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The Identification of Relationship Between Light Pollution and Roosting Sites of Barn Swallows using VIIRS DNB Imagery (Case Study: Java and Bali Islands)

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Abstract

Java and Bali Islands are functions as a lane for the migration of barn swallows *(Hirundo rustica)*. These islands have a high level of light pollution in Indonesia. Changes in light pollution levels impact the migration processes of nocturnal birds, especially true of their choice of roosting sites which are becoming more focused around urban areas. The purpose of this research is to find out the relationship between light pollution levels and the selection of roosting sites for barn swallows that migrate at night. This is important to know the impact of artificial electric lighting at night on an annual nocturnal bird migration that was identified by using the correlation analysis. That was carried out using Spearman's ranking as a correlation analysis method. Sources of data that were used in this research are Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) imagery data. VIIRS DNB was collected using Earth Engine. VIIRS-DNB data was processed by Google Earth Engine that can be used immediately. The results show that the correlation between light pollution and the selection of roosting sites is robust. That was indicated by the correlation value at 0.9. Based on the value, roosting sites and light pollution have a positive correlation. The higher light pollution in an area can increase the number of roosting sites. The nocturnal birds usually use the light for their direction and artificial electric lighting at night can be distracting their migration to a lighter place, urban area. Therefore, the number of correlation is high. The significance of light pollution on birds' roosting sites during the migration period in Java and Bali Islands was obtained from the z count value which was greater than the z tables, which is in 95%.

Keywords: Visible Infrared Imaging Radiometer Suite Day/Night Band (VIIRS DNB); Light pollution; Roosting site; Spearman's ranking

1. Introduction

As well as being a very biodiverse country, Indonesia is also experiencing a high level of biodiversity decline (National Geographic Indonesia, 2019). The list of species threatened by extinction in Indonesia includes 140 species of birds, 63 species of mammals and 21 species of reptiles. Indonesia has 728 conserved species which consist of 130 mammals, 390 birds, 48 reptiles, 8 fish, 20 butterflies, 12 molluscs, and 9 crustacea (Convention on Biological Diversity, 2020). Loss of biodiversity is being caused by climate change and by changes in human behaviour, one of which is the use of electricity for lighting at night (Hölker *et al.,* 2010). Artificial electric lighting could affect the biodiversity of plants and animals due to them being 'tricked' by changes in the duration of day and night, which is especially the case for nocturnal animals (Hölker *et al.,* 2010).

Excessive use of artificial light at night can disrupt the annual migration which is an important aspect of the cycle of survival for migratory birds (Cabrera-Cruz *et al.*, 2018). Bird migration usually occurs twice a year, namely in September to November (autumn migration) to avoid winter and in February to April (spring migration) to return to the breeding area (Raptor Indonesia, 2012). Artificial light at night has effects determining the orientation of bird migration paths. Changes in land use resulting from human activities affect the use of electric outdoor lighting at night which can interfere with night-time bird migration. An example of the influence of light pollution disrupting bird migration is the death every year of 600 million birds in Chicago as they crashed into skyscrapers during their migration (McLendon, 2019). The researcher stated that this phenomenon happens as migratory birds tend to be attracted by the city's lights, resulting in disorientation. These bird deaths often occur in urban areas as they migrate at high speed and crash into buildings (Hardoko, 2019). Also, in the US, Houston and Dallas experience bird deaths during the migration season. The Cornell Lab of Ornithology estimates that at least half of migratory birds die every year.

The same phenomenon also occurs in Yogyakarta during the barn swallows migration season. These birds often perch on electric cables, especially at the Gondomanan road intersection, and scattered white patches of barn swallows dropping along Suryotomo Street are evidence of this. This species, consisting of eight subspecies, can be found throughout the northern hemisphere that forms their natural habitat. Barn swallows breed in the spring and summer in the northern hemisphere and then migrate south through Africa, Southeast Asia, the Philippines, and Indonesia to Papua and Australia during the autumn and winter (Firman, 2018). The barn swallows had disorientation during the migration period that was caused by light pollution.

The programme manager of Wetland International Indonesia, Yus Rusilla Noor, states that if the process of bird migration is disrupted there will be an explosion of pest populations which may result in crop failures in Indonesia (Tirtaningtyas, 2018). The disrupted migration which happens due to this 'trapping' and causes irregular migration might disturb the balance of the ecosystem in an area affected. This situation also occurs frequently in Java and the disruption of bird migration activities originating from the west to east corridor could negatively affect agricultural activities in the East Java Province. Harvesting failures resulting from growth in populations of planthoppers and rats would increase due to the reduced number of predator birds.

Every year, thousands of raptors migrate to the south via two routes. The first route is the Eastern Inland Corridor, followed by raptors from the southeast of Siberia through eastern China to the Malaysian peninsula and landing in Indonesia, specifically Java and Bali. The second route is the Pacific Coast Corridor. As birds travel along these corridors they look for places to roost at night (Septian, 2017). Therefore, Java and Bali are important islands for the annual migration of these birds.

Most of the night-migrating birds are small songbirds that migrate at night to avoid avian predators (Smith, 2007). Under normal circumstances, the migration process would be helped by the moon and starlight which guides migratory birds to reach their migration destinations. Unfortunately, higher artificial light levels have made these natural light sources less visible in the night sky. As a result, birds have difficulty determining the direction and therefore look for roosting sites (Wilson, 2011). The process happening with barn swallows in Yogyakarta. Hundreds of birds perch on electric cables and disturb road users. In contrast to their usual feeding and breeding behaviour in low levels of light pollution, these migratory birds are instead found in urban areas with high levels of light pollution (Dwyer *et al.*, 2013)

Remote sensing data such as the Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) free cloud composite imagery is essential for determining light density levels across Java and Bali in their function as annual bird migration routes in Indonesia. VIIRS DNB imagery displays recordings taken at night and is used to analyse the effects of night lighting and outdoor artificial light affecting the nocturnal activity of plants and animals (Longcore, 2004).

The use of VIIRS DNB imagery is important due to the ability to provide data on light pollution on the earth's surface and recording at night that corresponds to the migration time of Barn Swallows (Carbrera-Cruz *et al.,* 2018). The dynamic movement of migration required the use of imagery data that is up to date, fast and effective. Therefore, image processing has been done by Google Earth Engine, which was a cloud-based platform that can visualize complex spatial data by analysis using the Javascript API (Integreted Development Environment) (Sawungrana, 2019).

This imagery is used to identify the relationship between light pollution and roosting sites of the barn swallows in Java and Bali and the impact on the habits or behaviours of these birds in their migration activities, specifically finding roosting sites. Being aware of the factors that affect migratory birds' roosting places at night is necessary for determining which conservation actions would best maintain the balance of the ecosystem. The impact of light pollution on bird migration and their relationship with ecological balance has been documented in a previous study (Tuxbury and Salmon, 2005).

Research related to ecological or biodiversity problems caused by light pollution at night has looked at barn swallows and marine turtles and other wildlife in areas near human settlements and other ecosystems (Longcore, 2004). Light pollution causes changes in the reproductive physiology, migration, and foraging of many species and ultimately leads to biodiversity loss. Some seabirds are intimately linked with the light features in their environments because they are nocturnally active (Rodrigues *et al.,* 2011). Ecological light pollution has deleterious effects on the behavioural and population ecology of organisms in natural settings (Longcore, 2004), leading to wildlife having to bear the physiological, epidemiological, and ecological consequences of this type of pollution (Navara and Nelson, 2007). Research by Cabrera-Cruz *et al.* (2018) conducted the ALAN (Artificial Light at Night) association test on several birds species, namely Crwoned Sparrow, Wood Warblers, Waterflow, Shorebird, and Warbler which was carried out using the Boosted Regression Tree (BRT). This test was carried out to see the level of artificial light at night that is greatest during breeding, non-breeding, or migration of nocturnal birds. The results of this study indicated that the migration route has a high artificial light level and urban areas have higher migration species richness.

Ismail *et al.* (2020) regarding the roosting behavior of Wintering Barn Swallow (Hirundo rustica) in Peninsular Malaysia is a graph of the habits of Asian kites during the migration process when resting at their roosting site. Barn Swallows head to the roosting location starting at sunset and are in an urban area.

This study considered the types of objects under study, namely light pollution and bird occurrence. Types of the data are ordinal and not normally distributed, so the accuracy test is carried out with Spearman's rank which is non-parametric. This research really considered the condition of the study area, Java and Bali Islands, which are located in Indonesia and are tropical countries. This condition makes it difficult to get imagery with clear sky conditions, and the imagery provided is recording a monthly average, which is an important consideration. The correlation between light pollution and the roosting site of Barn Swallows shows the influence of human activities, especially in urban areas. This can be used to analyze and make considerations in carrying out development in urban areas. Urban development isn't only viewed from a human perspective but in a broader scope, that's ecology. Urban planning is very important to do to prevent migration failure and cause an imbalance in the ecosystem.

2. Materials and methods

2.1 Data selection

The roosting site data used in this study was obtained from the occurrence data of the Global Biodiversity Information Facility (GBIF) through GBIF's official website, GBIF.org. GBIF is an international network and research infrastructure funded by world governments which aims to provide open access data for various living creatures coordinated by GBIF's official secretariat in Copenhagen, Denmark. The GBIF's network comes from various participating countries and organizations, working through coordination nodes, and providing facilities for institutions in the world with predetermined standards so that institutions from various countries can provide information about location and time of sighting of species which is then validated (GBIF: The Global Biodiversity Information Facility, 2020). The light pollution data in this study was obtained using VIIRS DNB imagery from Google Earth Engine. The data used was monthly data chosen as the lowest cloud data for each year during the period 2013 to 2018. The data obtained through GBIF.org is crowdsourced or is a form of accumulated participatory data, that obtained (information or input into a particular task or project) by enlisting the services of a large number of people. Data quality therefore depends on people's participation in reporting the species data.

The VIIRS DNB imagery used was selected based on the times of least cloud cover over Java and Bali islands, in order to obtain the best results for light pollution reflection. The data collected were the monthly data for each year from 2013 to 2018. The selection of the imagery was also based on the time of migration, being between September and November. The data being used were not the annual average data as these were affected by cloud cover. The annual average data could not best represent the maximum level of light pollution in an area since the average result might be influenced by cloud cover, even though the said VIIRS DNB data have been corrected with regard to the influence of clouds.

Cloud in a particular month could reduce the annual average value of the reflected light pollution in a region under the maximum condition, i.e. not covered by cloud. Therefore, the data used are the one-month VIIRS DNB images of each year which has the lowest cloud cover in the study area in 2013–2018 during the migration period.

The cloud cover filter used RCFC (Raw Cloud-Free Composite) data. The identification of the level of light pollution is based on the data obtained with VNL correction and is automatically corrected by the correction of sunlit, moonlit, high energy particles, stray light, lightning, outlier removal, background seeds, surface lighting, and gas flares, so that the data obtained are the radiance data in units of nano watts per square centimeter per steradian (nW/cm^{2}sr).

The research area in Figure 1 is located in the islands of Java and Bali. Java Island was chosen because of the annual bird migration route through Java Island and also because of the high socio-economic activity. Java Island is included in the 13th largest island in the world. Furthermore, the economic and government activities are carried out on this island. So that it affects environmental conditions and the behavior of annual bird migration. The research location was also carried out on the island of Bali. The island of Bali is the 7th most densely populated island in Indonesia (Central Statistics Agency, 2015).

2.2 Classification of light pollution levels

The light values obtained from the DNIRS VIIRS imagery data were then classified into eight classes before the correlation test was performed. The classification of light pollution was based on the Falchi *et al.* (2016), as shown in Table 1.

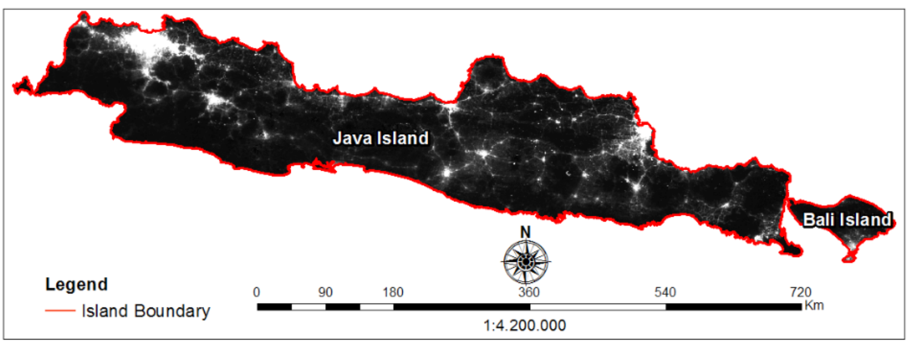

Figure 1. VIIRS-DNB imagery for Java and Bali islands recorded in September 2018

Table 1. Classification of light pollution

Class	Radiance (nW/cm²sr)
1	0–0.15
2	0.151–0.25
3	0.251–0.5
4	0.51–1.5
5	1.51–10
6	10.1–50
7	50.1–75
8	>75

Source: (Stare, 2020)

2.3 Relationship analysis

The relationship analysis was carried out using Spearman. Changes in light pollution and roosting site conditions were displayed multi-temporally using graphics. Changes to the graph could give an idea of the condition of both variables. Spearman correlation is a non-parametric test used to measure the degree of relationship between two ordinal variables. Spearman assumes that data are not normally distributed and so falls into the category of non-parametric statistics. Non-parametric tests do not require measurements with a high degree of accuracy, as required by parametric tests, as they are used to analyse data on ordinal and nominal scales (Siegel, 1997). Previous research on correlation relationships has been conducted by Nurbandi *et al.* (2018), who analysed the relationship between Normalized Difference Built-Up Index (NDBI) values and light pollution using the same method, namely Spearman's ranking.

The relationship analysis was performed with Spearman's ranking in which the data tested were the value of light pollution from the VIIRS DNB imagery and the barn swallows' roosting sites in a segment measuring 742 m by 742 m. The data sample used pixel values of artificial light in the image from the roosting sites. Thus, random sampling was used with a different number of samples for each year. Because birds movement during a migration season is not necessarily the same as the years before and after. Also, the spread of birds is extensive, hence the sample data used are bird occurrences in accordance with the time studied, as conducted by Gschweng *et al.* (2012). The formula to calculate r_s in Spearman's ranking is shown on other equation 1 in which

$$r_s = 1 - \frac{6\sum_{i=1}^{N} d_i^2}{N^3 - N} \quad (1)$$

where r_s = Spearman's rank correlation coefficient; N = number of observation pairs between one variable against another variable; and d = ranking differences obtained at each observation pair.

The results of r_s illustrate the correlation formed from the two data tested i.e. light pollution and the barn swallows' roosting sites. The significance level was obtained using equation 2:

$$z = r_s\sqrt{n-1} \quad (2)$$

where z = z count value; r_s = Spearman correlation value; and n = number of samples.

The calculation results for the z value were then compared with the z table values according to the percentage of accuracy used, in which 95% or 0.05 and z table value of 1.959964 is used as the upper and lower limits for determining whether to reject or to accept H_0 or H_1. H_0 means light pollution not influence roosting site, while H1 means that roosting site influenced by light pollution. The statistical data testing was then continued until the annual r_s value was obtained.

If the Spearman correlation value is close to 1 it indicates that the two variables – light pollution and roosting site – have a strong correlation. As well as the correlation values, it is also necessary to pay attention to the variable relationship's direction. Positive (+) results indicate a proportional relationship between the two variables while a negative (-) result indicates an inverse relationship. If the second relationship's direction is negative, it indicates that a higher level of light pollution generates fewer roosting sites in that location.

These results can then identify the patterns formed on the graph between light pollution and roosting sites. These patterns will show the relationship between the two data variables, namely light pollution and roosting sites.

3. Results and Discussion

Relationship analysis was conducted using the Spearman model, as the data used were classified as an ordinal dataset. The chosen light pollution data were classified according to Falchi *et al*. (2016) with the levels divided into eight classes.

The calculation of the results of processing data on light pollution and roosting sites is shown in Table 2. Before conducting the correlation test, it was necessary to distribute the samples. The number and distribution of samples used were based on the points of barn swallow occurrence in that year. This sample determination method was carried out by Gschweng *et al.* (2012) in their research to model the semi-annual Eleonora's falcon *(Falco eleonorae)* habitat in Madagascar based on satellite tracking results. The data used by Gschweng *et al.* (2012) were from November to April and the number of samples each month varied according to the distribution patterns that occurred each month. It was caused by the changes in direction that might have occurred; other conclusions point to the fact that the study's object is dynamic and has a wide dispersion level during the annual migration season. Therefore, it is difficult only to carry out sampling in consistent areas.

Table 2. Correlation values of light pollution with roosting sites

Year	Number of samples	R	Z	Alfa (95%)	Limit
2013	40	0.903846	5.644517	0.05	1.959964
2014	32	0.964168	5.36826	0.05	
2015	50	0.964034	6.748235294	0.05	
2016	78	0.956322	8.391692887	0.05	
2017	106	0.976955	10.01081427	0.05	
2018	141	0.983079	11.631951	0.05	

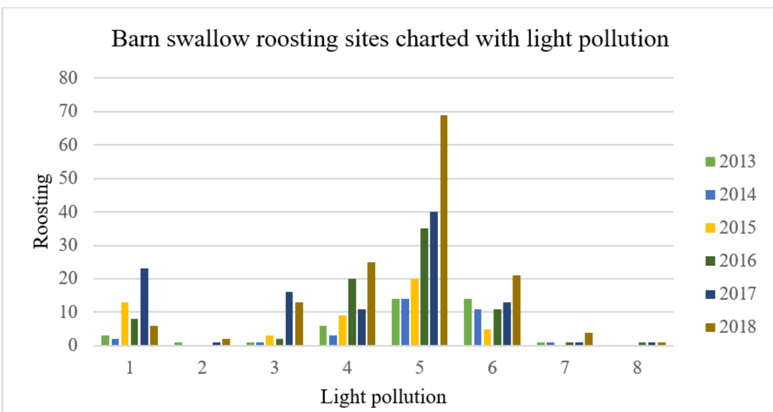

Figure 2. Relationship graph of roosting site with light pollution

It was also applied in the barn swallow study. The samples were not selected only in areas used as roosting sites because what is analysed is the change in distribution. Therefore, there is a possibility of changes in the area or points that become resting sites for new swallows during the annual migration season. The annual number of sample points of each bird species during the migration season is the occurrence points appearing in that year.

Based on the results of statistical testing between bird roosting sites and light pollution it was found that the average correlation value between 2013 and 2018 was 0.9. It indicates the light pollution conditions affected the selection of bird roosting sites during the annual migration season from 2013 to 2018 in Java and Bali. This strong relationship is influenced by the birds' attraction to light during the migration period, using light as their orientation method. The artificial lights on the ground in the study site are brighter than the natural lights in the sky, causing directional disturbance during the migration period which leads to birds descending to this luminous location.

Light pollution is based on the light values taken from the VIIRS DNB imagery. Brighter artificial light coming from the Earth's surface causes less light to be projected into the sky (International Dark Sky Assosiation, 2020). The effect is very strong for bird species that migrate at night and while resting or perching in the dark. Therefore, these light conditions will affect the choice of direction and location of roosting. For reference, Yogyakarta is filled with barn swallows in the evening. Migration by barn swallows occurs at night until the early morning just before sunrise (Winkler, 2006) and the birds migrate together at night until early morning (Powell and Blackwell, 2001).

The effect of night-time light in determining birds' migration path orientation is related to the cryptochromes or physiological features of the birds' eyes, in that they are sensitive to blue light. Migratory birds are known to depend on the Earth's magnetic field to help them migrate, and many of these birds are also known to migrate at night when less light is available. Researcher have found that migratory birds' cryptochromes enhance their ability to respond to blue light, which enables them to sense and respond to magnetic fields (Trubus.id, 2019). Therefore, annual night-time migration behaviour, physiology of the bird's eyes, and disturbance of blue light orientation are the causes of changes in barn swallows' resting locations during the migration period.

As shown in Figure 2 the roosting sites increase consistently up to the fifth class of light pollution and gradually decrease from the sixth class. The seventh and eighth classes have low occurrence because light pollution in Indonesia has generally not yet reached these levels, existing only in Surabaya and Jakarta in limited spots. Thus, the number of birds in the seventh and eighth classes is relatively small. Furthermore, there is no data on the appearance of birds in the seventh and eighth classes before 2016 as areas with light pollution of more than 50 nW /cm^2sr^{-1} were then small in extent and few in number. The increase in Indonesia's electricity usage since 2015 is most likely the leading cause of recent changes. Spots with light pollution values of above 50 nW/cm^2sr^{-1} are only found in Jakarta and Surabaya, because these two regions have high electricity consumption compared to other regions. East Java consumes 14,494.65 GWh and Jakarta-Banten consumes 19,312.03 GWh, meaning that these two regions used 48.13% of the total 67,105.54 GWh Java electricity consumption in 2018 (Ministry of Energy and Mineral Resources, Directorate General of Electricity, 2020)

Indonesia has only a very small area with above 50 nW /cm^2sr^{-1} of light pollution, the highest class with a wide range of coverage in the country is the fifth class, with light pollution values of 1.51 – 10 nW/cm^2sr^{-1} in suburban areas. This area has moderate vegetation conditions and sky brightness of 20.49 – 19.50 mag/$arcsec^2$. The moderate vegetation allows barn swallows to find food and shelter and the light pollution attracts birds to come down and rest due to the difficulty of finding their migration paths because the light pollution obstructs them from seeing the stars.

Based on the correlation values in Table 2, the overall data gives a positive value and is a unidirectional relationship. Hence, as the value of light pollution increases, the barn swallows roosting sites found will also increase. The overall result of the z count is greater than the positive z value of the table and the negative result of the z count is smaller than the z table, which confirms that the relationship between the two variables is significant and that light pollution does indeed affect the birds' roosting sites significantly. It is proven by the comparison of the number of bird roosting sites in the fifth light pollution class which is higher than for the previous classes.

The number of roosting sites in the fourth and fifth class areas, indicated in light green and yellow, is consistently increasing corresponds with the map of light pollution distribution in Java and Bali, in which indicated by light green or yellow areas that are consistently growing from year to year. This roosting site data follows the pattern of changes in light pollution in Java and Bali. From the two data it also appears that the seventh and eighth classes, which have the highest levels of light pollution, show very low roosting values. There is no roosting data for birds in this class. Therefore, the roosting numbers peaked in the fourth and fifth classes because light pollution in Indonesia is still moderate compared to other developed countries in the region such as China and Australia.

The relationship between light pollution and the roosting site is different for each year, as shown in Figure 3. Based on the quality of the imagery data, light pollution is better visualized using a migration month in the dry season, as there is usually too much empty pixel data in the rainy season due to obstruction by the cloud. The roosting site data distribution in the rainy season will experience data shortages and become outliers in statistical calculations because the data does not have associated light pollution pixels. Therefore, the images used are for the months of migration in the dry season, which takes place from September to November. The difference between the two seasons is that there are more roosting sites in the dry season. Figure 3 shows the distribution of existing roosting sites. The selected image is the highest quality imagery with the least interference and not too many blank pixels.

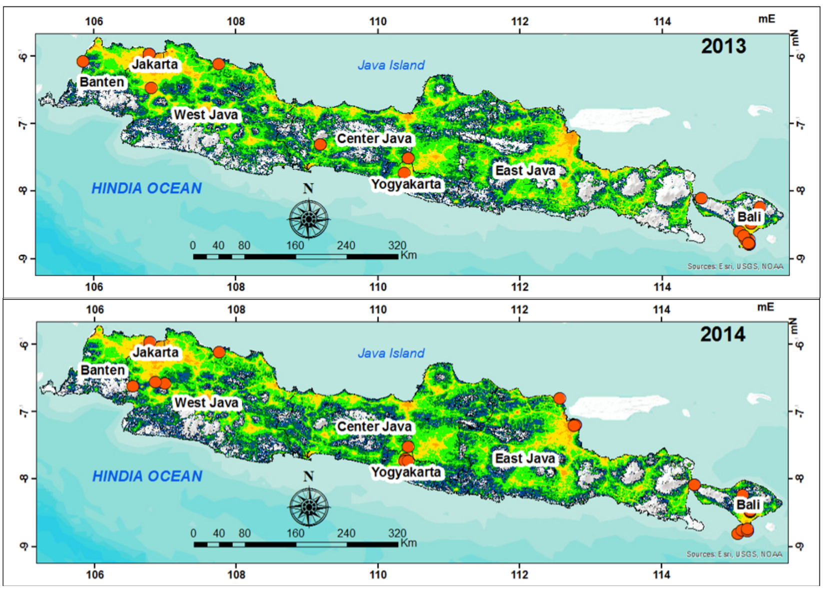

Figure 3. Map distribution of roosting sites with light pollution levels in Java and Bali in 2013–2018

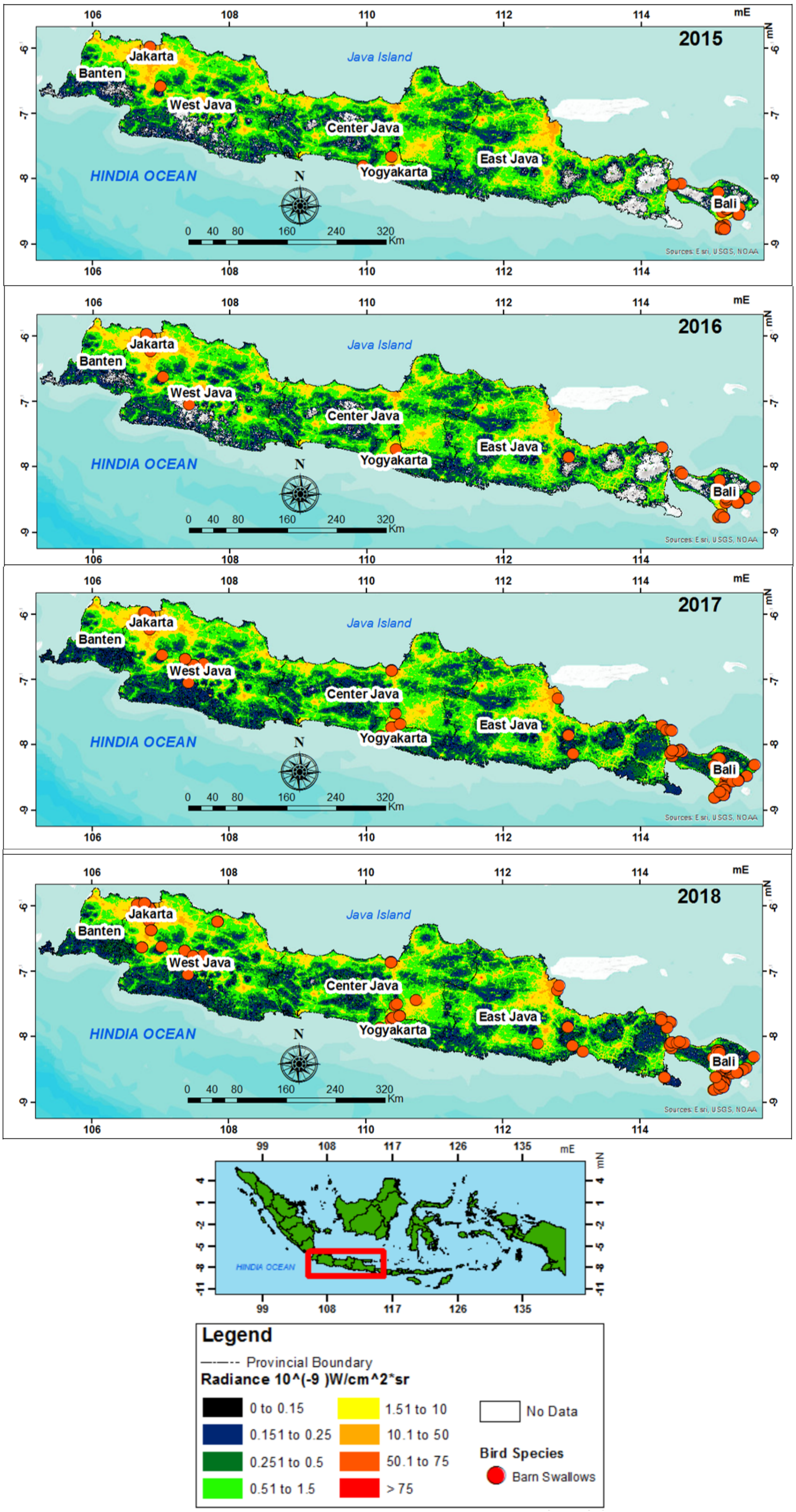

Figure 3. Map distribution of roosting sites with light pollution levels in Java and Bali in 2013 – 2018

4. Conclusion

Relationship analysis using the Spearman's ranking method results in a correlation value of 0.9, meaning that the relationship between roosting sites and light pollution levels is strongly positive. It means that more higher light pollution in an area will lead to more roosting sites of barn swallows. Based on the z counts measured against z tables, z count > z table, so that alternative hypotheses (H1) are accepted, thus indicating that light pollution is significantly influencing the roosting sites of birds. The test is carried out with 95% accuracy (significance of 0.05). Light pollution can disrupt the orientation of birds during migration. Artificial light is brighter than the light in the sky. Birds will look into brighter light and affect the choice of roosting locations. Therefore, since 2013-2018 there has been an increase in the location of roosting sites in urban areas. Light pollution and the choice of roosting sites during the migration period influence each other.

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