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Regional Consequences of Seawater Intrusion on Rice Productivity and Land Use in Coastal Area of the Mekong River Delta

Akihiko KOTERA[1]*, Toshihiro SAKAMOTO[2], Duy Khang NGUYEN[3] and Masayuki YOKOZAWA[1]

[1] Agro-Meteorology Division, National Institute for Agro-Environmental Sciences (Tsukuba, Ibaraki 305–8604, Japan)
[2] Ecosystem Informatics Division, National Institute for Agro-Environmental Sciences (Tsukuba, Ibaraki 305–8604, Japan)
[3] Center for Water Resources Technology, Southern Institute of Water Resources Research (Ham Tu, Q.5, Ho Chi Minh, Vietnam)

Abstract

This study investigates rice productivity in the coastal area of the Mekong River Delta, Vietnam focusing on relationships with the influences of seawater intrusion and recent changes in the land use at regional scale. We examined the statistical data on rice production at 30 districts of 4 provinces in the coastal area for the years 2003–2005, together with the average salinity concentration observed at 48 points in canals and rivers during the dry season. As an index of the extent of seawater intrusion to be compared with rice statistical data in each district, average salinity of each district was derived by using spatial interpolation from the data in the observation points. It was shown that seawater intrusion was the major factor leading to regional differences in rice cropping systems and land use patterns in the region. Rice cropping intensities, which is defined as the ratio of planted area to district area, decreased with increasing salinity level in canal water, but rice yields averaged over the district are independent of the salinity level. To avoid salinity stress to rice growth, rice cultivation in the coastal area is mainly undertaken during the period when seawater intrusion is weakened by the seasonal decrease in salinity in the rainy season. Specifically, in districts with high salinity, the salinity-free duration required for rice cultivation is short. There, rice cropping intensities are potentially limited by the salinity. In addition, recently, the area of paddy fields in the coastal area has been decreased through land use conversion to aquaculture, especially shrimp farms. Intensity of aquaculture, which requires brackish water, was also limited by seawater intrusion. Thus, rice production in the coastal area of the Mekong Delta was limited by the interrelationship between seawater intrusion and land-use diversification.

Discipline: Agricultural environment
Additional key words: cropping pattern, rice yield, salinity

Introduction

Seawater intrusion caused by tidal fluctuations and low river-water levels is considered to be a major constraint to agricultural production in coastal areas[18]. This is particularly the case in delta regions with large lowland plains facing the sea. Here, seawater intrusions can reach deep into the delta through rivers and canals, resulting in salinity contamination to irrigation water[14]. The extent of seawater intrusion varies widely with time and place; it is influenced by seasonal and annual changes in river flow[14]. Furthermore, there is concern that seawater intrusion may be amplified by rising sea levels and changing rainfall patterns due to global climate change in the near future[19].

The coastal area of the Mekong River Delta, Vietnam (VMD), located at the southern end of the Indochina Peninsula (Fig. 1), has also been severely affected by seawater intrusion[14]. The whole VMD produced 19 million tons of rice in 2005, of which 72% was produced by seven provinces in the upper part of the VMD, and the remain-

*Corresponding author: e-mail akotera@affrc.go.jp
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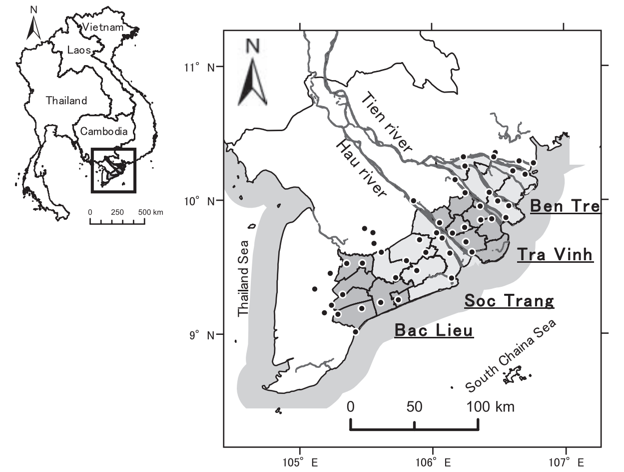

Fig. 1. Location map of the study area
The study area is constituted by 30 districts of 4 provinces in the coastal area of the Mekong Delta. ●: 48 salinity observation points.

ing 28% was produced by six provinces in the coastal area[10]. These differences in rice production between inland and coastal provinces have been expanding recently. Rice production in the upper part of the VMD had increased approximately 3.3-fold during the last two decades, whereas rice production in the coastal area only increased approximately 1.9-fold during the same period[10]. Thus, recent rice production in the coastal area is lower than in the upper part of the VMD. There is concern that rice productivity in the coastal area might be potentially limited by seawater intrusion.

Until recently, only single rice cropping had been conducted in the coastal area of the VMD in the rainy season using traditional varieties, because of the influence of seawater intrusion. Since the early 1990s, in response to intensive demand for rice by government policy, the government started to build a series of sluices that could be closed at high tide to protect the paddy area from seawater intrusion and an improved canal network to increase the supply of freshwater from rivers[18]. Such improvements in the hydrological infrastructure made it possible to produce two or three rice crops per year using high-yielding varieties with short growth durations. Although as a result, rice productivity in the coastal area has increased by overcoming seawater intrusion, rice production in the coastal area is still lower than in the upper part of the VMD.

Recently, the area of aquaculture, especially shrimp farms which brings higher market price than rice, has been expanding drastically in the coastal area of the VMD[3,6,13]. The conversion from paddy fields to shrimp culture has been accelerated since the deregulation of farmland use in 2000. Additionally, the preferential support policy for the development of larger farms with the concentration of land and capital were established by the Vietnamese government in response to high demand for more income[3,6]. Canal and river water management for salinity protection also has been changed with the conversion of land to aquaculture, as brackish water is required for shrimp farming.

As a consequence of recent hydrological developments and changes in land utilization, it seems that the influence of seawater intrusion on regional rice productivity has also changed. Although there have been extensive studies about salinity effects on rice plants physiologically at the field scale[9,12,15,20], little recent information is available on interrelationships between seawater intrusion and rice production in the coastal area at a regional scale. Such information could be indispensable for planning agricultural policy and new research for developing new methods to increase and stabilize agricultural productivity in coastal areas. This paper, therefore, aims to describe the interrelationship between seawater intrusion, rice production and land utilization at the regional scale, by using district-level statistical data on rice production and observed data of the salinity levels in rivers and canals in the coastal area of the VMD.

Study area

The study area comprises 10,449 km^2 constituted by Ben Tre, Tra Vinh, Soc Trang, and Bac Lieu Provinces on the coastal side of the Mekong Delta, facing the South China Sea (Fig. 1). The total population in these four provinces in 2005 was 4,462,000 persons[10]. The climate is tropical monsoon, with rainy (May to November, with southwestern monsoon) and dry seasons (December to April)[8]. Annual rainfall in the study area is around 2,000–2,400 mm. Average temperature ranges from 28.5°C in April-May to 25°C in December-January. Following the land classification of the Mekong Delta by Chiem[7], the study area is classified as a coastal complex characterized by the influence of the sea, which has created a micro-topography of sand ridges, inter-ridges and coastal flats. The sand ridges are 2–5 m above sea level and 5–40 km long, lying parallel along the coastline. The inter-ridges are low-lying areas, below sea level, located between the ridges. Most natural streams in the coastal area are distributed in the inter-ridges area.

Figure 2 shows a typical pattern of rice cropping in the coastal area investigated by the authors in Soc Trang Province in 2006. In the coastal area of the VMD, to avoid salinity stress on growing rice, patterns of rice cropping are limited by the availability of freshwater from rain or canals. In areas with a long duration of high salinity above a critical level for rice growth, only a single rain-fed rice crop with a long duration variety can be produced. In areas protected from seawater intrusion by artificial sluices in the dry season, irrigated Dong Xuan rice can be grown, thus allowing for triple cropping of rice.

Data

1. Salinity concentration

Salinity concentrations (g/L) in river and canal waters were measured at low and high tide every day for 6 months from January to June during three years (2003–2005), at 48 points (Fig. 1). The salinity concentrations from July to December were not measured. This series of salinity measurements have been conducted under ‘the Mekong Delta Salinity Monitoring Project’ (*Du an giam sat man Dong Bang Song Cuu Lon*, in Vietnamese) conducted by the Southern Institute for Water Resources Research, Vietnam since 2002.

By focusing on the high salinity period in the dry season, the low salinity period during the year, which is required for rice cropping, could be evaluated, since seawater intrusion in the rainy season is weakened by the seasonal increase in the river discharge of the Mekong River when the salinity concentration in most areas decreases to zero in the beginning of the rainy season. While indicators such as duration of salinity exceeding a threshold value or maximum salinity during the period have been widely used for evaluating the intensity of seawater intrusion[14,18], the former may have an instantaneous abnormal value potentially, and the latter requires a threshold of salinity optionally and the available data to evaluate was only 6 months. On the other hand, the average salt concentration is the simplest index among them but is strongly correlated with these indices (Figs. 3 and 4). Therefore, we used the average salt concentration for 6 months in the dry season as an index for the intensity of seawater intrusion in evaluating relationships between the salinity and the rice production from the statistical data.

To estimate the spatial distribution of the average salinity concentration, we applied the spline interpolation method using ArcGIS9.1 (ESRI Inc., CA) to the 48 observation data points. Then the area average in each district was derived, to enable comparison between the intensity

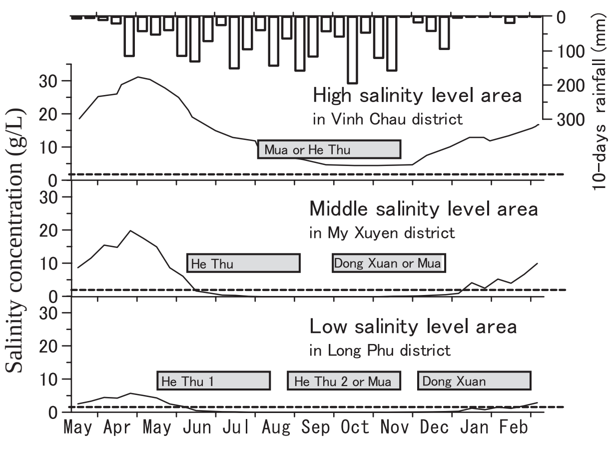

Fig. 2. Typical rice cropping patterns, seasonal fluctuation of the salinity concentration in the canal and ten-days rainfall at Soc Trang Province in 2006
- - - : Critical salinity for irrigation.

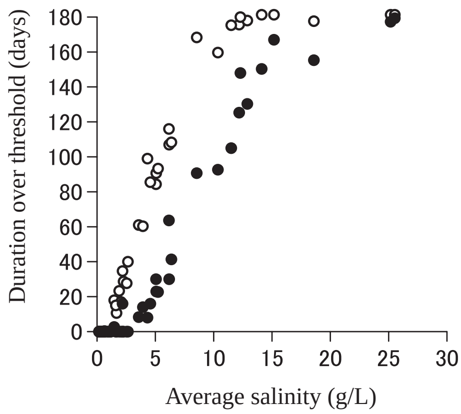

Fig. 3. Relationship between duration of salinity exceeding thresholds and average salinity during January 1 to June 30 in the 48 observation points
○: 5 g/L, ●: 10 g/L. R = 0.899 in 5 g/L, R = 0.957 in 10 g/L.

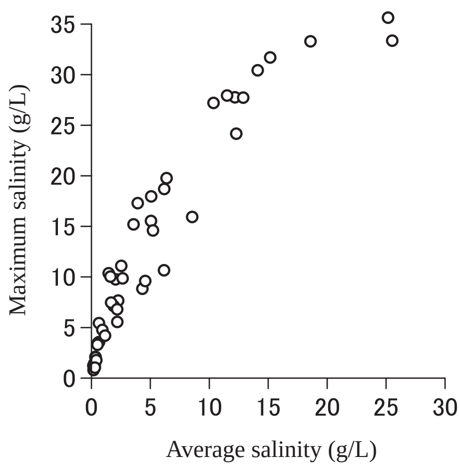

Fig. 4. Relationship between maximum salinity during the observation period and average salinity during January 1 to June 30 in the 48 observation points
R = 0.932.

of seawater intrusion and statistical data of 30 districts in the coastal area.

2. Statistical data

Statistical data on rice production in the four coastal provinces of the Mekong Delta were collected from the Statistical Yearbooks for 2003, 2004 and 2005, issued by the local statistical office in each province[4,5,16,17]. During 2003–2005, the total number of districts in the four provinces increased by subdivision, from 30 to 32. For simplification of analysis, therefore, the data of the new districts were reintegrated into the original districts before they were divided.

Data on rice production in the Vietnamese Statistical Yearbook was classified into three seasons: spring (Dong Xuan, in Vietnamese), autumn (He Thu) and winter (Mua). The names of the cropping seasons, however, do not necessarily correspond to actual planting times, because the rice cropping calendar varies widely according to the regional environment and the development of cropping technologies in historical times. Recent data for the coastal area of the Mekong Delta cultivating single or double short-duration rice crops show that the spring (Dong Xuan) crop is sown around September and harvested around December (Fig. 2, middle) and that the autumn (He Thu) crop is mainly sown around June and harvested around August (Fig. 2, top or middle). The winter (Mua) crop mostly uses long-duration rice varieties cultivated during the rainy season (Fig. 2, top or middle). Moreover, triple rice cropping in coastal provinces utilizes a spring (Dong Xuan) crop in the dry season, followed by two rice crops in the rainy season with an autumn (He Thu) crop (Fig. 2, bottom). To avoid confusion in the cropping names, we use the Vietnamese cropping names (Dong Xuan, He Thu and Mua) in this study.

To show a general profile of the regional distribution of the rice productivity, we used "annual total rice production per district area (ton/km^2)" [production / district area]. For evaluating multi-cropping rice production at regional scale, we defined "rice cropping intensity" as [seasonal or annual planted area / district area] and "yield (ton/ha)" as [seasonal or annual production / seasonal or annual planted area] for each district.

Results and discussion

1. Salinity concentration

The salinity levels in the 30 districts, averaged for 2003–2005, ranged from 0.6 to 14.4 g/L (average, 4.8 g/L; SD, 12.6 g/L) (Fig. 5). The salinity levels in 2003, 2004 and 2005, averaged for 30 districts, were 3.7, 5.0 and 5.7 g/L, respectively. Over the 3 years, average salinity tended to increase in most districts. This increase in salinity was mainly caused by decreased river flows[14]. In addition, changes in water management practices related to the expanding shrimp culture, which requires brackish water also might be a factor for increasing the salinity concentration. However, it is not clear whether the changes reflect a long– or short-term trend. Although we have not mentioned the mechanism of changing salinity in this paper, further investigation is necessary to understand this issue.

2. Regional distribution of rice production

Figure 6 shows the spatial distribution of annual total rice production per district area [production (ton) /

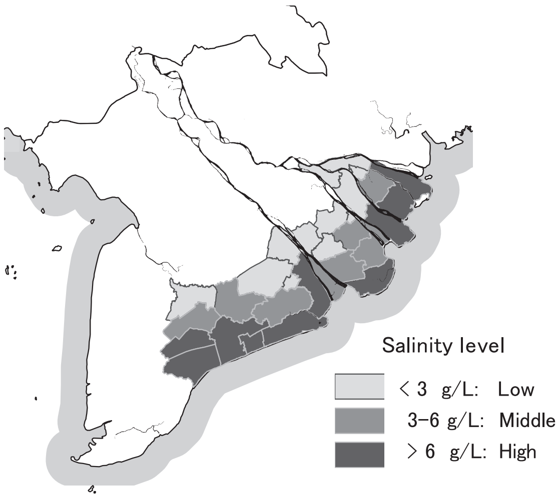

Fig. 5. Distribution of the average salinity level for January 1 to June 30 in 2003–2005 in the 30 districts

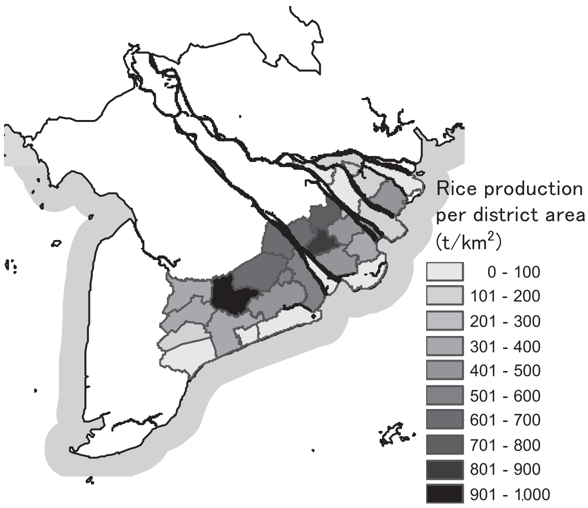

Fig. 6. Distribution of annual rice production (t) per district area (km^2) averaged for the period 2003–2005

district area (km^2)] in the 30 districts, averaged over 2003–2005. Annual total rice production per district area in the 30 districts ranged from 9 to 916 t/km^2 (average, 339 t/km^2; SD, 273 t/km^2). The regional differences in rice production in the coastal area were large at the district level. Annual rice production per district area tends to be lower in districts with high salinity (Fig. 7), while there were no significant correlations against the salinity levels ($R = -0.34$).

3. Relationship between rice yield and salinity

There were no significant correlations between the annual rice yields in 30 districts and the average salinity, with yields ranging from 3.0 to 5.5 t/ha (Fig. 8). The annual yields averaged over the 30 districts were 4.1, 4.3 and 4.4 t/ha in 2003, 2004 and 2005, respectively (Fig. 9). The average yield has increased, while the salinity has increased. The yields of the Dong Xuan, He Thu and Mua crops averaged over 30 districts were 5.1, 4.3 and 3.9 t/ha, respectively. The corresponding average yields over the whole VMD in 2003, 2004 and 2005 were 5.6, 4.2 and 3.5 t/ha, respectively. Thus, the average yields of the He Thu and Mua crops were higher in the coastal area than in the entire VMD.

It is documented that paddy water salt concentrations in excess of 1.9 dS/m (1 g/L) can reduce rice yields[11]. However, most rice cultivation in the coastal area avoids salinity stress by shifting the cropping season (Fig. 2). To keep salinity-free conditions during the rice cropping seasons, farmers utilize mainly rainfall during the rainy season and fresh irrigation water during the periods of no rain. Salinity-free conditions and adequate water resources allow the introduction of advanced technologies such as high-yielding rice varieties. Therefore, rice yield even in high-salinity areas might be still high as shown in Fig. 9.

On the other hand, as an exceptional case, the yields of the Dong Xuan crop decreased in districts with higher salinity, whereas the yields of the He Thu and Mua crops were not correlated with salinity (Fig. 10). In districts with low salinity (0–3 g/L, Fig. 5), the yields of the Dong Xuan crop were higher than those of the He Thu and Mua crops. The cultivation environment for the Dong Xuan crop in the dry season produces high yields given adequate freshwater, because of higher solar radiation and lower risk of damage due to heavy rain during heading and maturity stages in the dry season than in the rainy season, when He Thu and Mua crops are grown. However, in most paddy fields in districts with high salinity (> 6

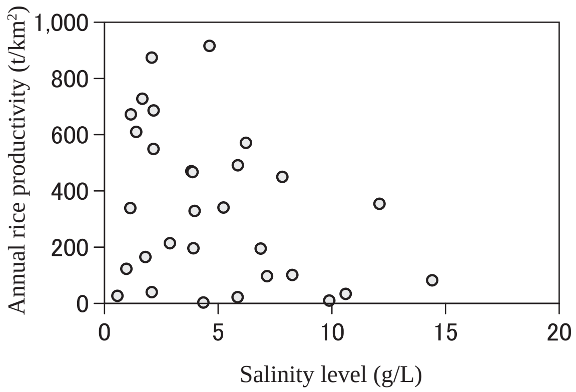

Fig. 7. Relationship between annual rice production (t) per district area (km^2) and the average salinity for January 1 to June 30 in 2003–2005 in the 30 districts

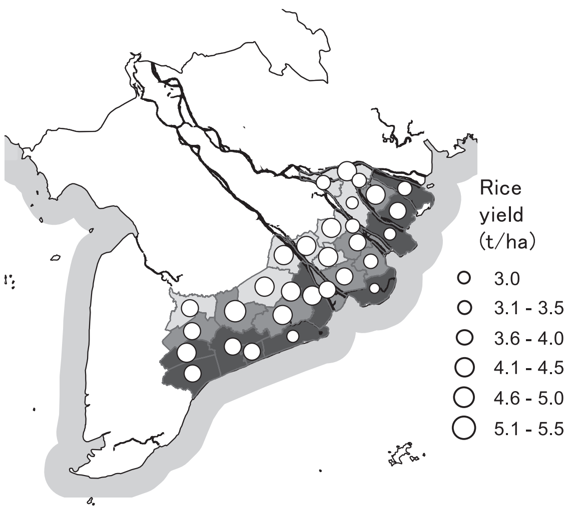

Fig. 8. Distribution of annual rice yield and salinity level averaged for the period 2003–2005

Rice yields are described by the size of the circle and the legend of salinity levels is shown in Fig. 5.

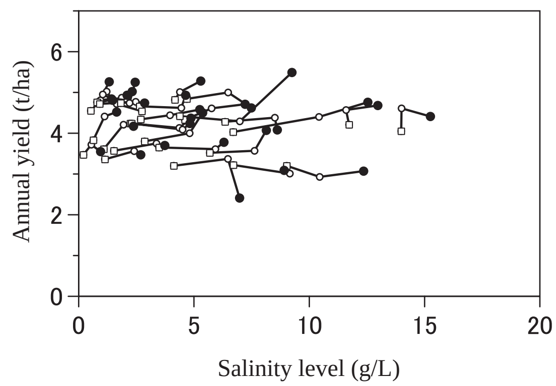

Fig. 9. Relationship between annual rice yield and salinity level in the 30 districts in the period 2003–2005

□: 2003, ○: 2004, ●: 2005.

g/L, Fig. 5), freshwater during the dry season is insufficient because of an increment of salinity in the canal water and little rain in this season. Therefore, dry stress, otherwise salinity stress has reduced the yield of Dong Xuan crops in these districts with high salinity. This is the special case when seawater intrusion occurs earlier than normal so that rice cannot be harvested before salinity increases. Local farmers know empirically that the mass death of water hyacinth *(Eichrornia crassipes)* on the surface of the canal water implies high salinity concentrations in the canal water damaging the rice growth.

4. Relationship between rice cropping intensity and salinity

Annual rice cropping intensities decreased in districts with high salinity (Fig. 11). The salinity-free duration could be shorter in high-salinity areas depending on seasonal fluctuations in salt concentrations (Fig. 2). That is, the possible number of rice crops, i.e. single, double or triple in a year would be limited by the salinity level. On the other hand, annual rice cropping intensities in districts with low salinity are independent of such seasonal changes, resulting in large variability in the number of rice crops (Fig. 12). The relationship between maximum annual cropping intensity and salinity described an envelope line which indicates that potential cropping intensities were limited by salinity (Fig. 12). The average annual crop intensity in whole districts decreased from 1.2 to 1.0 during the 3 years. Specifically, the crop intensity in districts near the envelope line (Fig. 12) decreased by much larger than the average. These results suggest that salinity was a factor limiting potential cropping intensity but did not affect the possible attainable cropping intensity in the coastal area.

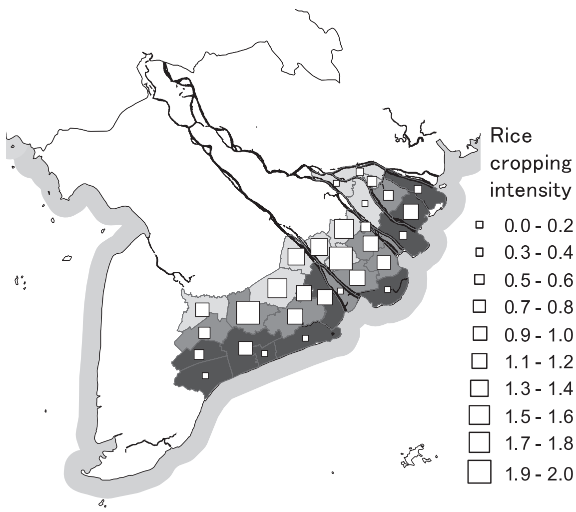

Fig. 11. Distribution of annual rice cropping intensity with salinity level for the period 2003–2005

Rice cropping intensities are described by the size of quadrangles and the legend of salinity levels is shown in Fig. 5.

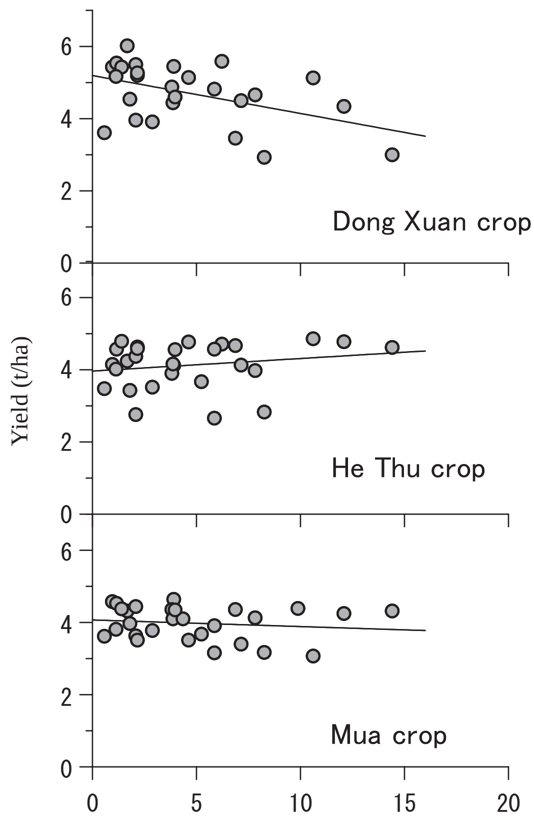

Fig. 10. Relationship between rice yields of the Don Xuan (top), He Thu (middle) and Mua (bottom) crops and salinity levels during the period 2003–2005

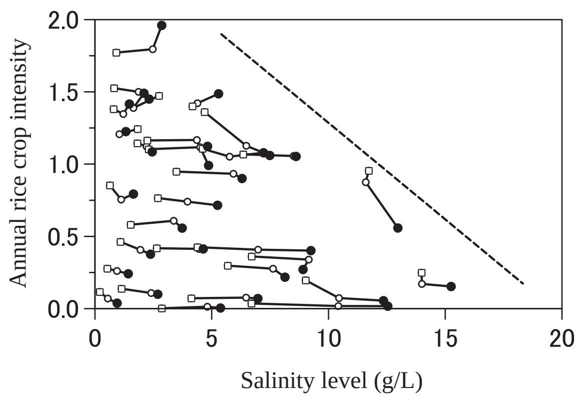

Fig. 12. Relationship between annual rice cropping intensity and salinity level in the 30 districts in the period 2003–2005

□: 2003, ○: 2004, ●: 2005. - - -: Envelope line on potential crop intensity.

Although the cropping intensities in the three cropping seasons showed similar relationships with salinity, the dependency of salinity was different for each cropping season (Fig. 13). Specifically, the cropping intensities in districts of the Mua crop with high salinity depend on salinity less than the Dong Xuan and He Thu crops. For the Mua crop as a single crop, the necessary minimum amount of freshwater could be provided by rainfall, so that the effect of seawater intrusion on the cropping intensity in the Mua Crop was weaker.

Figure 14 shows the relationships among salinity, the cropping intensity of rice and the intensity of aquaculture in 2005. Recently, the area of paddy field in the coastal area has decreased through land use conversion to aquaculture, especially shrimp farms[13]. These land use changes compensate each other, that is, the more intensive aquaculture, the less rice cultivation. It may be explained by the concept of production possibilities frontiers[1,2]. A concept of production possibilities frontier is based on the different quantities of two goods that an economy could efficiently produce under limited production resources. In Fig. 14, the districts data along the line describe trade-offs between rice cropping and shrimp farming. The line indicates that increased intensity of one product reduces maximum intensity of the other product, as resources are transferred from one product to the other. Increased salinity reduces the intensity of rice cropping and increases the intensity of aquaculture. However, low-salinity agricultural districts with low intensities of rice and aquaculture were dominated by a land use for the other crops, mainly orchards. Thus, possible attainable rice cropping intensity was limited by increasing crop diversification in both high- and low-salinity districts.

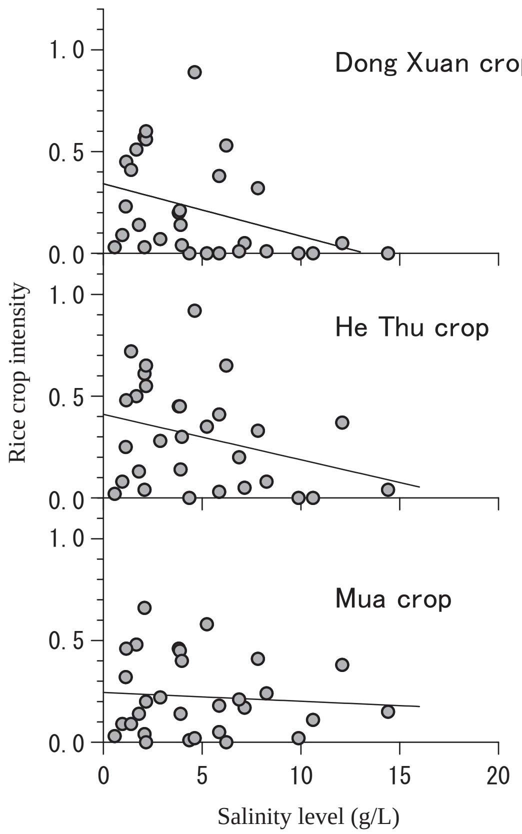

Fig. 13. Relationship between rice cropping intensities of the Don Xuan (top), He Thu (middle) and Mua (bottom) crops and salinity level during the period 2003–2005

Conclusions

The interrelationships between seawater intrusion and land-use diversification limited rice production in the coastal area. These limitations led to a regional disparity in rice productivity in the coastal area. Although rice is known as an especially salt-sensitive crop[11,12], the statistical data from the districts showed that seawater intrusion was affecting the cropping intensity of rice rather than the yield. To achieve the high yield level, rice cropping patterns and planting areas were limited to avoid the influence of salinity stress on rice growth. Reducing the rice cropping intensity could also retain high-rice yields in districts with high salinity. If seawater intrusion was to decrease rice yield, a farmer would not cultivate a rice crop because of the low profit involved. Economic circumstances in Vietnam have recently changed radically, together with increased profitability in rural areas. As a

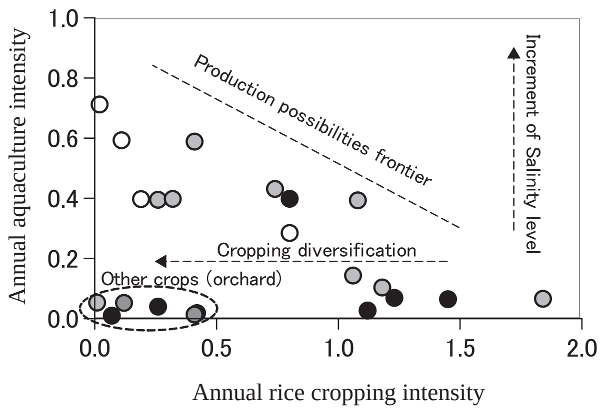

Fig. 14. Relationships between the intensity of the aquaculture and the rice cropping with salinity level in 22 districts of Soc Trang, Bac Lieu, and Ben Tre Provinces in 2005

Salinity level (mg / L): ○; < 2.5, ◌; 2.5–5, ◉; 5–10, ●; > 10.

result, there has been pressure to replace paddy fields that have low attainable rice yields due to high salinity with more profitable crops. Although shrimp farming, which uses brackish water and can bring a high income, has become widely accepted by farmers as an alternative to rice, rice cropping may still have an advantage in terms of sustainability of production, low economic investment and low stress to environments. It seems that agriculture in the coastal area of the VMD is at a trial-and-error stage in terms of increasing land productivity from rice monoculture. The regional disparity in rice production revealed in this study could be a driving factor to encourage agricultural development in the coastal area through land-use diversification.

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