Inland low-salinity shrimp farming in the central plains region of Thailand

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ABSTRACT: *Thailand is the world's largest producer of farmed black tiger shrimp which earned approximately $2 billion US in export revenues during 1999. The need for large volumes of brackish water to fill pond enclosures has traditionally limited the cultivation of tiger shrimp (a marine species) to a relatively narrow band of coastal land. Thai farmers have discovered, however, that it is both feasible and profitable to grow tiger shrimp in areas far removed from the coast by trucking hyper-saline water inland and mixing it with freshwater drawn from irrigation canals or natural streams. Small-scale tiger shrimp farms are now common in traditional rice growing areas such as Chachoengsao, Prachinburi, Supanburi and Nakhon Pathom. The development of low salinity culture techniques has been a major factor which facilitated the spread of tiger shrimp farming into freshwater areas. Other contributing factors include the substantial economic profits that shrimp culture provide as compared to rice cultivation, government policies that promote shrimp farming as a means of rural economic development, and the belief that inland freshwater areas are free from virulent shrimp pathogens.*

The rapid development of inland shrimp farm in the Central Plains region has, however, been accompanied by growing concerns over the potential environmental impacts associated with this activity. Specific impacts include soil salinization, water quality degradation as a result of effluent disposal, and water use conflicts with competing activities such as rice farming. Although many inland low salinity shrimp farms are small (less than 1 hectare in size) over 22,000 hectares of pond area were identified in a recent national inventory of this activity. This magnitude of development suggests that inland shrimp farming may have the potential to effect both local and regional soil and water resources.

1 Introduction

Inland shrimp farming is a relatively recent development in aquaculture that allows a marine species (the black tiger shrimp Penaeus monodon) to be raised in freshwater areas under mesohaline conditions (3–10 ppt). The emergence of low salinity shrimp farming within rice-growing regions of central Thailand has raised concerns regarding potential environmental

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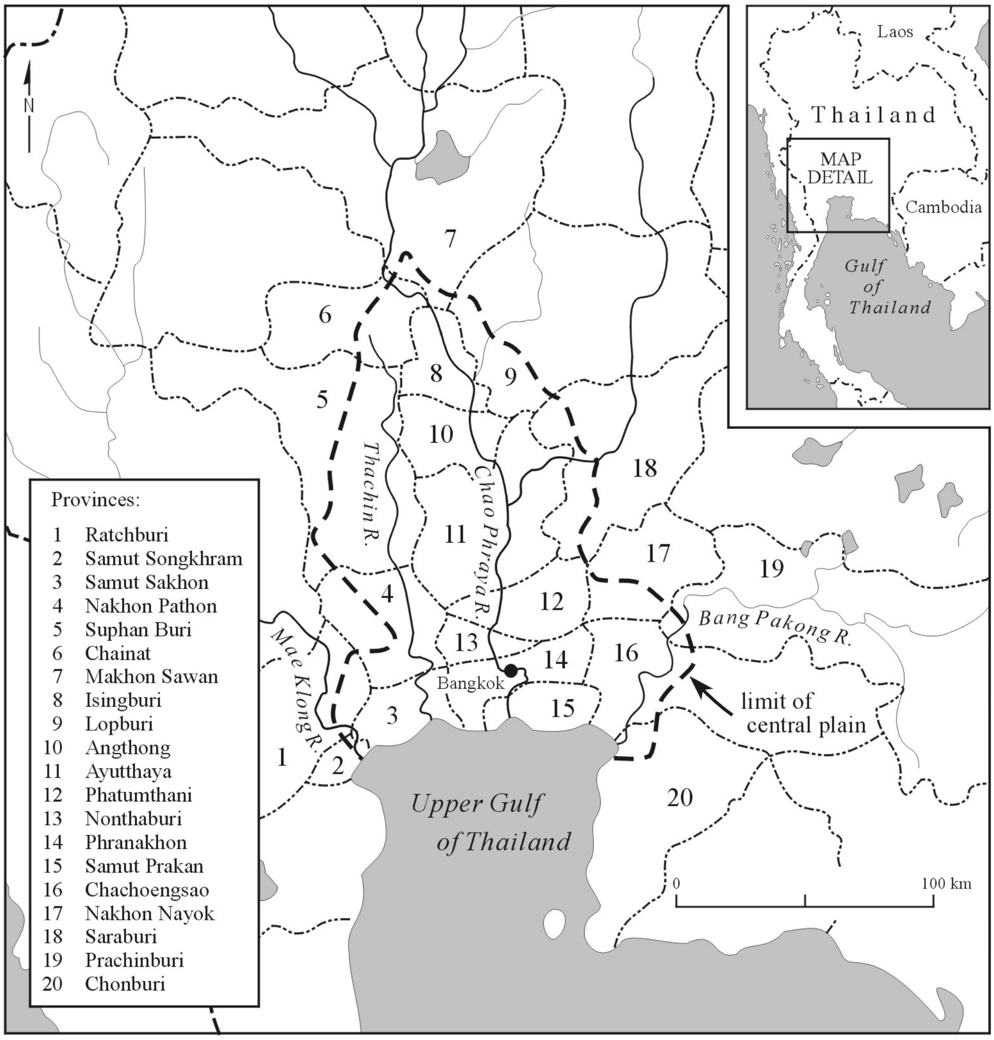
impacts, and the suitability of conducting this activity within highly productive freshwater agricultural areas. Specific environmental impacts of concern include soil salinization, water quality degradation as a result of effluent disposal, and water use conflicts with competing activities such as rice farming (Flaherty et al, 2000; Pongnak, 1999). This paper provides an overview of inland low-salinity shrimp farming in central Thailand. It describes the evolution of this form of aquaculture, discusses husbandry techniques, and examines the controversy over potential environmental impacts. For the purpose of this discussion, low-salinity tiger shrimp culture in freshwater areas is henceforth referred to as inland shrimp farming.

2 Development and evolution of inland shrimp farming

The need for large volumes of brackish water to fill pond enclosures has traditionally limited the cultivation of black tiger shrimp to a relatively narrow band of coastal land within tropical regions. This was certainly the case during the first wave of intensive aquaculture development in central Thailand during the 1980s, when shrimp farms in the Upper Gulf Region were established within the estuaries of the major rivers such as the Chao Phraya, Bang Pakong, Tha Chin, and Mae Khlong (Figure 1). Dry season saline intrusion is a common characteristic of these low gradient systems, and the seasonal availability of brackish water within streams and irrigation canals encouraged the construction of a second generation of tiger shrimp farms some distance upstream in areas such as Chachoengsao (Flaherty and Vandergeest, 1998). Brackish water is unavailable in upstream areas during the wet season, however, when higher stream flows counteract tidal influences. Low salinity shrimp culture was originally developed to overcome this limitation and provide a second annual crop (Flaherty et al., 1999). Culture techniques evolved through experimentation led by local shrimp farmers (Banpasirichote, 1993). These individuals discovered that if saline water was trucked-in from the coast when natural supplies of brackish water were unavailable, tiger shrimp post-larvae could be acclimatized to a low-salinity environment (Miller et al., 1999). Although familiarity and availability were the primary reasons for utilizing tiger shrimp in these experiments, this species is well known for its tolerance to significant variations in temperature and salinity (Laubier, 1990).

Low salinity shrimp farming expanded rapidly after the technical viability of this culture system was established, and farmers discovered that the high profits derived from shrimp production could easily offset increased costs associated with trucking salt water from the coast. These factors facilitated the spread of inland shrimp farming into freshwater agricultural areas that never experience seasonal salt water intrusion. Farms that draw freshwater from the existing rice irrigation infrastructure, and purchase saline water from tanker truck operators, now exist hundreds of kilometers from the coast in areas such as Changwats Prachinburi, Supanburi, Nakhon Pathom and Nakhon Nayok (Department of Land Development, 1999a).

FIGURE 1. CENTRAL PLAINS REGION OF THAILAND



The development of shrimp farming in freshwater areas was also hastened by on-going problems with water-borne viral disease outbreaks (e.g., white sport virus, yellow head) that substantially reduced production in coastal shrimp farming areas. Poor environmental conditions along the coast, combined with the susceptibility of coastal shrimp farms to disease, led some analysts to predict that overall Thai farmed shrimp production may decline (Dierberg and Kiattisimkul, 1996). With the development of low salinity shrimp culture techniques, however, farmers no longer required direct access to contaminated coastal waters. Development opportunities are limited only by basic site suitability criteria (e.g., relatively flat land and a reliable source of freshwater), salt water transportation expenses, and land leasing costs (Flaherty and Vandergeest, 1998). Inland shrimp farming could have represented as much as 40 percent of Thailand's total cultured shrimp production by late 1998 (Limsuwan, 1998), and an inventory conducted during this period by the Department of Land Development identified 22,455 hectares of land devoted to inland shrimp farming in the central region (Table 1).

TABLE 1 INLAND SHRIMP FARMS IN THE CENTRAL REGION OF THAILAND *

PROVINCE	AREA (ha)	PROVINCE	AREA (ha)
Chachoengsao	8375	Ang Thong	193
Prachinburi	4577	Khrung Thep	51
Nakhon Pathom	2204	Lopburi	48
Nakhon Nayok	1752	Chai Nat	46
Chonburi	1631	Nakhon Sawan	44
Suphanburi	1359	Nonthaburi	22
Samut Prakan	518	Kanchanaburi	19
Ayutthaya	451	Saraburi	16
Ratchaburi	350	Singburi	12
Phetchaburi	322	Uthaithani	10
Pathum Thani	244	Samut Songkhram	5
Samut Sakhon	206		

* Source: Department of Land Development, 1999a

The expansion of inland shrimp farming into Thailand's irrigated rice growing areas was halted in 1998 when the Royal Thai government banned inland shrimp farming in all freshwater provinces on the basis of a recommendation from the National Environment Board (Srivalo, 1998). Governors in coastal provinces were subsequently instructed to designate land within these areas as freshwater (where shrimp farming would be banned) or brackish water (where shrimp farming could continue). A joint committee including representative of the Departments of Land Development, Pollution Control, and Fisheries is also currently considering the fate of inland shrimp farming in seasonally brackish areas such as the Bang Pakong River Basin that are not easily classified using this approach. The Bang Pakong River Basin includes portions of Chachoengsao, Prachinburi, Chonburi, and Nakhon Nayok provinces, and the joint committee will submit a report and recommendations to the Thai government by January 2001.

In spite of the prohibition on shrimp farming within freshwater provinces over the past 2 years, concerns continue to exist over the capacity of the Thai government to enforce the ban, the manner in which brackish water and freshwater areas have been designated, and the possibility that the ban on inland shrimp farming could be relaxed (Flaherty et al., 2000). These concerns are reinforced by several factors. Shrimp farming plays an important role in the Thai economy, with sales to the United States, Europe and Japan earning approximately $2 billion USD in export revenue during 1999 (Bangkok Post, 2000a). The Thai government has also been a staunch supporter of shrimp farming, and is presently encouraging farmers to raise more shrimps so as to offset a worldwide shortfall caused by disease outbreaks in

Latin America (*ibid*). Although there may be some potential for increasing shrimp production through the intensification of existing farms, this strategy is accompanied by a higher risk of disease outbreaks and crop failure. It is likely, therefore, that increased production will require additional pond area which will be supplied by new operators entering the industry and/or existing farmers expanding their operations. With the further development of shrimp farming in Thailand's coastal areas increasingly constrained by high land values, more effective protection of mangrove forests, and concerns over the risk of disease owing to poor environmental conditions (Dierberg and Kiatismkul, 1998; Vandergeest et al., 1999), renewed pressure is likely to develop for the expansion of shrimp farming into freshwater areas (Bangkok Post, 2000b)

3 Husbandry and operating procedures

Inland shrimp farming practices are generally similar to those used in typical coastal operations which feature high stocking densities, aerated ponds, and a reliance on pelletized feeds, fertilizers and chemo-therapeutants. The primary difference is that while coastal farms use naturally occurring seawater (15-30 ppt) to fill and replenish pond enclosure, inland farms combine freshwater with saltwater purchased from coastal salt pans or saltwater concentrate operations. This approach achieves an initial pond salinity level between 4 and 10 ppt. Further freshwater inputs are subsequently used to offset evaporation and seepage losses, and this process can reduce pond salinity levels to near zero by the time of harvest unless supplementary salt is applied (e.g. trucked saline water or bagged salt). Even though naturally occurring brackish water is seasonally available in some areas of the Central Plains Region during the dry season (e.g., Bang Pakong River Basin) few inland shrimp farms will use this supply source due to the potential presence of viral pathogens and other contaminants such as pesticides (Ponza, 1999).

Thailand's transition from a small-scale producer into the world's largest exporter of cultured shrimp, has been facilitated by the development of over 1,500 small-scale "backyard" hatcheries (Kongkeo, 1994). A substantial low-salinity hatchery sector has developed in provinces such as Chachoengsao to support the inland shrimp farms, and these operations have made several adaptations to produce shrimp at the post-larvae (PL) stage of development that are acclimatized to a lower than normal salinity. Acclimation begins during the early post-larval stages in fry rearing tanks containing full strength seawater. Over a period of three to five days, salinity levels are gradually reduced from 30 ppt to 10 ppt by adding freshwater. The PL are ready for sale and delivery to farms when they are 12 to 15 days old.

A variety of methods are used to continue the acclimation process after the PL are delivered to the farm site (Miller et al, 1999; Ponza, 1999). The simplest method involves slowly mixing water contained in the PL transport packages with pond water until a salinity similar to the grow-out environment is achieved. A second technique involves maintaining the PL in a separate nursery pond for 45-60 days where they are acclimatized to lower salinity levels. The PL are then transferred to the larger grow-out pond by means of lift or bag nets. The most common PL acclimation method is, however, the use of a small PVC or earthen bund nursery pen constructed within the grow-out pond. In this approach, the grow-out pond is initially filled with fresh water to a depth of 30 to 80 centimeters, and saltwater is pumped into the nursery pen. For a typical 0.6 hectare grow-out pond using the nursery pen method, two 15 metric tonne truck loads of 60 ppt water are required to raise the salinity of the nursery pen water to approximately 10 ppt. (Miller et al, 1999). Sections of the plastic PVC paneling or bund are removed over the first 7 to 10 days and replaced with mesh to allow the saline pen water to slowly mix with freshwater in the rest of the grow-out pond. The PL are released from the nursery pen into the full grow out pond after the acclimation period is complete. Salinity in the full grow-out pond can range from 3 to 8 ppt at the end of the acclimation period depending on a variety of factors including pen size, water depth, and initial salinity levels.

Freshwater is generally added to the grow-out pond at a rate of 5 to 10 cm every 10 days during the grow-out period until a maximum pond water depth of 1.3 to 1.5 metres is achieved. The use of reservoirs to enhance water management during the grow out period is becoming more common, but these facilities can only be constructed on farms with adequate land holdings and the farmer must be willing to sacrifice production area (Flaherty et al, 2000). Reservoirs act as a buffer between water sources that contain disease pathogens or surface water pollutants, and can serve as receptacles for nutrient enriched harvest effluent. They are used to allow sediment to settle out of canal water before being added to the ponds, and reservoirs encircling the production ponds can also reduce saline water intrusion to adjacent rice paddies. The most common and simplest reservoir system is a water ditch barrier between shrimp ponds and surrounding rice paddies.

The standard grow-out period for inland culture systems is a relatively short 100-120 days. Harvest at inland farms occurs earlier than in most coastal operations as a result of falling salinity levels and the negative effect this has on shrimp health and development. Shrimp produced by inland farms average 50 pieces per kilogram at harvest (Ponza, 1999, Miller et al, 1999) which is quite small in comparison to coastal operations. Prices vary widely from crop-to-crop owing to international market fluctuations, but a typical price during the year 2000 for small shrimp sized at 50 pieces per kilogram is approximately $10 USD per kilogram (Shrimp World Incorporated, 2000). Although yields vary greatly between operations, a successful inland shrimp farm can produce 5 metric tonnes per hectare twice a year. Assuming the current farm gate price for small shrimp, a farmer with one hectare of his holdings devoted to shrimp culture would have a gross annual income of US $100,000 (based on two crops). This is at least 25 times the income of a typical rice farmer in central Thailand, and illustrates how lucrative shrimp farming can be compared to rice cultivation. It also explains why rice farmers who can raise the investment capital are willing to take a gamble on raising shrimp. In cases where rice farmers are unwilling or unable to invest themselves, there is ample opportunity for leasing paddy land to outside investors at rents that greatly exceed what they could obtain growing rice. Although than income estimate does not take account of the significant capital costs associated with pond construction, farm infrastructure such as pumps and aerators, and feed; successful shrimp farmers can commonly recoup their initial investment within one year. This assumes, of course, that they do not experience catastrophic disease problems which can lead to crop failures.

4 Environmental impacts

The ban on inland shrimp farming initiated a heated debate over the nature and significance of environmental impacts. Inland shrimp farmers were outraged at the imposition of the ban on their activities in freshwater areas, and argued that it was based on a biased environmental impact assessment information (Bangkok Post, 1998). Specific issues of dispute are the potential for salinization of agricultural soils, water pollution stemming from the discharge of pond effluents, and competition between agriculture and aquaculture for freshwater supplies.

4.1 Soil salinization

Salinization can occur directly through the deposition and accumulation in salts in soils located immediately beneath the pond enclosure, or indirectly as a result of seepage into adjacent agricultural areas. Indirect salinization impacts could also be produced through the disposal of saline effluents into streams or irrigation canals which are subsequently used to irrigate rice paddies or orchards.

The most recent estimate of land subject to direct salinization impacts as a result of inland shrimp farming in the central region is 22,455 hectares (Table 1) and we estimate salt loading to be roughly 2.7 metric tonnes per hectare per crop. This value assumes that 3 truckloads (15 metric tonnes each) of saltwater at 60 ppt are required for each hectare of inland shrimp pond. Since almost all farms produce two crops per year, annual salt inputs would be 5.4 metric tonnes per hectare per year. Use of the PL nursery pens reduces overall salt requirements, but this approach is not universal and salt inputs are substantially higher on farms that maintain pond salinity levels at 10 ppt throughout the grow-out period. This estimate also does not consider the common practice of adding bagged salt during the grow-out period to maintain salinity. Given these factors, a 5.4 MT per hectare annual salt loading figure should be considered conservative.

The significance and extent of indirect soil salinization effects are, however, much more difficult to assess. Recent studies conducted by the Thai Ministry of Science and Technology (1999) suggest that seepage can increase salinity in soils from 50 to 100 meters from the edge of inland shrimp ponds. Caution must be exercised in assessing the amount of land actually effected by indirect impacts because impact pathways are extremely complex and mitigating factors exist (e.g., natural soil flushing by monsoon rains). Given the size and agricultural importance of the areas potentially effected, however, the significance of direct and indirect soil salinization impacts should not be underestimated. Much of the land converted to shrimp pond was highly productive rice paddy, and the cost of returning this land to agricultural production if shrimp farming fails could be substantial (Land Development Department, 1999b).

4.2 Water pollution

While water quality problems are common in all shrimp farming areas, these can be especially problematic in inland regions where small streams and irrigation canals posses a relatively low assimilative capacity. The majority of the nutrients added to shrimp ponds in the form of fertilizer or pelletized feed are not incorporated into the shrimp, but end up being deposited in pond sediments or discharged as effluent (Funge-Smith and Briggs, 1998; Tookwinas, 1997.). Most small inland shrimp farms ponds completely drain grow-out ponds at harvest, and release large quantities of untreated effluent directly into adjacent water bodies. Only a relatively small number of large operations treat and recycle effluent within holding reservoirs. The decomposition of organic waste in surface waters reduces dissolved oxygen levels, can suffocate or smother aquatic fauna, and produces toxic chemicals such as ammonia and hydrogen sulfide (Primavera, 1998).

Inland shrimp farms operate somewhat differently than coastal operations, as very little effluent is released during the first 60 days of the grow-out cycle (Braaten and Flaherty, 2000). Feed requirements are relatively modest at this point, and additions of freshwater are usually sufficient to maintain water quality in the pond. During the latter half of the culture cycle, however, water exchange is used to maintain the growing environment and effluent is discharged. A significant amount of nutrient enriched effluent is also released during harvest when the ponds are completely drained. Very little information is available on the composition and impact of inland shrimp farm effluent, but it has been estimated that culture period and harvest effluent contain BOD concentrations of between 10 and 25 milligrams per litre (Pollution Control Department, 1996, Ingthamjitr, 1999). Although the effect of shrimp farm effluent on receiving waters is of concern, a much more serious issue exists with regard to the disposal of semi-liquid sludge that remain in the grow-out ponds after harvest. This material consists of uneaten feed, faeces, and sediments eroded from the pond enclosure (Funge-Smith and Briggs, 1998) and is a highly polluting with BOD concentrations of 1500 milligrams per litre or higher. Pumping pond sludge directly into adjacent water bodies is illegal, and this material is usually maintained on site where is it is kept in holding ponds or packed onto pond banks. The illegal dumping of pond sludge into freshwater bodies is not uncommon, however, due to a lack of farmer awareness and regulatory enforcement (Department of Pollution Control, 1996; Braaten and Flaherty, 2000).

Other important water pollutants originating in shrimp ponds are the chemo-therapeutant products added to the ponds by the farmers. These chemicals can leave the ponds through effluent, seepage through pond bottoms, and through the removal and disposal of bottom sludge. One of the most common and worrisome pond additives is antibiotics. Most commercial shrimp feeds are enriched with common antibiotics such as oxytetracycline. Studies of fish farms have shown that the majority of antibiotics added in feed are not assimilated by fish but go into environment (Weston, 1996). Once in the environment antibiotics can have a wide range of effects. In surface water, they may lead to antibiotic resistant pathogens or accumulate in the tissues of wild fish. If they accumulate in sediments, antibiotics may prevent natural bacterial decomposition and consequently alter the natural benthic environment (Chua et al, 1989).

5 Water use conflicts

It is not surprising that inland shrimp farming evolved within traditional rice growing areas of Thailand, as the activity requires substantial quantities of fresh water to fill pond enclosures and maintain environmental conditions during the grow-out period. The presence of plentiful fresh water supplies is critical to the success of inland shrimp farming, and irrigation infrastructure originally developed for rice cultivation is easily adapted to aquaculture. Water use impacts associated with shrimp farming typically involve excessive consumption or competition between rice and shrimp farmers for limited supplies (Miller et al, 1999).

Although limited information is available on inland shrimp farm water use, a recent study has been completed on this topic (Braaten and Flaherty, 2000). This study found that a typical inland shrimp farm consumes approximately 9000 m^3 of water per hectare per crop, and withdraws approximately 2600 m^3 per hectare per crop. These figures are roughly similar to the amount of water required to raise crops such as wet rice, banana or sugarcane, and suggests that inland shrimp farming should not have a significant effect on consumptive water use within irrigated agricultural areas. In non-irrigated areas, however, inland shrimp farming may still have the potential aggravate existing water use conflicts. The dry season is the optimum period for raising shrimp, and this preference may increase fresh water demand during a period of limited supply. Dry season demand for freshwater may even increase in areas that have saltwater naturally available as a result of intrusion, because shrimp farmers generally avoid this water source due to concerns over quality and virus transference. Water use conflicts are also possible as a result of groundwater pumping. A ban on groundwater pumping for aquaculture purposes has been imposed in coastal areas of Thailand to prevent subsidence and protect agricultural and domestic water supplies, but the prevalence of this practice in the inland shrimp farming sector is currently unknown.

6 Conclusions

Inland shrimp farming presents a situation where significant short-term economic benefits may be obtained, but at the risk of creating significant environmental impacts. Of the impacts discussed above, soil salinization is clearly the most critical issue due to the potential for inland shrimp farming to cause long term damage to agricultural areas which may be difficult and expensive to reverse (Ministry of Science and Technology, 1999). Cumulative effects are a second area of concern. Although many inland low salinity shrimp farms are less than 1 hectare in size, the existing magnitude and density of development in many areas may have the potential to degrade regional soil and water resources (Flaherty et. al., 2000). Cumulative effects represent the additive or inter-active effects of multiple small-scale activities (such as shrimp farming) on larger ecological units such as watersheds. Although the short-term impact of an individual inland shrimp farm on regional environmental quality is likely to be limited or negligible, the long-term cumulative effect of a large number of inland shrimp operations on regional soil and water conditions may be substantial due to the slow accumulation of salt and other waste products.

Current studies into the environmental impacts of inland shrimp farming in Thailand are focusing on the site-specific effects of individual operations. Although these studies will undoubtedly increase our understanding of specific environmental concerns, this approach cannot address the potential cumulative effects produced by large numbers of inland shrimps farms operating in dense concentrations. If inland shrimp farming continues in some form within Thailand, we believe that research into the long-term regional implications of this activity must be undertaken to insure the security of soil and water quality in Thailand's agricultural heartland.

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