Geosfera: Jurnal Penelitian Geografi (GeoJPG)
Vol. 2, No. 1, Juni 2023, Hal. 22-29
DOI: https://doi.org/10.34312/geojpg.v2i1.20186

p - ISSN: 2962-5424
e - ISSN: 2962-5416

An Overview of the Population Dynamics Model Based on Climate Parameters

Syahrizal Koem[1*], Rakhmat Jaya Lahay[1], Moch. Rio Pambudi[1]

[1] Department of Earth Science and Technology, Universitas Negeri Gorontalo, Indonesia
*Email Koresponden: s.koem@ung.ac.id

Diterima: 01-06-2023 **Disetujui: 11-06-2023** **Publish: 30-06-2023**

Abstract *Understanding how the environment, especially climate, affects the growth of pests (life cycle) is very important to create management techniques that reduce or eliminate damage to rice plants and minimize the resulting losses. This study aims to describe population dynamics modeling based on the influence of climate parameters using the DYMEX software. Climate and life cycle characteristics, which can be processed in the DYMEX life cycle module, are two important elements in modeling the rice stem borer. Egg, larval, and imago populations exhibit a variety of climate-related effects. The larval stage is most visible in the month of MJJA, where rainfall intensity is low or during the dry season. This indicates that the larval stage can survive through diapause in the dry season. The correct numbers must be used to initialize and parameterize models created using DYMEX. Overall, DYMEX can produce good simulation results in all life stages of the modeled insects. However, obtaining good, precise simulation results requires the user's accuracy in building the model, especially the values of the input parameters. In addition, to test the results of the DYMEX simulation, it is necessary to validate them with the actual conditions of the population in the field.*

Keywords: *DYMEX; population dynamics model; rice stem borer; simulation*

1. INTRODUCTION

It is a fact that both natural and manufactured agroecosystems are vulnerable to the current climate change phenomenon, and the rice ecosystem is no exception (Vennila et al., 2019). In the rice ecosystem, insect pest populations are one of the main pests of rice plants. At the vegetative and reproductive stages, more than 100 insect pests attack rice plants, but only a quarter are important pests in various agro-climatic zones (Bhatt et al., 2018; Khush, 1997). According to reports by Shah et al. (2022), 217 species of insects, including leafhoppers, stem borers, and leaffolders, feed on rice plants from planting to harvest, resulting in an overall 37% loss. Climate change is a global phenomenon that will impact insect pest populations in the future (Koem et al., 2014; Nurhayati et al., 2017). For example, the stem borer's response to climate change may vary by area due to ambient conditions. In warmer regions, insects survive near the high end of their favorable temperature range, so any temperature increase will negatively impact their growth and development (Bale & Hayward, 2010).

Indonesia has a tropical climate, meaning it often has high temperatures, abundant rainfall, and high humidity levels. Development of the rice stem borer population under these climatic conditions is very likely. Since the long dry season that occurred in 1982–1983, it was known that climatic factors caused the death of the yellow stem borer (henceforth called YSB), while the long dry season only allowed the white stem borer (henceforth called WSB) to survive because its larvae can diapause and survive up to 10-12 months (Litsinger et al., 2006). Changes in rainfall distribution can majorly impact the surrounding organisms, especially pests, which tend to vary in extreme environmental situations such as the El Nino phenomenon. The stem borer population is one problem that requires control measures to prevent damage to rice plants. Of the five species of stem borer, WSB was more dominant. In 1999, the dominant species was YSB, except in Indramayu Regency, which was dominated by WSB (Suharto & Sembiring, 2007).

The WSB pest is a tropical species occurring in areas that have a distinct dry season and wet season (Litsinger et al., 2006). In Indonesia, the WSB pest is more dominant in attacking rice plants, especially on the north coast of West Java Province. Natanegara & Sawada (1992) reported that outbreaks of WSB pests had appeared in Indramayu District since 1988/1989, namely in Lohbener, Pangkalan, and Wirakanan, with attack areas reaching ± 3000 ha and 300 ha of which were seriously attacked and did not even produce results. Knowing population dynamics directly related to the environment and climate can help design management measures to prevent damage and loss of rice crops. Thus, the interaction of insect pest populations and climate must be simulated each time the planned population enters a new life stage. DYMEX is a software modeling framework that can analyze the growth, mortality, and population dynamics of insect populations over time by determining life stages and cohorts in changing climates and exploring the effects of factors such as climate, species interactions, and anthropogenic disturbances on population dynamics (Gu et al., 2018; Li et al., 2016; Yonow et al., 2004) The purpose of this study is to provide a simple description of population dynamics modeling based on the influence of climate parameters using the DYMEX software.

2. METHOD

2.1. Climate Data

This study uses minimum and maximum temperature, relative humidity, and rainfall data for 2003–2006 from three stations owned by the Balai Penelitian Agroklimatologi dan Hidrologi (Research Institute for Agro-Climatology and Hydrology, henceforth called BALITKLIMAT), namely: Sukamandi station (BALITPA) with an altitude of 50 meters above sea level, Pusaka Negara station (IPPTP) with an altitude 56 meters above sea level, and Kuningan Station (IPPTP) with an altitude of 577 meters above sea level (Figure 1). Pusaka Negara and Sukamandi are administratively located in Subang Regency. Based on the topography, the Subang district area can be divided into three zones, namely: mountainous areas (southern Subang), hilly and plain areas (central Subang), and lowland areas (northern Subang).

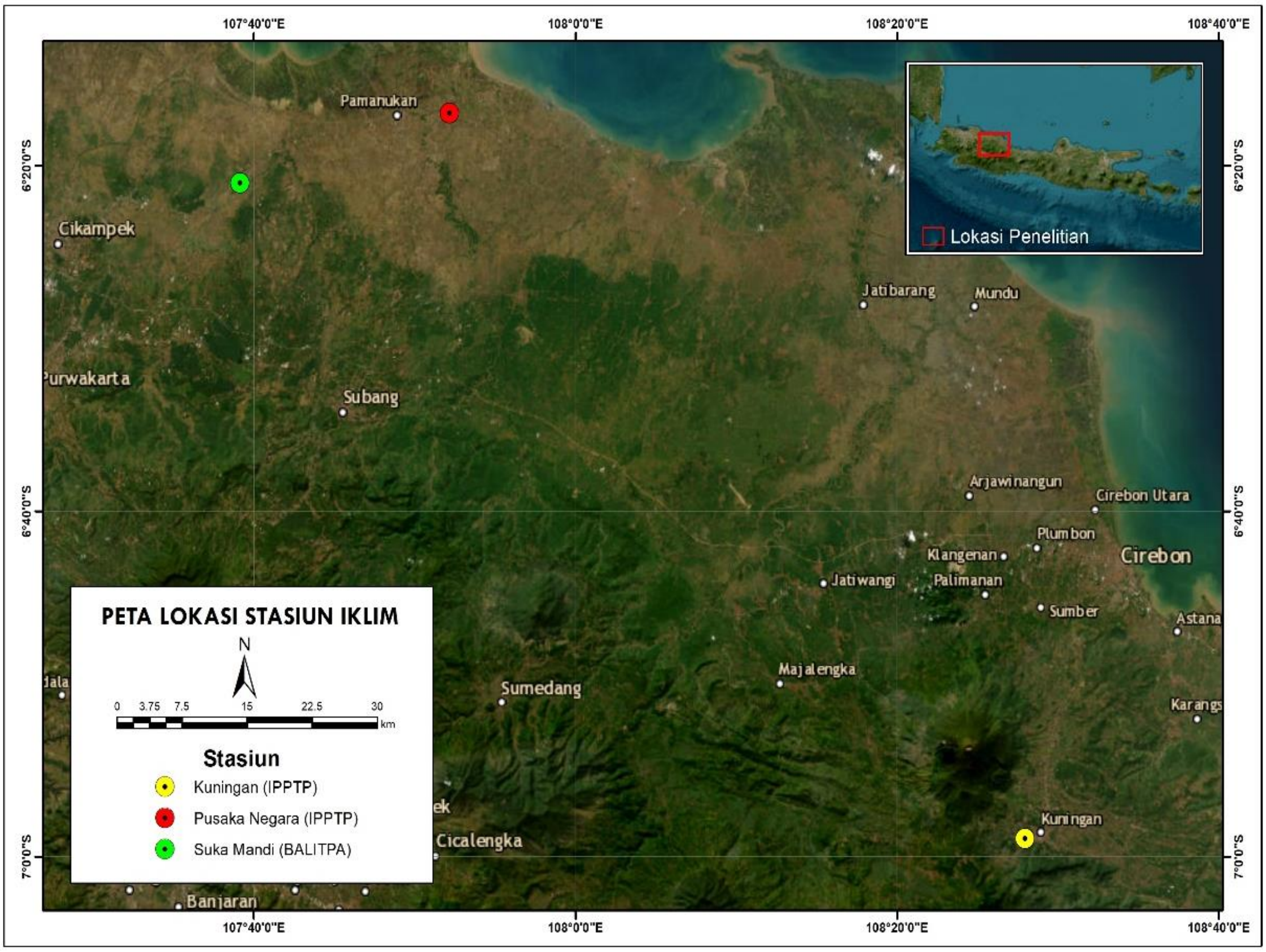

Figure 1. Station location map

2.2. Population Modelling

Model Description

Modeling WSB population dynamics requires two main components, namely climate and life cycle parameters which can be processed in the DYMEX life cycle module. In this study, one or more life stages consisting of egg, larva, pupa, and imago were developed in DYMEX (Figure 2). DYMEX identified four life stages in the WSB life cycle: egg, larva, pupa, and imago. A series of functions describing life cycle processes, including development, mortality for each life stage, transfer of individuals from one life stage to the next, fertility, and imago production rates (Nahrung et al., 2008).

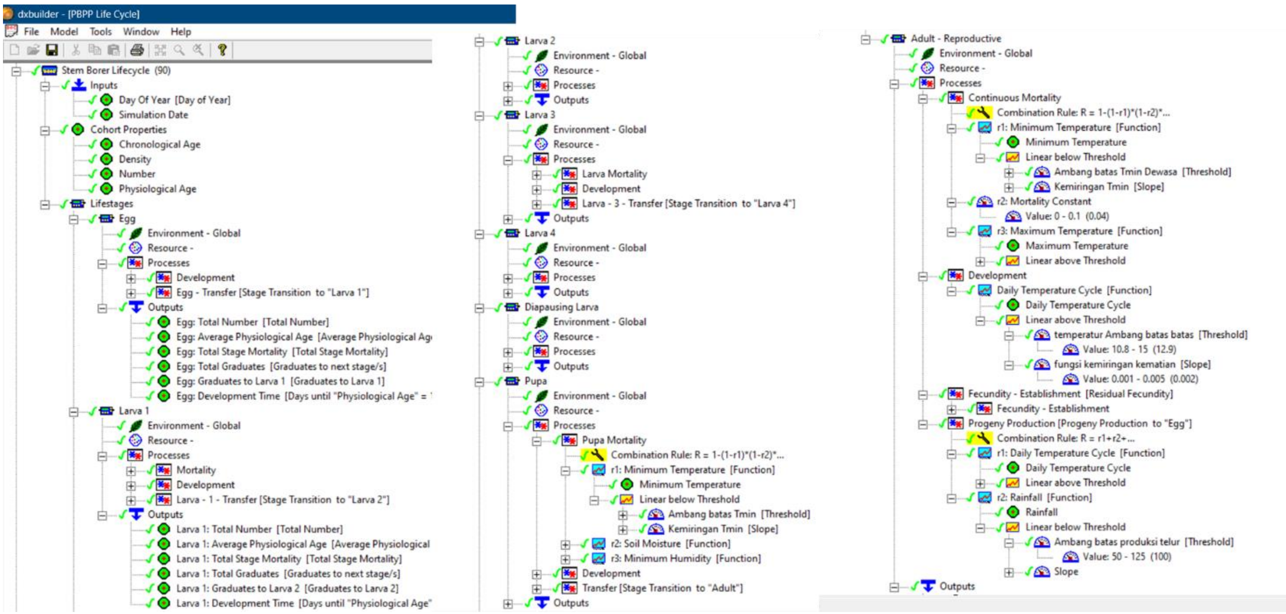

Figure 2. The WSB life cycle model framework within DYMEX.

Development and Mortality: Egg, Larva, and Pupae

The temperature thresholds for the development rates of eggs, larvae, and pupae used in DYMEX are presented in Table 1. The average percentage of development per day of eggs, larvae, and pupae of WSB increases with increasing temperature, while the total development period decreases with increasing temperature.

Table 1. Threshold temperature and degree days WSB development rate

Stages	Threshold temperature (°C)	Degree days (°C)
Egg	11.27	108.40
Larvae	8.72	373.30
Pupae	5.92	112.90
Imago to eggs	10.80	594.60

Source: (Rahman & Khalequzzaman, 2004)

Although the development temperature threshold value reported by Rahman & Khalequzzaman (2004) was obtained in the Bangladesh region, this value is assumed to apply to the WSB used in the north coast of West Java, because these two regions have the same climate type, namely tropical climate, and pests. WSB is an endemic pest in the tropics.

Model Initialization

Before running the simulation, the model must be initialized. Initialization includes setting various values needed to run the model (Maywald, Bottomley, et al., 2007). The values used in the simulation include soil moisture components and sex ratios (Table 2). The simulation was run from 1 January 2003 to 31 December 2006 for each location on the northern coast of West Java.

Table 2. Initialize the values used in the simulation

Model Variables	Initialization Value
Soil moisture:	0.5
Soil moisture capacity(mm)	150
evapotranspiration coefficient	0.8
Basal evapotranspiration (mm)	0
Sex ratio	2:1

3. RESULTS AND DISCUSSION

3.1. Climatic Conditions of the Study Area

Kuningan is included in the tropical climate area, based on dividing climate patterns into areas with monsoon climate types. The monsoon circulation strongly influences the monsoon climate type, with the peak rainfall in January and the lowest rainfalls in August (Aldrian & Dwi Susanto, 2003). The average air temperature in 2003 reached 24.8 ºC; in 2004, it reached 24.9 ºC; in 2005, it reached 24.9 ºC; and in 2006, it reached 24.6 ºC. The minimum temperature in 2003-2006 ranged from 20-23 ºC, and the maximum temperature ranged from 25-29 ºC (Figure 3). The highest rainfall throughout 2003 and 2004 occurred in January, reaching 372.4 and 673.8 mm, while the total annual rainfall reached 1878.4 and 2488 mm (Figure 3). In 2005 and 2006, the highest rainfall occurred in December and January, reaching 412 and 531.4 mm, while the total annual rainfall reached 2300.2 and 2220 mm.

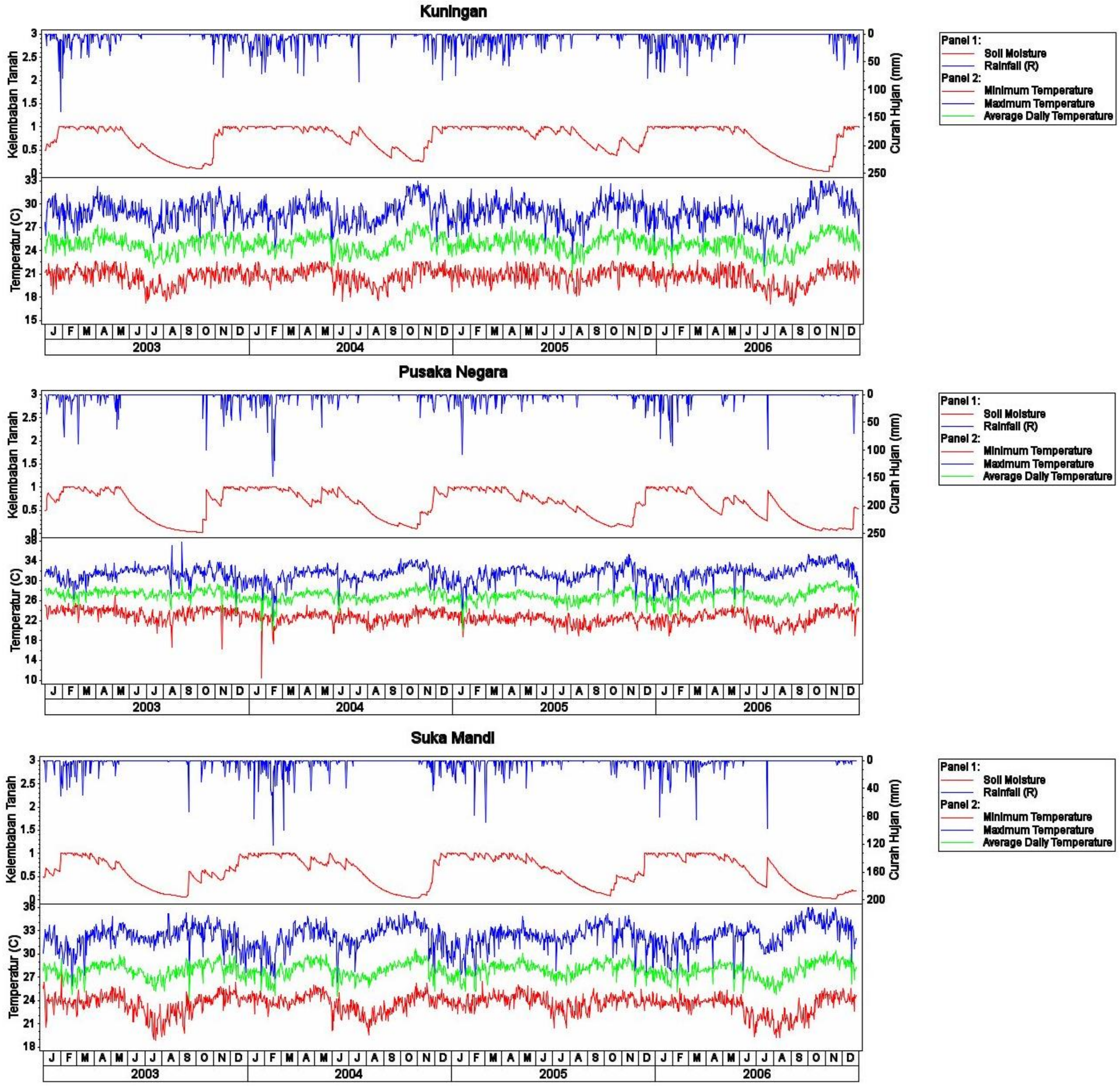

Figure 3. Climatic conditions in the Kuningan, Pusaka Negara, and Sukamandi regions in 2003-2006.

In general, the climate type at Pusaka Negara and Sukamandi stations is the same as at Kuningan station; that is, areas with a monsoon climate type that are very vulnerable to El Nino events are more identical to dry or dry season, which is characterized by increasing temperature and decreasing rainfall intensity. The maximum temperature during 2006 occurred in September with an average of 33.8 ºC to October with an average of 34.6 ºC for the Sukamandi area (Figure 3), while the rainfall throughout 2006 in September and October did not rain. Throughout 2003, there was no rain in the Pusaka Negara, namely in the month of JAS, and the average maximum temperature reached 32°C (Figure 3).

3.2. WSB Population Dynamics Simulation In DYMEX

The model used in this study simulates the influence of climate on the dynamics of WSB from 2003-2006 at three locations with different altitudes and latitudes, namely Sukamandi, Pusaka Negara, and Kuningan. Climate impacts for the three regions show different effects on the egg, larvae, and imago populations (Figure 4), with the lowest population in the Kuningan area ± 500,000 egg population in October 2004, 2005, and 2006. The Pusaka Negara area is the area with the largest population Egg population was higher, around ± 1,000,000, which occurred in February and March 2004. As for the Sukamandi region, the highest peak of the population occurred in February 2004, with around ± 650,000 egg population. The peak egg population for the Sukamandi and Pusaka Negara areas occurred in the same month. , this is because the two regions have almost the same climate pattern. After all, they are located 50-60 meters above sea level, so the WSB has a higher population in the region. The WSB is more well-developed at altitudes below 200 meters above sea level, and rainfall is not more than 200 mm(Tjahjadi, 1989).

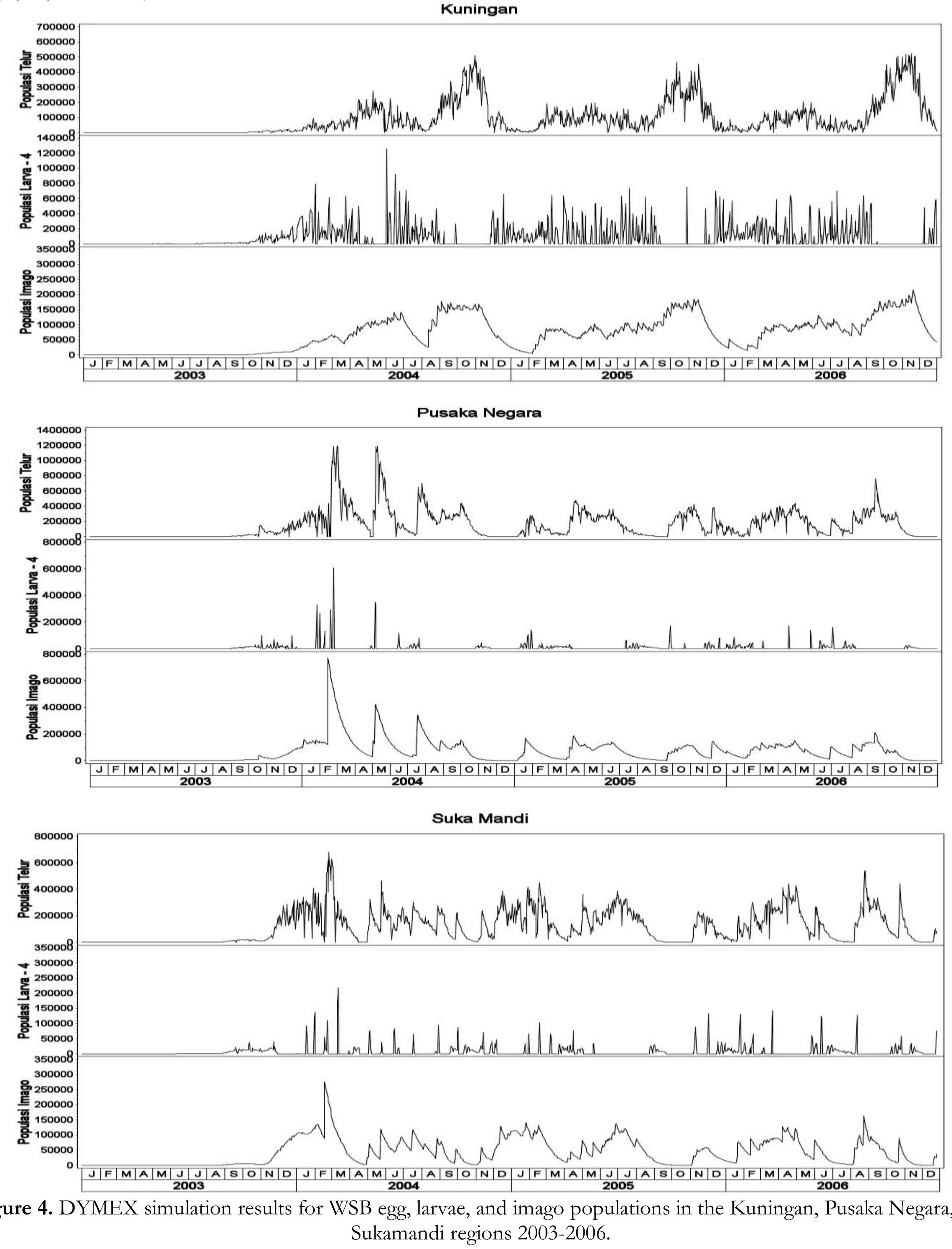

Figure 4. DYMEX simulation results for WSB egg, larvae, and imago populations in the Kuningan, Pusaka Negara, and Sukamandi regions 2003-2006.

The intensity of rainfall in the Kuningan area can trigger the emergence of the WSB because during the rainy season, the WSB diapauses during the dry season. Figure 4 shows that throughout the years between 2004-2006, WSB population density in the three regions was always there, but the population in the Kuningan area was small. The development of this population is more influenced by temperature. According to Maywald, Kriticos, et al. (2007) that 90% of population growth is influenced by temperature, where the higher the temperature, the higher the rate of population development, as long as it is still within the ideal temperature threshold for WSB to develop. In the larval stage, for the Kuningan area, the highest occurrence was in the month of MJJA 2003-2006 with low rainfall intensity or during the dry season. This illustrates that the larval stage in the Kuningan area can survive. The density of larvae in the Pusaka Negara and Sukamandi areas occurs in the DJFM month during the rainy season. Seeing the age of WSB, which ranges from 42-50 days, the DJFM month or the rainy season is a good time for WSB development, starting from the egg stage to becoming an imago.

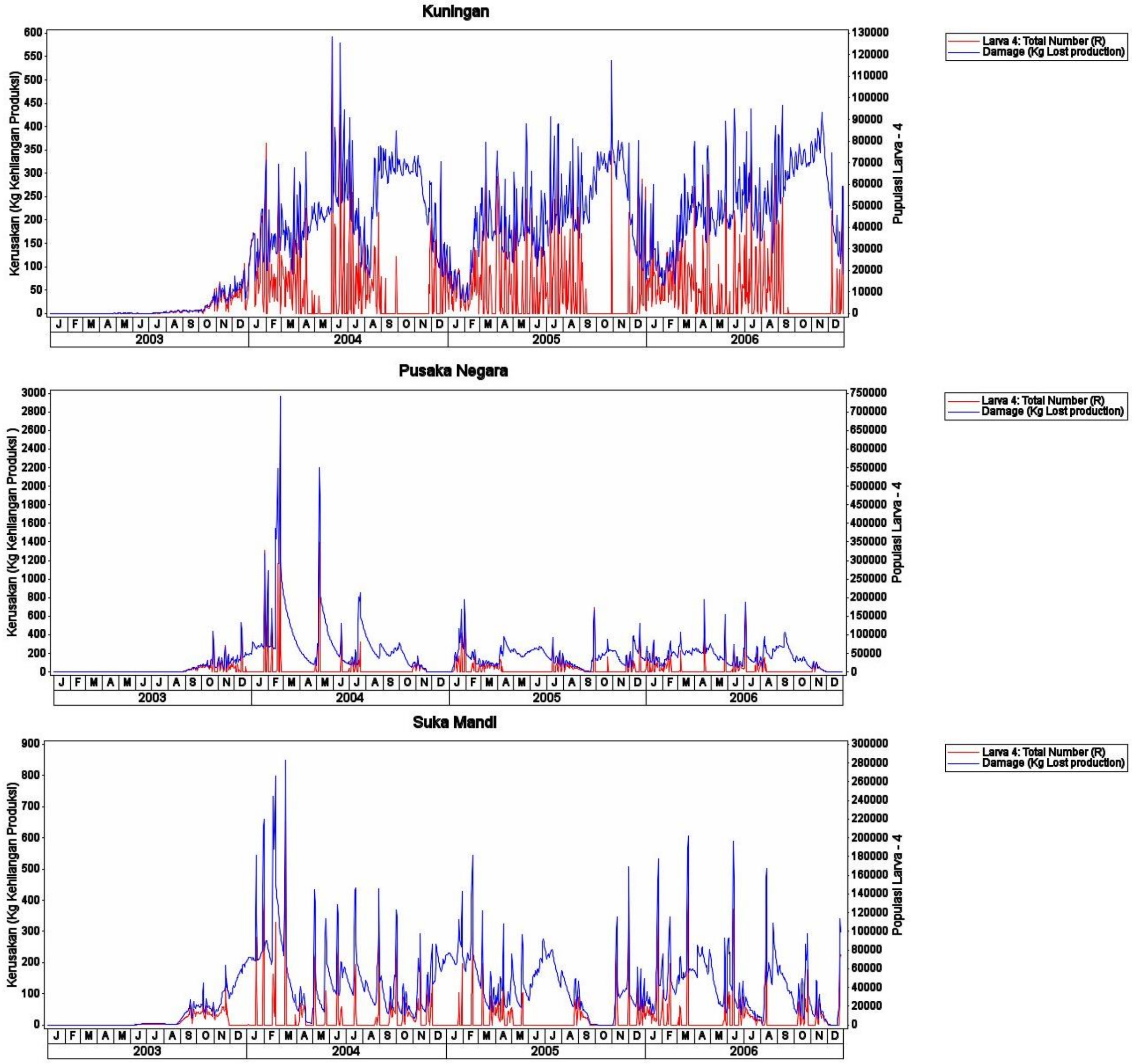

Figure 5. DYMEX simulation results for the level of damage (Kg of production loss) in the Kuningan, Pusaka Negara, and Sukamandi areas in 2003–2006.

In 2003, the DYMEX model did not provide an overview of population dynamics for the three locations, not that there was no development at all WSB stages in the field. This was because DYMEX required adjustment of process parameters at the start of the simulation (Maywald, Kriticos, et al., 2007). Emergence began to appear in September. This caused the model work not to be maximized at the simulation's start. Another thing that becomes a problem in the output of the simulation results is the number of deaths in the larval stage population until it reaches a value of 0 is not followed by the number of population deaths in the imago stage.

3.3. WSB Damage Simulation

The simulation of the damage caused by WSB is assumed to occur in the 4th instar larval stage, which is the last instar larvae that will drill the rice stalks. The level of damage caused by WSB in the Kuningan region reached 2900 kg in February 2004; the number of larvae populations accompanied the amount of damage, so the higher the larval population, the higher the damage.

There was damage in October and November 2004-2006, while the number of larvae populations was absent. This was due to the performance of the built model that still needed to be initialized and parameterized with the right values. The same thing happened in the Pusaka Negara and Sukamandi areas. It can be seen that the higher the number of larvae populations, the higher the damage that will be caused. Population numbers and damage levels for the Kuningan area are more dominant in the dry season but not as severe as what happened in the Pusaka Negara and Sukamandi areas (Figure 5). This is caused by the topography of the Kuningan area, which is at an altitude above 200 meters above sea level, so the temperature is lower. This condition does not support the development of the WSB. The Pusaka Negara and Sukamandi areas, located below 200 meters above sea level and high temperatures, trigger a high population of WSB larvae in the region. Damage events in the Pusaka Negara and Sukamandi areas are more dominant in the rainy season, and this is because WSB larvae in these areas do not diapause.

4. CONCLUSION

The climate impacts for the three regions show different effects on egg, larva, and imago populations. In the larval stage, for the Kuningan area, the highest occurrence was in the month of MJJA 2003 – 2006 with low rainfall intensity or during the dry season. This illustrates that the larval stage in the Kuningan area can survive. The density of larvae in the Pusaka Negara and Sukamandi areas occurs in the DJFM month during the rainy season. The month of DJFM, or the rainy season, is a good time for WSB development from the egg stage to the imago. The topography of the Kuningan area is at an altitude above 200 meters above sea level, so the temperature is lower. This condition does not support the development of the WSB. The Pusaka Negara and Sukamandi areas, located below 200 meters above sea level and high temperatures, trigger a high population of WSB larvae in the region. The development time needed by the WSB in the Kuningan area is longer than in the Pusaka Negara and Sukamandi areas. Overall, DYMEX can produce good simulation results in all life stages of the modeled insects. However, obtaining good, precise simulation results requires the user's accuracy in building the model, especially the values of the input parameters. In addition, to test the results of the DYMEX simulation, it is necessary to validate them with the actual conditions of the population in the field.

5. REFERENCES

Aldrian, E., & Dwi Susanto, R. (2003). Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *International Journal of Climatology*, *23*(12), 1435–1452. https://doi.org/10.1002/joc.950

Bale, J. S., & Hayward, S. A. L. (2010). Insect overwintering in a changing climate. *Journal of Experimental Biology*, *213*(6). https://doi.org/10.1242/jeb.037911

Bhatt, N., Joshi, S., & Tiwari, S. N. (2018). Pests of Rice. In Omkar (Ed.), *Pests and Their Management* (pp. 9–50). Springer Singapore. https://doi.org/10.1007/978-981-10-8687-8_2

Gu, S., Han, P., Ye, Z., Perkins, L. E., Li, J., Wang, H., Zalucki, M. P., & Lu, Z. (2018). Climate change favours a destructive agricultural pest in temperate regions: late spring cold matters. *Journal of Pest Science*, *91*(4), 1191–1198. https://doi.org/10.1007/s10340-018-1011-z

Khush, G. S. (1997). Origin, dispersal, cultivation and variation of rice. *Plant Molecular Biology*, *35*(1–2). https://doi.org/10.1007/978-94-011-5794-0_3

Koem, S., Koesmaryono, Y., & Impron. (2014). Pemodelan fenologi populasi penggerek batang padi kuning Scirpophaga incertulas (Walker) berbasis pengaruh iklim. *Jurnal Entomologi Indonesia*, *11*(1), 1–10. https://doi.org/10.5994/jei.11.1.1

Li, Z., Zalucki, M. P., Yonow, T., Kriticos, D. J., Bao, H., Chen, H., Hu, Z., Feng, X., & Furlong, M. J. (2016). Population dynamics and management of diamondback moth (Plutella xylostella) in China: The relative contributions of climate, natural enemies and cropping patterns. *Bulletin of Entomological Research*, *106*(2), 197–214. https://doi.org/10.1017/S0007485315001017

Litsinger, J. A., Alviola, A. L., Dela Cruz, C. G., Barrion, A. T., Canapi, B. L., & Batay-An, E. H. (2006). Rice white stemborer Scirpophaga innotata (Walker) in southern Mindanao, Philippines. I. Supplantation of yellow stemborer S. incertulas (Walker) and pest status. *International Journal of Pest Management*, *52*(1). https://doi.org/10.1080/09670870600552497

Maywald, G. F., Bottomley, W., & Sutherst, R. W. (2007). *DYMEX Model Simulator Version 3*. Melbourne: CSIRO Publising. www.hearne.com.au

Maywald, G. F., Kriticos, D. J., Sutherst, R. W., & Bottomley, W. (2007). *DYMEX Model Builder Version 3*. Melbourne: CSIRO Publising. www.hearne.com.au

Nahrung, H. F., Schutze, M. K., Clarke, A. R., Duffy, M. P., Dunlop, E. A., & Lawson, S. A. (2008). Thermal requirements, field mortality and population phenology modelling of Paropsis atomaria Olivier, an emergent pest in subtropical hardwood plantations. *Forest Ecology and Management*, *255*(8–9). https://doi.org/10.1016/j.foreco.2008.02.033

Natanegara, F., & Sawada, H. (1992). *Ledakan Serangan Penggerek Batang Padi Putih (Scirpophaga innotata wlk) di Pantai Utara Jawa Barat. Di dalam: Laporan Akhir Kerja Sama Teknis Indonesia-Jepang Bidang Perlindungan Tanaman Pangan (ATA-162).*

Nurhayati, E., Koesmaryono, Y., & Impron. (2017). Predictive Modeling of Rice Yellow Stem Borer Population Dynamics under Climate Change Scenarios in Indramayu. *IOP Conference Series: Earth and Environmental Science*, *58*(1). https://doi.org/10.1088/1755-1315/58/1/012054

Rahman, M. T., & Khalequzzaman, M. (2004). Temperature requirements for the development and survival of rice stemborers in laboratory conditions. *Insect Science*, *11*(1). https://doi.org/10.1111/j.1744-7917.2004.tb00179.x

Shah, F. M., Razaq, M., & Islam, Y. (2022). Contemporary Management of Insect Pests in Rice. In N. Sarwar, Atique-ur-Rehman, S. Ahmad, & M. Hasanuzzaman (Eds.), *Modern Techniques of Rice Crop Production* (pp. 349–376). Springer Singapore. https://doi.org/10.1007/978-981-16-4955-4_20

Suharto, H., & Sembiring, H. (2007). Status Hama Penggerek Batang Padi di Indonesia. *Apresiasi Hasil Penelitian Padi. BPTP*, 61–71.

Tjahjadi. (1989). *Hama dan Penyakit Tanaman*. Kanisius.

Vennila, S., Bagri, M., Tomar, A., Rao, M. S., Sarao, P. S., Sharma, S., Jalgaonkar, V., Prasanna Kumar, M. K., Suresh, S., Mathirajan, V. G., Chatterjee, S., Tanwar, R. K., Kumari, A., & Prabhakar, M. (2019). Future of Rice Yellow Stem Borer Scirpophaga incertulas (Walker) Under Changing Climate. *National Academy Science Letters*, *42*(4). https://doi.org/10.1007/s40009-018-0751-x

Yonow, T., Zalucki, M. P., Sutherst, R. W., Dominiak, B. C., Maywald, G. F., Maelzer, D. A., & Kriticos, D. J. (2004). Modelling the population dynamics of the Queensland fruit fly, Bactrocera (Dacus) tryoni: a cohort-based approach incorporating the effects of weather. *Ecological Modelling*, *173*(1). https://doi.org/10.1016/s0304-3800(03)00306-5