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Land use dynamics of the Nasso campus of the Nazi Boni University of Burkina Faso using remote sensing data

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Abstract

The conservation of plant diversity has become a priority for public authorities, especially in a context marked by climate change coupled with human activities. An assessment of plant resources is therefore essential to propose strategies for their sustainable management. It is in this context that this study set out to assess the vegetation dynamics of the nasso campus from 1994 to 2021. To achieve this, satellite images from 1994 to 2021 were classified using the maximum likelihood algorithm. A field check was carried out to gather relevant information for validating the classifications made. The mapping revealed an extension of natural vegetation (savannahs) from 58.5 ha in 1994 to 508.41 ha in 2021, with average annual rates of 1.83% for treed savannahs and 148.38% for shrub savannahs. One of the key facts is the considerable reduction in the area of agrosystems between 1994 and 2021. However, land pressure and the expansion of the city of Bobo-Dioulasso pose a serious threat to the site. Measures must therefore be taken to protect the site, otherwise, in the short term; it will be invaded by local populations. This could lead to the loss of the nasso campus's biodiversity and pollution of the water.

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Introduction

Conserving forest biodiversity has always been a major concern for African states. Indeed, forests occupy almost a third of the earth's surface and life is strongly linked to their existence (FAO, 2015). Over a billion people depend on forests for their livelihoods (FAO, 2020). The majority of terrestrial biodiversity is sheltered by forests (MEA, 2005). Forests provide habitat for over 80% of amphibian species, 75% of bird species and 68% of mammal species (Vié *et al.,* 2009). Despite their important role in maintaining equilibrium on earth, forests have suffered and continue to suffer from all forms of pressure (FAO, 2010). Between 2015 and 2020, the world's forest area shrank by an average of 10 million hectares per year, compared with 16 million hectares per year in the 1990s. The global forest area shrank by more than 80 million hectares between 1990 and 2020 (FAO, 2020). There are a multitude of international conventions and national measures aimed at preserving biodiversity. Indeed, the Convention on Biological Diversity is today the main legally binding instrument whose main objective is "the conservation of biological diversity and the sustainable use of biological resources, and the fair and equitable sharing of the benefits arising out of the sustainable use of genetic resources" (Convention on Biological Diversity, 1992). In Burkina Faso, the sustainable management of protected areas is one of the Government's priorities (Tankoano *et al*., 2016). Despite the adoption of all these conventions and policies, at global level, forest losses between 2005 and 2010 were 0.14% per year, with West Africa standing out for a deforestation rate of 0.46% per year (FAO, 2010). The Sahelian zone, with its limited and more vulnerable forest resources, saw a decline in forest stands of 1.07% per year between 2005 and 2010 (FAO, 2010). This phenomenon of exacerbated degradation of forest ecosystems does not spare Burkina Faso's plant formations. According to a study by the Permanent Secretariat of the National Council for the Environment and Sustainable Development (SP/CONEDD, 2006), around 11% of Burkina Faso's land is highly degraded and 34% is moderately degraded. This has had harmful consequences, such as the reduction and imbalance of vegetation cover and the weakening of forest ecosystems (SP/CONEDD, 2006). Anthropogenic action is thought to be one of the major causes of this disturbance to forest ecosystems (N'da et *al.,* 2008). Some authors, such as Boulain (2004) and Sambou (2004), also point out that climate change, combined with other anthropogenic factors such as agricultural clearing, overgrazing, the harvesting of timber and handicrafts, service and energy woods, and bushfires, are considered to be the sources of this sometimes profound degradation of forest formations, including those in the classified estate. Unfortunately, the State's classified forests are now severely degraded in some parts of the country. It is therefore more than urgent to investigate other sites with biodiversity conservation potential. This is the case of the nasso campus, which was created in 1995, and which raises several research questions: What are the dynamics of the woody cover on the nasso campus? What impact will the university have on this dynamic? What proportion of areas has remained stable?

To provide answers to these research questions, and to contribute to the conservation of biodiversity and ecosystem services on the Nasso Campus, this study entitled was initiated.

The overall objective of this study was to improve knowledge of the level of vegetation cover degradation on the nasso campus. Specifically, it involved the map of the Nasso Campus site in 1994, 2006 and 2021; and analyzes the dynamics of the Nasso Campus vegetation cover.

Materials and methods

Study site

This study was conducted in the nasso Campus which is located in northwest of Bobo-Dioulasso (Fig. 1). According to the phytogeographical division drawn up by Guinko (1984), the area belongs to the southern Sudanian sector, characterized by a dry season and a rainy season. Annually precipitations in the area range from 800 to 1100 mm and temperatures range from 25°C to

30°C. Hydrography is characterized by the presence of some twenty springs, the most important of which is the Guinguette spring. Groundwater is abundant, as the city of Bobo-Dioulasso obtains its drinking water from springs tapped by the Office National de l'Eau et de l'Assainissement (ONEA) at Nasso. The landscape of the study area is occupied by wooded savannahs, shrub savannahs, grassy savannahs and gallery forests.

The study material consisted of Landsat satellite images. The satellite data consisted of three (03) Landsat satellite images of scene 197/052 from 1994, 2006 and 2021. The 1994, 2006 and 2021 Landsat images of the Nasso Campus were downloaded free of charge from www.earthexplorer.usgs.gov. Only images with less than 10% cloud cover were selected for the different date sequences defined in this study. QGIS 3.22 software was used for pre-processing, processing and post-processing of the satellite images.

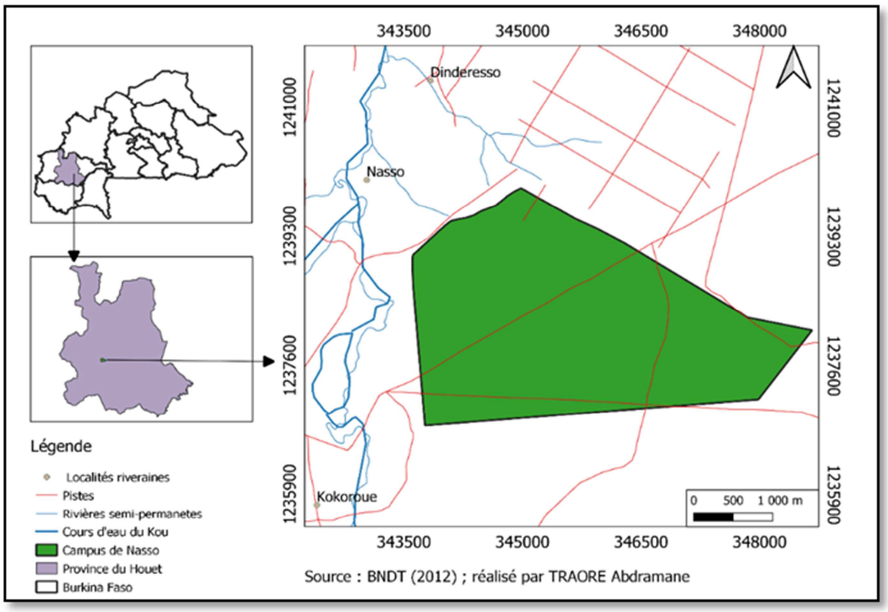

Fig. 1. Nasso campus location map

Satellite image processing chains

Pre-processing operations

Pre-processing is the set of preliminary operations to be carried out before analyzing and extracting information from images (Jofack-Sokeng *et al.*, 2016). These operations are necessary for the comparison of satellite images taken over the same study area at different dates. According to Baghdadi *et al.* (2018), to map land cover using images from different dates, it is advisable to have data corrected for the effects of *Top of Atmosphere Reflectance* (TOAR) solar irradiance. This was achieved using the Semi-Automatic-Classification Plugin (SCP) extension in Qgis 3.16. The SCP extension includes the Dark Object Subtraction (DOS) atmospheric correction command. This method is accurate and reliable in the visible range, but proves unreliable in the near-infrared and mid-infrared ranges according to Baghdadi *et al.* (2018). As for the geometric corrections, we checked that the images conformed to the UTM WGS84 zone 30 N projection.

Extraction of the study area and creation of the multi-band layer

The extraction of the Nasso Campus and its periphery was carried out with the aim of reducing the size of the images and thus lightening processing operations. This involved creating a sub-scene covering only the Nasso Campus and its periphery, using the "Cut multiple rasters" tool in the Semi-Automatic-Classification Plugin (SCP) extension of the Qgis software. The various images were cut to the same dimensions to facilitate comparison. Bands 1, 2, 3, 4, 5, 6 and 7 were used to create a multi-band layer using the Qgis "Band set" command.

Color compositions and NDVI

The Normalized Difference Vegetation Index (NDVI) was calculated using Qgis software, in order to differentiate between land use classes. NDVI and color composition were used to interpret images and select training and control plots. It is determined from the near-infrared and red bands, whose difference increases with the intensity of the green leaf (Yan and Roy, 2014).

$$NDVI = \frac{PIR-RED}{PIR+RED} \quad \text{Eq. 1}$$

With PIR: the near-infrared reflectance of vegetation and RED: the red-band reflectance.

This step is designed to facilitate visual interpretation and identification of land-use classes. This involved the creation of color compositions on the raw bands and image enhancement. These operations result in much sharper images and are easier to interpret (Tankoano *et al.*, 2016). The color composition derived from the combination of spectral bands 5, 4, and 3 was selected for the OLI images, as it enabled better differentiation of land-use classes while highlighting vegetation. Contrast enhancement was then applied to show the different surface types on the images.

Choice of regions of interest

Color compositions and NDVI (Normalized Difference Vegetation Index) were used to select training and control plots. To this end, using the Qgis SCP extension, we selected plots representative of each land cover type by materializing polygons called regions of interest (ROIs). The 2021 image was taken as the reference image for the selection of training plots for the other images.

Supervised maximum likelihood classification

Supervised classification using the Maximum *Likelihood* algorithm was applied to all images using the SCP extension of the Qgis 3.16 software. For this study, we chose the maximum likelihood algorithm because it allows the distribution of pixels to their membership classes if the probability of membership is high (Kpedenou *et al.,* 2016). Several authors have used it successfully (N'da *et al.*, 2008; Inoussa *et al.*, 2011; Kpedenou *et al.*, 2016; and Tankoano *et al.*, 2016). According to Kouassi (2007), it is the most widely used in supervised classification for its performance in producing land cover maps.

Classification validation

To validate the classification, we proceeded in several steps following the methodological approach of Tankoano *et al.* (2016). The first step is thematic validation based on a visual analysis of the comparison between the image of the colored composition and the classified one. The second step is statistical validation based on analysis of the confusion matrix, which enabled us to determine the accuracy of each of the classifications. The final step was "field verification", which involved collecting data in the field. Indeed, any remote sensing work on a subject requires field verification to confirm the results (Provencher and Dubois, 2007). This approach enabled us to confirm the effectiveness of the processing and the results obtained.

Post-processing of satellite images

Post-classification processing was carried out by applying a 3×3 median filter to all classified images to sharpen them by eliminating isolated pixels. Next, we vectorized the classified images. Finally, the vector files were used to produce land cover maps for the Nasso Campus in 1994, 2006, and 2021.

Assessment of vegetation cover dynamics

The surface areas of the different land cover classes were determined using Qgis software. This assessment was used to analyze changes in the surface areas of the different land cover types between 1994 and 2021. The average annual rate of change for each land use type was calculated using the formula:

$$Tx = \left(\frac{\frac{S2021-S1994}{S1994}}{t}\right)*100 \quad \text{Eq. 2}$$

With Tx: average annual rate of change; S_{2021}: area of a land-use class in 2021; S_{1994}: area of a land-use class in 1994; t: duration of the period 1994-2021 (24 years).

Land use dynamics map

The dynamics of land use types on the Nasso Campus were determined using Qgis software. For that, the 1994 classification and the 2021 classification were superimposed, and the land-use change command enabled us to determine the various transitions in land-use types between 1994 and 2021. This analysis highlighted three states of vegetation cover dynamics, namely stability, regression and progression.

Results

Validation of classifications: confusion matrices

Cartographic analysis of the images revealed 5 land-use classes which are identical on all images. Confusion matrices show the percentage of well-classified pixels on each diagonal and the percentage of poorly-classified pixels off the diagonal (Tables 1, 2 and 3). Overall accuracy is 89.90% for the 1994 image, 87.57% for the 2006 image and 88.90% for the 2021 image. The Kappa index is of the order of 87% for the 1994 image, 85% for the 2006 image and 86% for the 2021 image.

Table 1. Confusion matrix of landsat images from 1994

	Classes	Reference data				
		TS	SS	PLT	AGR	BS
Data classification	TS	84,52	1,80	8,37	01	4,31
	SS	2,06	97,65	0,29	00	00
	PLT	10,7	00	80,61	6,79	3,12
	AGR	1,11	0,55	6,97	92,21	00
	BS	1,61	00	3,76	00	92,57
	Total	100	100	100	100	100

Overall accuracy: 89.90%; Kappa index: 87%

TS: tree savannah; SS: shrub savannah; PLT: plantation; AGR : Agrosystem; BS: bare soil

Table 2. Confusion matrix of landsat images from 2006

	Classes	Reference data				
		TS	SS	PLT	AGR	BS
Data classification	TS	90,42	00	17,43	00	1,1
	SS	00	96,6	2,34	00	00
	PLT	7,77	1,38	77,59	00	0,9
	AGR	00	00	0,91	84,73	00
	BS	1,36	0,04	1,47	7,04	97,29
	Total	100	100	100	100	100

Overall accuracy: 87.57%; Kappa index: 85%

TS: tree savannah; SS: shrub savannah; PLT: plantation; AGR: Agrosystem; BS: bare soil

Table 3. Confusion matrix of landsat images from 2021

	Classes	Reference data				
		TS	SS	PLT	AGR	BS
Data classification	TS	97,36	0,25	0,98	1,06	0,54
	SS	1,11	98,41	0,59	00	00
	PLT	0,66	0,96	95,94	00	1,56
	AGR	00	00	0,07	98,7	5,96
	BS	0,9	0,46	1,5	0,25	90,63
	Total	100	100	100	100	100

Overall accuracy: 88.90%; Kappa index: 86%

TS: tree savannah; SS: shrub savannah; PLT: plantation; AGR: Agrosystem; BS: bare soil

Land cover status of the Nasso campus in 1994, 2006 and 2021

Land cover mapping in 1994 revealed that anthropized areas (agrosystems, bare soil and plantations) accounted for almost 93.94% (938.14 ha) of the Nasso Campus, compared with savannahs (trees and shrubs) which occupied only 6% (58.5 ha). This shows the high degree of anthropization of the site at that date (Fig. 2).

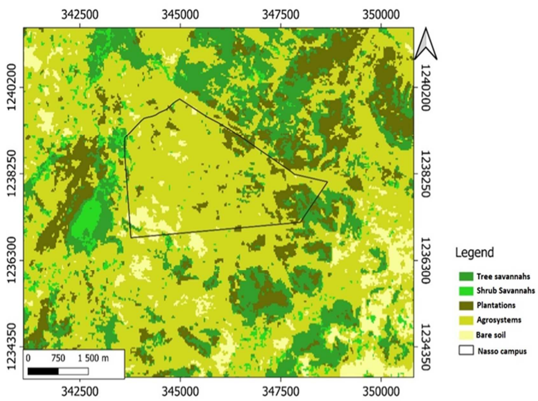

Fig. 2. Land use map 1994

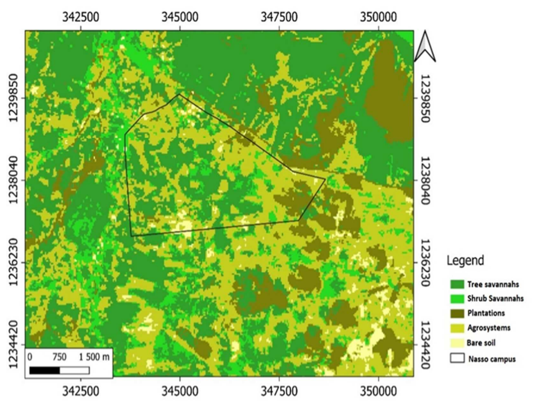

Fig. 3. Land use map 2006

With 544.59 ha, anthropized areas represented around 54.53% of the Nasso Campus in 2006 (Fig. 3). Savannahs occupied 454.05 ha in 2006, or around 45.47% of the Nasso Campus.

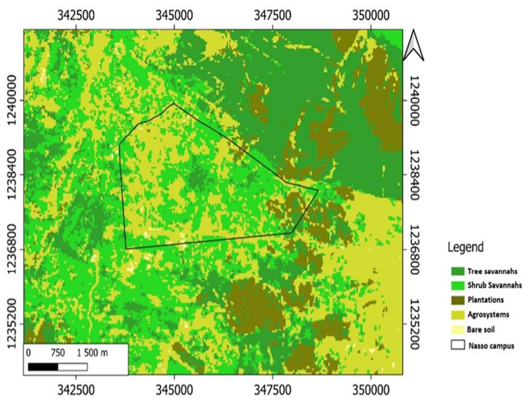

Fig. 4. Land use map 2021

In 2021, anthropized areas represented around 49.09% (490.23 ha) of the Nasso Campus. Savannahs occupied 508.41 ha or around 50.91%. This shows a resumption of the vegetation process on the study area (Fig. 4).

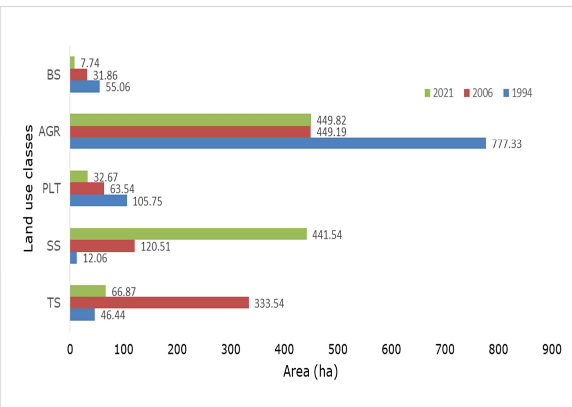

Fig. 5. Surface area dynamics of land use classes from 1994 to 2021

TS : tree savannah; SS: shrub savannah; PLT : plantation; AGR : Agrosystem; BS: bare soil

Land use class dynamics

Analysis of the vegetation map results has enabled us to assess variations in land use classes between 1994 and 2021. Fig. 5 shows an increase in wooded savannah and shrub savannah between 1994 and 2021. However, plantations, agrosystems and bare soil decreased over the same period. The dynamic change map shows that between 1994 and 2021, three classes of vegetation cover have been identified: increasing, decreasing and stable (Fig. 6).

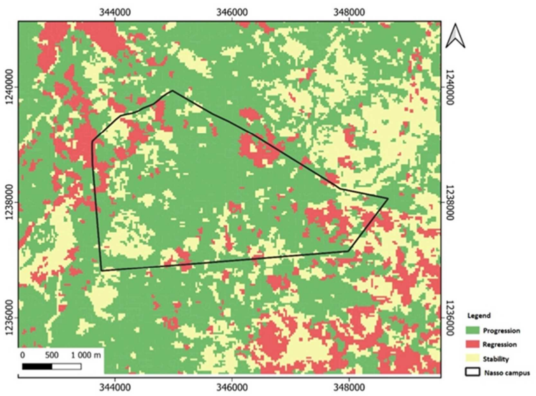

Fig. 6. Land cover dynamics map of the Nasso campus 1994-2021

Discussion

Vegetation description and processing of satellite images of the nasso campus

The cartographic results highlighted 5 land-use classes: wooded savannahs, shrub savannahs, agrosystems, plantations and bare soil. Field verification confirmed the presence of these classes. We noted a predominance of savannahs on the Nasso Campus. This predominance of savannahs can be explained by the country's climatic conditions, as savannahs are plant formations associated with seasonal dry conditions in hot regions (Guinko, 1985). According to Thiombiano and Kampmann (2010), Burkina Faso is a country characterized by savannah, which occupies more than 80% of its plant cover.

In terms of classification quality, we obtained satisfactory results, but with some confusion between certain classes. These confusions could be linked to the similarity of spectral signatures between these classes. For example, in some places, plantations are very similar to wooded savannahs, and the same is true between agrosystems and savannahs. Agrosystems are sometimes presented as bare earth, which could explain the relatively high levels of confusion observed between certain classes. Indeed, authors such as Tankoano *et al.* (2015), Kpedenou *et al.* (2016) and Bourdouxhe (2017) have shown that confusion between certain land cover classes has a significant impact on overall classification accuracy. According to these authors, these confusions are linked to very close spectral signatures between some land use/land cover classes, to the spatial resolution of the images chosen and to the choice of training plots. Notwithstanding these confusions, the cartographic results are statistically valid in terms of the overall accuracy values obtained. Accuracy values were 89.90% for the 1994 image, 87.57% for the 2006 image and 88.90% for the 2021 image. The closeness of these accuracies demonstrates the accuracy of the training plots selected. Considering the heterogeneity of the Sahelian environment, such results are justified by the quality of the images used (Inoussa *et al.*, 2011; Bourdouxhe, 2017). Thus, our cartographic results are validated because the accuracies of the various classifications are greater than 50% (Pointus, 2000).

Land cover dynamics

The vegetation cover dynamics of the Nasso Campus from 1994 to 2021 revealed a recovery in natural vegetation. We noted an annual progression rate of around 1.83% for tree savannahs and 148.38% for shrub savannahs. This progression of vegetation could be explained by the practice of shifting agriculture in the area. This form of agriculture favors the development of shrubs in abandoned fields, and only shrubs can regenerate rapidly. Information gathered from resource persons in the area revealed that, before 1994, the nasso campus and its surrounding areas were agricultural zones and training centers (military training center and seminary). This information could justify the majority presence of agrosystems on the 1994 land-use map. However, we observed a regression of plantations and agrosystems with respective regression rates of 2.88% and 1.76%. The creation of the Université Nazi Boni (UNB) and the implementation of pumping stations by the Office National de l'Eau et de l'Assainissement (ONEA) could also explain the decline in the area of agrosystems and plantations. These two structures have played a major role in limiting anthropogenic activities in the study area and its outskirts, which were once highly anthropized zones. However, the up-and-down evolution of plantations and agrosystems could be explained by the inadequacy of measures taken to halt human activity. In fact, in the field, we were able to observe the presence of farms and fields still in use. The presence of these anthropogenic activities would lead to the modification of agrosystems and plantations over time and space. Furthermore, the increase in tree savannahs could be explained by confusion with certain agrosystems, as some of the latter have high tree densities, causing them to be grouped in the tree savannah class during image classifications (Tankoano *et al.,* 2023). The search for new fertile land and the abandonment of degraded land by farmers could also justify the increase in savannas (N'Da *et al.,* 2008; Diallo *et al.,* 2011). The decline in plantation areas could be a reflection of their transformation into agrosystems. We were able to observe a certain similarity between these two land-use/ land cover classes during field verification. The dynamics map showed a predominance of the progression class, which confirms that vegetation, is recovering. This predominance of progression is linked to the presence of the University and ONEA facilities. In addition, the fact that part of the site has been defended to protect the city of Bobo-Dioulasso's water supply could also explain this situation. The dissuasive presence of the University and ONEA has been beneficial for the vegetation. However, it should be noted that the departure of a large part of the University's central administration to Bobo-Dioulasso has led to renewed interest in the estate. This can be explained by the renewed anthropization of the site.

Conclusion

The main objective of this study was to assess the vegetation dynamics of the Nasso Campus using remote sensing data. At the end of our study, Landsat image processing enabled us to map the nasso campus and determine the characteristics of its land use/land cover classes. The methodological approach adopted enabled us to discriminate between 5 classes of land cover, namely tree savannahs, shrub savannahs, agrosystems, plantations and bare soil. The cartographic results revealed an increase in wooded savannahs and shrub savannahs from 46.44 ha and 12.06 ha respectively in 1994 to 66.87 ha and 411.54 ha in 2021. We are thus witnessing a process of savanization of the nasso campus. This process has been at the expense of agrosystems and plantations. This observation could conceal certain disparities between 1994 and 2021, as we were able to observe an ongoing anthropization process in the field. This situation will worsen in the short term with the departure of the central administration of the Nazi Boni University in Bobo-Dioulasso.

For next study we recommend the followings.

1. An in-depth study using very high-resolution images (drone images) to better detect changes in the Nasso Campus landscape.
2. Analysis of spatial structure indices to assess the landscape ecology of the Nasso Campus;
3. Reinforcement of surveillance by the installation of a fence (a living hedge) to protect the estate and the Nasso Campus water table

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