Mangrove ecosystems in the coastal zone of Kutch, western India, used for traditional pastoralism: effects of climate change and social conditions on long-term biomass variability

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Abstract

Mangroves cover a large area of the coastal region of Kutch in the state of Gujarat in western India. The Maldharis, the inhabitants of this region, have been using mangrove forests for traditional livelihoods such as the rearing of Kharai camel, which feeds mainly on mangrove leaves. The objective of our interdisciplinary project is to explore direction of changes for the sustainability of this community. Since the linkage between the ecosystem services of the mangrove forests and the traditional pastoralism of this community is one important aspect to consider, a clear description of the historical evolution of this ecosystem is an important step for basic information. In addition to collecting narrative-based information from communities, we are using satellite remote sensing data to develop a quantitative description of mangrove biomass since the 1980s. Using Landsat multispectral imageries, we calculated spatial averages of NDVI for several target forest components. The overall NDVI of mangrove forests in the region has increased from 1988 to the present, suggesting an increase in biomass. However, it has been decreasing from the late 1990s to the early 2000s. The most likely reason is that the low precipitation (drought) in the late 1990s to early 2000s increased the salinity of soil and groundwater, which in turn increased water stress. Contrastingly, the lack of significant changes in NDVI due to a single year of drought suggests that mangrove forests are resilient to drought. On the other hand, it is inferred that several factors were involved in the increase of NDVI since the early 2000s. Two of these factors are the higher precipitation during this period and the fact that the Forest Department has been restricting pastoralists' access to mangrove forests since 2005. These results suggest that climatic conditions and pastoralism intensity influuence the long-term variation of NDVI values in each forest segment. This also suggests that local pastoralists harvested leaves and branches from the mangrove forests as resources but did not destructively take forest trees. This suggests that the Maldharis base their livelihood on maintaining the mangrove forests.

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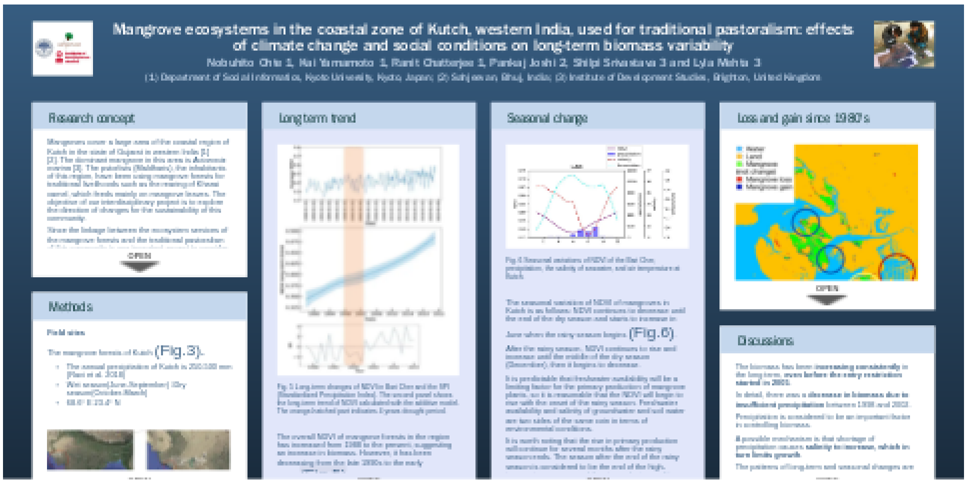

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PRESENTED AT:

RESEARCH CONCEPT

Mangroves cover a large area of the coastal region of Kutch in the state of Gujarat in western India [1][2]. The dominant mangrove in this area is *Avicennia marina* [3]. The pstorlists (Maldharis), the inhabitants of this region, have been using mangrove forests for traditional livelihoods such as the rearing of Kharai camel, which feeds mainly on mangrove leaves. The objective of our interdisciplinary project is to explore the direction of changes for the sustainability of this community.

Since the linkage between the ecosystem services of the mangrove forests and the traditional pastoralism of this community is one important aspect to consider, a clear description of the historical evolution of this ecosystem is an important step for baseline information (Fig.1).

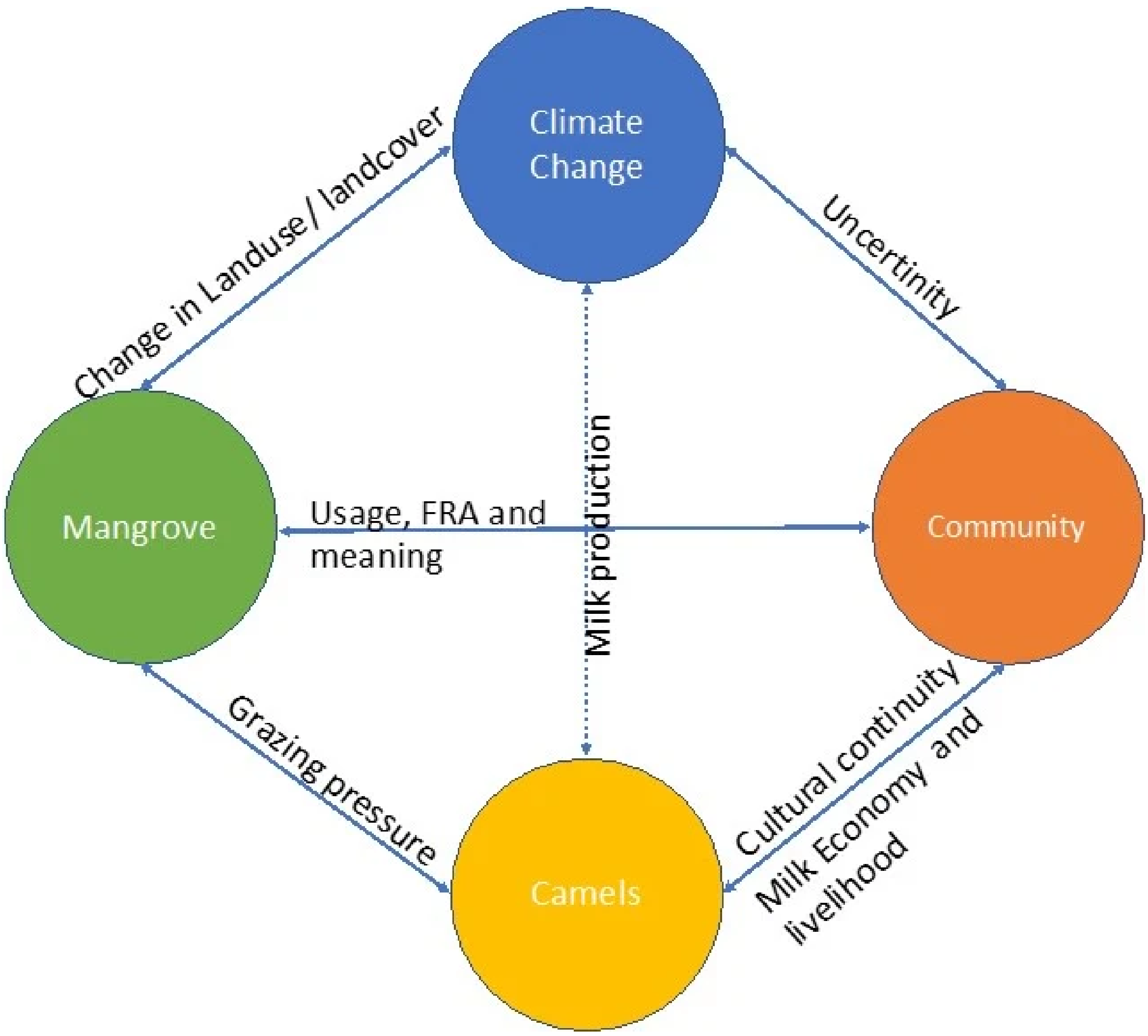

Fig. 1 Conceptual diagram of linkages between the study elements of the TAPESTRY project.

TAPESTRY is one of the projects of the program "Transformations to Sustainability (T2S)". T2S is an international collaborative program funded by NORFACE and Belmont Forum, which contributes to re-structuring the domain of sustainability research by putting the social sciences, as well as the humanities, at the heart of interdisciplinary research on sustainability, making a step-change in scale and scope for research programming in this area.

For this work, we felt it necessary to accumulate evidence, matching the narratives of local people with scientific descriptions of mangrove forest ecosystems (Fig.2).

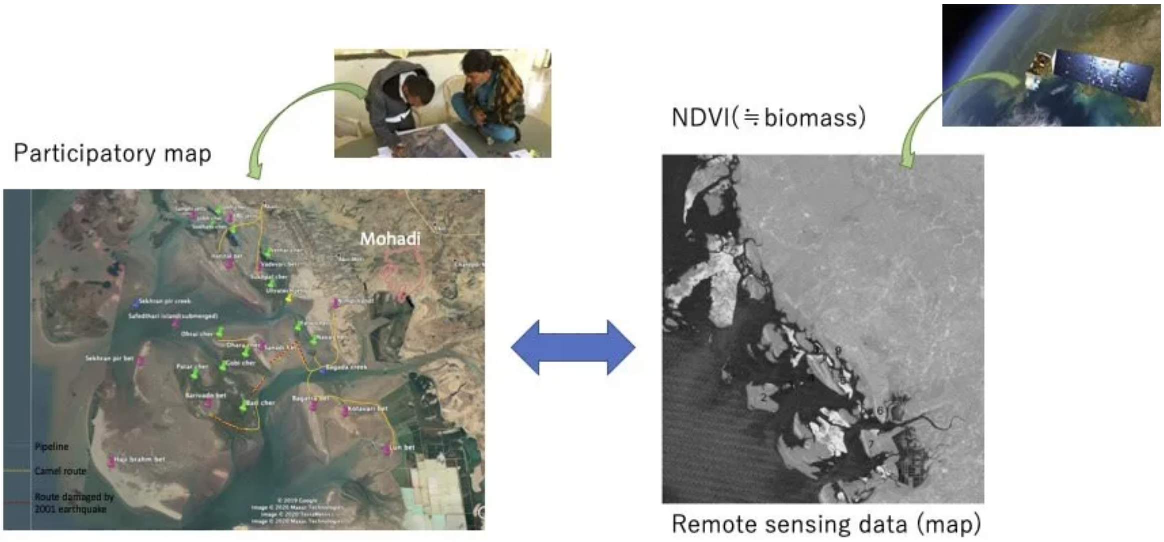

Fig. 2 Combination of the participatory mapping and geographical information analysis to reveal the details of the traditional use of natural resources of the community

METHODS

Field sites

The mangrove forests of Kutch (Fig.3).

- The annual precipitation of Kutch is 250-500 mm (Ravi et al. 2018)
- Wet season(June-September) Dry season(October-March)
- 68.6° E 23.4° N

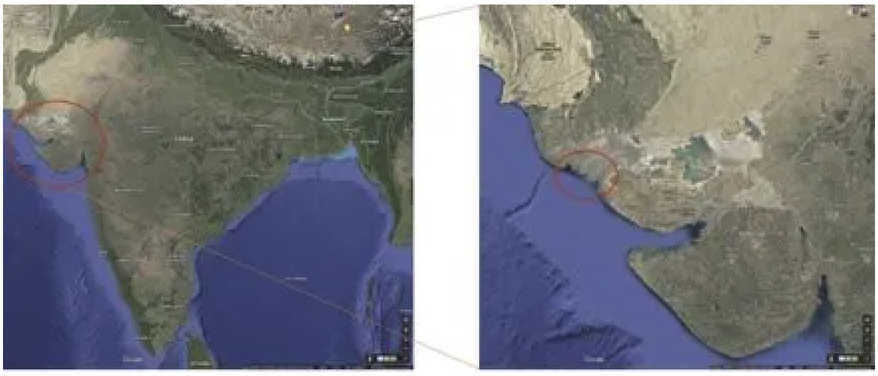

Fig. 3 Location of the study site

We identified several mangrove forests ("Chers") that were named by local residents. To collect qualitative information of each Cher, some participatory mapping events were conducted with local pastelists who were using the mangrove forests (Chers, Fig.4).

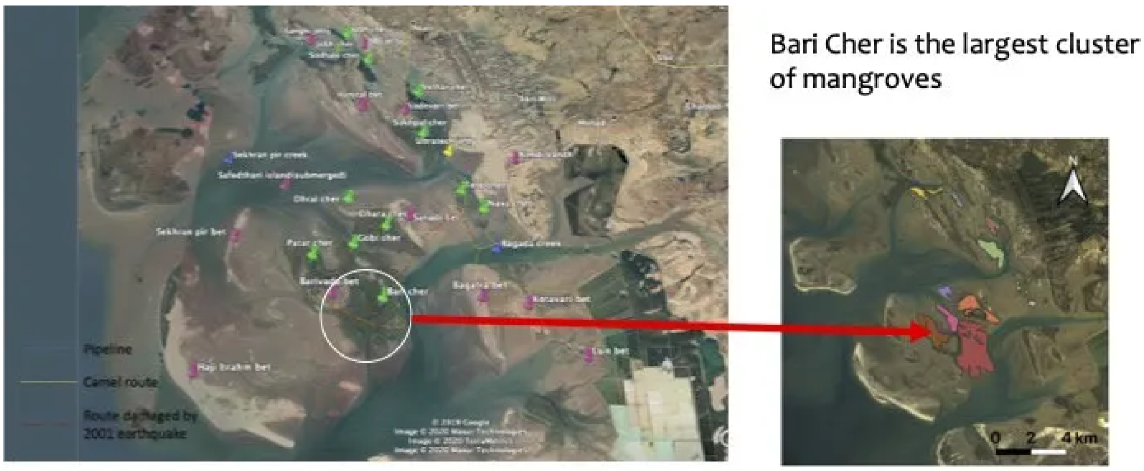

Fig. 4 Target island (Bari cher) identification with participatory mapping by the local pastoralists

Approaches

We used Landsat-5, 7, and 8 images, medium spatial resolution data, to investigate the long-term dynamics of mangrove forests by calculating NDVI, one of the vegetation indices that is considered to indicate the plant activity or biomass.

For discussion on the effects of the climatological conditions, the Standardized Precipitation Index (SPI), which is an index of the drought and dryness, was calculated from the precipitation data in the study area.

To discuss the loss and gain of the mangrove coverage, the changes in coverage were evaluated by pixel-based landcover maps for two years, 1988 and 2019.

Data sets:

Multispectral images of Landsat-5, Landsat-7, and Landsat-8 were used on the data analysis platform, Google Earth Engine (https://earthengine.google.com/).

- spatial resolution 30m（With some exceptions） and temporal resolution 16 days, respectively
- Covering the period 1988-2020
- The regression time is 16 days, but the images are not acquired at this frequency.

NDVI calculation:

Use the reflectance of red wavelengths (R) and near-infrared wavelengths (NIR),

$$NDVI = (NIR-R)/(NIR+R)$$

Plant leaves absorb red light but reflect near-infrared light. Take a number between -1 and 1. The closer it is to 1, the more active the plant is considered to be.

Long-term trend extraction:

To obtain a trend in long-term changes of NDVI, the additive model was applied. In statistics, an additive model (AM) is a nonparametric regression method. Given a data set of n statistical units, where represent predictors and is the outcome, the additive model takes the form:

$$g(\mu) = w0 + f1(x1) + f2(x2)+. . . +fn(xn)$$

For this particular time series of data (NDVI), the following equation was used.

$$g(\mu) = w0 + f1(year) + f2(month)$$

Because significant seasonal variation (high in winter and low in summer) was found, f2 was assumed to be a cyclic function. The calculation was made with the *mgcv* package of R (https://www.r-project.org/).

SPI (Standardized Precipitation Index):

SPI is widely used as an index for indicating the degree of drought condition [4] .

$$SPI = (X_i - X_{mean})/\sigma$$

Xi: Precipitation in the year i

X_{mean}: Average precipitation rate of the target period.

σ: Standard deviation of the precipitation calculated from X_i and X_{mean}.

We use the APHRODITE precipitation data set to calculate SPI. The APHRODITE project develops state-of-the-art daily precipitation datasets with high-resolution grids for Asia [5]. The datasets are created primarily with data obtained from a rain- gauge-observation network (https://www.chikyu.ac.jp/precip/english/index.html).

Salinity of seawater in the surrounding area

As a proxy of the salinity of the groundwater which is utilized by mangroves, we referred to the salinity of the seawater in the surrounding area of the target islands. The Hybrid Coordinate Ocean Model (HYCOM) [6] is a grid of ocean model data provided with a spatial resolution of 0.08°. It is a grid of ocean models provided at a spatial resolution of 0.08°. We used seawater salinity data from this dataset. The data was obtained using Google Earth Engine.

LONG TERM TREND

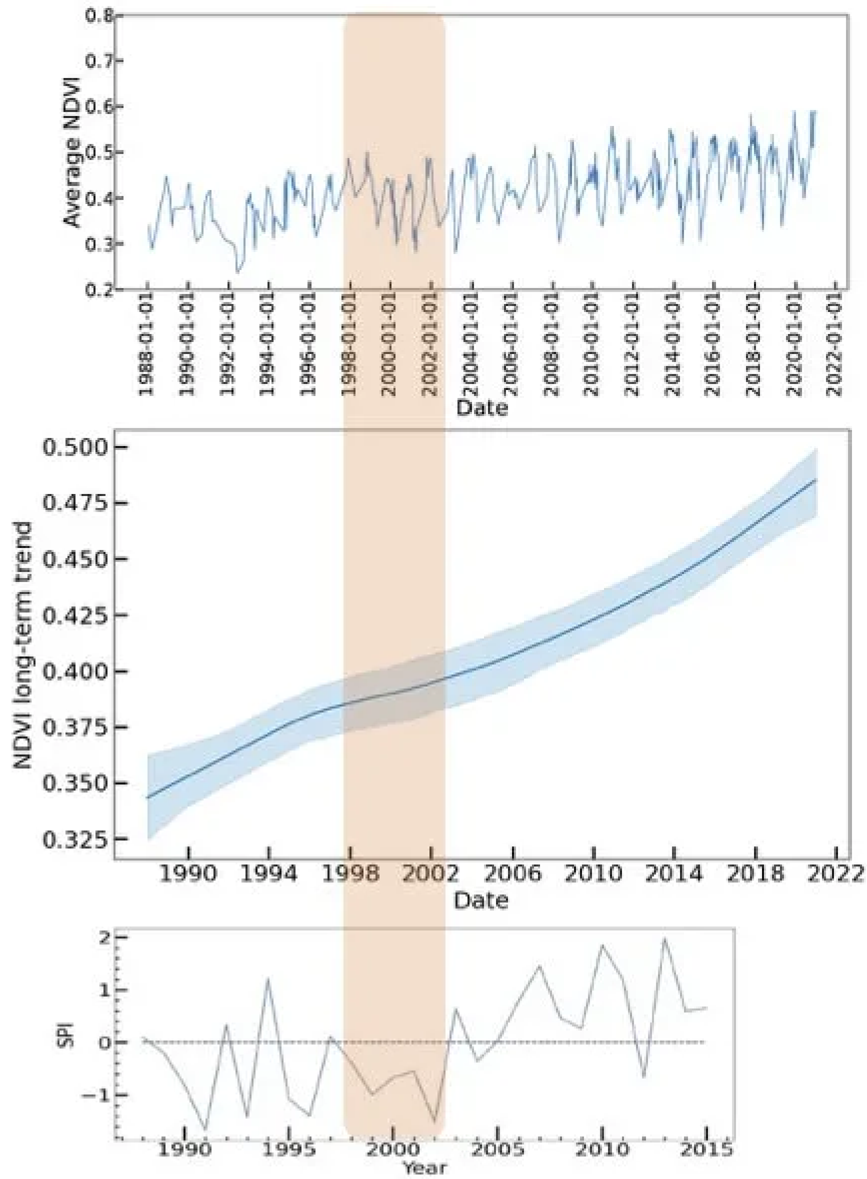

Fig. 5 Long-term changes of NDVI in Bari Cher and the SPI (Standardized Precipitation Index). The second panel shows the long-term trend of NDVI calculated with the additive model. The orange-hatched part indicates 4 years drought period.

The overall NDVI of mangrove forests in the region has increased from 1988 to the present, suggesting an increase in biomass. However, it has been decreasing from the late 1990s to the early 2000s (Fig.5). The most likely reason is that the low precipitation (drought) in the late 1990s to early 2000s increased the salinity of soil and groundwater, which in turn increased water stress. Contrastingly, the lack of significant changes in NDVI due to a single year of drought suggests that mangrove forests are resilient to drought. On the other hand, it is inferred that several factors were involved in the increase of NDVI since the early 2000s. Two of these factors are the higher precipitation during this period and the fact that the Forest Department has been restricting pastoralists' access to mangrove forests since 2005.

These results suggest that climatic conditions and pastoralism intensity influence the long-term variation of NDVI values in each forest segment. This also suggests that local pastoralists harvested leaves and branches from the mangrove forests as resources but did not destructively take forest trees. This suggests that the Maldharis base their livelihood on maintaining the mangrove forests.

This mangrove forest does not have a closed canopy even in its current state. In addition, there is little vegetation cover other than mangrove plants. Therefore, changes in NDVI are expected to have a direct relationship with changes in the biomass of the canopy (fresh leaves) of mangrove plants.

SEASONAL CHANGE

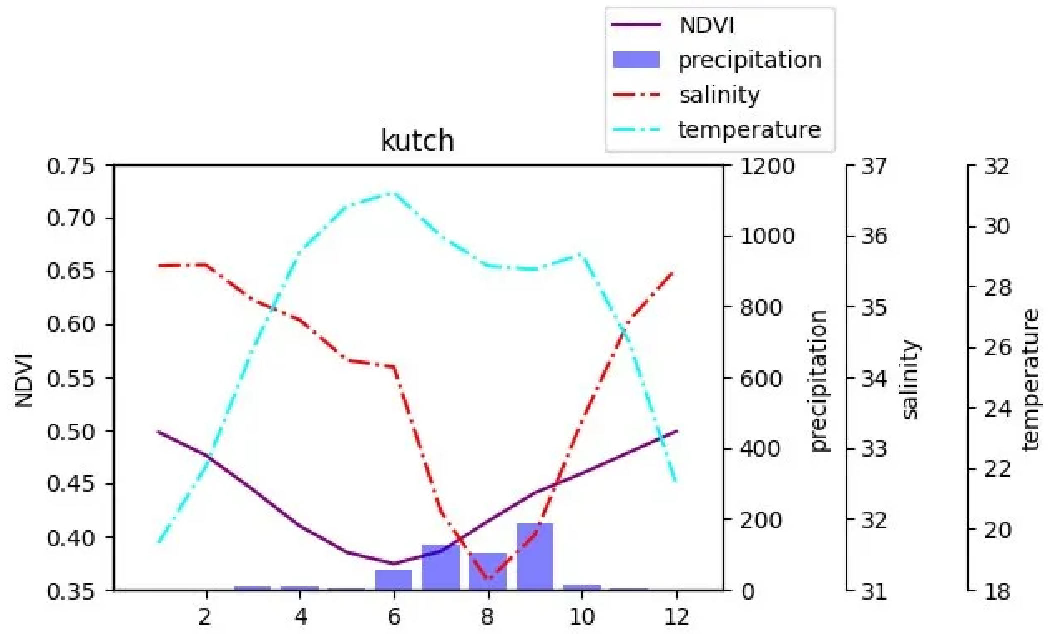

Fig. 6 Seasonal variations of NDVI of the Bari Cher, precipitation, the salinity of seawater, and air temperature at Kutch.

The seasonal variation of NDVI of mangroves in Kutch is as follows: NDVI continues to decrease until the end of the dry season and starts to increase in June when the rainy season begins (Fig.6).

After the rainy season, NDVI continues to rise and increase until the middle of the dry season (December), then it begins to decrease.

It is predictable that freshwater availability will be a limiting factor for the primary production of mangrove plants, so it is reasonable that the NDVI will begin to rise with the onset of the rainy season. Freshwater availability and salinity of groundwater and soil water are two sides of the same coin in terms of environmental conditions.

It is worth noting that the rise in primary production will continue for several months after the rainy season ends. The season after the end of the rainy season is considered to be the end of the high-temperature season and the atmospheric conditions are more suitable for primary production. Therefore, mangroves are expected to continue photosynthesis until the availability of groundwater and soil water decreases.

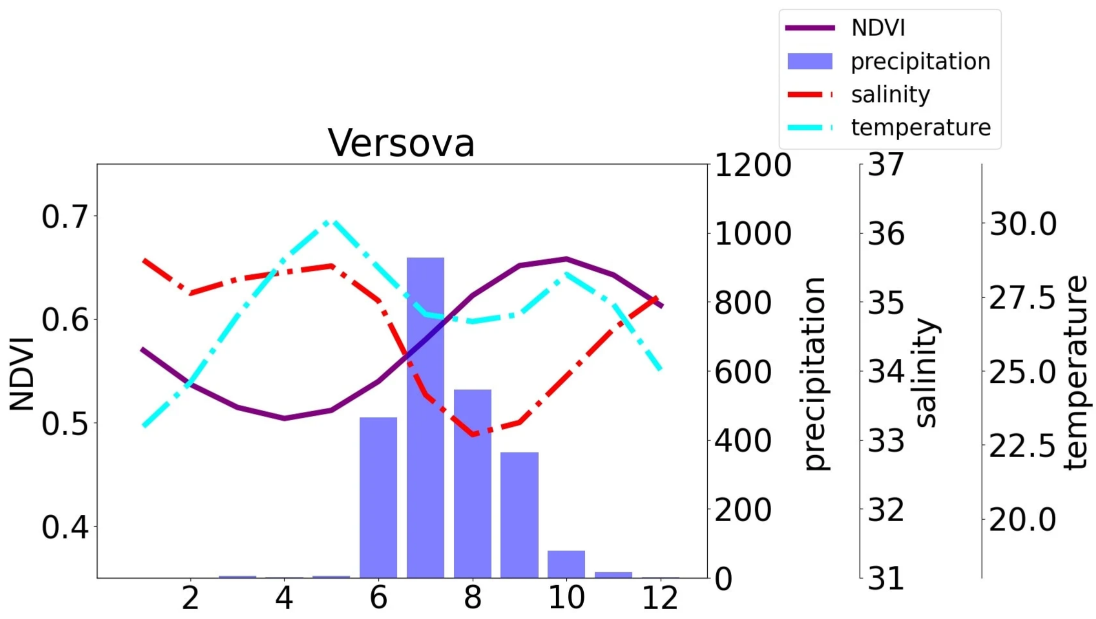

Fig. 7 Seasonal variations of NDVI of the Bari Cher, precipitation, the salinity of seawater, and air temperature at Mumbai (Versova).

It is interesting to compare this seasonal change with the change in NDVI in mangrove forests in areas with high precipitation. The figure above shows the seasonal variation of NDVI in Mumbai (Versova), which is in Western India, but at a lower latitude than Kutch and with more precipitation (Fig.7).

In Mumbai, the rise in NDVI ended with the end of the rainy season. It can be imagined that the growth of mangroves in Mumbai is dependent on the supply of precipitation, whereas the mangroves in Kutch are dependent on the stored ground and soil water. This is a characteristic of mangrove plants in arid regions.

LOSS AND GAIN SINCE 1980'S

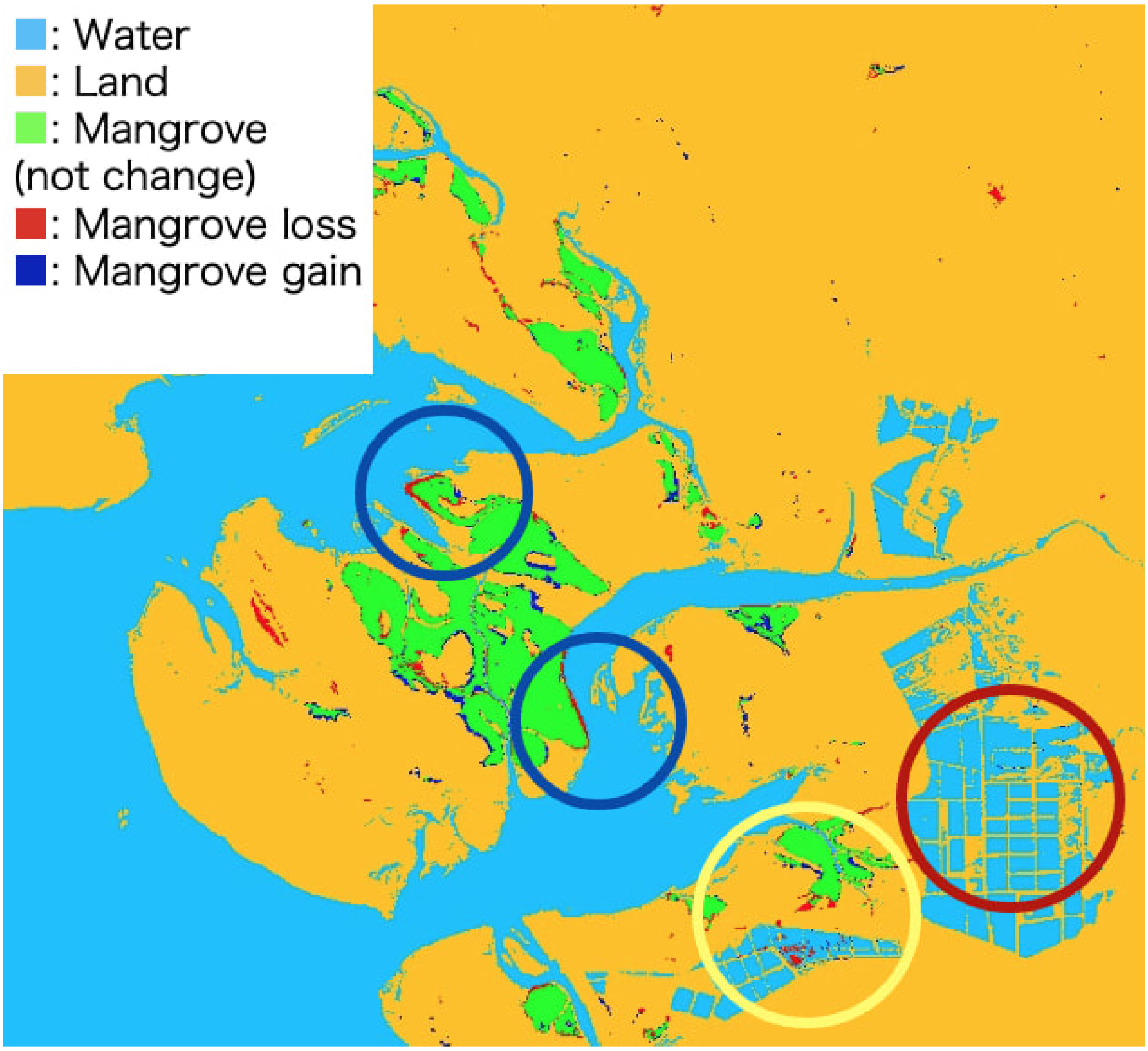

Fig. 8 The change in coverage of mangroves during the period from 1988 to 2019.

From 1988 to 2019, a clear decrease in mangrove cover was seen in the ocean-facing portions of the island (Blue circle, Fig.8). This may be an effect of loss of substrate due to wave erosion. In some inland areas, there was an increase in cover.

In addition, a slight loss of vegetation was observed in the vicinity of the salt fields as they were developed (yellow circle). Large salt fields were developed in the southeast of this region (red circle). The total increase in mangroves was 226.89 ha. The total decrease in mangroves was 229.86 ha.

DISCUSSIONS

The biomass has been **increasing consistently** in the long term, **even before the entry restriction started in 2005**.

In detail, there was a **decrease in biomass due to insufficient precipitation** between 1998 and 2002.

Precipitation is considered to be an important factor in controlling biomass.

A possible mechanism is that shortage of precipitation causes **salinity to increase, which in turn limits growth**.

The patterns of long-term and seasonal changes are **different between Kutch and Mumbai**. Additional information on the mangroves of Mumbai is needed, but a comparison with this reveals that **the mangroves of Kutch are adapted to an arid environment.** In other words, the mangroves in Kutch continue to grow for about three months after the rainy season ends. This suggests that they are **dependent on the availability of groundwater and soil water**.

The loss and gain of mangrove vegetation cover was **not a significant change in the area** as a whole. This suggests that **the pastoralists' use of mangroves was not destructive, but sustainable**, with livestock feeding on the leaves and collecting branches.

As a factor of loss, **erosion by seawater** is considered, and there is a concern that **this will increase with the rise of sea level**. In addition, there was a small amount of destruction caused by salt pan development.

As a factor of gain, the expansion of vegetation cover due to natural growth is observed. In addition, a plantation in certain areas has been promoted since 2010, but only in a few areas relative to the total area.

AUTHOR INFORMATION

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