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Antibiotic contaminants in coastal wetlands from Vietnamese shrimp farming

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Received: 4 June 2010 / Accepted: 17 February 2011 / Published online: 23 March 2011

Abstract

Background and purpose Shrimp culture has been expanded rapidly in recent years in coastal wetland zone of Vietnam due to favorable natural conditions. However, this industry has caused several negative impacts to the environment. One of the critical issues is the excessive application of antibiotics including human medicines. These chemicals could be released from shrimp ponds and then accumulated and contaminated of the ecosystem. This review article discusses a whole range of findings that address various aspects of the usage, occurrence and potentially environmental risks of antibiotics released from shrimp farming, with emphasis on the South Vietnam coastal wetland.

Methods The published information on the usage and occurrence of antibiotics in Vietnamese shrimp farming has been reviewed. A global comparison was also carried out. This follows by a brief overview of the transport and fate of these antibiotics in the environment.

Results Several antibiotics commonly used in Vietnamese shrimp culture have been detected in wastewater and sediment of the ponds, as well as in surrounding coastal wetlands, resulting in the existence of antibiotic-resistant bacteria. However, their transport and fate could not be clearly defined.

Conclusions The well-documented accumulation of antibiotics in mud and sediments in Vietnamese coastal wetlands potentially poses serious risks for the local wetland ecosystems. Thus, research on the transport and fate of antibiotics' residues from the ponds into the surrounding environment is urgently needed.

Responsible editor: Thomas Braunbeck

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Keywords Antibiotics · Shrimp farming · Coastal wetland

1 Background and purpose

Vietnam has enormous potential for coastal aquaculture with shrimp culture being dominant. Since 1986, there has been a major acceleration in the use of Vietnamese coastal wetlands for shrimp culture (FAO/NACA 1995). The farming system of brackishwater culture can be grouped into traditional extensive, improved extensive, semi-intensive and intensive culture. Brackish-water shrimp (*Penaeus* species) is the main species raised along the coast. The total area used for brackish-water shrimp culture in 2009 was 6,600 ha, which represents a slight decrease as compared to 2008 (Table 1). The top five shrimp-producing provinces of Vietnam during the period 2000–2009 were Ca Mau (98,100 tonnes in 2009), Bac Lieu (65,700 tonnes), Soc Trang (60,350 tonnes), Kien Giang (31,207 tonnes) and Ben Tre (19,300 tonnes) (Vietnam General Statistic Office). All five of these provinces are in the Mekong Delta region of Vietnam.

However, rapid expansion of intensive shrimp farming without appropriate planning has created various environmental problems. Destruction of mangrove wetlands is just one of the major environmental impacts of shrimp farming. Among the potential environmental impacts, such as the increase of algal production, the dissolved oxygen depletion at the water–sediment interface and the organic enrichment of the sediments, also the potential toxic effect of the chemicals used to control shrimp diseases must be considered. More precisely, the majority of added antibiotics are not assimilated by target organisms but go into environment through discharge. Once in the environment, these chemicals could contaminate the sensitive ecosystem

Reproduced from *Environ. Sci. Pollut. Res.*, **18**: 835-841 (2011).

Le Phi Nga: Participant of the 21st UM, 1993-1994.

Table 1 The statistical data on Vietnamese shrimp farming

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Shrimp culture area (ha)										
−Total	340,500	476,700	516,200	580,400	604,400	533,200	616,700	638,800	636,100	629,900
Of which										
+ Freshwater culture area	324,100	454,900	509,600	574,900	598,000	528,300	612,100	633,400	629,200	623,300
+ Marine and brackish water culture area	16,400	21,800	6,600	5,500	6,400	4,900	4,600	5,400	6,900	6,600
Shrimp production (tonnes)										
−Total	93,500	154,900	186,200	237,900	281,800	327,200	354,500	384,500	388,400	413,100
Divided by region										
+ Red River Delta	4,450	5,953	9,023	11,645	13,023	13,321	14,098	16,054	14,512	14,829
+ Northern midlands and mountainous area	69	57	66	102	123	312	355	388	294	205
+ Central coastal area	18,188	25,591	27,490	33,499	33,201	33,311	37,214	43,563	51,216	68,123
+ Central highlands	18	52	54	62	55	64	62	88	61	71
+ Southeast of Vietnam	1,786	4,827	6,674	10,351	12,772	14,426	15,948	14,896	15,207	17,489
+ Mekong delta	68,995	118,432	142,908	182,221	222,643	265,761	286,837	309,531	307,070	312,415

Source: Vietnam General Statistic Office

of the surrounding wetland. Not only the banned antibiotics (e.g. chloramphenicol), but also authorized antibiotics are potentially toxic to wild organisms and algae (Ferreira et al. 2007). The main outcome is that an extensive use of antibiotics has led to the proliferation of drug-resistant bacteria (Wollenberger et al. 2000; Tuan et al. 2005; Akinbowale et al. 2006). In particular, due to their negative impact on the ecosystem, several antibiotics are already classified as pollutants, e.g. trimethoprim, erythromycin, lincomycine and sulfamethoxazole.

In fact, Vietnamese shrimp farming has already been affected by several diseases, which are caused mainly by bacteria (*Vibrio* spp., *Pseudomonas* spp., *Aeromonas*, etc.). As a result, antibiotics are frequently used in shrimp culture. For example, in 2009, about 70% of the shrimp farming in Long An province was affected, indicating the ineffectiveness of antibiotic drugs. However, there is a lack of information on the environmental impacts of antibiotics on Vietnamese coastal wetlands. Most of the studies have been focused solely on antibiotic residues in food samples as a requirement for shrimp export. Thus, the aim of this review is to provide information on the use of antibiotics in Vietnamese shrimp farming, and to briefly discuss the hazards and risks for the environment and human health caused by these management practices.

2 Antibiotic usage in Vietnamese shrimp farming

Small-scale or household aquaculture accounts for approximately 70 % of aquatic production in Vietnam (Tai 2003). The use of veterinary medicines and other drugs and chemicals in aquaculture, especially shrimp farming, has developed rapidly over the last 10 years in Vietnam. According to Tai (2003), there were about 138 antibiotics used in Vietnamese aquaculture, of which 32 antibiotics were used for shrimp culture and 39 for shrimp larvae rearing. In 2007, there were approximately 230 domestic companies producing or selling products used in aquaculture, of which 136 produced drugs and/or chemicals. These chemicals are also imported into Vietnam from 15 countries, the leader being Thailand, with products also imported from India, China, Indonesia, Taiwan POC, USA, France, Germany, etc. (Tai 2003). Although both large-scale and small-scale farmers have become more prudent in using drugs and chemicals, the use of antibiotics to kill or to inhibit the growth of micro-organisms is widespread. A similar situation prevails in shrimp farming worldwide. Seventy-four percent of the 76 interviewed farmers in Thailand have used antibiotics in shrimp pond management. Most farmers used them prophylactically, some on a daily basis, and at least 13 different antibiotics were used (Holmoström et al. 2003).

Oxytetracycline was the most widely used antibiotic for many years, but in the past decade, quinolones and the combination of sulfadiazine and trimethoprim became more popular in Asian shrimp farming (Holmström et al. 2003; Tai 2003; Nga 2004). In Mekong Delta, the percentages of Vietnamese farmers used those antibiotics are accounted 43% for enrofloxacin and 25% for norfloxacin, respectively. In addition, sulfamethoxazole, cotrimoxazole and trimethoprim are also used (Nga 2004). In Thailand, the number of users is 29 farmers (norfloxacin) and 9 (enrofloxacin), respectively. Other common antibiotics are oxytetracycline and sulfonamides (Holmström et al. 2003).

However, it is difficult to know all the names and the quantity of antibiotics used; only a few farmers have supplied detailed information on the antibiotics they use. Moreover, many farmers are not well-informed about efficient and safe application practices. The most commonly used antibiotics, according to the literature and field survey data, are shown in Table 2. The most common antibiotics used in shrimp farming in Vietnam could be divided into five groups: (1) fluoroquinolones (enrofloxacin, norfloxacin, ciprofloxacin and oxolinic acid); (2) sulfonamides (sulfamethoxazole, sulfadiazine), (3) tetracyclines (oxytetracycline), (4) diaminopyrimidines (trimethoprim, ormethoprim) and (5) unclassified (griseofulvin and rifampicin).

Recent data collected from Can Duoc district (Long An province) have shown that lately the most commonly used antibiotics are sulfonamides in combination with trimethoprim. TMT, the most frequently used antibiotic (73% of the interviewed farmers) is a mixture of trimethoprim and sulfadiazine. The next most commonly used are Osamet (53% of the farmers) and Cotrim (40% of the farmers), which are composed of sulfadimethoxine and ormethoprim as well as trimethoprim and sulfamethoxazole, respectively. In Can Gio district (Ho Chi Minh City), the main diseases are 'white spots' and 'white faeces'; norfloxacin and trimethoprim have been frequently used to treat both of these diseases (Fig. 1). Presently, the adult shrimps are regularly checked by authority for antibiotic residues so the usages are more restrained. However, the new concern is with the rearing of shrimp larvae, because in this case, no supervision is required. To sum up, antibiotics are intensively used nowadays to combat disease in shrimp. More seriously, in Can Gio district, beside ciprofloxacin, the most common antibiotics for shrimp larvae are two human pharmaceuticals (rifampicin and griseofulvin). Similarly, the application of rifampicin for shrimp larvae has also been reported in the Philippines (Tai 2003).

3 Occurrence in aquatic environments

Antibiotics used widely in shrimp rearing do result in high levels of residues in shrimp ponds as well as in the surrounding environment. The potential biological or ecological side effects of such chemicals are mainly related to the organism exposure, the level of which depends on the quantities used, the mode of application (via feed or diluted in water), farm type and technologies applied.

In Vietnamese shrimp culture, antibiotics are commonly administered as medicated feed, injection or in the case of topical applications as a bath formulation. In fact, antibiotics can sometimes leach from the feed pellets into the pond water even before the pellets are consumed by shrimps; they will then accumulate on the pond bottom. According to previous studies, 60–85% of the drug can be excreted through the faeces without any modification, depending on the type of antibiotics used. Furthermore, the bioavailability of many antibacterial agents is relatively low and drugs may also enter the environment via faeces and urine (Björklund et al. 1991). In the case of oxytetracycline, 95% of the drug dose passes through the host

Table 2 The most common used antibiotics in Vietnamese shrimp farming

No.	Commercial name	Composition	Percentage of farmers (%)	Usage for
1	Ciprofloxacin 500 mg	Ciprofloxacin	100	Larvae
2	Cotrim	Sulfamethoxazole	8.7	Postlarvae to adult shrimp
3	Cotrim-La	Sulfamethoxazole, Trimethoprim	n.a	Postlarvae to adult shrimp
4	Daitrim	Sulfamethoxazole 10%, Trimethoprim 2%	n.a	Postlarvae to adult shrimp
5	Griseofulvin 500 mg	Griseofulvin	100	Larvae
6	N300	Norfloxacin, hydrochloride 30%	n.a	Postlarvae to adult shrimp
7	Osamet	Sulfadimethoxine 25%, Ormetoprim 5%	11.2	Postlarvae to adult shrimp
8	Prawnox	Oxolinic acid 25%	n.a	Postlarvae to adult shrimp
9	Rifampicin 300 mg	Rifampicin	100	Larvae
10	Romet 30	Sulfadimethoxin 25%	n.a.	Postlarvae to adult shrimp
11	Silva 54	Sulfadiazine, Trimethoprim	n.a	Postlarvae to adult shrimp
12	Sulfa-prim	Sulfadiazine, Trimethoprim	21.74	Postlarvae to adult shrimp
13	TA-2 oxytetracyline	Oxytetracyline	100	Larvae
14	TMT	Sulfadiazine, Trimethoprim	15.9	Postlarvae to adult shrimp

Note: data collected from 71 farmers (including two larvae farming) in wetland of Can Gio and Can Duoc districts

n.a the data is not available

Fig. 1 A typical shrimp pond in coastal wetland of Can Gio district, Ho Chi Minh City

organism and is then simply released into the surrounding environment (FAO 2005). Nevertheless, deposition of drugs from uneaten feed or faeces on or in under-cage sediment can be a major route of environmental contamination for pharmaceuticals used in aquaculture (Björklund et al. 1991; Lunestad et al. 1995). From shrimp ponds, antibiotics are released into surrounding bodies of water. Hence, some of the drugs entering the environment in waste feed and faeces are also taken up by wild fish, shellfish and crustacean inside the shrimp ponds as well as in the surrounding environment, many of which are also exploited for human consumption.

For shrimp farming located in Vietnamese coastal wetlands, a screening study on the residues of selected antibiotics (norfloxacin, oxolinic acid, trimethoprim and sulfamethoxazole) has been carried out by Tuan and Munekage (2004). The authors have collected samples from various typical shrimp farms in Vietnamese coastal wetlands (Tien Hai-Giao Thuy, Xuan Thuy, Can Gio and Ca Mau). The results have confirmed the presence of antibiotic residues in the water and mud of the shrimp ponds as well as surrounding wetlands (Table 3). The global comparisons have shown the enrichment of all studied antibiotics in surface water in Vietnamese wetlands, as compared with lower level detected in other locations. The normal concentrations of antibiotics range from not detected up to nanogram per liter (ng/L) and could be increased up to a maximum level of microgram per liter (μg/L) (Kümmerer 2009). In Vietnam, antibiotics in surface water (both surface and bottom layers) have been detected in all locations up to milligram per liter (mg/L). Similarly, remarkable high antibiotic concentrations are found in sediments, which could rise up to thousand milligrams per kilogram. For example, the concentrations of oxolinic acid ranged from 1.81 to 426 mg/kg. By comparison, in Finnish and Italian fish farms, maximum values in sediments have been reported to be only 0.2 and 247 mg/kg, respectively (Björklund et al. 1991; Lalumera et al. 2004). Another study (Managaki et al. 2007) indicates that in Vietnam, only a few antibiotics (viz., sulfamethoxazole, sulfamethazine, trimethoprim and erythromycin-H_2O) have been detected in the rivers and canals of urban and rural sites, at concentrations of 7–360 ng/L. It may be that aquaculture in general and shrimp culture, in particular, are the major sources of antibiotic residues in the adjacent aquatic systems.

One of the seriously negative impacts of antibiotics in the environment is the fact that they are most likely inducing antibiotic resistance in bacteria. This leads directly to a decrease in the effectiveness of antibiotic usage for targeted organisms. Furthermore, it affects wild organisms and consequently alters the human immune system, indirectly causing severe health problems in humans. These could potentially cost millions of dollars for the medical

Table 3 Comparision of antibiotic concentrations in aquatic system

	Oxolinic acid	Norfloxacin	Sulfamethoxazole	Trimethorpim	References
Surface water (μg/L)					
Surface layer–shrimp pond, Vietnam	10–25,000	60–6,060	40–2,390	80–1,040	Tuan and Munekage (2004)
Bottom layer–shrimp pond, Vietnam	10–2,310	84–4,040	40–5,570	80–2,030	Tuan and Munekage (2004)
US stream	n.a.	0.0120	1.9	0.71	Kolpin et al. (2002)
River–fish farm, Italy	n.a.	n.a.	n.a.	0.34	Lalumera et al. (2004)
Sediment (mg/kg)					
Shrimp pond, Vietnam	1.81–426	6.51–2,616	4.77–820	9.02–735	Tuan and Munekage (2004)
Fish farm, Finland	0.2[a]	n.a.	n.a.	n.a.	Björklund et al. (1991)
Fish farm, Italy	247	n.a.	n.a.	n.a.	Lalumera et al. (2004)
Sewage treatment plant effluent		106[a]	2,800[a]	7,900[a]	Giger et al. (2003), Batt et al. (2007)

n.a data not available

[a] Maximum level

treatment of those who become ill and no longer respond to previously effective drugs. Antibiotic-resistant bacteria, e.g. *Bacillus* and *Vibrio,* have been discovered in coastal wetlands in Vietnam with an antibiotic concentration of 0.1 μg/ml (Tuan et al. 2005). The incidence of resistance to trimethoprim and sulfamethoxazole was higher as compared with norfloxacin and oxolinic acid. Thus, if the usage of antibiotics in Vietnamese shrimp farms remains unregulated, the emergence of more and more antibiotic-resistant bacteria should be expected.

4 Degradability of antibiotics in coastal wetland

Studies of the degradability of antibiotics have been done not only for marine environments, but more generally for all aquatic systems. Once antibiotics are released into the waters or sediments, they are subjected to transformation or degradation at various rates, depending on the nature of the antibiotic and environmental factors such as light, temperature and/or microbial activities. An overview of results for the degradability of antibiotics used in Vietnamese shrimp farming is summarized in Table 4.

4.1 Photodegradation

Light plays a major role in the degradation of all fluoroquinolones (Holmström et al. 2003; Knapp et al. 2005; Lai and Lin. 2009; Ge et al. 2010; Sturini et al. 2010). However, there are various half-lives (T1/2), ranging from a few hours in the laboratory (Knapp et al. 2005) to a few days (Lunestad et al. 1995) or even months in natural aquatic environments (Turiel et al. 2004). The seawater constituents could inhibit their photodegradation (Ge et al. 2010). In addition to chemical characteristics, these variations can mainly be attributed to discrepancies in light regimes under which the experiments have been conducted (Schmitt-Kopplin et al. 1999; Andreozzi et al. 2003). Sturini et al. (2010), Ge et al. (2010) and Knapp et al. (2005) have confirmed that the degradation of enrofloxacin in natural water is strongly affected by light. The results of Lai and Lin (2009) have also shown that oxolinic acid is photodegraded in pond waters under natural illumination conditions. This experiment has shown that with the maximum possible illumination conditions in pond water near the surface, the T1/2 values of oxolinic acid are 2.3–4.8 days, which is similar to results obtained by Lunestad et al. (1995). On the other hand, oxolinic acid does not degrade significantly in dark waters. Holmström et al. (2003) also mentioned that norfloxacin is rapidly destroyed by photolysis in pure water.

Similarly, Lunestad et al. (1995) have reported that tetracycline (oxytetracyline) is degraded within 21 days when stored at sea level. In contrast, other groups of antibiotics (sulfonamides and trimethoprim) are classified as stable in the presence of light (Lunestad et al. 1995). To the best of our knowledge, no available data for griseofulvin and rifampicin can be found in the literature.

In Vietnamese aquaculture, it is a common practice to drain and sun-dry pond sediments after the harvest. This does imply that fluoroquinolones would be susceptible to photodegradation if present in the sun-dried slurry.

Table 4 The degradation characteristics of antibiotics applicable to Vietnamese coastal wetland conditions

Antibiotic	Degradability in aquatic system			
	Phytodegradation	Hydrolysis	Biodegradation	Remarks
Enrofloxacin	Yes	No, solubility 130 g/l	n.a.	Kow 4.45 so it is a lipophilic chemical
Oxolinic acid	Yes/high	Relatively low	Low, but enhanced with light	
Norfloxacin	Yes/high	Relatively low	n.a.	
Ciprofloxacin	Yes/high	Relatively low solubility 30 mg/l	Low	Kow 2.5
Sulfamethoxazole	No	No	No-Low[a]	Resistant bacteria could increase the biodegradability
Sulfadiazine	n.a.	No	No[a]	
Oxytetracycline	Yes/relative high	Yes; solubility 1 mg/l	n.a.	
Trimethoprim	No	No	No[a]-Low	Resistant bacteria could increase the biodegradability
Griseofulvin	n.a.	n.a.	n.a.	
Rimpapicin	n.a.	n.a.	n.a.	

n.a data not available

[a] According to OECD 301 test

4.2 Hydrolysis

Fluoroquinolones are resistant to hydrolysis with the solubility ranges from 30 to 130 g/l (Chee-Sanford et al. 2009; Kümmerer 2009). Similarly, Loftin et al. (2008) have reported that at pH 7 and 9, sulfonamides and trimethoprim are much more stable in the range of aqueous solutions. Thus, the hydrolysis of these antibiotics is not to be expected in surface water, groundwater or anaerobic lagoons. The recent study of Henderson et al. (2009) has confirmed that in respect to the bioconcentration factor, sulfamethazine belongs to the class of persistent hydrophobic contaminants. Thus, sediment is a potential sink for this contaminant.

Some instability in water can be demonstrated for certain tetracyclines (Halling-Sørensen et al. 2000). In general, the hydrolysis rates for oxytetracycline increase as the pH level deviates from pH 7 and as temperature increases. The T1/2 of oxytetracycline under investigation varies due to differences in temperature, light intensity and flow rate from one test tank to another. At pH 7, the T1/2 are 41 and 155 h for temperature of 22°C and 35°C, respectively. At pH 9, the T1/2 decreases to18 and 39 h, respectively. Thus, the tetracyclines tend to degrade quite rapidly under conditions similar to those encountered in natural water and lagoons.

4.3 Biodegradation

Besides chemical and photochemical degradation, the biodegradability of antibiotics, i.e. their susceptibility to decomposition by living organisms, is another important factor. Only a few studies have discussed the biodegradation of fluoroquinolones in aquatic environments. In fact, most fluoroquinolones are considered not to be biotransformed or biodegraded (Al-Ahmad et al. 1999; Turiel et al. 2004; Chenxi et al. 2008). It has been postulated that the high fixation rates of fluoroquinolones compounds to the surface or in pores of the sediment matrix may effectively protect them from biodegradation (Halling-Sørensen et al. 2000). The laboratory-scale experiment carried out by Lai and Lin (2009) has shown that a slow biodegradation of oxolinic acid occurs in the shrimp pond sediment slurry in the dark. This shows that in addition to light, microbial activities can also affect the degradation of oxolinic acid and fluoroquinolones. Degradation of oxolinic acid becomes even faster after re-addition in the same sediment slurry in the light.

For other antibiotics, the data are also scarce. In the laboratory, common OECD tests have been developed to assess the ‘ready biodegradability’ (OECD 301) and ‘biodegradability’ (OECD 308) of antibiotics. Results of OECD 301 test carried out by Alexy et al. (2004) have shown that among the most frequently applied antibiotics in Vietnam, fluoroquinolones, sulfonamides and trimethoprim are not readily biodegradable. The readily biodegradable ones account for less than 4% of the antibiotics used during testing period of 21 days. However, studies by Samuelson et al. (1994) and Tuan et al. (2005) indicated that trimethoprim and sulfamethoxazole can be degraded by antibiotic-resistant bacteria in marine sediments, while other antibiotics such as oxolinic acid and flumequine seem to be more stable as to resist bacterial degradation. So, for the long-term period, the presence of resistant bacteria could enhance the biodegradation process of these antibiotics.

Maki et al. (2006) have reported a decrease of more than 50% for oxytetracycline from its initial concentrations in marine sediments, suggesting that bacterial degradation was strong enough to influence the dynamics of antibiotic residues.

It could be summarized that several antibiotics (norfloxacin, oxolinic acid, trimethoprim and sulfamethoxazole), commonly used in Vietnamese shrimp culture, have been detected in wastewater and mud of the ponds. Hence, these antibiotics do indeed enter and accumulate in surrounding coastal wetlands. Over time, this accumulation leads to the selection of existing antibiotic-resistant bacteria. However, since the accumulation and degradation processes of used antibiotics are very complicated and multi-factors dependent, so their transport and fate in Vietnamese coastal wetland could not be clearly defined.

5 Conclusion

In Vietnam, most of the aquaculture areas are located in the coastal wetlands, which belong to the conservation area, where antibiotics were and are extensively used. It is clear that the well-documented accumulation of antibiotics in mud and sediments poses potentially serious risks for the local wetland ecosystems.

Despite their widespread use, published data on the amounts and use patterns of antibiotics in Vietnam are scarce. Previous studies have focused mainly on the detection of residues of banned antibiotics (chloramphenicol, nitrofuran, etc.) in food samples (shrimp). The issues related to the transport and fate of antibiotics’ residues from culturing ponds into the surrounding environment are still relatively new and remain in the early stages of research. Therefore, further studies in this field are needed.

Acknowledgments This research is supported by the Vietnam’s National Foundation for Science and Technology Development (NAFOSTED), Project 105.09.30.09. The authors thank Dr. Paul Truong and Prof. Lewis Hinchmann for English editing. This manuscript benefited from comments provided by two anonymous reviewers and the editor.

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