ผลกระทบของอุทกภัยในปี 2554 ต่อกิจกรรมเพาะเลี้ยงหอย บริเวณอ่าวบ้านดอน จังหวัดสุราษฎร์ธานี

The Effect of Flooding in 2011 on Shellfish Culture at Bandon Bay, Surat Thani Province

อมรภัค ณ นคร[1*] พนาลี ชีวกิดาการ[1] และ สมทิพย์ ด่านธีรวนิชย์[2]
Amonpak Nanakorn[1*], Panalee Chevakidagarn[1] and Somtip Danteravanich[2]

บทคัดย่อ

งานวิจัยในครั้งนี้มีวัตถุประสงค์เพื่อศึกษาสถานการณ์ของกิจกรรมเพาะเลี้ยงหอย บริเวณอ่าวบ้านดอน จังหวัดสุราษฎร์ธานี จากเหตุการณ์อุทกภัยในปี 2554 รวมทั้งการวิเคราะห์แนวทางสำหรับการลดผลกระทบจากเหตุการณ์อุทกภัย การศึกษานี้มีการเก็บข้อมูลทั้งข้อมูลปฐมภูมิและข้อมูลทุติยภูมิ ซึ่งประกอบด้วยข้อมูลเกี่ยวกับพื้นที่เพาะเลี้ยงหอย ต้นทุนและผลประโยชน์จากการเพาะเลี้ยงหอย รวมทั้งข้อมูลคุณภาพน้ำทะเลชายฝั่งของพื้นที่อ่าวบ้านดอน ในช่วงฤดูฝน การลงพื้นที่เพื่อเก็บข้อมูลและสัมภาษณ์เชิงลึกผู้เพาะเลี้ยงหอยจำนวน 25 ฟาร์ม เกี่ยวกับการดำเนินการเลี้ยงหอย การจัดการการเลี้ยง และผลกระทบที่ได้รับจากการเปลี่ยนแปลงคุณภาพสิ่งแวดล้อม ซึ่งผลการศึกษาในครั้งนี้ พบว่า หลังเหตุการณ์อุทกภัย ปี 2554 ข้อมูลต้นทุนการผลิตที่น้อยลง และผลกำไรที่สูง จึงทำให้หอยแครงเป็นชนิดพันธุ์ที่นิยมเลี้ยงบริเวณอ่าวบ้านดอนเพิ่มขึ้น นอกจากนี้บริเวณอ่าวบ้านดอนตอนในซึ่งตั้งอยู่ใกล้แม่น้ำตาปี พบว่า มีค่าความเค็มต่ำสุด และปริมาณแบคทีเรียสูงสุด ขณะที่บริเวณชายฝั่งด้านตะวันออกของแม่น้ำตาปี พบว่า มีค่าสารอาหารและการสะสมของตะกอนสูง ซึ่งการเปลี่ยนแปลงคุณภาพน้ำในช่วงฤดูฝนหรือช่วงการเกิดอุทกภัยส่งผลกระทบต่อการลดลงของผลผลิตหอย ดังนั้น หน่วยงานรัฐจำเป็นต้องสนับสนุนให้มีระบบเตือนภัย การทำความสะอาดผลผลิตหอย และการรวมกลุ่มของผู้เพาะเลี้ยง เพื่อพัฒนาการเพาะเลี้ยงหอยบริเวณอ่าวบ้านดอนในทิศทางที่ยั่งยืนต่อไป

คำสำคัญ: การเลี้ยงหอย, อ่าวบ้านดอน, อุทกภัย

[1] คณะการจัดการสิ่งแวดล้อม มหาวิทยาลัยสงขลานครินทร์ วิทยาเขตหาดใหญ่ จังหวัดสงขลา 90110
[1] Faculty of Environmental Management, Prince of Songkla University, Songkhla Campus, Songkhla 90110
[2] คณะวิทยาศาสตร์และเทคโนโลยีอุตสาหกรรม มหาวิทยาลัยสงขลานครินทร์ วิทยาเขตสุราษฎร์ธานี จังหวัดสุราษฎร์ธานี
[2] Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani Campus, Surat Thani 84000
* Corresponding author: lumyaichutong@hotmail.com

Abstract

The purpose of this study was to study situations of shellfish culture at Bandon Bay, Surat Thani province, since flooding in 2011. In addition, this paper proposes recommendations to reduce the impact of flooding on shellfish farming. This paper carried out both primary and secondary data consisting of cultural areas, costs and benefits of production and coastal seawater characteristics during the rainy season. Field observation and in-depth interviews were carried out in 25 selected farms which had cultural operations, managing techniques, and environmental impact. The results showed that after flooding, because of economic concerns, blood cockle culture has been popular at Bandon Bay due to low production costs and high profits. The flooding had severe effects on shellfish culture. Particularly, as the inner bay was near the discharge point, it was the lowest in salinity and the highest in bacteria levels in the rainy season. The east side of the Tapi River was the highest in nutrients and had the highest sediment accumulation. The change in coastal seawater quality during rainy seasons or flooding affected shellfish production. The government sectors need to support farmers for warning systems, sanitary control and strong networking. Farmer cooperation can be an additional driver for the sustainable development of shellfish farming.

Keywords: Shellfish culture, Bandon Bay, Flooding

Introduction

Climate change is an additional driver of change in coastal environments. There is increasing evidence that the world climate is changing with significant changes in rainfall, temperature and sea levels (Handisyde et al., 2014). General impacts increased temperature leading to changes in weather patterns with more rainfall in some areas, more frequent occurrence of extreme weather with increased storms, flooding and sea level rise. Climate change may be changes in seasonality and typical tracks of storm events (Edwards, 2015: Allison, 2011: De Silva and Soto, 2009). For the flooding in March 2011 in Surat Thani, the statistical data of accumulated rainfall and runoff was 809.4 millimeter and 2,386.9 million cubic meters, respectively, which were the highest for a number of decades (Surat Thani Meteorological Station, 2014: Royal Irrigation Department Thailand, 2014). The event caused a great amount of freshwater, sediment and organic matter to be discharged from inland areas to the Tapi River and Bandon Bay. The worst flood in Surat Thani affected coastal shellfish culture. Almost all oyster (Crassostrea lugubris and Crassostrea belcheri), blood cockle (Anadara granosa and Anadara nodifera) and green mussel (Perna Vindis) production was destroyed. Because, the water quality was the important cause, particularly the reduction of salinity and increasing of total suspended solid. Shellfish products were decreased by flooding during 2010-2011, ranging from 7.89-13.75 thousand tons, i.e., 85 percent reduction of products as compared with 2009 (Department of Fisheries: DOF, 2014). Not only flooding affected the reduction of products, but also the event impacted on operating materials, processing costs and benefits. Those included loss of spat, and the spread of pests and diseases (De Silva and Soto, 2009). The main objective of this paper was to study situations of shellfish culture during the flooding of 2011. This study carried out both primary and secondary data which included shellfish culture, operating technologies, environmental quality, production costs and social benefits. All data were analyzed for the recommendations, which will be used to reduce the flooding impacts. With the aims that the local government sectors will use those recommendations for future management.

Materials and methods

Study areas

Bandon Bay locates along the middle part of Southern Thailand's east coast along the Gulf of Thailand. This study covers 4 districts, namely, Chaiya, Thachang, Kanchanadit and Don Sak (Figure 1). The data collection was carried out from 2012 to 2013. The 25 selected farmers were from 3 farms in Chaiya, 5 farms in Thachang, 14 farms in Kanchanadit and 3 farms in Don Sak. All selected farms were considered by various species (Crassostrea lugubris, Crassostrea belcheri, Anadara granosa, Anadara nodifera and Perna Vindis).

Data collection

Data collection in this study was carried out in 2 parts which could be addressed as follows:

Field observation and in-depth interviews were carried out by structured questionnaires. The interviews were conducted with farmers about cultural operations, managing techniques, and environmental impacts. The data on interviews covered the participation of farmers, encouragement of local government sectors and regulations of culture.

The secondary data was on culture areas, costs and benefits of production. Those were collected from Surat Thani Provincial Fisheries Office (SPFO) and Department of Fisheries (DOF). The culture areas, costs and benefits were analyzed for comparison before flooding (during 2006-2009) and after flooding (during 2012-2013). Coastal seawater characteristics during 1997-2013 in the rainy season, were reported by the Pollution Control Department (PCD) during 1997-2013 and Surat Thani Provincial Fisheries Office (SPFO) during 2001, 2010-2011, 2013.

Data analysis

Mean statistical analyses were used to analyze all secondary data , while standard deviation (SD) was used to analyze seawater quality. The seawater quality results were compared with Thai Marine Water Quality Standard for aquaculture (PCD, 2006).

Results and Discussion

Performance and culture technologies

From observations and in-depth interviews, blood cockle and oyster culture are carried out at 500-3,000 meters from the coast, and green mussel culture is carried out more than 3,000 meters from the coast. Figure 2 shows technologies for shellfish culture, inter-tidal bottom culture are applied for oyster culture while suspended culture are applied for green mussel culture. Blood cockle culture is freely scattered on the sediment. *Crassostrea lugubris*, *Crassostrea belcheri* and *Anadara nodifera* seed breed in the Bandon bay while *Anadara granosa* and *Perna Vindis* seeds have been imported from Malaysia. Harvesting and cleaning are carried out by laborers for oysters and green mussels, while hydraulic machines were used for blood cockle harvesting and cleaning.

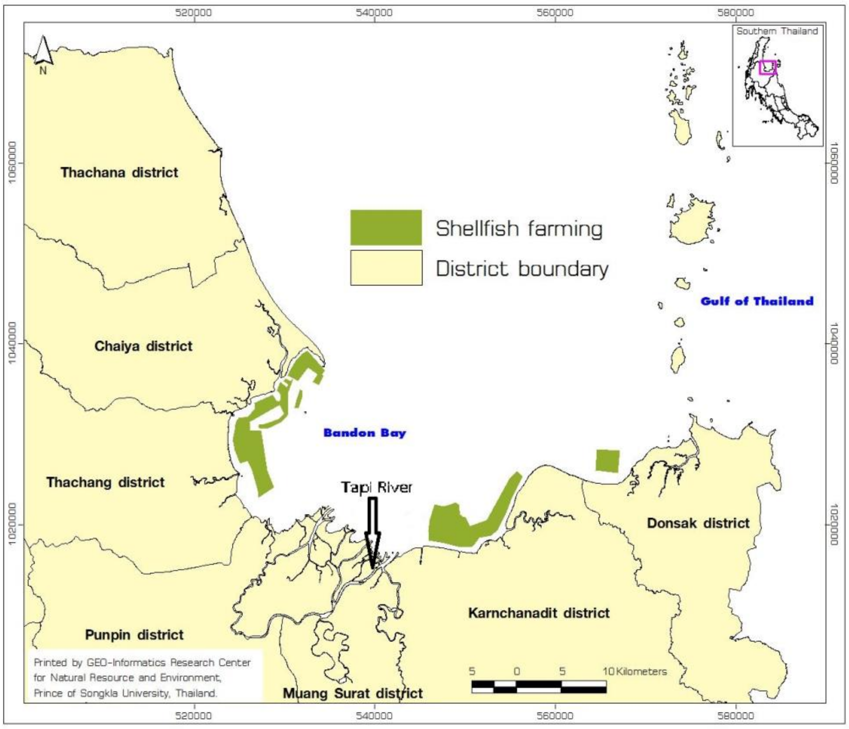

Figure 1. Bandon Bay and shellfish culture areas, Surat Thani province Thailand (Sources: Informatics Research Center for Natural Resources and Environment Southern Regional Center of Geo-Informatics and Space Technology, 2015.)

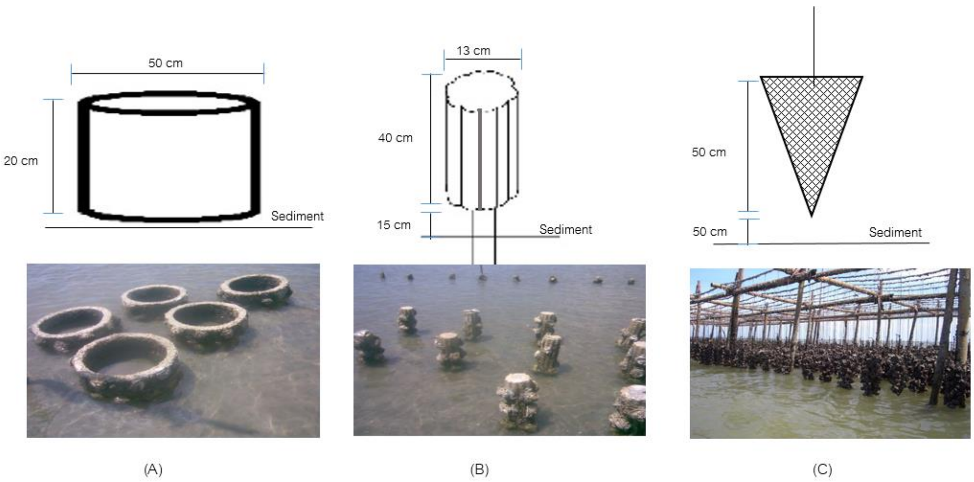

Figure 2 Bottom culture for oysters (A) cement chimneys and (B) cement pipes. Suspended culture for green mussels (C) net bags at Bandon Bay, Surat Thani province. Sources: surveyed during 2012-2014

Costs and benefits

After flooding, the production cost for blood cockle culture became very low because of seed cost. Nearly 84 percent of the production cost of blood cockle culture was seed cost. However, most of the farmers collected blood cockle (mainly *Anadara granosa)* spat from the inner bay, instead of importing it from abroad. In addition, in 2012-2013, the price of shellfish increased, as compared with before flooding, in 2007-2009 (Table 1). In particular, oyster prices increased greatly. Unfortunately, oyster seeds were decreased by flooding. Oyster culture was inter-tidal bottom culture which caused a low oyster yield. The on-bottom culture was of a lesser quality and lower oyster weight, difficult for biofouling elimination and predator avoidance, and particularly gained lower profits than the floating culture (Alfsen, 1987; Tanyaros, 2015).

The bottom culture associated with being near the discharge point could be affected by flooding as mortality increase, metals accumulation, bacterial contamination, etc (Aschenbroich et al., 2015; Fiandrino et al., 2003). Therefore, blood cockles have been popular for shellfish culture at Bandon Bay while oyster culture was carried by households or related with blood cockle culture.

Shellfish culture areas and production

The most intensive shellfish culture was in Kanjanadit, Thachang, Chaiya and Donsak, (Table 2). The main reasons for the high growth of shellfish in Kanjanadit are higher algae diversity, additional nutritious food consisting of attached benthic diatoms and stable algae concentrations in the sediment (Kaewnern and Yakupitiyage, 2007).

Table 1. Shellfish productions at Bandon Bay, in different species before and after flooding

Topics	Pacific oysters (N=73)		Blood cockles (N=526)		Green mussels (N=89)	
	Before	After	Before	After	Before	After
Production (kg/rai/year*, oysters/rai/year)	3,652.32	436.84	2,253.00	1,176.26	7,794.35	3,725.93
Price (THB /kg*, THB/oysters)	9.42	50.90	18.99	34.36	8.69	30.67
Total cost (THB/rai/year)	13,804.04	14,273.02	21,664.37	13,848.02	41,646.55	42,814.81
Income (THB /rai/year)	33,971.51	21,791.41	41,545.33	40,842.24	65,129.21	113,925.93
Profit (THB /rai/year)	20,167.48	7,518.39	19,880.96	26,994.22	23,482.67	71,111.11

Sources: Calculated from SPFO (2014a)

Note: Values represent is average; N is total number of farm; * is production of blood cockles and mussels; ** is price of blood cockles and mussels; Data from 2007-2009 is calculated for “Before flooding” , during 2012-2013 is calculate for “After flooding” ,USD 1 is approximately THB 32, (THB is Baht); 625 rai = 1 km^2

Table 2. Productions of shellfish culture at Bandon Bay, in different districts before and after flooding

		Culture areas (rai)			Products (thousand tons)		
District	Species	Before	After	Percentage	Before	After	Percentage
	Anadara granosa/nodifera	3,258.79	1,288.40	14.75	4.64	2.37	6.70
	Crassostrea lugubris	323.64	268.50	0.41	1.09	0.36	2.15
	Perna vindis	1,327.25	0.00	9.93	3.70	0.00	10.91
Chaiya	*Summary of area*	*4,909.68*	*1,556.90*	*25.09*	*9.43*	*2.73*	*19.76*
	Anadara granosa/nodifera	6,433.12	5,913.30	3.89	9.16	4.68	13.22
Thachang	*Summary of area*	*6,433.12*	*5,913.30*	*3.89*	*9.16*	*4.68*	*13.22*
	Anadara granosa/nodifera	19,592.10	12,680.02	51.73	18.05	9.22	26.05
	Crassostrea belcheri	4,311.50	3,953.27	2.68	13.30	4.34	26.43
	Perna vindis	1,360.00	248.65	8.32	3.90	0.69	9.47
Kanjanadit	*Summary of area*	*25,263.60*	*16,881.94*	*62.73*	*35.25*	*14.25*	*61.95*
	Anadara granosa/nodifera	2,004.07	994.70	7.55	2.85	1.46	4.10
	Crassostrea belcheri	97.09	0.00	0.73	0.33	0.00	0.97
Donsak	*Summary of area*	*2,101.16*	*994.70*	*8.28*	*3.18*	*1.46*	*5.07*
	Total	38,707.56	25,346.84	100	57.02	23.12	100

Sources: Calculated from SPFO (2014b) and DOF (2014)

Note: Values represent is average; Data from 2006-2009 is calculated for "Before flooding" and in 2012 is calculated for "After flooding"

In 2012, after the summer flood, there were large mortalities of shellfish at Bandon Bay. There were decreases in production in each district at 50.07, 29.58 and 20.38 percent, for blood cockles, oysters and green mussels, respectively. Those results were compared with production in 2009, before flooding (DOF, 2014). Oysters and blood cockles were highly decreased in Kanjanadit, while green mussels were highly decreased in Chaiya. The reduction of these products in Kanjanadit can be explained by water quality change and sediment accumulation.

Those were affected by freshwater runoff from the Tapi River, which is very close to Kanjanadit. High accumulation of sediment can occur at Kanjanadit where there are high densities of oyster culture. Oysters are cultivated on the bottom, sticking on permanent structures, which are cement chimneys and pipes (Figure 1) that are driven into the sediment. The structures could be caused the high retention time of water that it affected to sediment accumulation. Meanwhile, shellfish culture in Chaiya was located north of the bay. Suspended materials for green mussels culture was wiped out with violent waves. Green mussels have replaced oyster culture and blood cockle culture.

Coastal water quality and sediment quality in the rainy season at Bandon Bay

According to the analysis of coastal seawater quality at Bandon Bay, Surat Thani province from 1997 to 2013 that was analyzed in the rainy seasons (Table 3), the shellfish culture areas were directly affected by coastal water quality. Because, the culture areas were located at the offshore. The main pollutions were from inland activities draining into the bay. In particular, near the Tapi River and the inner bay, those coastal water qualities were worse than others. The inner bay area is the location of Thachang, Meuang and Kanjanadit. The lowest salinity was in the inner bay area, which was reported at 0 ppt in the rainy seasons.

Salinity is positively correlated with condition index (whole weight, shell widths and lengths) in blood cockles, oysters and green mussels. Both lower and higher salinity of the water affected the mortality of shellfish through low oxygen exchange, low food filtration, etc (Jarernpornnipat and Buppha, 2012).

During the rainy season, discharge from Tapi River is very high and the wind direction is from the west. Consequently, nutrient loads dispersed to the right of the Tapi River mouth in Kanchanadit and Donsak (Jarernpornnipat et al., 2003). In addition, Kanjanadit carried out 49.87 percentage of the total shrimp culture in Bandon Bay (Surat Thani Coastal Fisheries Research and Development Center, 2013). Nutrient loading from the culture ponds were released to the coastal bay through effluent when maintaining water levels in the culture ponds and harvesting.

Table 3. The values represent the mean and standard deviation (SD) of coastal water quality in rainy seasons during 1997-2013, in different districts at Bandon Bay.

Parameters	N	Shellfish culture areas				
		Chaiya	Thachang	Meuang	Kanjanadit	Donsak
Salinity (ppt)	392	20.71±8.93 (0.0 - 33.0)	13.04±9.03 (0.0 - 30.0)	8.97±8.07 (0.0 - 31.0)	15.94±6.58 (0.0 - 27.0)	23.68±5.36 (2.0 - 31.0)
Transparency (meter)	342	0.68±0.40 (0.01 – 1.80)	0.41±0.29 (0.10 – 1.35)	0.49±0.27 (0.07 – 1.30)	0.37±0.24 (0.10 – 1.50)	0.30±0.23 (0.05 – 1.00)
Total suspended solids (mg/L)	338	40.57±28.10 (15.3 – 139.3)	44.25±38.87 (6.66 – 208.0)	32.15±28.03 (2.0 – 171.5)	45.21±32.90 (9.3 – 196.0)	50.03±29.19 (3.3 – 144.0)
Ammonia nitrogen (μg/L)	377	164.0±266.7 (0 – 1,773.0)	125.38±183.19 (0 – 1,095.6)	184.64±294.83 (0 – 1,562.7)	209.2±269.28 (0 – 1,278.0)	199.65±338.96 (0 – 1,424.4)
Nitrate nitrogen (μg/L)	389	81.4±126.56 (0 – 515.7)	102.0±305.9 (0 – 2,663.0)	176.58±451.36 (1.63 – 3,985.2)	305.3±586.5 (0.2 – 4,099.6)	303.0±937.47 (0 – 4,026.1)
Phosphate phosphorus (μg/L)	376	27.2±29.66 (0 – 136.2)	27.16±32.50 (0 – 191.8)	27.92±33.90 (0 – 205.5)	63.75±63.47 (1.0 – 296.0)	86.48±176.92 (0.6 – 795.2)
Chlorophyll a (μg/L)	246	0.94±1.89 (0 – 8.27)	3.39±10.6 (0 – 65.49)	0.44±1.01 (0 – 5.21)	6.49±20.51 (0 – 130.38)	6.69±14.96 (0 – 60.18)
Total coliform bacteria (MPN/100 ml)	263	336.5±537.5 (0 – 1,600)	2,413±12,377 (0 – 92,000)	6,230±23,095 (0 – 160,000)	1,393±2,926 (2 – 22,000)	452.6±668.8 (0 – 1,600)
Fecal coliform bacteria (CFU/100 ml)	246	172.5±390.4 (0 – 1,600)	333.6±618.7 (0 – 3,300)	1,074±2,838.8 (0 – 16,000)	743.9±1,679.3 (0 – 9,200)	269.5±530.4 (0 – 1,600)

Sources: Calculated from PCD (2014) and SPFO (2014c)

Note: N is total number of data; Data from PCD: Two months per year; Data from SPFO: 12 months per year

In rainy seasons, the mean values of ammonia nitrogen, nitrate nitrogen and fecal coliform bacteria in each district were not within the range of standard values of coastal seawater quality for aquaculture areas (Thai Marine Water Quality Standard announced in 2006). Those values should be less than 100 μg/L, 60 μg/L and 70 CFU/100 ml for ammonia nitrogen, nitrate nitrogen and fecal coliform bacteria, respectively (PCD, 2006). Meanwhlie, total coliform bacteria should be less than 1,000 MPN/100 ml but in the inner bay were higher than the Thai Marine Water Quality Standard. Therefore, during or after flooding, shellfish culture could be affected by water quality Bacteria affected oyster quality because fresh oysters were consumed without depuration. Depuration should be also done in specialized plants, in particular using ozone for disinfecting sea water (Alfsen, 1987); oysters are cleaned to achieve good quality. However, in Thailand, the lack of or lower sanitary control for oyster processing was always found and, consequently, health hazards were caused by oysters.

During the rainy season at Bandon Bay high organic matter in sediments was found, when compared with the dry season (Sukudom et al., 2015). The huge discharge of freshwater included sediment loading to the coast. In particular, the east side of the Tapi River higher organic matter was found in the sediment than other areas. The range of organic matter was 1.60-3.86 percent, while coastal sediment particles had clay loam characteristics (Roekdee, 2015; Phodfueang et al., 2015). Moreover, the densities and durations of shellfish culture influenced altered sediment geochemistry. Sedimentation rates increased from the bio-deposition of shellfish feces and pseudofeces, all of which increased the organic carbon content of sediments (Burkholder and Shumway, 2011; Mesnage et al., 2007). During flooding, tidal flooding and freshwater discharge in shellfish culture areas, particularly close to the effluent discharge point where soil anoxic conditions were most affected, while the pH reduction may have directly affected larval shellfish survival. That may have also promoted the proliferation of opportunistic pathogens and developed larvae susceptible to infectious agents (Elston and Ford, 2011). Those were found in each shellfish area at Bandon Bay, especially at Kanjanadit. Therefore, Kanjanadit could be high affected by flooding, in both water quality and sediment quality.

Conclusion and Recommendations

The results of this study, inter-tidal bottom culture and culture areas (near the coast) caused the high mortalities of blood cockles and oysters, compared with the suspended culture of green mussels. After flooding, with concern to the economic aspect, blood cockle culture was promoted because of numerous natural spat and low production costs when compared with before flooding. The shellfish farms at the sensitive points, where were inner bay which were near the discharge point and on the east side of the Tapi River. Water quality, including salinity, nutrients and bacteria, affected shellfish production. Therefore, the tools were real-time water quality monitoring. In particular, salinity should be detected at the Tapi River and the inner bay. Those were important for reducing the flooding impacts. Technology for the shellfish operations included geographic information systems (GIS), depuration plants and hatcheries. GIS can be applied for site selection, determining and monitoring special zoning for natural spat of blood cockles, in order to avoid or minimize the risk from flooding. On the other hand, seawater disinfection is used for cleaning including shellfish products, depuration plants and screening tools. These proceeds should be of concern to ensure production quality, particularly during the rainy season and flooding. Oyster hatcheries would conserve the spat and replace the lack of natural juveniles or uncertain supplies of seed. Local government sectors should support technology and disseminate knowledge for efficient shellfish culture.

Acknowledgements

The authors sincerely thank the Graduate School at Prince of Songkla University and the Office of the Higher Education Commission at the Ministry of Education, Thailand for financial support. In addition, the authors would like thank the Surat Thani Provincial Fishery Office for information support.

References

Alfsen, C. 1987. Shellfish culture in France. 1st Edition. Bangkok, Thailand: Southeast Asian Fisheries Development Center.

Allison, E. H., M. C. Badjeck, and K. Meinhold. 2011. Chapter 17: The implications of global climate change for molluscan aquaculture. *In*: S. E. Shumway. Shellfish Aquaculture and the Environment. Oxford, United Kingdom: John Wiley & Sons.

Aschenbroich A., C. Marchand, N. Molnar, J. Deborde, C. Hubas, H. Rybarczyk and T. Meziane. 2015. Spatio-temporal variations in the composition of organic matter in surface sediments of a mangrove receiving shrimp farm effluents (New Caledonia). *Science of the Total Environment*. 512–513, 296–307.

Burkholder, J. M, and S. E. Shumway. 2011. Chapter 7: Bivalve shellfish aquaculture and eutrophication. *In*: S. E. Shumway. Shellfish Aquaculture and the Environment. Oxford, United Kingdom: John Wiley & Sons.

De Silva, S. S. and D. Soto, 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *In*: K. Cochrane, C. De Young, D. Soto and T. Bahri. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. Rome: FAO Fisheries and Aquaculture Technical Paper.

Department of Fisheries (DOF). 2014. Database on statistic of shellfish area and product in Surat Thani province during 1999-2012. Bangkok: Ministry of Agriculture and Cooperatives.

Edwards, P. 2015. Aquaculture environment interactions: Past, present and likely future trends. Aquaculture. 447, 2–14

Elston, R. A, and S. E. Ford. 2011. Chapter 13: Shellfish diseases and health management. *In*: S. E. Shumway. Shellfish Aquaculture and the Environment. Oxford, United Kingdom: John Wiley & Sons.

Fiandrino, A., Y. Martinb, P. Gota, J. L.Bonnefontb and M. Troussellier. 2003. Bacterial contamination of Mediterranean coastal seawater as affected by riverine inputs: simulation approach applied to a shellfish breeding area (Thaulagoon, France). Water Research. 37, 1711–1722.

Handisyde, N., D. S. Lacalle., S. Arranz, and L. G. Ross. 2014. Modelling the flood cycle, aquaculture development potential and risk using MODIS data: A case study for the floodplain of the Rio Paraná, Argentina. Aquaculture. 422–423, 18–24.

Informatics Research Center for Natural Resources and Environment Southern Regional Center of Geo-Informatics and Space Technology. 2015. Shellfish culture areas at Bandon Bay in Surat Thani province. Songkhla: Faculty of Environmental management, Prince of Songkhla University.

Jarernpornnipat, A., O. Pedersen., K. R. Jensen., S. Boromthanarat., S. Vongvisessomjai, and P. Choncheanchob. 2003. Sustainable management of shellfish resources in Bandon Bay, Gulf of Thailand. Coastal Conservation. 9, 135-146.

Jarernpornnipat, A and N. Buppha. 2012. Effects of environmental factors on condition index of blood cockle (*Anadara* spp.) In Bandon Bay, Suratthani-Thailand. *In*: Proceedings of International Fisheries symposium-IFS (2012)-Seed production and aquaculture system. December 6-8, 2012, Can Tho city, Vietnam.

Kaewnern, M. and A. Yakupitiyage. 2007. Situation analysis of mollusc culture in Bandon Bay and contribution to control eutrophication. Ph.D. Thesis. Asian Institute of Technology, School of Environment, Thailand.

Mesnage, V., S. Ogier., G. Bally., J. R. Disnar., N. Lottier., K. Dedieu., C. Rabouille, and Y. Copard. 2007. Nutrient dynamics at the sediment–water interface in a Mediterranean lagoon (Thau, France): Influence of biodeposition by shellfish culture activities. Marine Environmental Research. 63, 257–277.

Phodfueang, J., B. Plongon, and J. Salaenoi. 2015. Environmental condition of cockle farm in Bandon Bay, Gulf of Thailand. *In*: Proceedings of International Conference on Plant, Marine and Environmental Sciences (PMES-2015). January 1-2, 2015, Kuala Lumpur, Malaysia.

Pollution Control Department (PCD). 2006. Designated Thai Marine Water Quality Standard, in case used for aquaculture purposes. Ministry of Natural Resources and Environment. Bangkok, Thailand. Accessed 13 January 2016, http://-www.pcd.go.th/info_serv/reg_stdwater-02.html#s5.

Pollution Control Department (PCD). 2014. Database on coastal water quality in Surat Thani province during 1997-2013. Bangkok, Thailand: Ministry of Natural Resources and Environment.

Roekdee, U. 2015. Assessment of Heavy Metals Impact in the Ecosystem in Bandon Bay at Surat Thani Province and Using the Oyster as a Biological Index. Ph.D. Thesis. Prince of Songkla University.

Royal Irrigation Department Thailand. 2014. Hydrology and Water Management Center for Southern Region. The Runoff Statistical Data in Surat Thani during 1997-2013. Bangkok: Royal Irrigation Department Thailand.

Surat Thani Coastal Fisheries Research and Development Center. 2013. Data of shrimp farmers in Bandon Bay (2010-2012). Bangkok: Department of Fisheries.

Surat Thani Meteorological Station. 2014. The statistical data of yearly rainfall in Surat Thani province during 1997-2013. Surat Thani: Surat Thani Meteorological Station.

Surat Thani Provincial Fisheries Office (SPFO). 2014a. Database on shellfish benefit in Surat Thani province during 2007-2009, 2012-2013. Bangkok: Department of Fisheries.

Surat Thani Provincial Fisheries Office (SPFO). 2014b. Database of shellfish culturing area in Surat Thani province during 2006-2013. Bangkok: Department of Fisheries.

Surat Thani Provincial Fisheries Office (SPFO). 2014c. Database of coastal seawater quality at Bandon Bay in Surat Thani province during 2001, 2010-2011, 2013. Bangkok: Department of Fisheries.

Sukudom, C., M. Kaewnern., I. Wudtisin., T. Yoshikawa., Y. Okamoto., K. Watanabe., S. Ishikawa, and J. Salaenoi. 2015. Organic contents and pH profiles of sediments in cockle farm at Bandon Bay, Surat Thani Province. Khon Kaen Agriculture Journal. 43(3), 265-276.

Tanyaros, S. 2015. Oyster biology and aquaculture. Bangkok: Chulalongkorn University