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Thermal Stratification in Saline Shallow Water Bodies

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Abstract

Thermal stratification occurs in water bodies because of the heat that is absorbed during daytime and the heat that is released during nighttime. Understanding the behavior of water temperature in shallow waters is important for practical applications in aquaculture. In this study, thermal stratification in the closed saline water bodies of three aquaculture ponds has been investigated with different initial salinities of 0, 15, and 30 psu at the Klongwan Fisheries Research Station, Kasetsart University in the Prachuap Khirikhan province, Thailand. Further, the weather and the vertical profiles of water temperature were measured at 10-min intervals from June 1 to October 31, 2017. During the observation period, the solar radiation at noon time was approximately 400-700 W/m^2, the air pressure was higher than 100 kPa, and the air temperature was approximately 25 °C-35 °C. Further, rainfall occurred only for a short duration, and only a low amount of rainfall was received during the observation period. Over the whole observation period, 90% of the observed wind speeds was less than 4 knot, while the remaining 10% of the recorded speeds was high and ranged from 5 to 10 knot. A high wind speed was observed during nighttime. After sunrise, short-term stratification was observed during daytime, and stratification disappeared gradually as the water surface started cooling. The disappearance of stratification was caused by the thermal exchange between the air and the water surface. In case of saline water, the amount of heat exchanged during daytime and nighttime was higher than that observed in case of fresh water because the heat capacity of saline water was lower than that of fresh water.

Keywords: Heat capacity, Saline water, Shallow water, Thermal stratification

Introduction

Thermal stratification occurs in shallow water bodies because of the heat that is absorbed during daytime and the heat that is released during nighttime. The behavior of water temperature in shallow waters plays an important role in practical applications of aquaculture. In case of fish ponds, the density gradient in water as influenced by the temperature is directly related to the consequent growth rate of fish. Furthermore, the temperature of shallow water is one factor that influences the occurrence of diseases in fish (Jacobs *et al*., 1997 and Jacobs *et al*., 1998).

Some external disturbance factors during daytime in shallow water include the incoming light radiation, air temperature, wind velocity, and water quality. These external factors may cause thermal stratification in small and shallow water bodies. During nighttime, the external factors are the long-wave radiation of water, air temperature, and wind speed, which trigger the development of a mixing layer with varying water temperatures from the air-water interface.

In this study, the thermal stratification in closed saline water bodies of the aquaculture ponds in

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Thailand was considered. During stratification, the thermal structure was dominated by the surface heat fluxes. The vertical thermal structure profiles were compared and were explained by considering three different ponds with different salinity concentrations. The weather and vertical profiles of the water temperature in each pond were recorded during end of summer season to end of rainy season in 2017 at the Klongwan Fisheries Research Station, Kasetsart University in the Prachuap Khirikhan province, Thailand.

Materials and Methods

Field observations were conducted in experimental ponds at the Klongwan Fisheries Research Station (11°45′18″N, 99°47′33″E), Kasetsart University, in the Prachuap Khirikhan province, Thailand (Fig. 1). The variations in weather and water properties were monitored from June 1 to October 31, 2017. This period coincided with the occurrence of the rainy season at the research station. Field observations were conducted in three ponds, and different salinity conditions were set using seawater before beginning continuous observations on May 30, 2017. Fig. 1 and Fig. 2 depict the study site and a schematic of the experimental ponds, respectively. During the observation period, the salinity and water depth were adjusted only once before beginning the observation (salinity; 0 psu, 15 psu and 30 psu, water depth; 1.2 m in each ponds). Therefore, the variation in salinity and water depth depended on the weather conditions. The air temperature, humidity, solar power, rainfall amount, and air pressure were measured at 10-min intervals by HOBO (a weather station and data logger) at a height of 2 m above the water surface. The vertical profile of the water temperature in each pond was simultaneously recorded; readings were obtained in the vertical direction at 0.2-m intervals using HOBO temperature logger (Pendant Temperature Light 64K Data Logger).

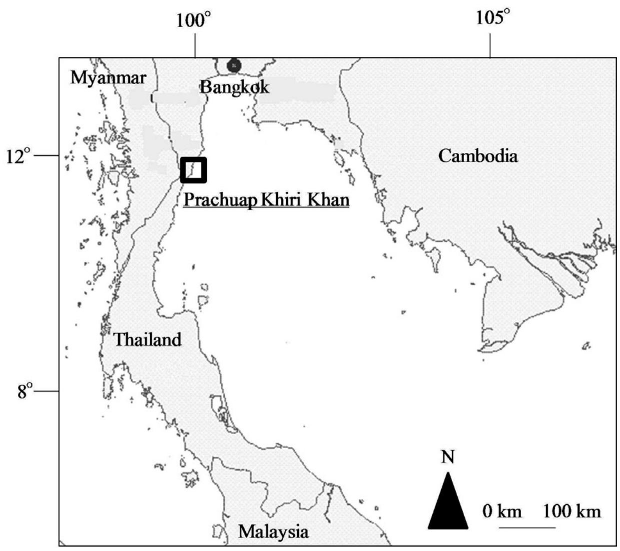

Fig. 1 Study site at the Klongwan Fisheries Research Station, Kasetsart University, in the Prachuap Khirikhan province, Thailand

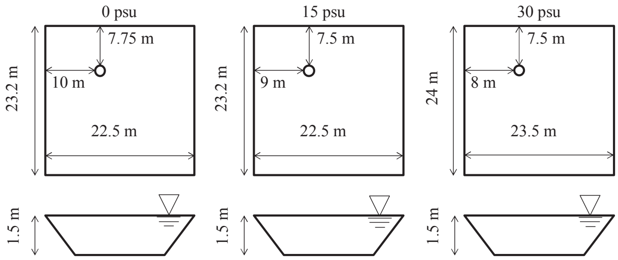

Fig. 2 Schematic of the experimental ponds

Results and Discussion

The variations in weather parameters, such as solar power (W/m^2), air pressure (kPa), air temperature (°C), and rainfall (mm), are presented in Fig. 3. The solar power and air temperature were considerably high because the observations were conducted during the end of summer season to end of rainy season. For the majority of the observation period, the solar radiation at noon was approximately 400-700 W/m^2, air pressure was higher than 100 kPa, and air temperature was approximately 25 °C-35 °C; further, the region received rainfall for short durations, and the rainfall amount was low. When rainfall occurred during the day, the air temperature and solar radiation were observed to be lower than usual. In fact, 90% of the recorded wind speeds over the whole period were less than 4 knot (i.e., low speed), while the remaining 10% were higher (5-10 knot); these high speeds were recorded at nighttime.

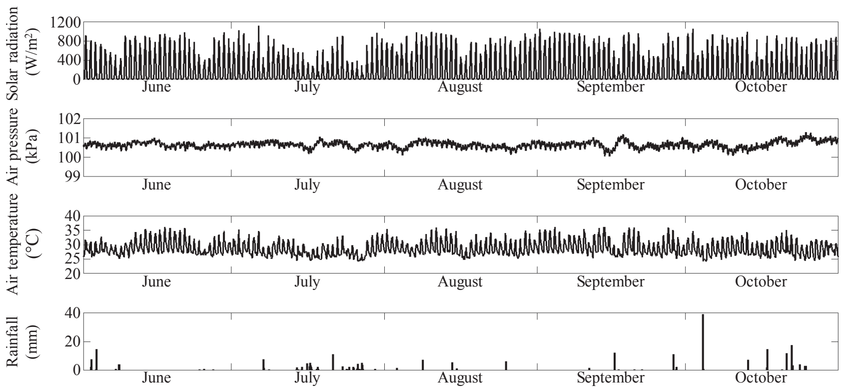

Fig. 3 Weather data at the Klongwan Fisheries Research Station during June 1-October 31, 2017

These weather tendencies indicated that both the solar radiation loads during daytime and radiative cooling during nighttime occurred within the observation period. This process is depicted in Fig. 4 by means of the water temperature profiles for June 1, 2017. The incoming solar radiation, which comprised long-wave and short-wave radiations, were immediately absorbed and transmitted into the water body. The water surface transmitted the short-wave radiation but absorbed the long-wave radiation, thereby heating the water surface.

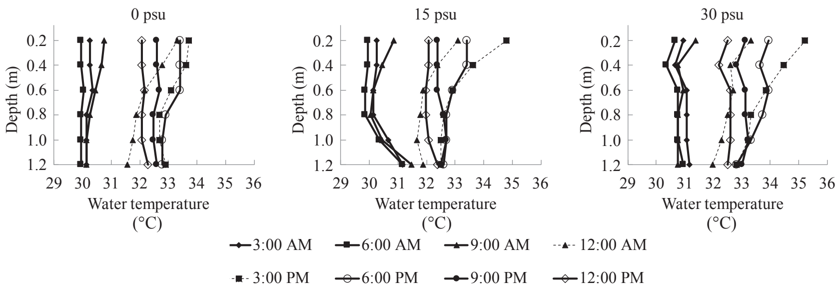

Fig. 4 Examples of the variations in the daily temperature behavior in ponds with different salinities on June 1, 2017

The rate of water heating depends on its heat capacity. The heat capacity is the amount of heat energy that is required to heat a gram of a material by 1 K. The higher the heat capacity, the more slowly will the material be heated if the same amount of energy is added. The heat capacity of freshwater is 4.182 J/(gK), while that of seawater is 3.993 J/(gK). Therefore, the saline water heat faster and reach higher temperatures than that reached by the freshwater.

At nighttime, heat was transmitted via long-wave radiations from the surface of the water body. The decrease in water temperature at the surface increased the water density in the layer that was responsible for the development of a mixing layer having uniform density. Thus, the difference in water temperature between the upper and lower layers decreased gradually; consequently, the depth of the mixing layer increased. In the upper water layer, a well-developed daily temperature cycle was observed. This cycle considerably diminished with depth. It was interesting to notice that the daytime and nighttime behaviors of the water temperature profile were similar to those reported earlier by Jacobs and coworkers (Jacobs *et al*., 1997 and Jacobs *et al*., 1998).

In Fig. 5, the day-averaged air temperature and the water temperature at three depths (bottom, 0.2 m above the bottom, 0.4 m above the bottom) are plotted. The results show that the mean maximum water

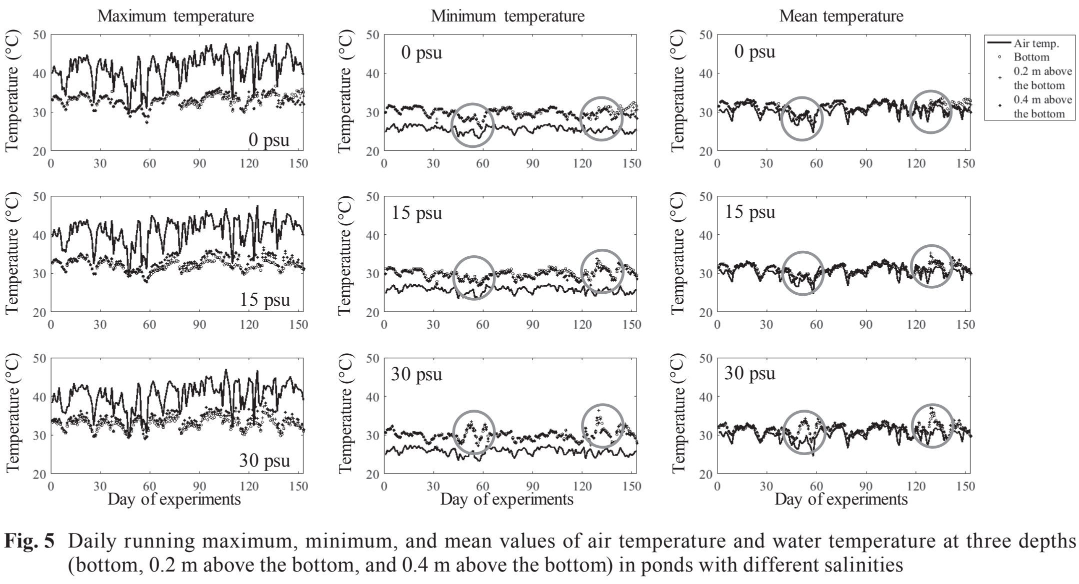

Fig. 5 Daily running maximum, minimum, and mean values of air temperature and water temperature at three depths (bottom, 0.2 m above the bottom, and 0.4 m above the bottom) in ponds with different salinities

temperature is always less than the maximum air temperature and that the minimum water temperature always exceeds the minimum air temperature. The range of the maximum and minimum water temperatures correlated well with the daily irradiation. In case of saline water (30 psu), the minimum and mean temperatures (3 °C – 5 °C) were higher than the other twice, as indicated by the circles. In other words, in a closed saline water body, thermal stratification may have been induced by the heat that was received at the salinity layer.

The maximum daily deviation from the daily mean air temperature versus the water temperature at 0.4 m above the bottom is depicted in Fig. 6. The linear regressions are also plotted as y = 6.84x in fresh water pond and as y = 10.33x and y = 6.45x in saline water ponds with salinities of 15 and 30 psu, respectively. Further, owing to the heat capacity of air, which was 0.72 J/(gK) at 300 K (27°C), air is quickly heated and attains a higher temperature than that attained by surface water.

The daily solar radiation and vertical temperature profiles of the three ponds during June 8-10, 2017, are depicted in Fig. 7. During daytime, after sunrise, short-term stratification occurred in the water (Andrew *et al*., 2007 and Talling, 2001). When cooling began in the afternoon, the slow and clear mix-

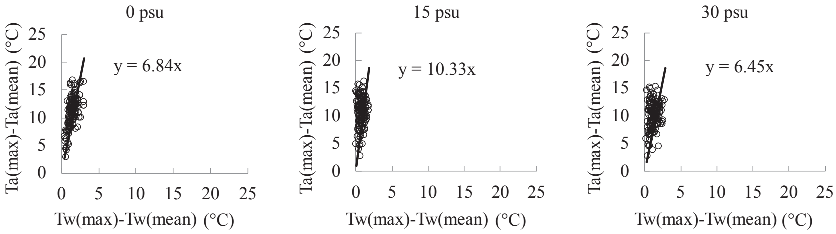

Fig. 6 Differences in the daily maximum temperature of water from the mean value at 0.4 m above the bottom versus that of air at a height of 0.5 m above the water surface in ponds with different salinities

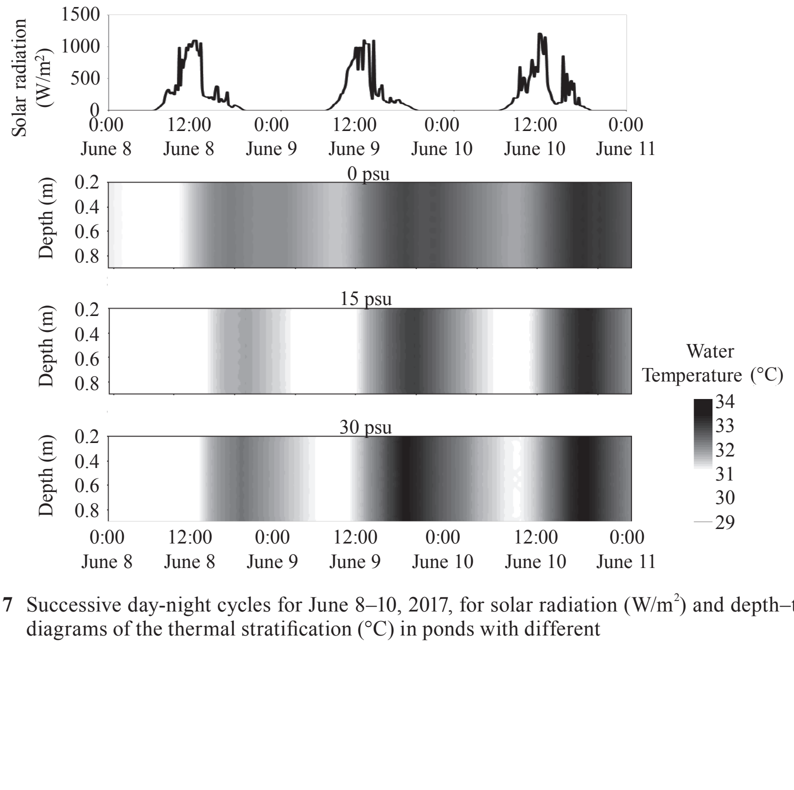

Fig. 7 Successive day-night cycles for June 8–10, 2017, for solar radiation (W/m^2) and depth–time diagrams of the thermal stratification (°C) in ponds with different

ing layer started developing from the surface of the water. By late night, a completely well-mixed structure was observed. Saline water released heat faster than the fresh water during nighttime. The wind measurements exhibited that the wind speed was low (<4 knot) throughout the entire period; consequently, well-forced convective mixing did not occur within the water body.

Conclusion

During daytime, a strong thermal stratification develops in the water body, whereas a mixed layer develops in the water surface during nighttime. In the upper water layer, a daily temperature cycle can be observed. This cycle is considerably weakened with increasing depth. The disappearance of stratification was caused by the thermal exchange between the air and surface water. The daily maximum water temperature agreed with the daily maximum air temperature. The water temperature ranging from the maximum to the minimum values was observed to correlate well with the daily solar radiation. The magnitudes of heat exchange during daytime and nighttime were higher in case of saline water than in case of fresh water because saline water exhibits lower heat capacity.

Acknowledgements

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