

# Dissolved Oxygen Dispersion Model Within Green Mussel Farming Area in Sri Racha Bay, Chonburi Province, Thailand

Monton Anongponyoskun<sup>1,\*</sup>, Sunthari Tharapan<sup>1</sup>,  
Alongot Intarachart<sup>1</sup>, Puvadol Doydee<sup>2</sup> and Pramot Sojisuporn<sup>3</sup>

---

## ABSTRACT

Dissolved oxygen (DO) is a major parameter in the aquatic environment and it is also necessary for all marine organisms, including mollusks. Thus, a case study was developed to model the DO distribution within a green mussel farming area in Sri Racha Bay, Chonburi province, Thailand. The model indicated that the water was well mixed, based on a mass balancing equation. The DO concentration varied depending on the sources and sinks of the DO which were applied to the model. A solution for the model was considered by an implicit method of successive over relaxation. In the model, the velocity of water was computed by the Princeton Ocean Model (POM). The output of the POM revealed that the seawater moved northward during the flood tide, while during the ebb tide, it moved southward with a maximum speed approximately 1 m.sec<sup>-1</sup>. The model was applied by adding and removing DO terms which were obtained from empirical experiments. On 29 January 2010 at 2100 hours, when low tide occurred, the DO concentration in the center of a floating raft of green mussel (*Perna viridis*) was lowest while the advection of water was dramatically slackened. Moreover, during night time, when there was no photosynthesis, the DO concentration was lowest. The results obtained from the model were acceptable compared with actual field observations. Similarly, the pattern of DO dispersion from the prediction at low tide also corresponded to the pattern of DO dispersion from the survey at low tide. Thus, the model could be used as a tool for predicting and estimating the amount of DO in a marine culture area in order to increase production and the preservation of the environment.

**Keywords:** dissolved oxygen, Sri Racha Bay, Princeton Ocean Model (POM), dispersion model, green mussel

## INTRODUCTION

Sri Racha Bay, Chonburi province, Thailand is a semi-open bay located in the eastern upper region of the Gulf of Thailand. Its coast is composed of mud flats, sandy beaches and rocky shoreline. There are several large areas in the

Bay which have been used for marine shellfish aquaculture. The main marine shellfish being cultured is green mussel (*Perna viridis*) using a floating raft technique.

Since green mussel culture has been promoted, the number of green mussel farms has expanded rapidly from 102 farms in 1999 (Seekao,

---

<sup>1</sup> Faculty of Fisheries, Kasetsart University, Bangkok 10900, Thailand.

<sup>2</sup> Research and Development Institute, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, 47000, Thailand.

<sup>3</sup> Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand.

\* Corresponding author, e-mail: ffsmta@ku.ac.th

2006) to 337 farms in 2008, while the culture area has increased approximately 6.5 times in the same period, so that at present, the area used for green mussel culture covers more than 440 ha with 2,250 lines of green mussel per hectare hung on floating rafts (Department of Fisheries, 2010). The increased amount of intensive green mussel farming affected the quality and quantity of their production and water quality. Thus, the total green mussel production was reduced from 46,131 t in 2003 into 8,579 t in 2008 (Department of Fisheries, 2010).

The reduction in green mussel production implies that there are limitations on the carrying capacity of green mussel aquaculture in Sri Racha Bay, probably due to inadequate dissolved oxygen (DO) in the seawater. To enhance sustainable green mussel production, several environmental aspects, including the carrying capacity of the surrounding waters need to be considered. In particular, the DO content, which is the major parameter indicating water quality, should be monitored.

In this study, a model was formulated and solved numerically to estimate the dispersion pattern of DO within the green mussel farming area in Sri Racha Bay, Chonburi province. The results of empirical experiments on the rate of respiration of green mussel with restricted activity, the rate of re-aeration of oxygen from the air, the oxygen uptake rate in the soil and the rate of oxygen consumption by marine organisms were applied in the model. The DO dispersion model was then used to identify the DO dispersion patterns in the green mussel culture area.

## MATERIALS AND METHODS

### Sources and sinks of dissolved oxygen

Boyd (1982) and Anongponyoskun and Sasaki (1996) reported that the major sources and sinks of DO in the water depended upon: 1) re-aeration of oxygen from the air, 2) oxygen production and consumption of aquatic

organisms, 3) oxygen uptake in the soil, 4) oxygen consumption of fish and 5) The advection and diffusion of seawater.

There is continual exchange of oxygen between the water surface and the air. The re-aeration rate of oxygen from air to water could be computed by Equation 1 (Thames Survey Committee, 1964):

$$\frac{dS}{dt} = \frac{K_1}{H} (S_s - S_{i,j}) = R_1 \quad (1)$$

where  $R_1$  is the exchange rate of oxygen between water and air ( $\text{mg.L}^{-1}.\text{sec}^{-1}$ ),  $K_1$  is the exchange coefficient ( $\text{m}.\text{sec}^{-1}$ ),  $S_s$  is the DO concentration at saturation ( $\text{mg.L}^{-1}$ ),  $S_{i,j}$  is the DO concentration ( $\text{mg.L}^{-1}$ ) at station (i,j) and  $H$  is the aeration depth (m).

The oxygen production and the oxygen consumption rates in water were measured by the Light and Dark Bottle technique (American Public Health Association, 1980). The oxygen consumption rate of green mussels was developed from Vichkovitten and Inoue (1997b). The oxygen uptake rate in the soil was developed from Vichkovitten and Inoue (1997a) and also using Choksuchart (2011). Since the DO is propagated with the flow, the pattern of DO dispersion strongly relates to the advection and diffusion of seawater which might be represented in terms of seawater velocity.

### Dissolved oxygen dispersion simulation

One way of analyzing the spread of DO in this study was the conservation equation of dissolved substances. This study was limited to well-mixed water. The vertical average mass conservation equation for the DO concentration can be written as Equation 2:

$$\frac{\partial S}{\partial t} + U \frac{\partial S}{\partial x} + V \frac{\partial S}{\partial y} = \frac{\partial}{\partial x} (K_x \frac{\partial S}{\partial x}) + \frac{\partial}{\partial y} (K_y \frac{\partial S}{\partial y}) + R \quad (2)$$

where  $S$  is the vertically averaged DO ( $\text{mg.L}^{-1}$ ),  $U \frac{\partial S}{\partial x}$ ,  $V \frac{\partial S}{\partial y}$  is the advective transport of DO in the east-west and north-south direction, respectively ( $\text{mg.L}^{-1}.\text{sec}^{-1}$ ),  $\frac{\partial}{\partial x} K_x \frac{\partial S}{\partial x}$ ,  $\frac{\partial}{\partial y} K_y \frac{\partial S}{\partial y}$  is the diffusive transport of DO in the east-west and north-south direction, respectively ( $\text{mg.L}^{-1}.\text{sec}^{-1}$ ) and  $R$  is the sources and sinks rate of DO at the site ( $\text{mg.L}^{-1}.\text{sec}^{-1}$ ).

The solution to the DO dispersion model was considered by the implicit method of successive over relaxation. The seawater velocity values were computed by the Princeton Ocean

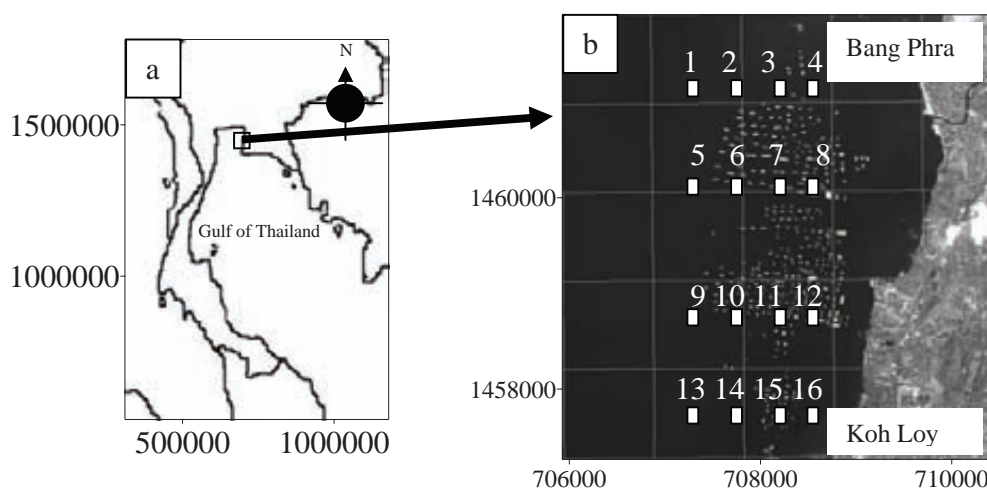
Model (POM). The amount of DO was varied depending on the sources and sinks of DO which were applied in the model. All parameters of the model are shown in Table 1.

### Model verification

The distribution of the green mussel culture area in Sri Racha Bay, Chonburi province is shown in Figure 1 as displayed by a satellite image of the Thailand Earth Observation System (THEOS) which was collected on 17 November 2009. The green mussel farms are distributed around the area of Bang Phra to Koh Loy which is in Sri Racha district, Chonburi province.

**Table 1** Parameters of the dissolved oxygen (DO) dispersion model.

Parameter	Unit	Symbol	Value
Grid spacing	m	dx,dy	300
Eddy diffusion coefficient	$\text{m}^2.\text{sec}^{-1}$	K	10
Initial DO concentration	$\text{mg.L}^{-1}$		7.0
DO concentration at saturation (temperature 28.5 °C and salinity 32.5 psu)	$\text{mg.L}^{-1}$	$S_s$	6.47
Exchange rate of oxygen between water surface and air	$\text{mg.L}^{-1}.\text{sec}^{-1}$	$R_1$	$\frac{0.11}{4} (6.47 - S_{i,j})$
Oxygen consumption rate in the water	$\text{mg.L}^{-1}.\text{hr}^{-1}$	$R_2$	0.15
Oxygen uptake rate in soil	$\text{mg.L}^{-1}.\text{hr}^{-1}$	$R_3$	0.09
Oxygen consumption rate of green mussel	$\text{mg.L}^{-1}.\text{hr}^{-1}$	$R_4$	0.03
Production rate in the water	$\text{mg.L}^{-1}.\text{hr}^{-1}$	$R_5$	0.45 (0800, 1000 and 1200 hours) 0.29 (1400, 1600 and 0600 hours)



**Figure 1** (a) Location of the study area in the upper eastern region of the Gulf of Thailand; (b) satellite image of green mussel farming area on 17 November 2009 and the 16 stations used for observation in Sri Racha Bay, Chonburi Province, Thailand (with 1 km gridlines).

The density of green mussel which was hung on floating rafts was 2,250 lines per hectare. Radiometric and geometric corrections of the model were performed based on WGS84 and UTM Zone 47. The area of interest in the model covered the green mussel farming area (1457000–1462000 N and 706000–710000 E) in Sri Racha district, Chonburi province—in the eastern upper region of the Gulf of Thailand.

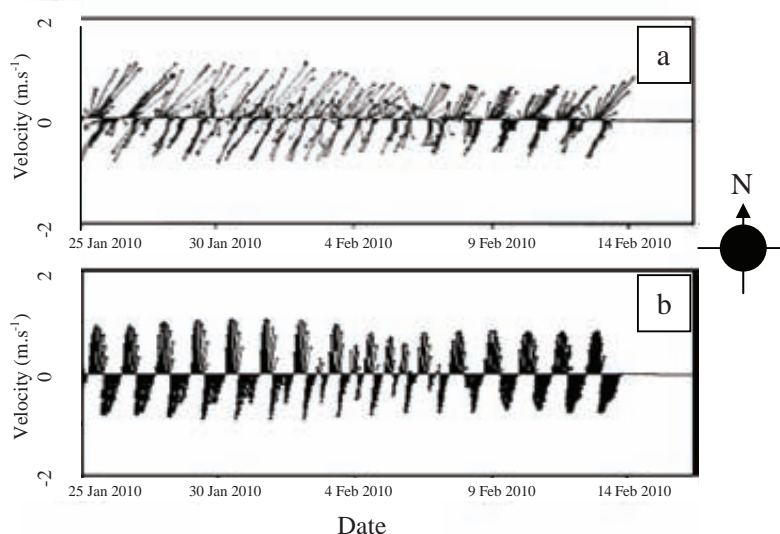
The seawater circulation in Sri Racha Bay was simulated by POM as developed by Anongponyoskun (2007). A boundary condition was defined by the four main tidal constituents ( $M_2$ ,  $S_2$ ,  $K_1$ , and  $O_1$ ) for the northern and southern boundaries. The western boundary was derived from interpolated data from the northern to southern boundaries. The model was verified using seawater velocity raw data which were measured every 10 min from 25 January 2010 to 13 February 2010 (for 20 days) by a current meter (SD 6000; MINI; Norway) at 707918 E, 1458486 N located 1 m below the sea surface.

The DO dispersion pattern was studied by applying the numerical model which was developed by Anongponyoskun *et al.* (2008). The parameter of sources and sinks of DO was applied

in the DO dispersion model. The model was verified by using the observed DO concentration measured at 16 stations using a DO meter (model 85; YSI Incorporated; Yellow Springs, OH, USA) every 2 hr around the green mussel culture area during the period from 1200 hours on 29 January 2010 to 1100 hours on 30 January 2010.

## RESULTS

The seawater velocity predicted by POM was calibrated by the raw seawater velocity data. Seawater velocities were indicated by arrows. The length and direction of each arrow represented the speed and direction of water flow, respectively. The results showed that seawater flowed northward ( $10^\circ$ – $40^\circ$ ) during the flood tide while southward flow ( $190^\circ$ – $220^\circ$ ) parallel to the shoreline was observed during ebb tide. The average maximum water velocity was approximately  $1 \text{ m}\cdot\text{sec}^{-1}$  (Anongponyoskun, 2007; Tharapan and Anongponyoskun, 2010). The trends of the phase and magnitude of the predicted velocities were similar to those of the observed velocities as shown by the stick diagrams in Figure 2.



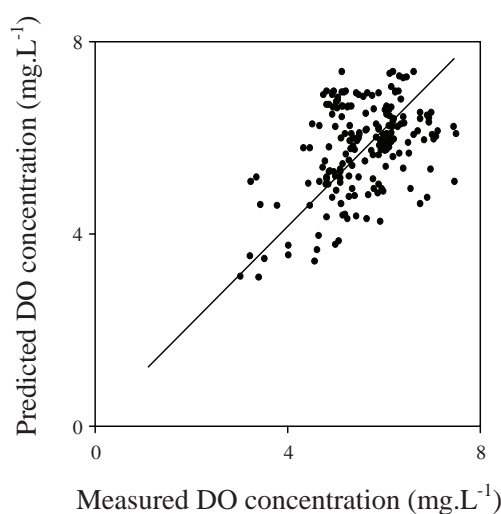
**Figure 2** Comparison of stick diagrams of (a) observed velocities during period from 25 January 2010 to 11 February 2010 with (b) predicted velocities.

The model of DO dispersion was introduced for predicting the pattern of DO spread in the area of green mussel culture. The model combined the physical and biochemical activities prevailing in the water body. The variation in the observed DO concentration, predicted DO concentration and seawater height at Station 6 measured from 1200 hours on 29 January 2010 to 1100 hours on 30 January 2010 is shown in Figure 3 and shows that the decline in the DO concentration during the night was essentially linear with respect to water height or tide; it was low when the water flow was slack and also at low tide during the night, and was high when the water was flowing rapidly and/or at high tide during the day. It seemed that advective and diffusive modes of transport of seawater in Sri Racha Bay were the main parameters which influenced the DO concentration.

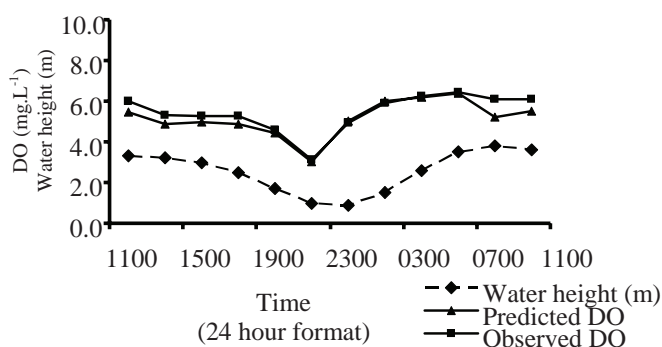
The predicted DO concentrations agreed reasonably well with the measured DO concentrations in the green mussel farming area as shown in Figure 4. The differences between the measured and the predicted DO concentration ranged between 0.0 and 4.0 mg.L<sup>-1</sup>. The average absolute difference between the measured and predicted DO concentration was 0.8 mg.L<sup>-1</sup>.

The predicted DO dispersion pattern in the green mussel culture area was calibrated

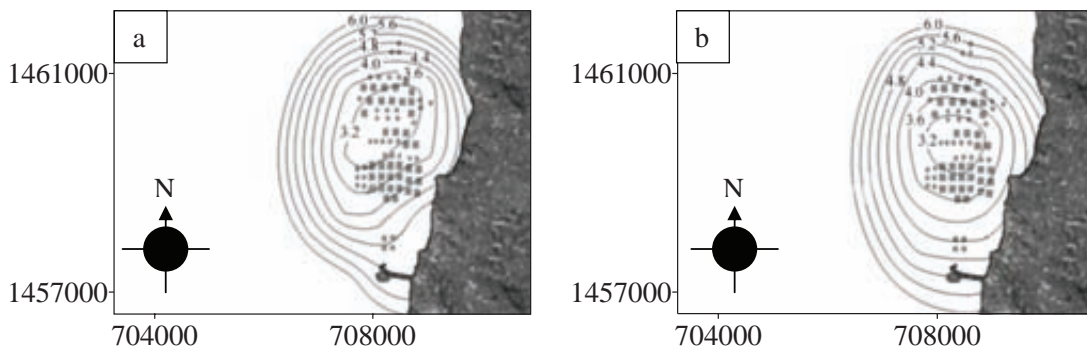
using the observed data measured with the DO meter from 1200 hours on 29 January 2010 to 1100 hours on 30 January 2010. At low tide (2100 hours on 29 January 2010), the results of the DO concentration between the simulated and field observations agreed well, showing that the area close to the center of the green mussel culture area where there was intensive culture had the lowest DO concentration (Figure 5).



**Figure 4** Relationship between measured dissolved oxygen (DO) and predicted DO concentrations.



**Figure 3** Variation in observed dissolved oxygen (DO) concentrations, predicted DO concentrations and seawater heights at Station 6 from 1200 hours on 29 January 2010 to 1100 hours on 30 January 2010.



**Figure 5** a) Observed and b) predicted pattern of dissolved oxygen diffusion contours ( $\text{mg.L}^{-1}$ ) in green mussel culture area, Sri Racha Bay, Chonburi province on 29 January 2010 (2100 hours).

## DISCUSSION

Sufficient oxygen in seawater is one of the key factors to facilitate normal green mussel activity. In a normal situation, the minimum DO level must be 50% saturation and this is recommended for purification systems (Ree *et al.*, 2010). In a circulating system, the DO concentration in the water can be affected by a number of factors such as aeration, seawater movement, green mussel respiration, consumption by other aquatic living organisms and production and use by aquatic plants in the seawater, and lastly by soil uptake. The DO concentration should be sufficient in order to provide the optimum conditions for growth and survival of all green mussels in the culture area.

In Sri Racha bay, the DO concentration at saturation (temperature  $28.5\text{ }^{\circ}\text{C}$  and salinity 32.5 psu) is  $6.47\text{ mg.L}^{-1}$ . Seawater could contain less DO at saturation than expected at night due to respiration by fish, plankton, other marine organisms and also uptake by sediment. The soil could also cause a reduction in the DO concentration within the culturing area. At night, the DO concentration was below saturation due to oxygen uptake by all organisms; it decreased to  $3\text{ mg.L}^{-1}$  at night and then decreased to less than  $2\text{ mg.L}^{-1}$  in the early morning (Boyd, 1982). The low DO concentration of less than  $3\text{ mg.L}^{-1}$  could

cause stress and/or mortality in green mussels. The depletion of DO could kill green mussels and could dramatically reduce feeding activity which would eventually result in growth reduction in the area where chronically low concentrations of DO in seawater occurred (Boyd, 1982). According to the results, the DO concentration in the green mussel culture area was influenced by seawater transportation. Thus, when fishermen modified the Sri Racha Bay for culturing purpose by adding floating rafts, these rafts profoundly affected photosynthesis and respiration by aquatic animals. There are interdependent links between the DO concentration and the physical patterns of circulation of seawater. The ecosystems in the bay involve photosynthesis, seawater circulation and community respiration (Howard, 1960). The increasing area of green mussel culture was considered as a negative impact on the DO concentration in the ecosystems. Therefore, the management of the area used for green mussel culture is an important subject for sustainable and suitable environment (Nyoman *et al.*, 2008). It is necessary to have good farming management in order to gain more production. The best way to solve this problem is to increase the distance between the floating rafts to be sufficient for good circulation of seawater. Easy circulation of seawater could relieve the effect of the lack of DO in the culture area.

The expansion of green mussel culture may cause over-exploitation and unsustainable levels of use of the natural resources. In order to solve such problems, this model could be a tool for predicting and estimating the amount of oxygen in marine culturing areas. Moreover, farmers could apply this model to improve and manage their marine culture in order to increase the production and preserve the environment.

### CONCLUSION

The output of the POM showed that seawater was northward flowing during flood tides while during ebb tides, it was southward flowing along the shoreline. The maximum speed of the seawater current in Sri Racha Bay was approximately 1 m.sec<sup>-1</sup>. There was an acceptable correspondence in the DO concentration between the simulated and field observations, showing that the area close to the center of the green mussel culture area had the lowest DO concentration. The DO dispersion model could be an important instrument for estimating the capability of DO concentration in order to gain sustainable production and preserve the environment.

### ACKNOWLEDGEMENTS

The authors wish to thank the Geo-Informatics and Space Technology Development Agency (GISTDA), Bangkok, Thailand for providing the satellite image dataset.

### LITERATURE CITED

- American Public Health Association. 1980. **American Public Health Association—Standard Methods for the Examination of Water and Wastewater, 15th Edition.** APHA—AWWA—WPCF, Washington DC. 1,000 pp.
- Anongponyoskun, M. and T. Sasaki. 1996. Numerical calculation of DO distribution in Yashima Bay, Japan. **Kasetsart J. (Nat. Sci.)** 30: 139–155.
- Anongponyoskun, M. 2007. Numerical model of tidal current used POM in Ao Siracha, Chon-Buri province, pp. 634–640. *In* **45th Kasetsart University Annual Conference (Fisheries and Agro-Industry).** Kasetsart University. Bangkok.
- Anongponyoskun, M., P. Sojisuporn, S. Meksumpun and S. Petpiroon. 2008. Application of remote sensing image and mathematical model for dispersion of suspended solid in the Upper Gulf of Thailand. **Kasetsart J. (Nat. Sci.)** 42: 299–305.
- Boyd, C.E. 1982. **Water Quality Management for Pond Fish Culture.** Elsevier Sci. Publ. Co. Amsterdam. 319 pp.
- Choksuchart, A. 2011. **Development of Mathematical Model on Oxygen Budget of Pacific White Shrimp (*Litopenaeus vannamei*) Culture in Earthen Pond.** MSc. Thesis. Kasetsart University. 96 pp.
- Department of Fisheries. 2010. **Fisheries Statistics of Thailand 2008.** Information Technology Center, Department of Fisheries, Ministry of Agriculture and Cooperatives. No.12/2010. 99 pp.
- Howard, O.T. 1960. Analysis of diurnal oxygen curves for the essay of re-aeration rates and metabolism in polluted marine bays, pp 547–555. *In* **Waste Disposal in the Marine Environment.** University of Florida.
- Nyoman, I.R., S. Saitoh and A. Miyazono. 2008. GIS-based multi-criteria evaluation models for indentifying suitable sites for Japanese scallop (*Mizuhopecten yessoensis*) aquaculture in Funka Bay, southwestern Hokkaido, Japan. **Aquaculture J.** 284: 127–135.
- Ree, G., K. Pond, D. Kay, J. Bartram and J. Santo Domingo. 2010. **Safe Management of Shellfish and Harvest Waters.** Page Bros. Ltd. Norwich, Norfolk, UK. 346 pp.

- Seekao, C. 2006. **Application of Geographic Information System and Remote Sensing for Green Mussel Raft Culture Zoning in Sriracha Bay, Chonburi Province**. MSc. Thesis. Kasetsart University. 147 pp.
- Thames Survey Committee. 1964. Absorption of Atmospheric Oxygen, pp.1054. *In* **Effects of Polluting Discharges on the Thames Estuary**. London.
- Tharapan, S. and M. Anongponyoskun. 2010. Application of numerical model for computing tidal current by changing amplitude of tidal constituents in Ao Siracha, Chonburi province, pp. 203–209. *In* **48th Kasetsart University Annual Conference (Fisheries and Agro-Industry)**. Kasetsart University. Bangkok.
- Vichkovitten, T. and H. Inoue. 1997a. Dissolved oxygen environments of the fish farm in Yashima Bay, Japan I. Primary productivity of sea water. **Kasetsart J. (Nat. Sci.)** 31: 385–391.
- Vichkovitten, T. and H. Inoue. 1997b. Dissolved oxygen environments of the fish farm in Yashima Bay, Japan II. Respiration of globefish (*Takifugu rubripes*). **Kasetsart J. (Nat. Sci.)** 31: 465–472.