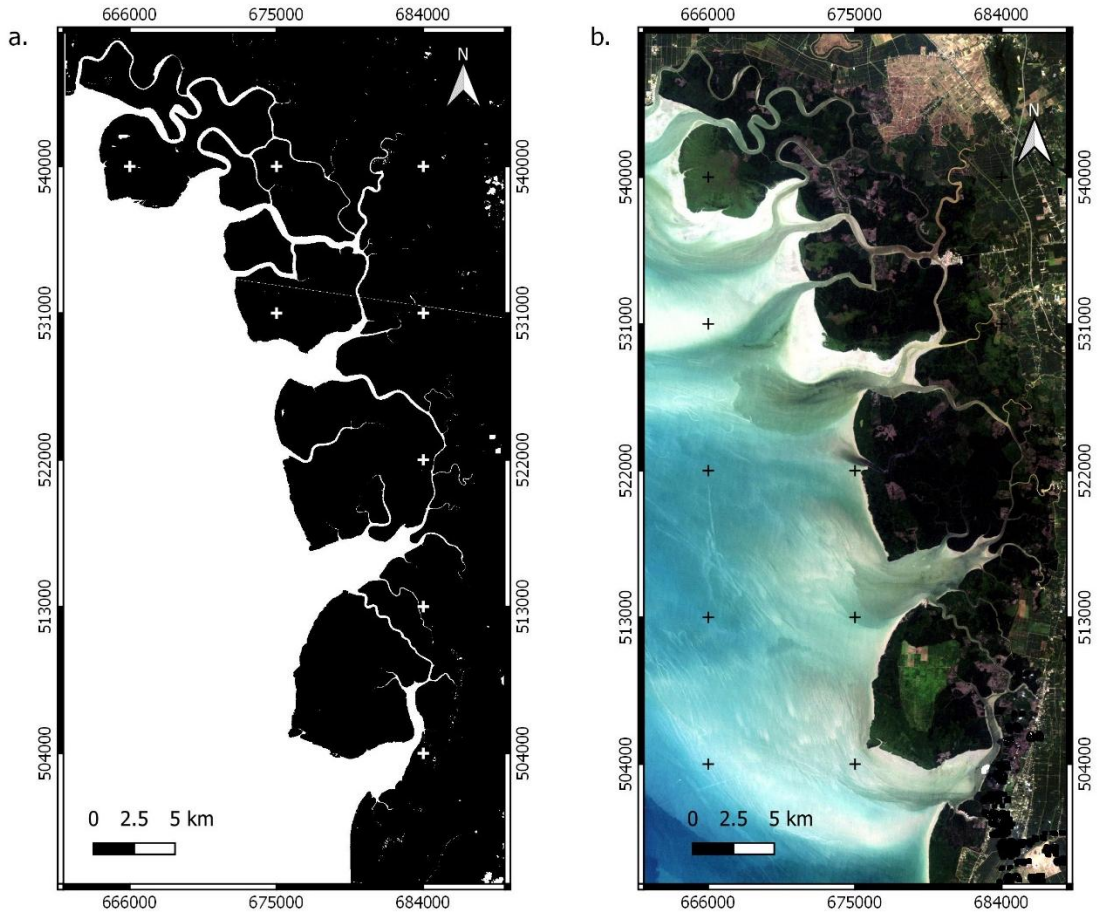

Figure S1. (**a**) The water mask map created based on the NDVI time series. White areas indicate water and creeks. Black areas are land areas. (**b**) Surface reflectance image of the area of the reserve from Landsat 5 taken in 2011. It is possible to observe how the water mask correctly capture the water bodies and creeks.

Figure S2. NDMI and NDVI time series for urban areas

Comparisons of the temporal trend in the NDMI and NDVI annual time series established that the NDMI time series was better to differentiate urban areas from water and vegetated areas (see Figure 3 in manuscript and Figure S2).

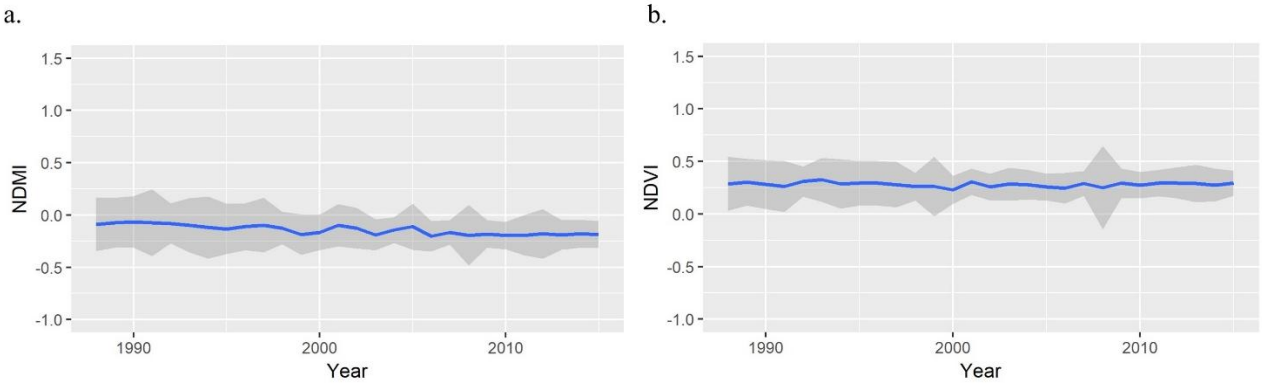

Figure S2. Examples of the (**a**) NDMI and (**b**) NDVI time series for urban areas from 1988 to 2015. The line indicates the mean value for each year and the grey area the standard deviation. The behaviour of 50 pixels is shown . We used a smaller set for the urban areas as these were marginally present in the surrounding area of the MMFR.

Figure S3. Time-series analysis: NDMI drop calculation

We calculated the drop value in the NDMI time series based on the previous year of clear-felling and the lowest value that the NDMI took during the recovery period (Figure S3). The average drop in the NDMI value was 0.57 ± 0.13.

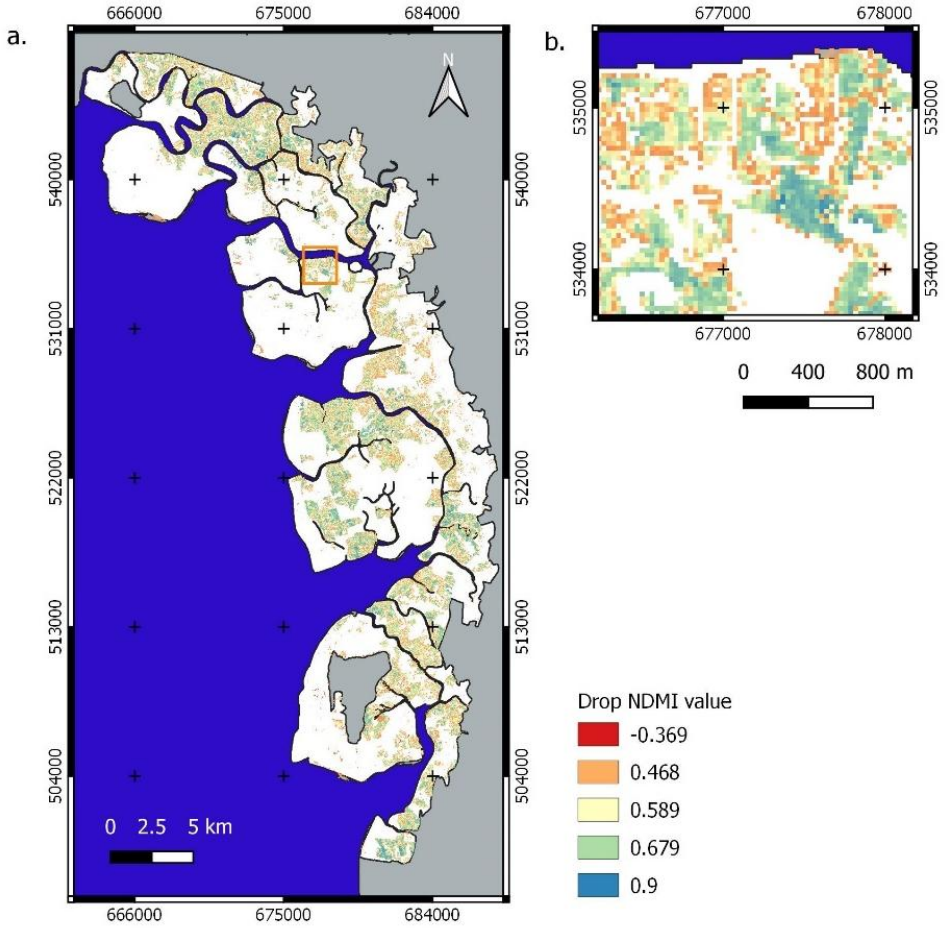

Figure S3. (**a**) The calculation of the drop value for the NDMI time series for each clear-felling event. The white areas indicate areas that were not clear-felled or that were not completely regenerated by 2015. Grey areas are not under management. (**b**) A detailed view from the area indicated with an orange square in Figure S3a.

Figure S4. Validation time-series analysis by means of comparison with point dataset

We compared 135 reference points that included 5 points per year of clear-felling. An example of one case where the year of clear-felling was correctly identified but there was an underestimation of the recovery time due to noise in the signal is shown in Figure S4a. Another example of correct identification of the year of clear-felling but of underestimation of the recovery time due to lack of information of the state before 1988 is shown in figure S4b.

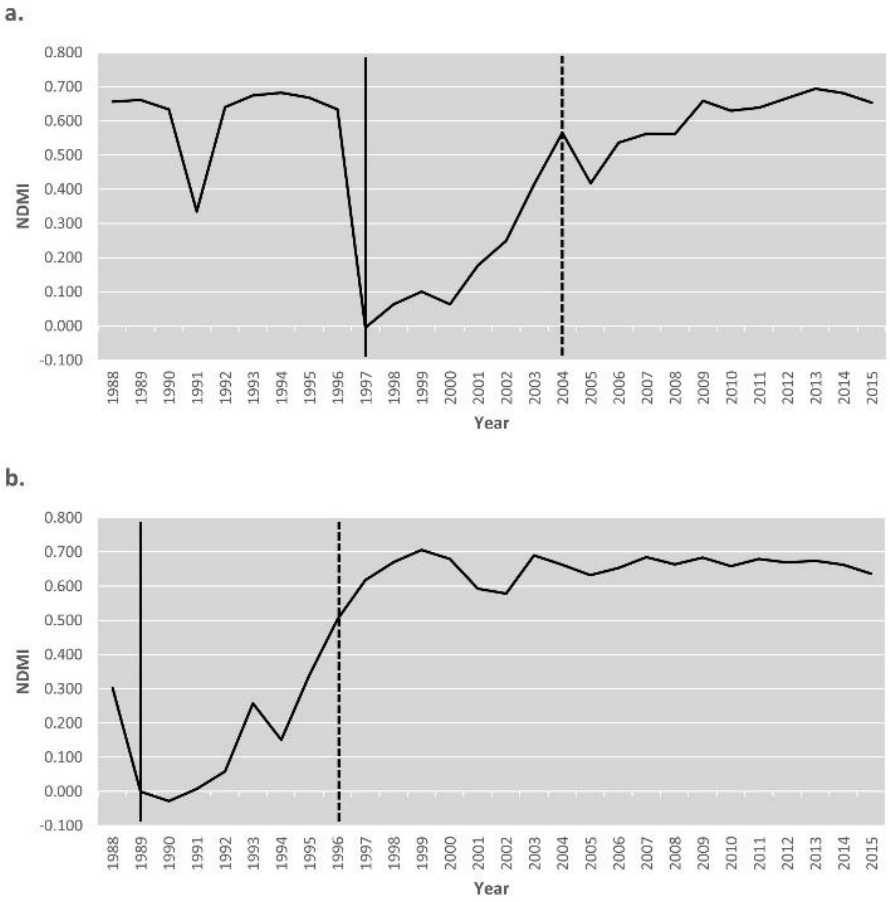

Figure S4. Examples of the identification of the year of clear-felling and the recovery time based on the algorithm. The black lines indicate the behaviour of the NDMI between 1988 and 2015. The straight black line indicates the year of clear-felling and the dashed line indicates the year of recovery identified by the algorithm. (a) An example where noise (*i.e.* a sudden decrease in the signal that does not match previous and following years of the series) in the previous state before clear-felling results in the underestimation of the recovery time by five years. (**b**) An example where there is not enough previous information and the recovery time is therefore underestimated by two years.

Figure S5. Validation time-series analysis by means of comparison with the management zones map

We compared the maps that resulted from the time-series analysis with the management plan maps. The management plan is defined every ten years and it includes the planning of the clear-felling activities. The management plan contains different maps which describe the areas where clear-felling activities are allowed. It also includes maps that indicate the year when certain areas are planned to be clear felled.

The first comparison was between the management zones defined in the management plan and the year of clear-felling map created in this study (Figure S5a). We identified clear-felling events in the productive and the restrictive productive zones of the reserve, that means, in the areas where clear-felling activities are allowed. We also identified a small number of clear-felling events in isolated pixels, mostly in the shorelines of the reserve. These cases can be due to changes in the moisture of the soil that affects the behaviour of the NDMI time series and create noisy signals that are wrongly identified as a clear-felling event. Additionally, we identified changes in three areas of different protective zones. In the first area,

depicted in Figure S5b with a white circle, the NDMI suddenly drops from 2010 onwards in an area of 40 ha. It was probably not a clear-felling event but another type of change in the mangrove forest structure. This area is an *Avicennia-Sonneratia* dominated forests according to the management plan and it is necessary to further investigate the cause of the change. Another type of change was captured in other two protective areas (Figure S5a and S5b, areas indicated with black circles), one a *Rhizophora* dominated forest and another a dryland forest according to the management plan. We observed noisy changes in the NDMI index and changes that resemble clear-felling events. These changes in the index time series require further investigation to determine if they were the result of a clear-felling event, lightning strikes or other types of disturbances.

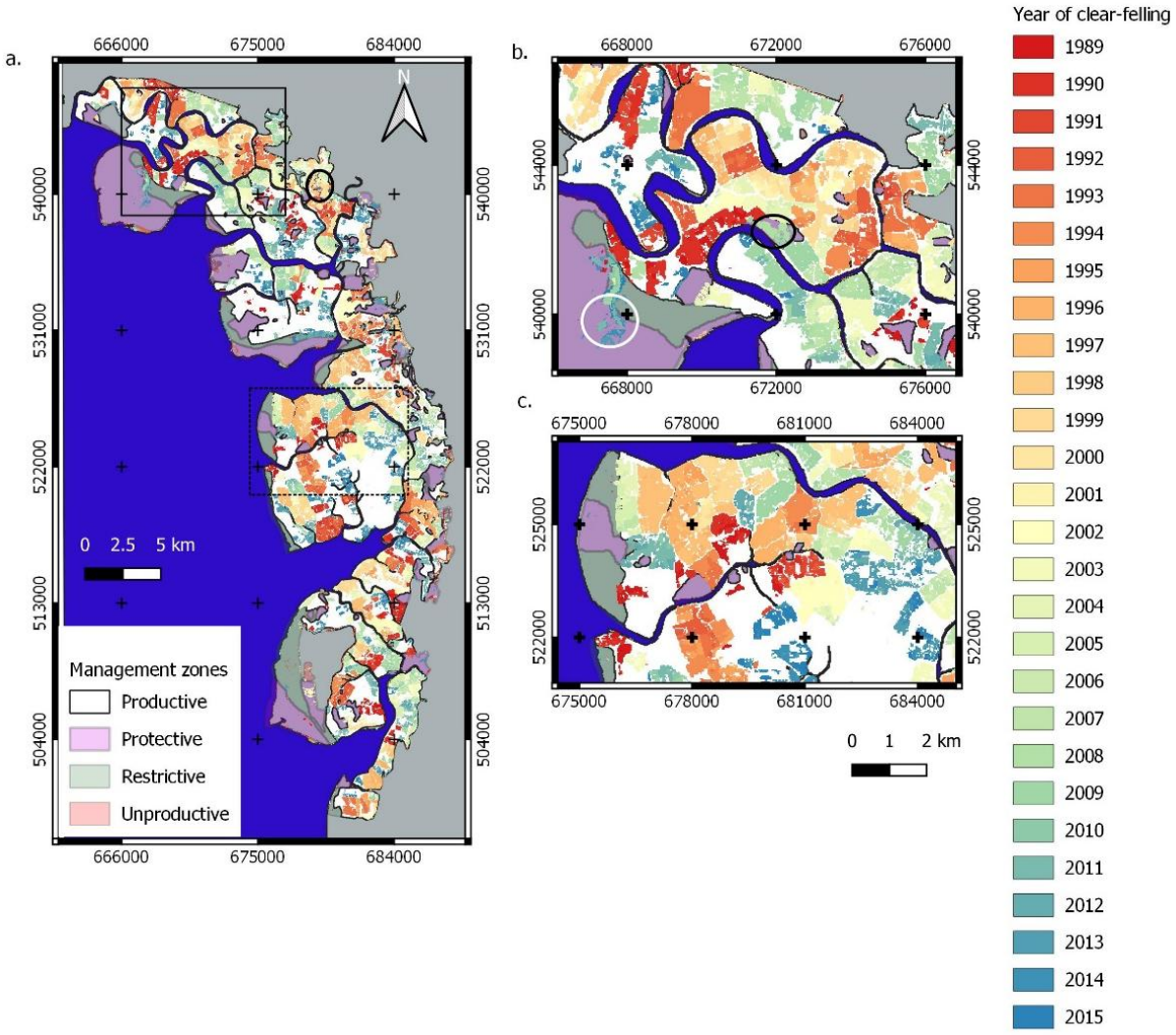

Figure S5. Comparison between the maps created in this study and the management plan of the MMFR. (**a**) The map indicating the year of clear-felling created in this study overlaid in the management zones map. The white areas indicate forest zones that were not clear felled between 1989 and 2015. The grey areas are outside the management of the reserve. The two smaller maps on the right side show a detailed view of (**b**) the area indicated with a black rectangle and (**c**) the area indicated with the dotted rectangle in figure (a). The white and black circles in the maps (a) and (b) indicate changes captured by the algorithm in two protective zones.

Table S1. Time-series analysis validation by means of comparison with the clear-felling planning.

The management plan is defined every ten years. One of the purposes of this plan is to define which coupes are going to be clear felled in the following ten years. For comparison purposes, we used the management plan from 2000 to 2009 and the plan from 2010 to 2019. Taking into account that each coupe is clear felled every 30 years, each management plan does not provide the information for all the coupes within the reserve. Nevertheless, by combining these two management plans we can have a fair amount of information that is useful to validate the maps created in this study.

In general, we observe a difference between the management plan map and the maps created in this study (Table S1). The actual clear felling observed in the satellite images occurs after 2.85 ± 1.15 years of the time suggested by the management plan. This difference is consistent through the whole area of the reserve. It is also observed that one coupe takes more than one year to be completely clear felled.

Additionally, for coupes that are planned to be clear felled between 2017 and 2019 (coupes 65, 76 and 68), the map created in this study indicates that these coupes were clear felled between 1989 and 1991. That means that the trees in these coupes are approximately 28 years old by the time they should be clear felled, which is in accordance with the 30-year rotation cycle used in the reserve.

Table S1. Comparison between the year of clear-felling defined in this study and the year of clear-felling planned by the management of the MMFR. The ID compartment corresponds to the number used in the management plans. The management plans used in this comparison correspond to the plans of 2000 to 2009 and 2010 to 2019 [8,46].

ID compartment	Planned year in management plan	Year indicated in the map of this study
65	2017	1989, 1990
66	2017	1989, 1990
74	2016	1990, 1991, 1993, 1994
76	2018	1990, 1991
62	2017	1989, 1990
68	2000, 2019	2001,2002, 1989, 1990, 1991
20	2010, 2011	2012, 2013, 2014, 2015
57	2010	2012, 2013, 2015
58	2011	2013, 2014
63	2001, 2002	2004, 2005, 2006,2007, 2004, 2005
70	2012	2013, 2014, 2015

72	2001, 2004	2002, 2003, 2007, 2008
75	2010, 2011	2012, 2013, 2014, 2015, 2014, 2015
58	2011	2013, 2014
77	2001, 2007	2002, 2003, 2008, 2009, 2010, 2011
58	2003	2005, 2006, 2007
60	2004, 2006, 2009	2006, 2007, 2008, 2009, 2011, 2012, 2013
63	2009	2011, 2012
32	2010	2012, 2013, 2014, 2015
39	2002, 2003, 2010	2004, 2005, 2006, 2007, 2005, 2006, 2007, 2013, 2014, 2015
30	2000, 2017	2001, 2002, 1989, 1990