Predictive Modeling of Rice Yellow Stem Borer Population Dynamics under Climate Change Scenarios in Indramayu

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Abstract. Rice Yellow Stem Borer (YSB) is one of the major insect pests in rice plants that has high attack intensity in rice production center areas, especially in West Java. This pest is consider as holometabola insects that causes rice damage in the vegetative phase (deadheart) as well as generative phase (whitehead). Climatic factor is one of the environmental factors influence the pattern of dynamics population. The purpose of this study was to develop a predictive modeling of YSB pest dynamics population under climate change scenarios (2016-2035 period) using Dymex Model in Indramayu area, West Java. YSB modeling required two main components, namely climate parameters and YSB development lower threshold of temperature (To) to describe YSB life cycle in every phase. Calibration and validation test of models showed the coefficient of determination (R^2) between the predicted results and observations of the study area were 0.74 and 0.88 respectively, which was able to illustrate the development, mortality, transfer of individuals from one stage to the next life also fecundity and YSB reproduction. On baseline climate condition, there was a tendency of population abundance peak (outbreak) occured when a change of rainfall intensity in the rainy season transition to dry season or the opposite conditions was happen. In both of application of climate change scenarios, the model outputs were generated well and able to predict the pattern of YSB population dynamics with a the increasing trend of specific population numbers, generation numbers per season and also shifting pattern of populations abundance peak in the future climatic conditions. These results can be adopted as a tool to predict outbreak and to give early warning to control YSB pest more effectively.

Keywords: DYMEX, rice yellow stem borer, climate change scenario.

1. Introduction

Agriculture is one of sector which is very vulnerable to climate variability or climate change that adversely affects plant productivity either directly or indirectly among others through pest organism's attacks. The presence of pest certainly becomes a limiting factor of crop production. One of the major pests of rice plants that has high level intensity of attacks and wider spread of the population in some Asian countries and Indonesia in particular, is *Scirpophaga incertulas* (Walker) (Lepidoptera:Pyralidae) which is famously called *Rice Yellow Stem Borer* (YSB). The development of YSB pest is very dominantly influenced by climatic factors that is very significant affected the pattern of population such as physiology, abundance, phenology and geographical distribution [1]. Furthermore, the cause of YSB pest spread was suggested as a result of climate change [2,3]. Therefore, it was predicted that the climate change would also affect the pest dimensional changes [4].

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In Indonesia, YSB is a major insect pest in rice plants, especially in the northern part of West Java Province. Indramayu District is one of endemic regions of YSB pests which is located and is renowned as an area of rice production centers that have a large enough contribution in national rice production. In general, this area is tropical regions that have a clearly dry season and the rainy season (*monsoonal*). The area also has lowland tophografy that is influenced by the sea breeze from the North Coast (Pantura), so it has a climate characteristics that tends to dry. Even though with that climatic conditions, YSB population was noted to be able to survive and thrive (adaptative) in the region, where the conditions may suitability for the pest with the minimum threshold temperature range of 10-15^{o}C and maximum of 35-40^{o}C [1].

The general assessment of climate change projections have been done to the long-term climate change scenarios based on emission scenarios, while the near-term climate projections was based on the results of climate prediction on decadal or interdecadal time-scale [5]. The study of near-term climate change projections at present time is very important, especially in relation to the efforts and government consideration for public policy in national development such as the development of agricultural sector, infrastructure and others. With regarding this issue, the information of climate change is very important, for example, in defining and preparing management planning and control strategies to anticipate pest attacks in the future (±10-20 years). The *5th Assessment Report* of the *Intergovernmental Panel on Climate Change* (IPCC AR5) has prepared the latest climate change projection data based on a scenario of near-term projections from 2016-2035 period [6]. We need new adapted-method of implementation of early warning systems of pest attacks in the future, particularly to support the implementation of YSB pest control measures to be more effective. Therefore, DYMEX Model may be able to help prediction of population dynamics which include the development and mortality process, abundance and YSB population peak time in climatic conditions which tend to fluctuate [7]. This research aimed to develop a predictive model of YSB pest population dynamics under climate change scenarios (2016-2035 period) using a DYMEX Model in Indramayu area, West Java.

2. Materials and Method

2.1. Data Analysis and Tools

Daily climate data of Jatiwangi region (6^{o}45'S - 108^{o}06'E, 50 meters above sea level) was obtained from Climatological Station Dramaga-Bogor (January 1st 1996 - December 31st 2015) contained minimum and maximum temperature, minimum and maximum humidity and rainfall data. For daily imago light trap populations data was obtained from the Installation of The Agency of Plant-Pests Organisms Observation and Forecasting (*Pengamat dan Peramalan Organisme Pengganggu Tanaman* (PPOPT) in Indramayu District (January 1st 2003 - December 31st 2009). YSB imago populations data were used to do calibration and validation test of imago population model outcomes. This study was performed using DYMEX 3.0 software to analyze YSB population dynamics and Microsoft Excel 2010 for data processing and statistical analysis.

2.2. YSB Population Dynamics Modeling

DYMEX model was used to analyze the relationship between climatic parameters and organism population changes in a certain region [8]. DYMEX consists of two parts, namely Builder (consists of various modules that are integrated for building models) and Simulator (to run the model that has been built in the builder). YSB modeling inputs in Builder was constructed from two main components, namely climate parameters and YSB development lower threshold of temperature (*To*). Climate parameters function was used to estimate soil moisture value that would be a main input models through the lifecycle process (*lifecycle module*). The lifecycle process in DYMEX described the process of development and mortality, the transfer of individuals to the next stage and the fecundity and reproductive [9]. In the lifecycle process, *timer* and *latitude module* are needed to determine *daylenght* value and then with the addition input variables of temperature and humidity the *evaporation* value can be estimated. Furthermore, the evaporation together with input variable of precipitation would estimate the *soil moisture* value. Because YSB is kind of *holometabola insect*, so it could be modeled from the eggs, larvae, pupae to adult (imago) phase (figure 1).

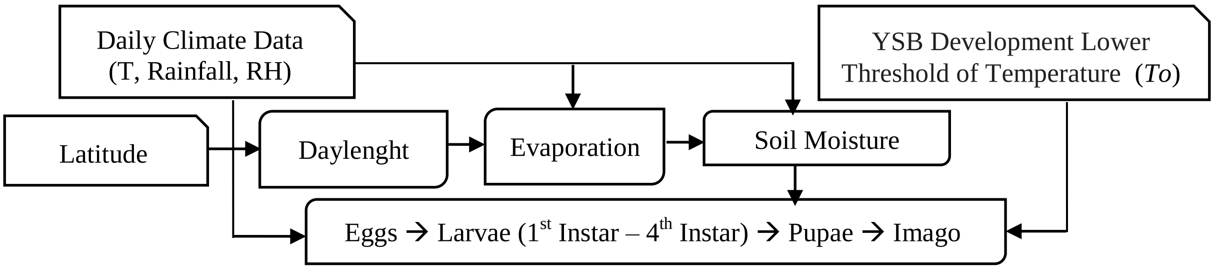


Figure 1. Diagram of YSB population dynamics in DYMEX Model.

The YSB development lower threshold of temperature value (*To*) was obtained from the value of the Development Rate (*DR*). *To* is a lower threshold temperature that could be tolerated by each phase of YSB development and has a relationship linear functions between temperature and *DR* value [10,9]. The *DR* value in each phase was determined using the equation $DR = 1/d$ [10a], where *d* was development period value (days) in egss, larvae and pupae phase at a constant temperature of 15-35^{o}C which could be obtained from the table 1 [1a]. Linear regression model between the *DR* and *To* value could be obtained by the equation $y = a + bx$, with $y = DR$; $x = To$; *a* and *b* = *constants* [2,9]. Determination of *To* phase imago was obtained from the equation of $DD = d\ (T\text{-}To)$, where *DD* is *Degree Days* and *T* is maximum temperature which is needed for the imago development at 35^{o}C [9,13].

Table 1. The development period in YSB phase of eggs, larvae and pupae at a constant temperature.

Constant Temperature (^{o}C)	Development Period (days)		
	Eggs	Larvae	Pupae
15	24.77	75.56	15.83
20	10.50	55.98	12.66
25	9.60	22.50	9.51
30	5.56	15.94	5.73
35	2.73	15.41	4.03

Source: Rahman and Khalequzzaman (2004)

The next process was setting mortality parameters in the model that was affected by the minimum temperature and soil moisture [8]. The transfer stages where the entire transfer phase after achieving full development, which reached physiological age is 1. If the physiological age threshold is set to a value of 1, the physiological age at any time would be the same as the accumulated degree days above threshold temperature of development [11,12,13]. The last stage was to determine the fecundity parameters and YSB reproduction. Fecundity is the ability of insects to reproduce that is modeled in the form of a YSB eggs potential parameter [14, 15]. Furthermore, in YSB reproduction process is assumed and controlled by the daily temperature cycles and precipitation [11,15].

DYMEX Simulator would be run after the Builder was formed to initialize the parameter inputs. Initialization models included setting values that is needed to run the model [8] and standard initialization implemented to ensure impersonation for simulation results [11]. The calibration and validation process of models could be achieved when value of accuracy level was over than 37%, and the model could be considered as a good result [11]. The evaluation of fitted models carried out based on the index of statistical coefficient of determination (R^2) between 0 – 1. The simulation model was applied using daily climate data with the baseline period of 20 years from January 1st 1996 - December 31st 2015 to analyze dynamic pattern of YSB population in Indramayu area at every stage of its development phase.

2.3. Climate Change Scenarios

Climate change scenarios (changes in air temperature and rainfall) based on a report AR5 [6] described the near-term climate change projections along 20 years period to the future (2016-2035). It referenced the baseline period (1996-2015) in sub region of Southeast Asia (10S-12N; 100E-150E) where Indramayu area is located. It was assumed that each value of climate change occurred in Southeast Asia region would represent the future climate change condition in Indramayu. It could be a new values to run the climate change simulation in DYMEX Model (table 2).

In this research the emissions increasing scenarios of *Representative Concentration Pathway* (RCP) was used. It consisted of RCP 2.6 model (*aggressive mitigation strategies*) and RCP 8.5 (*business as usual*). The different responses in dynamic population of YSB in each climate change scenarios on baseline climate conditions were analyzed using *t-test for two paired samples* (*paired two sample for means*) between the number of YSB populations before and after analysis of climate change scenarios.

Table 2. Temperature and rainfall changes under climate change scenarios (2016-2035 period).

Sub Region	Season	Climate Predictions in 2016-2035 Period					
		Tmin (°C)		Tmax (°C)		Rainfall (%)	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Southeast Asia	Rainy (Winter)	0.3	0.3	1.2	1.2	0	2
	Dry (Summer)	0.3	0.4	1.2	1.3	1	0

Source: IPCC (2013); Rainy Season: October-March; Dry season: April-September; RCP 2.6: lower emissions; RCP 8.5: high emissions; Tmin: minimum temperature; Tmax: maximum temperature

3. Results and Discussion

3.1. Value Determination of YSB Development Lower Threshold of Temperature (To)

By using a linear regression model [10], *To* value of YSB could be obtained after calculating the value of *DR* in each phase of YSB development of amounted to 0.040, 0.095, 0.104, 0.180, 0.366 (for eggs); 0.013, 0.018, 0.044, 0.063, 0.065 (for larvae) and 0.063, 0.079, 0.105, 0.175, 0.248 (for pupae) at a constant temperature (15-35°C). *DR* value was also obtained, which was used to determine *To* value where no developmet in every phase of YSB (*DR = 0*). Thus *To* value was obtained of amounted to 14.39°C, 11.3°C and 10.65°C respectively for eggs, larvae and pupae phase. *To* value of imago phase was determained using the *Thermal Constant* or *Degree Days* (*DD*) and the average age (*days*) [1a], amounting to 75.16°days and 4.76 days. The value was 19.22°C for imago phase (table 3). These data then were used as a reference in preparing input data in Builder, in particular for using the YSB *lifecycle module*.

Table 3. Result of *To* value for the development egg, larva, pupa and imago of YSB phase.

Development Phase	Regression Equations [a]	R^2	*To* (°C)	*DD* (°day)	*d* (day)	*DR* (day^{-1})
Eggs	y = 0.0147x – 0.2115	0.84	14.39	56.27	2.73	0.367
Larvae	y = 0.003x – 0.0339	0.93	11.30	365.22	15.41	0.065
Pupae	y = 0.0093x – 0.099	0.92	10.65	98.13	4.03	0.248
Imago	-	-	19.22	75.16	4.76	0.224

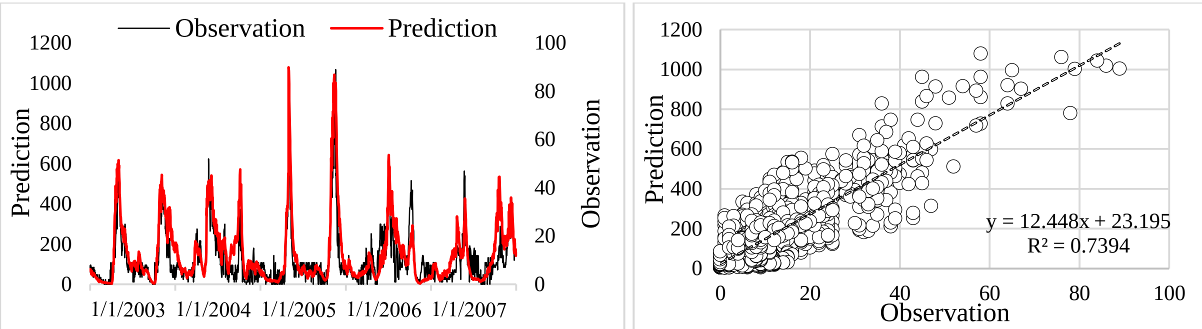
[a]Temperature range for determination of *To* value in 15-35°C; *DR*: Development Rate; linear regression model $y = a + bx$, ($y = DR = 0$ if no development; $x = To$, a and b are constants); R^2: determination coefficient; *DD*: Degree Days; *d*: development period (Tmax=35°C)

Initialization parameter in Simulator was used to determine initial population numbers in each development phase. It assumed that the simulation model would be executed to satisfy the conditions in the field population numbers significantly, although the other factors outside climate was ignored. The time taken for each YSB development phase at a constant temperature of 28-36°C could influence the development period that was shorter. But when the temperature above 36°C was given, it would potentially reduce the populations of egg, larva, pupa and imago up to 50% (rate mortality of 0.5) [11]. It showed that the majority of YSB populations under higher temperature would have inactivity condition (*aestivation*), and their mortality even faster when the temperature was increased continuously up to >40°C [1]. This was occured because they were no longer able to tolerate these conditions. Therefore, based on the light trap data in Indramayu area gained an average of ±10 moths of YSB adult females per night. With the assumption that the potential eggs (fecundity) was 400 eggs per moth [15,14], so there would be found 4000 eggs, then a successful hatch into the first instar larvae were 2000 larvae, and the larvae became pupae were 1000 and finally a pupa became imago were 500 moths.

3.2. Calibration, Validation and Simulation Model

The calibration process was carried out based on the model of study area using daily YSB imago population observations data (light trap) that were available (January 1st 2003 – December 31st 2007) by testing the mortality parameters in the development phase of YSB imago. The model was built by ignoring factors of natural enemies (*biological agents*) in egg parasitism, application of pesticides and fertilizer, irrigation technique, that were used to improved varieties of rice and the influence of host plant to the YSB population that can cause mortality rates. Mortality parameters setting was done at each phase of development, particularly the imago. The parameters value was assumed to include the effects of which can lead to high or low mortality in every YSB phase outside climatic factors. Mortality assumption constant in eggs, larvae and pupae phase was 0.01 per day, whereas the mortality imago modeled using the rate of mortality of 0.1 per day. It reduced the population by 10% [8]. The best value of mortality was approaching the fluctuation pattern of observation data [7]. The variation values in imago mortality was tested from 0.1 to 0.25 per day. When the higher imago mortality parameters were applied, the model did not produce good results. Probably the model outputs of imago populations was smaller.

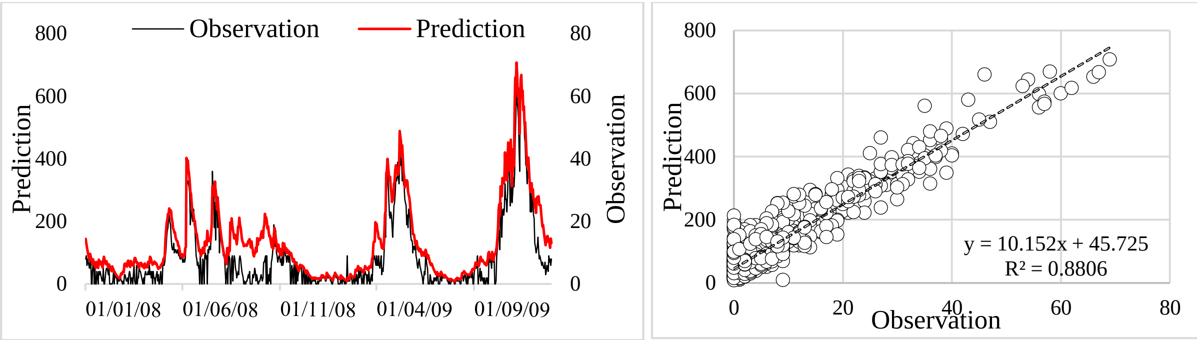
The best value on the calibration process was obtained at a mortality rate of 0.1 per day. It has been shown with R^2 value of 0.74. This condition could describe the prediction of peak abundance of YSB imago populations specifically population number per day. Although had a difference result, where the total predicted populations was higher than the observations number, however between them tended to have similar fluctuation pattern (figure 2a and 2b). In this regard, the observation data of light trap represented the presence or arrival indicators of YSB imago populations in a particular area. However, the data did not able to explain YSB imago populations number in the field related to the limitations of the scope area within the model. It was also associated to the YSB imago behavior (nocturnal insect pest) in response to the light where not all them attracted to the light traps depends on the power of the light or any changes occurred around the agroecosystem.



(a) (b)

Figure 2. (a) The YSB imago population dynamics pattern of calibration results with use a mortality of 0.1 per day (01/01/2003 to 31/12/2007) (b) The coefficient of determination (R^2) between the populations of YSB imago prediction and observation of the calibration results.

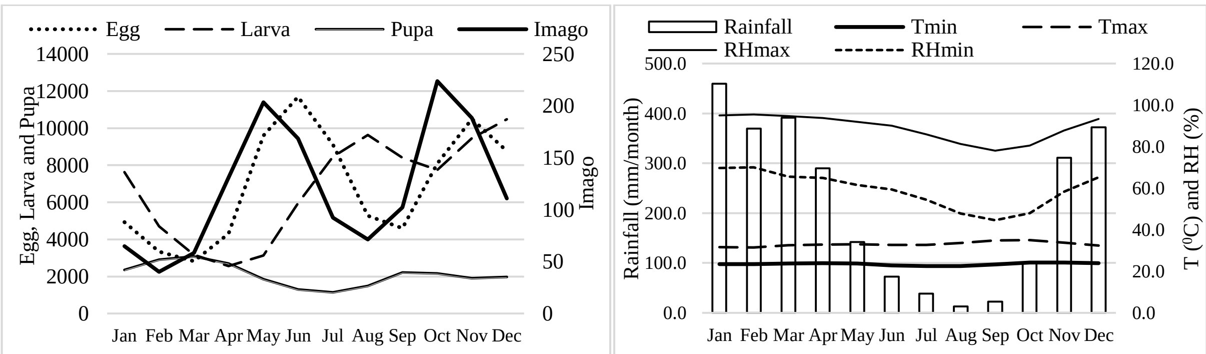
Validation of the model was also carried out starting from January 1st 2008 - December 31st 2009. The results of validation model process was run very well so that it was able to predict the peak abundance of population during the simulation period with R^2 value of 0.88 (figure 3a and 3b). The accuracy level between calibration and validation results of model showed a high enough value that was above 37% [11]. This indicated that the model was considered to have good results, which was able to give an ilustration that YSB population dynamics in Indramayu area was strongly affected by climatic factors. Furthermore, the model was also able to simulate the response of YSB on baseline climate conditions in January 1st 1996 - December 31st 2015 (± 20 years).



(a) (b)

Figure 3. (a) The YSB imago population dynamics pattern of validation results (01/01/2008 to 31/12/2009) (b) The coefficient of determination (R^2) between the populations of YSB imago prediction and observation of validation results.

Simulation of the Model calculated monthly in the baseline of climate conditions in Indramayu area indicated that there was a tendency of abundance or imago population peak was occured in October when rainfall began to increase (>100 mm/month) and a decrease in rainfall intensity (<300 mm/month) that was in May. The YSB imago populations may reach >200 moths/month (figure 4a). Rainfall intensity between 0-30 mm/week that was ideal for YSB imago development, so they tended to be high and growing faster in these conditions [16]. Additionally, climate variables such as rainfall intensity between 5-40 mm/week or more was used as a reference of peak value of emergence YSB females imago to reproduce or the most ideal conditions for YSB imago to lay their eggs [11,15]. Optimum climatic conditions at the transitional season was the ideal conditions for YSB imago developmentwith the minimum and maximum temperature was about 23.3-24.2°C and 32.9-35.0°C and the minimum and maximum humidity of 44.5-64.9 % and 78.1-93.7%. On the contrary, YSB imago populations were lowest during January - March which was <60 moths/month. It was occur when an increase in rainfall intensity was ±300-400 mm/month (figure 4). High rainfall resulted in high mortality of YSB imago development. Furthermore, if the rainfall intensity >100 mm/week, YSB imago populations tended to decline dramatically [16].



(a) (b)

Figure 4. (a) The YSB population dynamics pattern of monthly simulation results average on baseline climate conditions (b) Climatic characteristics of Indramayu region on baseline climate conditions.

For Annual perspective (monthly simulation), the prediction of the peak abundance and populations number of YSB in Indramayu occurred on the beginning of October or at the First

Planting Season (PS. I) and on May or Second Planting Season (PS. II). During this season YSB reached more than 200 moths, then followed by emerging the eggs which reached the peak in June (PS. I) and November (PS. II) up to 12000 eggs. Subsequently, the larvae populations reached the peak (+10000 larvae) on August (PS. II) and December (PS. I). As a result, the abundance of pupae rose gradually from January to March (PS. I) and from September to November (transitional season) which achieved approximately 2000-3000 pupae. This proved that the climate cobditions greatly influenced the development and pattern of YSB population dynamics in Indramayu area.

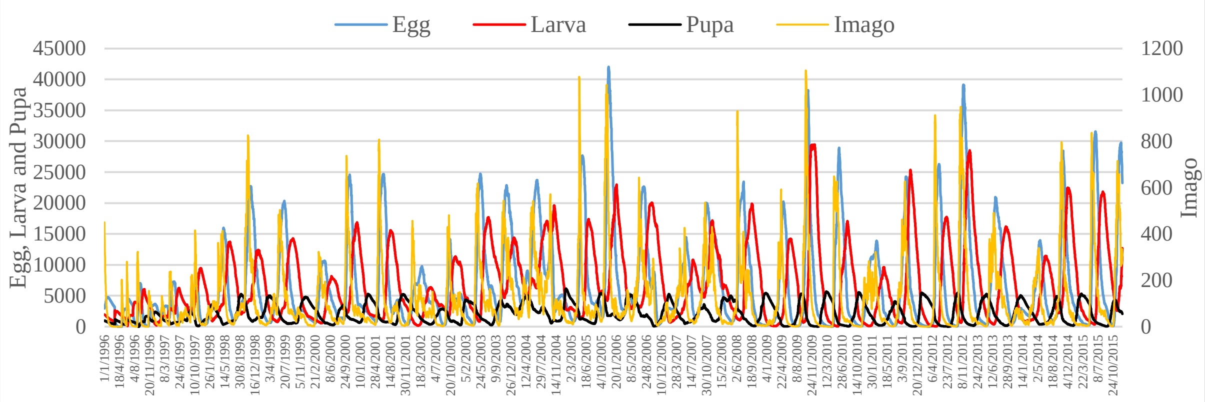


Figure 5. The YSB population dynamics pattern of daily simulation results on baseline climate conditions (period in 1996-2015).

For daily simulation, the model showed that YSB was continuously present, but the number was still relatively under control (below the threshold). In baseline climate conditions, the abundance of YSB imago populations tended to occur before rainy seson ended, and after dry season or during the early part of rainy season in every year. However, the potential explosion (outbreak) of YSB pests by climatic factors tended to occur when the phenomenon of extreme climate change was happened, such as after strong *El Nino* in 1997 followed by moderate *La Nina* which showed the explosion of YSB during the rainy season in 1998 (PS. 1998/1999). The other explosions occured when *Normal* or *La Nina* conditions and followed by weak to moderate *El Nino* were happened on PS. 2000/2001, PS. 2005 PS. 2005/2006, PS. 2008, PS. 2009/2010, PS. 2011/2012, PS. 2012, PS. 2013/2014, PS. 2014/2015, PS. 2015 and PS. 2015/2016 (figure 5). This data showed that the extreme environmental conditions such as *El Nino* and *La Nina*, which changes the distribution of rainfall could bring considerable influence to the surrounding organisms, including pests that tended to change drastically [17].

The high population of YSB has strong correlation with high or extreme temperature conditions, suggesting that high temperature triggers the development rate of YSB. Lower mortality rate also directly influenced the YSB developmental age which tended to make the cycle relatively shorter. In addition, the imago phase also reproduced faster under the high temperatures and low rainfall intensity conditions, which support the deployment of imago to be active until the laying of eggs. In normal conditions, each YSB female is able to produce about 100-600 eggs [14] and the age average of male and female are 2.5 and 5.09 day respectively [15]. It was assumed that the sex ratio between male and female was 1:2, and therefore one moth may produce approximately 400 eggs. It would also trigger the YSB development rate at the larva stages that have a lower mortality value. During the rainy season, larvae metamorphoses into pupae to become imago and imago reproduces quickly. If the temperature higher, the larvae development rate to the next stage would be more rapid. Therefore by the presence of host plants and water ability present every season or due to cropping pattern throughout the year (paddy-paddy-paddy) outbreak of YSB pest would be happened, where in a year might occur 2-3 generations of YSB populations.

3.3. Prediction of YSB Populations Under Climate Change Scenarios

The simulation models based on two climate change scenarios (RCP 2.6 and 8.5) in Indramayu area showed a significant difference in imago populations. The trend of populations for climate projection (2016-2035) for egg, larva and imago phase tended to increase, but pupa phase was decline from baseline conditions (table 4). The reason behind this was because pupa populations may be not able to tolerate high temperature which trigger their mortality. This may hamper the sustainability of pupae populations under those climate change scenarios. On the contrary, for the imago populations, it could support to its development. This probably due to YSB imago reached a comfort level at the optimum temperature of 33-35^{o}C. The simulation model of two types of climate change scenarios used in Indramayu region showed a very high model sensitivity to climate change impacts to YSB population dynamics pattern in the future (figure 6).

Table 4. YSB population dynamics under climate change scenarios in 2016-2035 period.

Scenarios	Development Phase	Egg	Larva	Pupa	Imago
Baseline	Average Monthly Populations	9.637	6.796	2.087	122
RCP 2.6	t_{value}	-7.06	-35.82	4.41	-14.20
	P_{value}[a]	0.000	0.000	0.000	0.000
	S/TS	S	S	S	S
	Average Monthly Populations	10.438	7.806	1.980	263
RCP 8.5	t_{value}	-9.92	-41.77	5.44	-16.65
	P_{value}[a]	0.001	0.000	0.000	0.000
	S/TS	S	S	S	S
	Average Monthly Populations	10.813	8.092	1.963	268

[a] Confedence level by 5%; S: Significant; NS: Not Significant

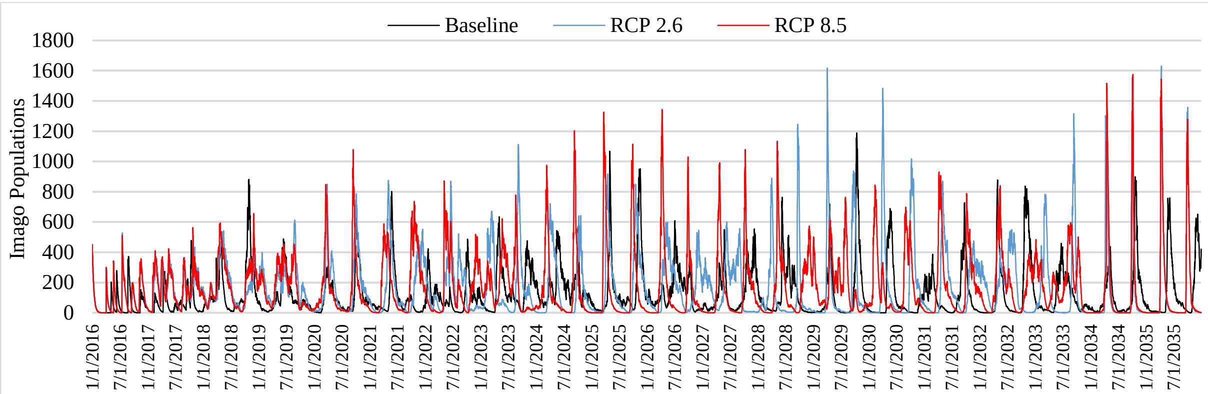


Figure 6. Prediction of YSB imago population dynamics in daily simulation (01/01/2016 to 31/12/2035) under climate change scenarios (RCP 2.6 and RCP 8.5).

The overall projection on application of two climate change scenarios described the rate of monthly YSB populations that was followed by shifting pattern of peak abundance in every phase. It occurred during 1-2 months ahead earlier than the baseline climate conditions. The increase of YSB populations in Indramayu area was due to highly comfort condition for YSB development or due to ideal growth conditions for each phase. The highest populations peak occurred during the changes of rainfall intensity, which from high to low or low to high (after rainy to dry season or after dry to rainy season). The monthly rainfall intensity that was changed from the baseline condition was 1.7 mm in dry season (RCP 2.6) and 3.3 mm in rainy season (RCP 8.5). In addition, increasing rainfall intensity, also followed by an increase in monthly minimum temperature which tended to be higher than the baseline climate condition which were 0.3^{o}C (RCP 2.6) and 0.4°C (RCP 8.5) in dry season, while monthly maximum temperature raised up to 1.2°C (RCP 2.6) and 1.3^{o}C (RCP 8.5). If during dry season it was supported by ideal humidity, so it was sufficient to provide optimum soil moisture levels, particularly in triggering the development of larvae and pupa phase. Both of the increase in temperature and precipitation significantly establish major influence to YSB imago development rate. From this, it can be calculated that the increasing abundance of specific YSB imago populations was more than 300 moths/month and generations number per year was reach more than 4 generations.

The prediction of monthly or seasonal YSB imago populations under the RCP 2.6 application scenario tended to be slightly higher than the RCP 8.5 before dry season (April-June) and ahead of rainy season (October-December). However, other conditions showed that the decreased back was happen ahead of rainy season peak (January-March) and in dry season peak (June-August) (figure 7). This might be due to YSB imago development rate in RCP 8.5 scenario that was highly influenced by the sensitivity of climate variables, particularly temperature and precipitation in every season differences. The mortality rate was 0.1 per day on RCP 8.5 application which tended to affect change in YSB imago populations. It was probably due to an increase in temperature and the rainfall intensity is too high. This factor could become a limiting factor of abundance which was slightly lowering the peak populations of YSB at the rainy or dry season.

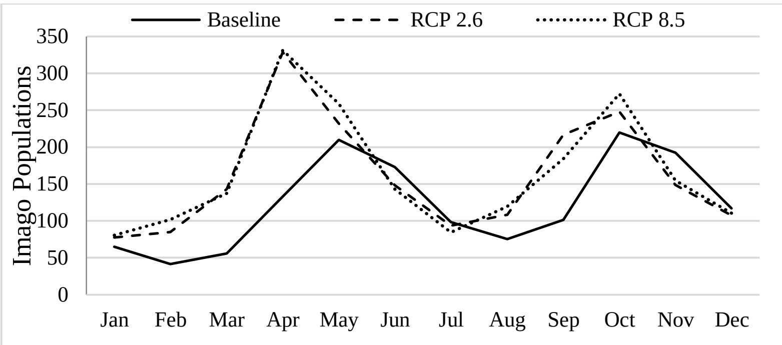


Figure 7. Prediction of monthly YSB imago population numbers under climate change scenarios.

In order to reduce the negative impact of the insecticides applied to control YSB pests, it is necessary to determine the economic threshold of insecticides application, so that the usage of insecticides is not excessive. The latest technology of YSB pest control was carried out immediately 4 days after the flight of moths (imago) both of the vegetative or generative phase, and it could be seen from the light trap catch [18]. The principle of this technology is not based on controlling intensity of larvae attack, but based on the effectiveness of YSB imago catches. The results of the study in West Java and Central Java showed that when the pest control was carried out after the attack, the rice yields went down. Therefore, the application of predictive YSB imago population dynamics under climate change scenarios as the output results from DYMEX Model become an alternative solution to determine the peak time of imago abundance.

4. Conclusions and Recommendations

The model DYMEX was able to predict the influence of climate on the dynamics of YSB population and produce a monthly or seasonal trend patterns, with the value of R^2 of 0.74 (calibration) and 0.88 (validation). The model was also able to predict the specific populations, generation number per season, and peak of populations in each season, and shifting pattern of peak abundance within climate change scenarios. The application of both climate change scenarios (2016-2035) of RCP 2.6 and RCP 8.5 was able to provide information required to assess the risk climate change impacts on YSB population densities for Indramayu farmers. Hence, the DYMEX Model could be used to formulate the management of YSB populations and control the pest in the future, especially on near-term projections. We recommend that for further assessments, the damage level analysis is required to estimate the potential yield losses due to the attack of YSB larva populations in the future, and to reduce the impact and improve control strategies more effectively.

Acknowledgment
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