# SPATIO-TEMPORAL MAPPING OF THE INVASIVE ALIEN SPECIES *Pinus* SP IN THE NORTHERN AREA OF THE LAGOA DO PEIXE NATIONAL PARK-RS

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ABSTRACT – A problem of global dimensions, the occupation of areas by invasive alien species is studied in this paper focusing on the increasing presence of *Pinus* sp in the Lagoa do Peixe National Park, at Rio Grande do Sul State, Brazil. From satellite imagery and the use of remote sensing and geoprocessing techniques, this paper presents a space-time mapping of the presence of this invasive alien species in the northern area of the Park, from 1985 to the 2017. Planted and disseminated areas of Pinus were mapped through visual analysis and pixel classification by the *Spectral Angle Mapper* (SAM) method, using images from the Landsat and Rapid Eye satellites. The results showed a constant growth rate in the areas of Pinus, with acceleration at the end of the analyzed period, confirming the invasive capacity of *Pinus* sp and the dispersion of their seeds by the wind. The excellent performance of the SAM algorithm in the identification of Pinus areas was demonstrated, as well as the importance of the use of satellite images in the analysis of the question.

Keywords: Remote Sensing; *Spectral Angle Mapper;* Forest Ecology.

# *MAPEAMENTO ESPAÇO-TEMPORAL DA ESPÉCIE EXÓTICA INVASORA Pinus SP NA ÁREA NORTE DO PARQUE NACIONAL DA LAGOA DO PEIXE-RS*

*RESUMO – Problema de dimensões globais, a ocupação de áreas por espécies exóticas invasoras é estudada neste trabalho com foco na presença crescente de* ***Pinus*** *sp no Parque Nacional da Lagoa do Peixe/RS. A partir de imagens de satélite e uso de técnicas de sensoriamento remoto e geoprocessamento, o artigo apresenta um mapeamento espaço-temporal da presença desta exótica invasora na área norte do Parque, desde 1985 até 2017. Mapearam-se áreas de Pinus plantado e disseminado através de análise visual e classificação de pixels pelo método* ***Spectral Angle Mapper*** *(SAM), utilizando imagens das missões Landsat e Rapid Eye. Os resultados encontrados mostraram taxa de crescimento constante nas áreas de Pinus, com aceleração ao final do período analisado, confirmando a capacidade invasora do* ***Pinus*** *sp e a dispersão de suas sementes pelo vento. Ficou demonstrado o ótimo desempenho do algoritmo SAM na identificação de áreas de Pinus, bem como a importância do uso de imagens de satélite na análise da questão.*

*Palavras-Chave: Sensoriamento Remoto;* ***Spectral Angle Mapper****; Ecologia Florestal.*

## 1. INTRODUCTION

Invasive alien species are currently a major cause of biodiversity loss on the planet, leading to changes in the structure and composition of ecosystems, to significant detrimental impacts on ecosystem services, affecting economies and the well being of human populations (IUCN, 2018).

Compared with other parts of the world such as Australia, New Zealand and South Africa, exotic conifer plantings are relatively recent in South America, but an invasive expansion has been observed along with a rapid increase of problems generated by it (Richardson et al., 2008). In Brazil, the genus Pinus has been reported as having an invasive potential of open areas (Ziller and Galvão 2002; Zanchetta and Diniz, 2006; Zenni and Ziller 2011). Ledgard and Langer (1999) consider that the spreading sites are spots from which the dispersion of Pinus seeds is amplified due to their position in local relief and direction of prevailing winds. In a model proposed by Richardson and Higgins (1998) the wind is considered as the only vector of dispersion of Pinus seeds, and the occurrence of new individuals drops exponentially with the distance from the source of seeds. In a similar way, Ziller and Galvão (2002) report that the relief associated with the direction of the wind is a key factor in seed dispersal of Pinus elliottii and Pinus taeda which, according to studies by Bechara (2003) in Florianópolis (SC), reaches its maximum in the months of April and May.

The process of invasion by Pinus happens in well-defined stages: the first stage generates dense dispersion surrounding the primary source of seeds with sparse scattering of isolated individuals as one moves away from the core source; the second stage begins when the secondary trees begin to produce seeds by their own; from this point the chances of a successful control are considerably reduced (Langdon et al., 2010).

The creation of early detection systems is an important step in the control of invasions by alien species, linking scientific knowledge to control methods (Ziller and Deochum, 2013). In addition to the traditional visual detection technique in field observations, remote sensing is an important tool in detecting, monitoring and evaluating the degree of invasion (Shaw, 2005; Bradley, 2013; Rocchini, 2015).

Studies to identify forests in Rio Grande do Sul State by remote sensing were done using images from the Landsat TM (Ducati et al., 1999) and Aster (Wagner and Ducati, 2005) sensors. In this State, an especially sensitive area is the Lagoa do Peixe National Park (Parque Nacional da Lagoa do Peixe), where Portz et al. (2011) identified areas of Pinus using the NDVI index. Likewise, Portz et al. (2011) identified areas of Pinus within and around the Park from pixel classification and NDVI images. However, none of these studies focused on Pinus existing specifically within the Park area, which is presently subjected to an important invasion process by this alien species. Therefore, considering this gap

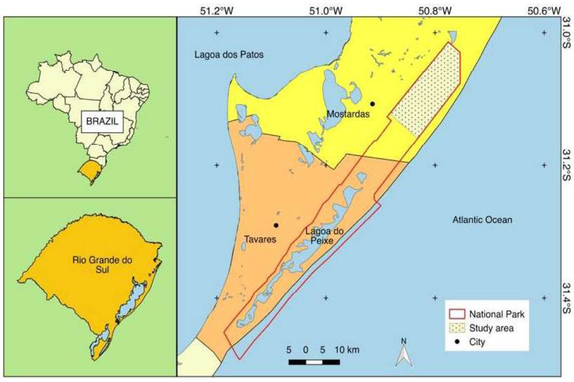


**Figure 1 -** PNLP and study area location.
***Figura 1 -*** *Localização do PNLP e da área de estudo.*

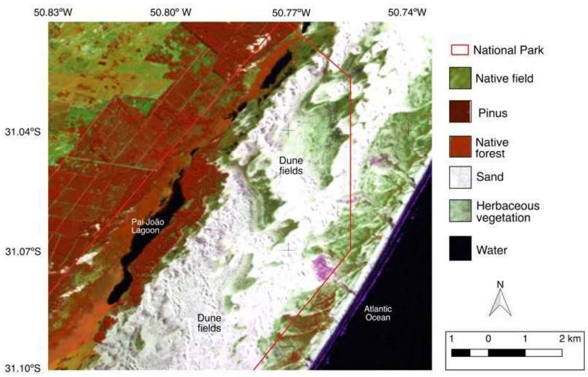


**Figure 2 –** False color composition RGB-453 Landsat-5 of 05/04/2005 showing the study area.
***Figura 2 –*** *Composição em falsa cor RGB-453 Landsat-5 de 04/05/2005 mostrando a área de estudo.*

and the possibility of contributing to the eradication of Pinus in the Park, this study aimed to:

1) Map the evolution of the area occupied by Pinus sp on the region of the Pai João lagoon, using satellite images from 1985 to 2013.

2) Map the presence of Pinus sp originated by seed dispersal in the dune field area, using satellite images between 2011 and 2017, describing its expansion.

### 1.2 Study area

The Lagoa do Peixe National Park is a protected area under management of the Chico Mendes Institute for Biodiversity Conservation (ICMBio). Created in 1986, it has an area of 36,721 hectares and is located in the coastal plain of Rio Grande do Sul encompassing area of the municipalities of Mostardas and Tavares. Its main objectives include conserving areas of the coastal ecosystems of the Lagoa do Peixe region, especially for protection of migratory bird species that depend on it for their life cyle (ICMBio, 2017). The Park (Figure 1) is included in the Brazilian list of Ramsar Sites as a priority area for the conservation of wetlands of international importance (Brasil, 2017). Figure 2 shows a map of the study area in a more detailed scale, indicating the main elements of the landscape.

## 2. MATERIAL AND METHODS

This study used images from TM, ETM + and OLI sensors, aboard Landsat 5, 7 and 8 satellites, acquired between 1985 and 2017. The images are generated with a spatial resolution of 30 meters, where the TM and ETM + sensor data are delivered in 8 bits, and the OLI sensor data is delivered in 16 bits. The Red, Green and Blue bands were used in the region of the visible spectrum, and NIR, SWIR 1 and SWIR2 bands in the region of the infrared spectrum. These Landsat scenes were obtained through the Earth Explorer portal and belong to the Tier 1 collection, consisting of georeferenced images in the WGS-84 datum and UTM projection. All Tier 1 Landsat data is radiometrically calibrated and is consistently geolocated over the full collection for all sensors. These images were already submitted to an atmospheric correction procedure, being available as the product Landsat Surface Reflectance (USGS, 2019).

Image selection followed two criteria. The first one was to select images with similar acquisition dates in order to obtain alike angles of solar illumination and to minimize seasonal effects on vegetation. The second criterion was, by visual inspection, to discard images obtained after periods of heavy rain, as such scenes are noticeably darker due to the greater absorption of electromagnetic radiation, since in addition to the characteristic absorptions of the water molecule, absorptions at neighboring wavelengths also occur, greatly reducing the spectral response of wet soils (Jensen, 2009). Landsat scenes of the following dates were therefore selected: 12/06/1985, 04/19/1988, 12/19/1995, 02/24/2000, 05/04/2005, 03/31/2010, 12/04/2013, 12/07/2014, 12/15/2017.

RapidEye images were also used, generated by a constellation of five satellites that contain identical and equally calibrated sensors. The scenes used in this study are of level 3A - RapidEye Ortho Product, whose data are delivered in 12 bits, spatial resolution of 5 meters, with geometric and radiometric correction applied to data (PLANET, 2016). The images are georeferenced in the WGS-84 datum and UTM projection. The selection was made using the same criteria used for Landsat images, with choice of the following scenes: 03/17/2011, 11/13/2013, 03/03/2015, 08/23/2017.

### 2.1 Visual analysis procedures and automatic classification pixels; the Spectral Angle Mapper classifier.

Landsat spectral bands Blue, Green, Red, NIR, SWIR1 and SWIR2 were used to test different color compositions by layer stack technique looking for the best visual separation between Pinus pixels and other classes; after several tests a false color composition of NIR, SWIR1 and Red was chosen. A visual analysis supported by field trips was made to identify the vegetal profiles in the area which were represented in the satellite images.

After this visual interpretation step, the images were submitted to automatic classification procedures using the K-means and Maximun Likelihood approaches. Results from the applications of these two algorithms in the identification of Pinus pixels were not superior to visual analysis. However, further tests with the Spectral Angle Mapper algorithm (SAM) showed better results and improved the visual classification of Pinus areas.

The SAM algorithm is a pixel classifier that is able to determine the similarity between spectral signatures by calculating the angle between the measured spectra and a reference one. Here, the spectra are treated as vectors in a space with dimensionality equal to the number of bands used. Reference spectral signature can be taken from laboratory using a spectroradiometer, or be extracted directly from the satellite image by selecting pure pixels for the desired target (Petropoulos et al., 2010). In this case the reference signature was taken directly from the image by selecting pure Pinus pixels, where the term spectral signature refers to the characteristic way of an object to reflect the electromagnetic radiation at the time of scene acquisition (Ponzoni et al., 2011).

In an image obtained by multispectral sensors, as it is the case presently treated, each signature can be represented by a vector in the N-dimensional space, in which N is the number of bands in the spectral curve. This vector has two main characteristics, a length corresponding to its magnitude and an angle with respect to the axes that define the coordinate system of the space. Small angles between the vectors indicate high similarity, and high angles indicate low similarity (Kruse et al., 1993; Cho et al., 2010). The analyst defines the maximum angle threshold between the reference spectrum and the pixel spectrum to be classified, and in this way pixels associated to vectors with an angle larger than the specified maximum angle threshold are not classified (Petropoulos et al., 2010).

Girouard et al. (2004) observed that the main limitation of the SAM method is the occurrence of spectral mixing; Freitas et al. (2008) report that spectral mixing occurs whenever the same pixel includes two or more spectral classes, and emphasize that the possibility of mixing increases with pixel size.

The occurrence of Pinus in this study is divided into two different areas:

1) Pinus planted in the area of Pai João Lagoon in silviculture plots with an average size of ten hectares. In this case, the growth of the trees formed a dense forest canopy, and despite the occurrence of spectral mixing at the edges, within the silviculture area the spectral response is due only to the reflectance of the forest canopy.

2) Pinus disseminated in the dune fields; in this case Pinus patches have varied sizes, going to less than one hectare, which makes the problem of spectral mixing more acute. To reduce the occurrence of spectral mixing with neighboring targets, we used RapidEye images, which have a smaller pixel size.

### 2.2 Calculation of Pinus area planted on the lakeshore of Pai João Lagoon

The variation of the Pinus area was measured using Landsat images of the years 1988, 1995, 2000, 2005, 2010 and 2013, classified by the SAM algorithm selecting the Pinus pixels.

The measurement considered images only until December 2013, because after this date a forest harvesting operation began in the area (ICMBio, 2013). Between 1988 and 2013 the area already belonged to the PNLP and in several surveys performed during this period there was no evidence of any human intervention in the planted Pinus area.

To obtain the reference spectral signature pure pixels were selected inside the silviculture plots. Following the technique used by Yi, (2007) different values were tested for the maximum angle threshold applied to the SAM classifier and the results were evaluated by visual analysis based on control points on the ground. After tests with several angular limits, the angular distance of 0.14 radians was chosen.

### 2.3 Calculation of Pinus area disseminated in the dune fields

Starting in year 2010, visual inspection of the Landsat images showed the increasing presence of Pinus pixels in the dune fields. Ground checks confirmed the visual analysis and showed that Pinus has developed in areas with some existing herbaceous vegetation. The presence of organic matter in the soil makes that these areas, in addition to containing more nutrients, have a greater capacity of retaining moisture, being a better substrate to the germination and growth of Pinus.

To reduce the spectral mixture that tends to be more pronounced in this area, images of the RapidEye mission with spatial resolution of 5 meters were used. Similar to the previous case, pure pixels were selected representing the reference spectrum, different values were tested for the maximum angular distance and after visual analysis at control points it was decided to use the angular limit of 0.20 radians.

### 2.4 Validation of classification

The validation of the classification made in the region of Pai João Lagoon was made using images available in the Google Earth (GE) portal as ground truth. The classification of the Landsat scene of 05/04/2005 was validated with GE images of 10/19/2005 and 08/13/2005 and for the Landsat scene of 06/27/2013 a GE image of 12/07/2014. The validation sample consisted of 100 random points on the area of Pinus pixels to evaluate the commission errors and 100 points on the surroundings of the classified area to evaluate omission errors. The validation of the classification in the dune field was made only for the RapidEye scene of 11/19/2017 using ground truth and points collection by a navigation GPS. Fifty random points were generated on the Pinus class to evaluate commission errors and fifty random points around the Pinus class to evaluate omission errors.

## 3. RESULTS

### 3.1 Variation of Pinus area planted on the region of Pai João Lagoon

During the 25-year period analyzed, the area of dense Pinus increased by 362% from 68.81 ha to 317.97 ha, according to data from Figure 3.

### 3.2 Variation of the area of Pinus disseminated in the the dune fields

The areas of Pinus in the the dune fields were separated into two regions, A and B, both formed around nuclei of seed dispersion originated by the first adult trees growing there. These results are shown in Figure 4 and Table 1.

### 3.3 Results of classification and validation

The Landsat-TM 2005 and Landsat-OLI 2013 images presented commission error values of 11%

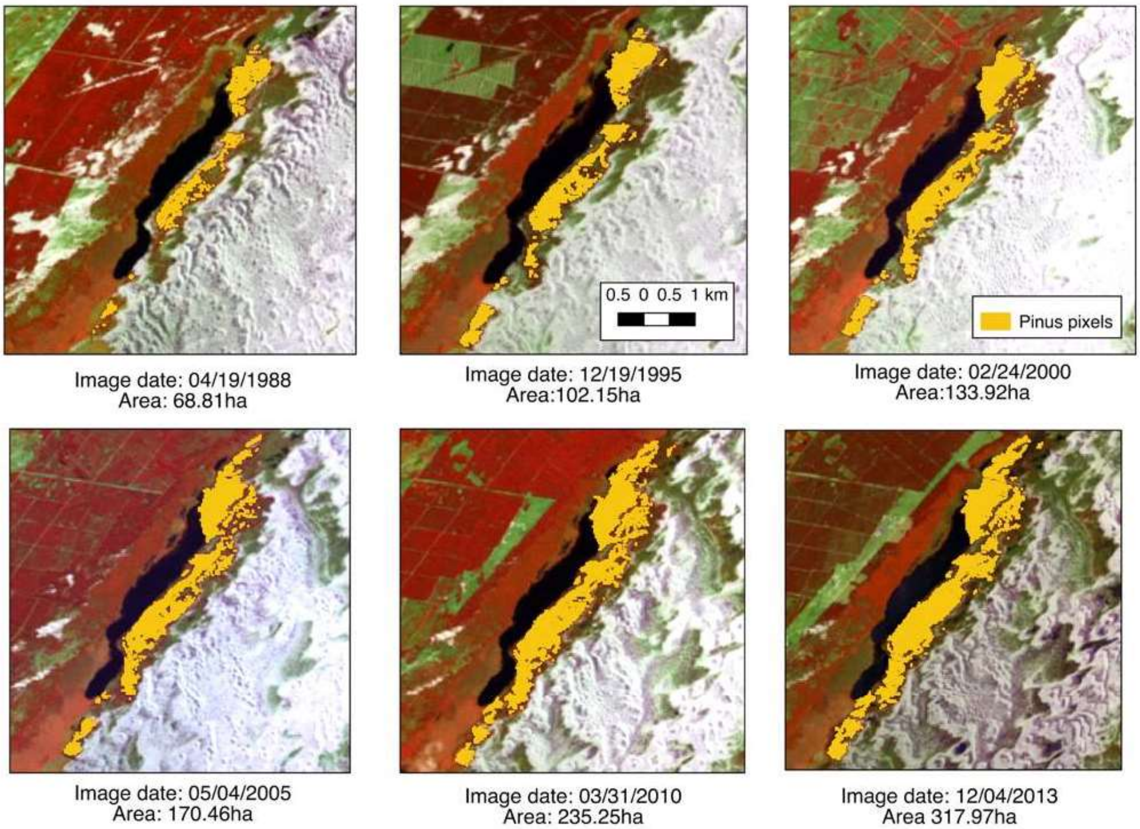


**Figure 3** – Pinus areas at Pai João Lagoon, SAM method with angular limit 0.14.
***Figura 3*** – *Pinus na área da Lagoa do Pai João, classificação SAM com limite angular 0,14.*

and 12% respectively, and omission errors of 9% and 16%, generating global accuracies of 90% and 86%. The RapidEye image of 2017 presented a 4% rate for commission errors and 18% for omission errors, generating a global accuracy of 89%.

## 4. DISCUSSION

Among the limitations in automatic pixel classification, we highlight two: the targets of interest may not be spectrally different in the bands available in the image, and the spatial resolution used may present pixels with spectral mixing (Lu and Weng, 2007; Meneses and Sano, 2012).

During the classification process performed in this study, spectral confusion trends were observed between the Pinus class and the native forest and native field classes. This spectral confusion occurred as the angular limit of the SAM classifier increased. However, on the eastern shore of Pai João Lagoon, Pinus was the only vigorous form of vegetation, reduced spectral confusion. The area occupied by this alien species had a constant growth rate with slight acceleration from the year 2000.

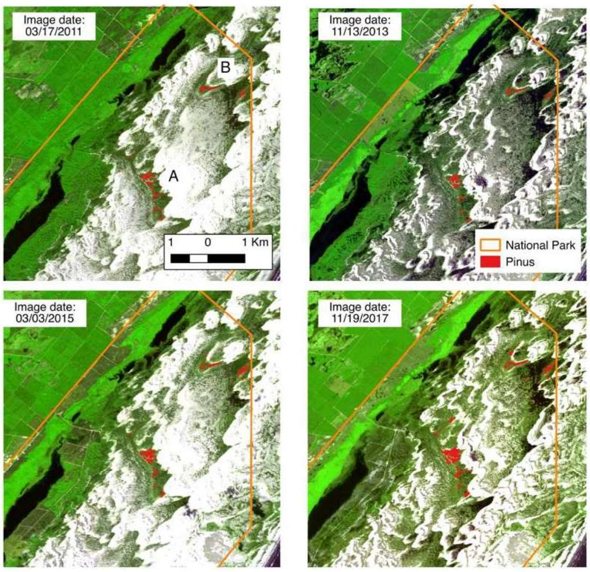


**Figure 4** – Pinus areas in dune fields, SAM method with angular limit 0.20.
***Figura 4*** – *Áreas de Pinus nos campos de dunas, classificação SAM com limite angular 0,20.*

The validation of this classification reached 90% global accuracy for the Landsat 2005 image and 86% overall accuracy for the Landsat 2013 image.

In the dune fields, we divided the classified area around the two dissemination nuclei A and B shown in Figure 4. Observing the entire period analyzed (2011 to 2017), the Pinus class had an increase of 364% in region A and 224% in a region B; however, in 2013 there was a point outside the growth curve, with a reduction in the number of Pinus pixels of 7% in region A and 10% in region B. Field inspections did not show mortality of Pinus, which could justify this reduction, so the most plausible explanation is related to the presence of wet soils after heavy rains, and consequent alteration of the spectral signatures of the pixels, the 2013 scene being noticeably darker.

Regions A and B were the first areas in the field of dunes to receive seeds from nearby forested areas, carried especially by wind; it was found that the first pixels of Pinus were detected at distances over 2 km of planted areas, showing the carrying capacity of the winds in the area. After the establishment of the first adult trees, the regions A and B started functioning as seed source nuclei, spreading preferentially in the northeast direction, which is the orientation of dominant winds. Over the years an increasing number of trees have reached the age of seed production, resulting in a mild acceleration in the expansion of the Pinus pixels area.

The validation in regions A and B presented a percentage of 4% of commission errors, showing that some areas where there was no Pinus were erroneously pointed out by the classifier. The percentage of omission errors was 18%, indicating that the angular limit of the SAM classifier could be slightly increased. However, a larger angular limit would tend to increase the rate of commission errors, classifying areas of more vigorous grasses as being Pinus.

**Table 1** – Pinus areas in dune fields from SAM method with angular limit 0.20.
***Tabela 1*** – *Área de Pinus em no campo de dunas a partir da classificação SAM 0.20.*

| Image date / Area | 03/17/2011 | 11/13/2013 | 03/03/2015 | 11/19/2017 |
|---|---|---|---|---|
| Region A | 2.76 ha | 2.56 ha | 5.14 ha | 10.02 ha |
| Region B | 1.5 ha | 1.35 ha | 2.65 ha | 3.36 ha |

The evaluation of errors of omission directly in the ground presented an additional difficulty. As a rule, it was considered that areas equal to or greater than one RapidEye pixel (25m2) should have been detected by the SAM classification. However, it has been observed in the field that there is no standard in the quantification nor in the density of sparse Pinus, so that irregular spots of various sizes occur, generating pixels with different degrees of spectral mixing. So in the ground validation, in face of small irregular groupings with an area close to 25m2, it was necessary to judge if there was an omission error in that pixel, a decision based in relatively subjective criteria. A more accurate validation can be made from the use of extremely high spatial resolution images obtained by unmanned aerial vehicles (UAVs).

Finally, there was influence of the movement of dunes, as it was verified on the ground that dunes moving towards NE-SW were covering adult trees in the dune field, a fact that was recorded in the historical series of satellite images. For the Pinus planted near the Lagoon, it was observed that their expansion in the W-E direction was partially contained by the advancement of dune fronts that move in the opposite direction.

## 5. CONCLUSIONS

The invasive capacity of Pinus sp already described in other studies was also presently observed. The wind was confirmed as the main factor of seed dispersal, distributing seeds in all directions, but mainly in the direction of the dominant wind in the region, NE-SW. The results of this work show that the invasion of Pinus will continue, to gradually occupy all available spaces suitable for fixing this species, excluding only permanently flooded areas and sterile areas such as dunes tops.

The science of remote sensing was essential for the analysis of Pinus invasion of the northern part of the National Park of Lagoa do Peixe, allowing to understand and map from the beginning the dynamics of this process.

As recommendations to the management of the area, it is important to be aware that the presence of Pinus tends to increase, so the actions necessary for eradication are urgent and the delay in these actions will unequivocally cause greater environmental losses. It is suggested to focus efforts on the elimination of the oldest seeds foci containing trees that are dispersing seeds; and in the impossibility of cutting such trees it is suggested to use the girdling technique. It is also essential to verify possible seed dispersal foci around the Park, mainly near the northeast limit due to avoid dispersion by dominant wind.

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