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RESEARCH ARTICLE - TERMITES

Termites of Iranian date palm orchards and their spatial and temporal distribution

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Abstract

This study was conducted during 2013-2014 to determine the dominant species and behavior of termites foraging in date palm orchards in Khuzestan province, Iran. Starting in early March, the 'cluster random sampling' method was used within sixty-five sampling plots. Termite species were sampled by breaking open mud tubing and collecting different castes, then bringing them to the laboratory for identification using ~~the~~ scientific keys. Glass microscope slides of different body parts, especially the labium, maxillae, palps, mandibles, labrum, and clypeus. The Simpson Diversity Index was used to determine the level of dominance. Results showed three species of termites, *Microcerotermes diversus* Silvestri, *Microcerotermes buettikeri* Chhotani and Bose and *Amitermes vilis* Hagen, all family Termitidae, are active in Khuzestan date palm plantations. *Microcerotermes diversus* was dominant with a correlation coefficient 0.997 and 8.87, respectively. Seasonal population fluctuations of workers, nymphs, soldiers and winged castes had several peaks over the years. According to Kriging map spatial distribution, four geographic severity groupings for *M. diversus* can be considered. These groups include low, medium, and high risk, and hotspot infestation geographic regions, with severity indices of 2.3 to 3.96, 3.97 to 4.82, 4.83 to 5.68, and 5.96 to 6.53, respectively.

Introduction

Several species of termites cause damage in date palm plantations in different regions of the world. Twenty-five species of termites (Isoptera: Termitidae) cause damage to wood tissue of date palm trees (Al-Jboory, 2007). Studies show that both temperature and rainfall affect the termite's geographical distribution. That's why termites are generally spread between 45 and 50 degrees north and south latitude. Therefore, most species of termites are found in tropical and subtropical regions (Sands, 1992). Iran has variety of climates. Southern and southeastern of Iran have desert climate based on Emberger classification and their ecological conditions are similar to the Arabian Peninsula and southwestern Pakistan (Yousof, 2010). Khuzestan province in the southwest is one of Iran's warmest provinces. This province has suitable climate for the growth and development of termites. Termite diversity of this province is affected by termite fauna in nearby geographic areas such as Persian Gulf and Oman Sea countries including Iraq, Saudi Arabia, Kuwait, Oman, Bahrain, Qatar, and the United Arab Emirates (Pearce, 1997). Termite distribution has been studied in Iran, Iraq, and the Arabian Peninsula. There are similar species in these countries as are found in Khuzestan Provence (Badawiet al., 1987; El-Shafie, 2012). *Microcerotermes diversus* Silvestri and *Psammotermes rajasthanicus* Roonwal and Bose have been reported from all areas with date palm plantations of Iran and Chabahar, respectively (Ghauryfaret al. 2005).Termites from the genera *Coptotermes*, *Psammotermes*, *Bellicostitermes*, and *Anacanthotermes ochraceus* Burmeister have been reported from Mauritania and Libya, respectively (Pearce, 1997). *Odontotermes nilensis* Emerson, *Odontotermes smeathmani* Fuller, and *Odontotermes obesus* Rambur have been reported in date palm orchards in northern Sudan. *Amitermes desertorum*

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Desneux and *Psammotermes hybostoma* Desneux from Egypt, *O. obesus* from India, and *M. diversus* from Saudi Arabia and Iraq have been reported in date palm orchards (Engel & Krishna, 2004).

According to other studies, caste densities of different species of termites fluctuate during the year depending on needs of for different castes, and also due to environmental conditions (Ghauryfar, 2005). Spatial and temporal knowledge of the pest's population dynamics are essential to development of IPM programs in each region over time. So that, the pest management professionals can be applied IPM offers as quickly as possible and with low cost (Rad & Latifian, 2005). The objective of this research was to determine the dominant date palm termite species and their spatial and temporal distribution of in date palm orchards of Khuzestan province, Iran, based on viewpoints of integrated pest management.

Materials and Methods

Location sampling time.

Sampling of date palm termites was done from March when air temperature increased in date palm orchards. The 'regional' or 'cluster' random sampling method was applied (Latifian & Solymannejadian, 2002). This sampling method was selected because the overall date palm sampling 'society' was too large. The geographical distribution of society members was such that sampling was not possible from all date palms due to resource constraints. Therefore, sampling societies were plotted, and a 1.0-ha date palm orchard was randomly selected within each society plot. According to previous studies, the number of necessary 1.0-hasampling plots was 65. A date palm garden was randomly selected and marked in each plot, then sampling was done at specific time intervals throughout the season (Latifian and Solymannejadian, 2002; Latifian & Zare, 2004). Fifteen date palm trees were selected randomly in each 1.0-ha orchard and severity of termite infestations were estimated (Table 1).The infestation index in each date palm orchard was estimated by using Equation 1:

$$\text{Infestation index} = \frac{a + 2b + 3c + 4d}{15}$$

In Equation1, a, b, c, and d were the number of trees with infestation severity 1, 2, 3 and 4, respectively. The frond mid rib or petiole is triangular in cross section with two lateral angles and one dorsal (Fig 1). Dead old fronds are not shed naturally, but remain attached to the mother palm and are usually removed by farmers during pruning (Nixon & Wedding, 1956). The symptoms of the injuries were recorded as a biological index for pest activity level. All eight locations annotated on the date palm tree in Figure 1 were evaluated for termite injury, with damage severity ratings based on codes provided in Table 1.

The different termite species castes were sampled by destruction of muddy channels on date palm trees. The samplings were done on base of petioles on the trunks of date palm because the maximum of channels termites were observed there. Then collected termites were transmitted into a container containing 80% ethanol by using a finer brush and requirements specification such as the name and date of collections were recorded on them (Longan & El Bakri, 1990). In addition, seasonal population fluctuations of different castes and their frequency relative to the total population were evaluated. Also, the dominant termite species were studied by similar sampling methods in date palm orchards located in areas within Longitudes 48°34' to 48°39' East, and Latitudes 31°14' to 31°19' North, every 15 days during the year.

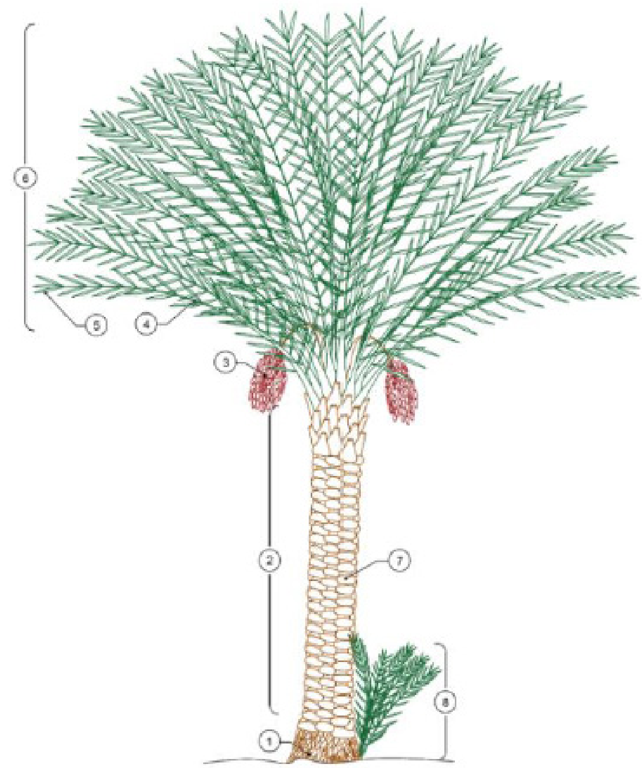

Fig 1. Diagram showing the morphology of date palm: (1) aerial roots, (2) trunk or stem, (3) fruit bunch, (4) leaf or frond, (5) leaflet, (6) crown, (7) scars at frond base or petiole, and (8) basal offshoot (Source: Oihabi, 1991).

Identification method

Some glass microscope slides were prepared for different parts of the termite body including mandibles, antennae, and labium. Termites were dissected using a subtle needle and then boiled in 10% KOH solution in water bath for 5 minutes. Then

Table 1. Estimation of termite infestation severity.

Infestation Severity	Selective Code	Infestation %
None	0	0
Low	1	1-25
Medium	2	26-50
High	3	51-75
Hot Spot	4	76-100

slides were autoclaved for one week at 50°C. Termite parts were measured by using a microscope with an ocular micrometer, and compared using identification keys (Longan & El Bakri, 1990; Strewart & Zalucki, 2006; Habibpouret al., 2010).

Dominant species determination.

The correlations between total termite populations and the relative density of each species were calculated. For this purpose, the total and individual termite species population density were estimated in each area by sampling of 15 date palm trees ~~as~~ utilizing previous methods (Varely & Gradwell, 1963).

Equation 2: $X = x_1 + x_2 + \ldots + x_n$

In Equation 2, X= total termite species population density, x_n= individual termite species population density. The species with greater correlation coefficient was designated as the dominant species in the region. Simpson Diversity Index was used for determining dominance. D is calculated by Equation 3 in an unlimited society (Zhang, 2016).

Equation 3: $D = \Sigma P^{2}$

Distribution models

Geostatistical methods were used for simulating distribution models. Geostatistical method is based on the spatial variables theory (Story & Congalton 1994; Wright et al., 2002). Spatial correlation between samples can be described as a mathematical model known as the variogram (Ellbsuryet al., 1998). If it is assumed that the total number of each pair of samples N (h) located at the distance h, then:

Equation 4: $$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(\dot{x}) - Z(\dot{x} + h]^{2}$$

$\hat{\gamma}(h)$ is called 'semi-variance' in the above equation. The values of semi-variance are plotted on the vertical axis for different distances to select the best models. The obtained curves drawn by this method known as variograms (Journel et al., 1978). Some variogram models (eg., Gaussian and spherical) had limited threshold levels, and others such as linear models did not. This means that variogram values were increased by increasing distance between samples (h) but not to a fixed extent (Katheriene, 2001). The distance after which semi-variance is constant is known as range of effects and is shown by R. The effect range is interval more than it; samples are independent and not affected to each other. This parameter determines the characteristic correlation and allowable interval sampling distance, and therefore the lag distance at which the semi-variogram (or semi-variogram component) reaches the 'sill' value. Presumably, autocorrelation is essentially zero beyond the range. Most of variograms don't show rapid changes at very short distances, so much semi-variance is not zero at the base of avariogram curve. So, in theory the semi-variogram value at the origin should be zero. If it is significantly different from zero for distance very close to zero, then this semi-variogram value is referred to as the 'nugget'. The nugget represents variability at distances smaller than the typical sample spacing, including measurement error (Goovaets, 1997).

The variogram model parameters can be used to estimate the distribution of insects. All interpolation algorithms estimate the value at a given location as a weighted sum of data values at surrounding locations. Almost all assign weights according to functions that give a decreasing weight with increasing separation distance. Kriging is a commonly used method of interpolation (prediction) for spatial data. The data are a set of observations of some variable(s) of interest, with some spatial correlation present (Katheriene, 2001).

Results and Discussion

Termite Species Dominance.

Three species of termites were collected from date palm orchards of Khuzestan province in Iran that all of them were from Termitinae (Termitidae). These species were *Microcerotermes diversus* Silvestri, *Microcerotermes buettikeri* Chhotani and Bose, and *Amitermes vilis* Hagen (Blumberg 2008; Carpenter & Elmer, 1978; Yousof, 2010).

Correlation coefficients between the relative abundance of each species with a total population of termite's species and their dominance index were calculated based on Equations 2 and 3 in each studied area that the results showed in Figure 2.

According to Figure 2, *M. diversus* with correlation

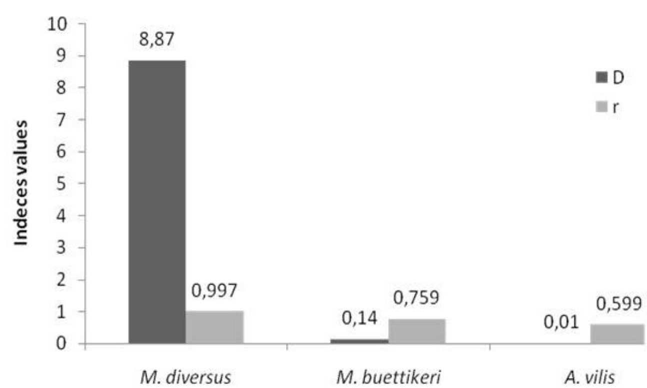

Fig 2. Correlation between the relative densities of each species with the total density.

coefficients and dominant index species 0.997 and 8.87 was introduced as the dominant species. Other species *M. buettikeri and A. vilis* were the second and third priority respectively. Twenty-two species of termites were reported in date palm-rich countries in Persian Gulf littoral (El-Shafie, 2012). One or more species have been dominant despite the several reported species that active in each region. *Heterotermes aethiopicus* Sjostedt is the have maximum frequency species in United Arab Emirates (Kaakeh, 2006). Twelve species, 6 genera and 3 families were reported from date palms orchards of Saudi Arabia but termites of the genus *Microcerotemes* were have maximum frequency (Faragalla & Al Qhtani, 2013). More than 45 percent of infections were related to *M. diversus* in date palm orchards of Iraq (Ali, 2007).

Seasonal Population Fluctuation of Dominant Species.

Fluctuations in populations of workers had two periods abundance during the year. The first period started from late March and continued to late May, and its peak was in late April. The second period started from late June and continued to early April of next year, and its peak was in late December. Nymph population also has four peak periods over the years. The first period lasted from late May to early August and had its peak in late July. The second period lasted from early August to early October and the peak was in late September. The third period started from early October to late November and its peak was in early November. The fourth period started from late October to late November and its peak was at early December (Fig 3).

Soldiers had the lowest population density in their colonies. Soldier number peaks corresponded with the peak of reproductive caste. Swarmer population fluctuations had four peak periods over the years. The first peak period started from early June to late September. The second period continued from late October to early December and peaked in late November. The third period started from early December, peaked in late December, and continued to early January. The fourth period started from early January, peaked in late January, and continued through late February (Fig 3).

The dominant species castes including alates, nymphes, soldier and worker had different fluctuations over the years in the two studied areas. The worker caste was more frequent in most cases. But the highest percentage of the population

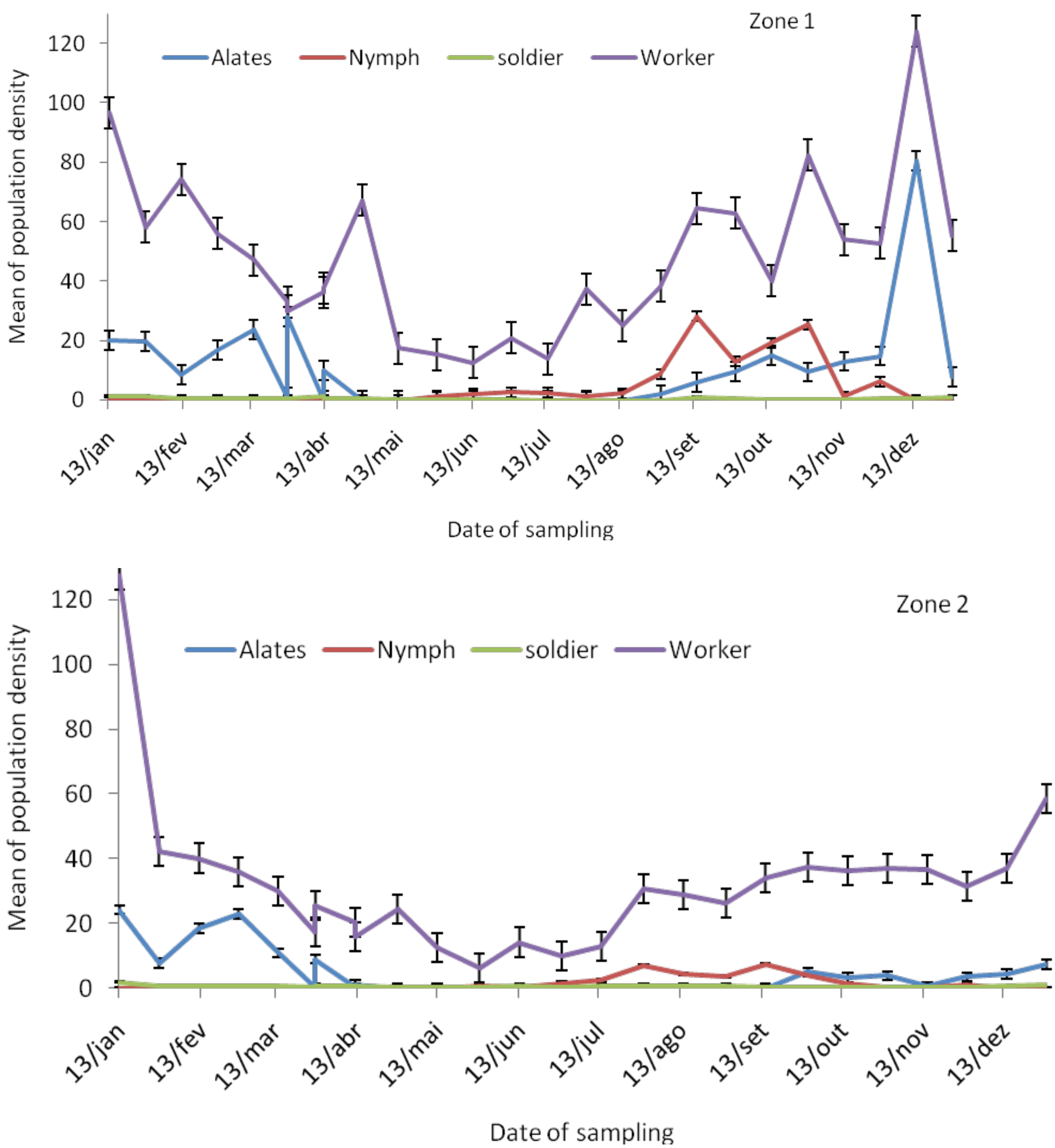

Fig 3. Seasonal variation of population density of various castes of dominant species termite in Khuzestan date palm orchards.

is over 90% of total population in the spring. Abundance of some castes including alates, nymphes and soldier decreased to near 0% during the year. The frequency percent of nymphs and alates decreased to less than 5% at the beginning of spring and during the summer, respectively (Fig 4).

Geographical Distribution.

Geographical distributions of three dominant species in Khuzestan date palm orchards are shown in Figure 5. Results showed that *M. diversus* had the greatest maximum range of distribution in the most date palm gardens in Khuzestan province. *Microcerotermes buettikeri* is distributed in the south and southwest of Khuzestan province, including Abadan, Khorramshahr, Shadegan, Sosangerd, and Azadegan counties. *Amitermes vitis* had limited distribution in Abadan and Arvandkenar counties.

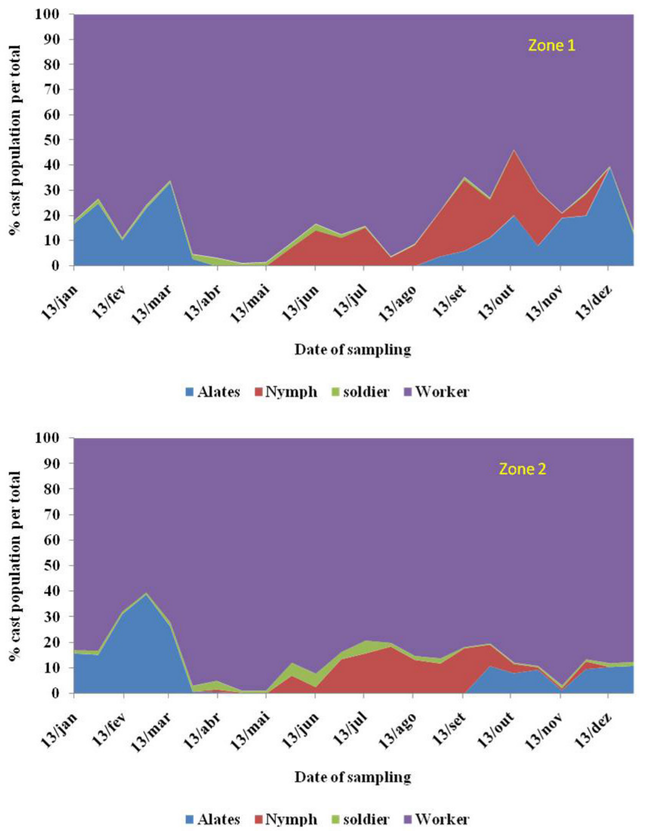

Fig 4. Percent of the population abundance of castes dominant termitespecies in Khuzestan date palm orchards.

The variogram of distribution *M. diversus* severity as dominant species were calculated based on spherical, exponential, linear, and Gaussian to sill models. Based on results (Table 2), spherical model of severity distribution was the more suitable fit than other models. The nugget effect of the sampling was 0.82 for geographic distances, which was a less effect than sampling intervals. Variogram effective range was 53.5 kilometers. This distance means that there is little correlation between the termite damage severity data when sampling intervals were more than this threshold level.

Table 2. Distribution Variogram models of date palm termite *M. diversus* severity.

Model	*E. range*	*Sill* (c_0+c)	*Nugget*	R^2
Spherical	53.5	1.19	0.22	0.85
Exponential	24.7	1.17	0.0006	0.45
Linear	78.9	1.22	0.69	0.41
Linear to Sill	42.7	1.19	0.29	0.29
Gaussian	72.57	1.18	0.34	0.28

This parameter showed the relationship between the density of date palm trees and injury severity by termites dates indicated in each area. Sill was 1.19, which indicates the aerial coverage ratio of date palm orchard areas by *M. diversus*. Variograms showed that there was a suitable trend for termite injury severity of this termite at the regional and local levels. The nugget effect was 0.2, which indicates that termite damage estimation error was extremely low by this model. Based on the model, four categories of termite injury severity were considered for regional control management planning in date palms orchards in Khuzestan province.

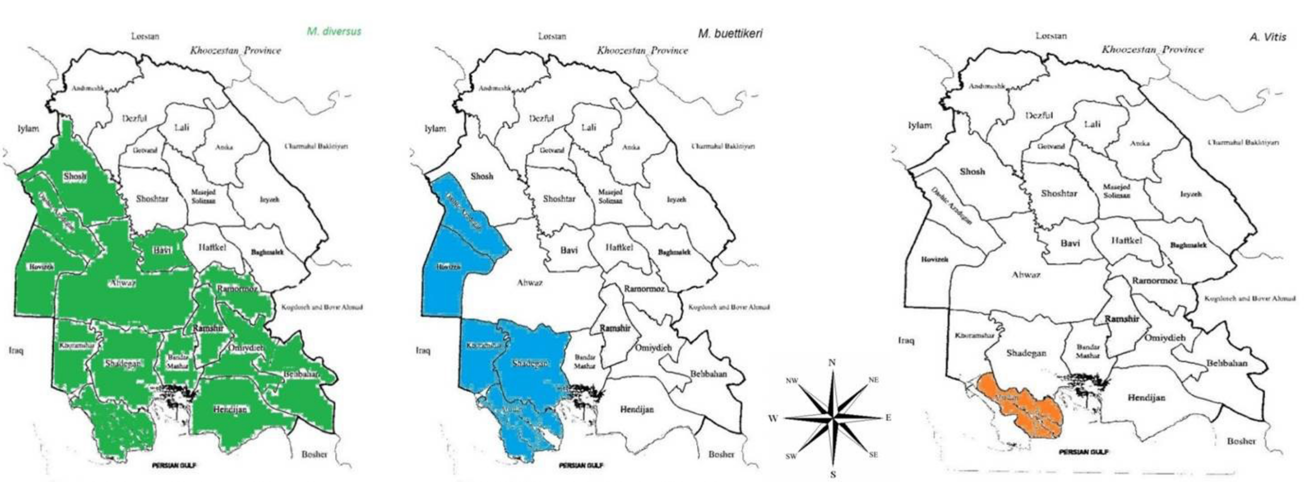

Fig 5. Geographical distribution of termite species indate palm orchards of Khuzestan province, Iran. Green =*M. diversus,* Blue=*M. buettikeri,* Orange=*A. vitis*

The first pathosystem included low-risk areas, where injury indices varied between 2.3 to 3.96. Termite injury to date palms was tolerable in this region. The second pathosystem included medium-risk areas where injury indices varied from 3.97 to 4.82. The termite injury can be reduced to a tolerable level by good horticultural management in this region. The third pathosystem included high-risk areas where injury indices varied from 4.83 to 5.68. Chemical control measures are necessary in these regions. The fourth pathosystem included the main foci injury areas injury indices varied from 5.69 to 6.53. Fine adjustment of monitoring a control program against termites is of utmost importance in this region (Fig 6).

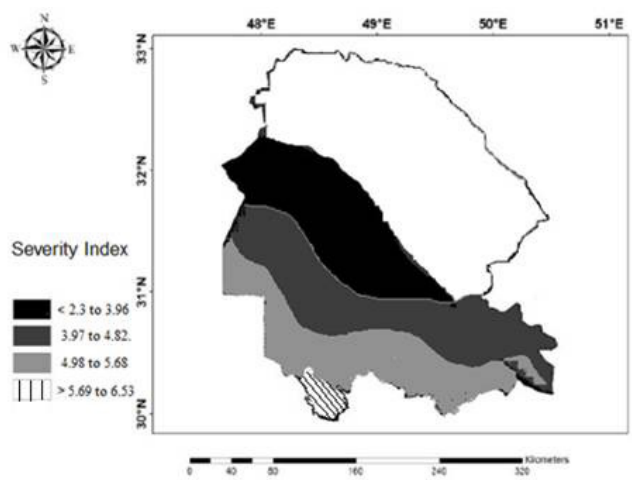

Fig 6. Kirging map of dominant termite species basedon severity index in Khuzestan province of Iran.

The cluster random sampling method has been used for studying the distribution of many species of termites in different parts of the world (Bankhead-Dronnet et al., 2015; Scheffrahn et al., 2016). In one study, the spatial distribution of *Syntermes* spp. simulated ~~by~~ using geostatistical methods in the Credo (Brazilian savannah), which has a sampling error was less than 5%. This methodology was successfully applied for the pest management plan of this termite in eucalyptus plantations (Santos et al., 2016). The distribution of *Nasutitermes* spp. was successfully estimated by the same method in Gran Sabena of Venezuela (Carmen, 2007). Termite distribution and diversity in a given area is relevant in the planning of effective termite control measures and the choice of termiticide to use to manage the infestation (Acda, 2013). The findings of this research are applicable to management of dominant termites in date palm gardens of Iran.

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