Preliminary risk assessment of Pacific whiteleg shrimp *(P. vannamei)* introduced to Thailand for aquaculture

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Marine shrimp (*Penaeus* spp.) are important commodities for several Asian countries, including Thailand (Briggs *et al*., 2005). Thailand had been one of the largest exporters of Black tiger shrimp *(P. monodon)* for decades until the outbreaks of viral diseases (white spot syndrome virus, WSSV; and yellow head virus, YHV) in the early 1990s. In response, low salinity shrimp farming techniques were developed and quickly applied in agricultural areas, especially rice fields (Szuster, 2001; Tiensosngrusmee, 2000). Further disease outbreaks, poor growth performance and declining prices for *P. monodon* led to the introduction of Pacific whiteleg shrimp *(P. vannamei)* to Thailand in 1998 (Briggs *et al*., 2005). *P. vannamei*, a species native to the Pacific coasts of Central and South America (Perez Farfante and Kensley, 1997), is known for its tolerance to a wide salinity range and its fast growth rate in brackish water (Holthuis, 1980).

Aquaculture of *P. vannamei* has rapidly expanded because of the species' fast growth, low incidence of native diseases and availability of domesticated strains. The annual production of *P. vannamei* in Thailand has surpassed *P. monodon* every year since 2004. In 2007, an estimated 441,450 tons of *P. vannamei* were produced, representing more than 99% of the total marine shrimp production in Thailand (DOF, 1999-2005). This rapid expansion has facilitated the release of farmed *P. vannamei* into natural environments (Senanan *et al*., 2007).

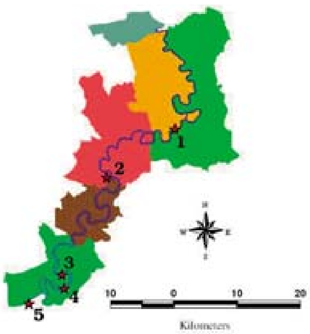

Figure 1. Sampling sites in the Bangpakong River (1 = Bangklah, 69 km from the river mouth; 2 = Muang, 45.8 km from the river mouth; 3 = Bangpakong 1, 10.5 km from the river mouth, 4 = Bangpakong 2, 6.5 km from the river mouth and 5 = the Bangpakong river mouth).

While aquaculture promises economic and social benefits, aquaculture escapees can pose ecological risks to the receiving aquatic environments (e.g., De Silva 1989; Naylor *et al*. 2001; Miller *et al*. 2004; De Silva *et al*. 2006). Some ecological impacts, such as reducing aquatic biodiversity or spreading alien pathogens, may undermine the sustainability of aquaculture and small-scale fisheries. By incorporating science-driven ecological risk assessment prior to new introductions and integrating a risk monitoring program, we may prevent such undesirable outcomes. This paper presents data relevant to ecological risk assessment of *P. vannamei* culture in Thailand, generated by studies conducted during 2005-2007 by our research team. This three-year research program, funded by the National Research Council of Thailand, used a case study of *P. vannamei* introductions to the Bangpakong River and along the east coast of Thailand. The research focused on the following aspects: (1) the quantity of escapes from farms located in the Bangpakong River watershed, (2) the ability of escapees to survive natural conditions, (3) the reproductive capacity of escapees, (4) the spread of Taura Syndrome Virus (TSV), an alien pathogen carried by *P. vannamei*, and (5) the ability of *P. vannamei* to compete for food with local species.

Figure 2. P. vannamei captured from the east coast area of Thailand (Trat province).

The research questions followed the risk assessment framework, consisting of the following steps: (1) identification of hazards (i.e., events leading to undesirable consequences), (2) assessment and prediction of the likelihood and severity of the harms (frequency/exposure analysis and harm/effect analysis), and (3) characterisation of risk (i.e., combined probability of the likelihood of hazard realisation and severity of harms). Our research program focused on step (1) and the beginning of step (2). In our context, hazards include (1) the escape of *P. vannamei* from farms to natural ecosystem; (2) the survival of escaped *P. vannamei*; and (3) the reproduction of escaped *P. vannamei*. We attempted to address two types of impacts, the spread of TSV and food competition. Senanan *et al*. (in press) provided detailed description of the framework and illustrated its use for the case of *P. vannamei* in Thailand.

We chose the Bangpakong River, one of the largest and most important estuary ecosystems in eastern Thailand, as a case study because (1) its watershed harbours the largest area of shrimp farming in eastern Thailand (8,900 hectares of Chacheangsao province in 2004, DOF 1999-2004), (2) its estuarine conditions provide viable habitat for escaped *P. vannamei*, and (3) already installed stationary stow nets within the main channel are quite effective in capturing wild shrimp, enabling us to obtain escaped *P. vannamei* from the wild.

Our research program has generated the first set of quantitative data that feeds into preliminary risk analysis of the releases of *P. vannamei*. These data answered the following questions: how many *P. vannamei* have escaped? Can escapees survive in the natural environment? Can escapees establish a natural population? What is the extent of geographic spread of the alien pathogen, Taura Syndrome Virus (TSV)? Can *P. vannamei* potentially compete with native shrimp species?

How many *P. vannamei* have escaped?

Results from Manthachitra *et al*. (2008), Senanan *et al*. (2007) and Senanan *et al*. (in press) indicated that *P. vannamei has escaped from farms to the Bangpakong River and the numbers of P. vannamei sampled in the river positively correlated with the location and area of shrimp ponds*. Mantachitr *et al*. (2008) used remote sensing and a geographic information system (GIS) to estimate location and total area of shrimp ponds (active, inactive, and abandoned ponds) in the Bangpakong River watershed and found that most ponds were located within 5 km of the river. During 2005-2007, the authors' estimates of active pond area ranged from 88.72 km^2 in 2007 to 116.81 km^2 in 2005. The highest concentration of shrimp ponds were found in the middle section of the Bangpakong River, including three districts of Chachoengsao province (Bang Khla, Mueang Chachoengsao and Ban Pho). Survey of marine shrimp populations in the Bangpakong River during the same period (Senanan *et al*., 2007, in press) confirmed the presence of *P. vannamei* in the river (Figure 1). Mean proportion of *P. vannamei* relative to all penaeid shrimp per net per year (all stations combined) ranged from 0.005 (June 2005) to 0.16 (January 2006), with the highest abundance detected in 2006. The presence of *P. vannamei* in the river may be a consequence of pond water releases during the intense farming activities of 2005. In addition, Barnette *et al*. (2008) and Senanan *et al*. (in press) detected high occurrence of TSV in sub-adult *P. vannamei* caught from the river. Their results might indicate the intentional release of diseased individuals into the river.

Our studies were not designed to address the issue of escapes of larval life stages from hatcheries, and the magnitude of this source remains unknown. However, hatcheries are highly concentrated in the Bangpakong watershed. The issue of larval escapes from hatcheries remains an important concern that will require additional research and monitoring.

Can escapees survive the natural environmental conditions?

Results from Panutrakul *et al*. (in press) and Chavanich et al. (2008) indicated that *P. vannamei escapees can likely survive the environmental conditions of the Bangpakong River and its river mouth*. Panutrakul *et a*l. (in press) conducted toxicological experiments to evaluate the physiological limits of larvae and juvenile of *P. vannamei* and *P. monodon* to extreme salinity and pH changes. The authors found that both species can tolerate a wide range of salinity and pH. For both life stages, *P. vannamei* could tolerate a wider range and more extreme changes of salinity and pH than *P. monodon* (Figure 2). The data suggested that both life stages of *P. vannamei* could adapt to estuarine conditions of the Bangpakong River where water quality, especially salinity, can fluctuate dramatically. During the dry season (December to May), the salinity in the Bangpakong River is within the tolerance limits of *P. vannamei*. Although the salinity in the river may approach zero at most sites during the wet season (June to November), *P. vannamei* would be able to migrate to the river mouth. Panutrakul *et al*. (in press) detected an increase in abundance and size over time of *P. vannamei* captured in the river and near the river mouth.

Chavanich *et al*. (2008) analysed stomach contents of wild-caught *P. vannamei* and local shrimp species. They found that *P. vannamei* consumed the same diet types in similar proportions as local shrimp species. The diet types included phytoplankton, appendages of crustaceans, remains of sea grass leaves, macrophytes, and small mollusc shells and unidentified detrital material (Figure 3). Stomach content analysis indicated that *P. vannamei* can utilise food resources available in the Bangpakong River and these resources were shared between *P. vannamei* and local shrimp species.

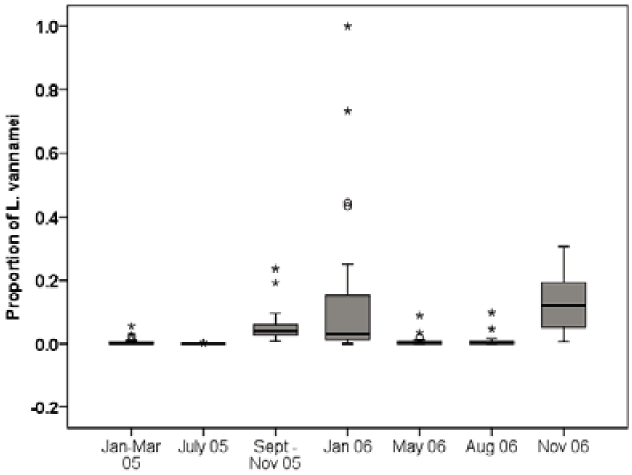

*Figure 3. P. vannamei abundance relative to the total number of Penaeid shrimp species (proportion of P. vannemei per net) in the Bangpakong River during January 2005 – November 2006. * and O indicate extreme values and outliers, respectively. (Data reported in Senanan et al. (2007) and Panutrakul et al. (in press)).*

Can escapees establish a natural population?

The maturity of *P. vannamei* escaped from farms to natural environments is another important factor determining their ability to establish a feral population. Senanan *et al*. (2008) compared the histology of gonads of wild-caught *P. vannamei* and captive *P. vannamei* of known ages. Captive individuals could develop mature gonads at 11 months after post larvae 15 (ovaries contained 50% mature oocytes; testes contained 80% mature sperm cells). They did not find sexually mature individuals in the wild although some wild-caught males larger than 19 g contained a small percentage of mature sperm cells. We still *cannot conclude that escapees can establish a feral population*. However, this study might have under-sampled sexually mature individuals due to inappropriate sampling sites and timing. This issue remains important for further investigation. A monitoring program in off-shore areas may provide opportunities for us to obtain sexually mature individuals.

What is the extent of geographic spread of the alien pathogen, TSV?

Using PCR and immunological analyses, Barnette et al. (2008) examined the occurrence of TSV and two local viruses (WSSV and YHV) in populations of *P. monodon* adults in the Gulf of Thailand, populations of local shrimp species and *P. vannamei* in the Bangpakong River. The data suggested that *TSV has already spread into the Bangpakong River and the Gulf of Thailand*. The authors detected the presence of TSV in *P. monodon* adults, local shrimp species of the Bangpakong River (ten species, namely *Penaeus monodon, P. semisucatus, P. merguiensis, Metapenaeus brevicornis, M. affinis, M. tenuipes, Parapenopsis hungerfordi, Macrobranchium rosenbergii,* and two other species belonging to the Family Caridae), and wild-caught *P. vannamei* (Figure 4). The authors also detected TSV in green mussel *(Perna viridis)*, blue swimming crab *(Portunus pelagicus)* and Asian seabass *(Lates calcarifer)*. TSV appeared to be more widespread in dry seasons compared to wet seasons. In addition, Barnette *et al.* (2008) showed that all three viruses can be horizontally transmitted among shrimp species (*P. vannamei, P. monodon* and *Macrobrachium rosenbergii*).

Can *P. vannamei* potentially compete with native shrimp species?

Chavanich *et al.* (2008) conducted food competition experiments pairing *P. vannamei* with one of two local shrimp species (*P. merguiensis* and *Macrobrachium* sp.) or blue swimming crab *(Portunus pelagicus)* (see also in Panutrakul *et al.*, in press). The authors concluded that *P. vannamei could potentially compete for food with both local shrimp species. In aquaria, P. vannamei often approached food items faster than the local species*. Although this study may not represent a natural situation, as only two individuals were paired in each aquarium, the findings raise important issues about food competition and may serve as a starting point for further ecological studies that address crucial ecological interactions between an alien species and the receiving biotic communities.

Although our research has both retrospective and predictive elements of risk assessment as *P. vannamei* is already present in Thailand, the approach used and the data generated from our research can provide guidance for many countries that plan to introduce *P. vannamei* or other alien aquatic species for aquaculture. Furthermore, the data raise some important management issues for countries that have already introduced this species for aquaculture. Some recommendations based on these data include the following:

1. Implement preventative measures to reduce the numbers of escapes from shrimp farms and hatcheries. In addition, releasing pond water containing diseased shrimp should be prohibited.

2. Sanitise ponds containing diseased individuals before releasing pond water into natural systems. This strategy will reduce the input of both pathogens and escapees into natural ecosystems.

3. Strengthen the screening requirements for pathogens in broodstock. Tighter import regulations may also help reduce the spread of pathogens from aquaculture facility to natural ecosystems.

4. Discourage polyculture of *P. vannamei* with local shrimp species because pathogens can transfer among them. This may lead to enhanced virulence of TSV in local shrimp species.

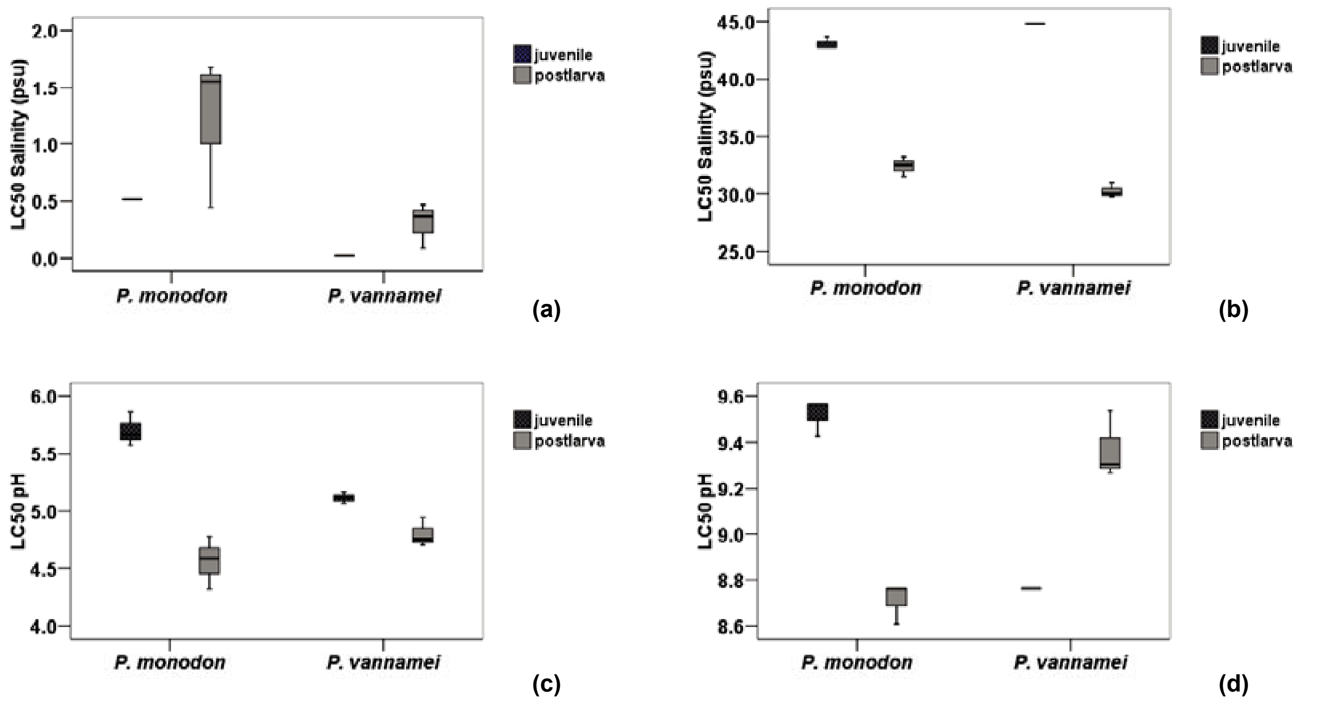

Figure 4. Boxplots of 96-hour LC50 of postlarvae and juveniles of P. vannamei and P. monodon at (a) low salinity (0-20‰), (b) high salinity (30-40‰), (c) low pH (4.5-6) and (d) high pH (8.6-9.6).

Figure 5. Diet types found in gut content of P. vannamei and local shrimp species of the Bangpakong River.

5. Establish a monitoring program for the presence of *P. vannamei* and TSV in the wild, especially the off-shore areas. Such a program will allow for the detection of the geographic spread of escapees and some of their impacts.

6. Communicate the risks associated with alien species to shrimp farmers, fishermen and other relevant parties to help prevent future escapes. These parties may also take part in a network to monitor realised impacts of *P. vannamei*.

7. Continue to support relevant research, including long-term monitoring of population establishment and realised impacts of P. vannamei, the development of risk decision-making tools, and the development of risk reduction/ mitigation strategies.

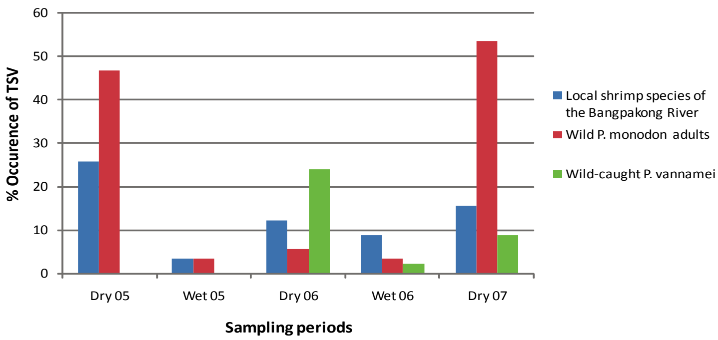

Figure 6. Percentage occurrence of Taura Syndrome Virus (TSV) in shrimp species local to the Bangpakong River, wild P. monodon adults and wild-caught P. vannamei during the dry and wet seasons of 2005-2007.

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