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A field survey of chemicals and biological products used in shrimp farming

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Abstract

This study documented the use of chemicals and biological products in marine and brackish water shrimp farming in Thailand, the world's top producer of farmed shrimp. Interviews were conducted with 76 shrimp farmers in three major shrimp producing regions, the eastern Gulf coast, the southern Gulf coast and the Andaman coast area. Farmers in the study used on average 13 different chemicals and biological products. The most commonly used products were soil and water treatment products, pesticides and disinfectants. Farmers in the southern Gulf coast area used a larger number of products than farmers in the other two areas. In the study, the use of more than 290 different chemicals and biological products was documented. Many of the pesticides, disinfectants and antibiotics used by the farmers could have negative effects on the cultured shrimps, cause a risk for food safety, occupational health, and/or have negative effects on adjacent ecosystems. Manufacturers and retailers of the products often neglected to provide farmers with necessary information regarding active ingredient and relevant instructions for safe and efficient use.

Keywords: Shrimp; Aquaculture; Environment; Pesticides; Disinfectants; Antibiotics

1. Introduction

The shrimp farming industry is an important economic sector in many Asian countries, including Thailand, which is the world's top producer. During the 1980s the Thai shrimp farming sector developed rapidly, and has since 1993 produced 235,000–275,000 t of cultured shrimps annually (FAO, 2001). The export of farmed shrimps generates large amounts of foreign exchange into the country. For example, in 2000 and 2001 shrimp exports earned Thailand annually more than 2 billion USD, [1] corresponding to 3–4% of the country's total export value (Bangkok Post, 2001a,b,c, 2002; ITN, 2002). Concurrent with its achievements, the shrimp farming industry has been subject to criticism from environmentalists and scientists due to different negative effects on the environment (Primavera, 1998; Flaherty et al., 2000; Naylor et al., 2000). Concern has been expressed regarding the use of chemicals in shrimp farms, and its potential impacts on the environment and human health (Subasinghe et al., 2000; Gräslund and Bengtsson, 2001). However, the ongoing debate is suffering from lack of information. A survey of chemical use in Philippine shrimp farms was conducted in 1990 (Primavera et al., 1993), and availability of more data and information on shrimp farming management systems would be valuable for further discussions. Antibiotic use in Thai shrimp farms was further investigated, in parallel to the present study, showing that the use was extensive and often inappropriate (Holmström et al., in press). The aim of this study was to provide information on the use of different groups of chemicals and biological products in Thai marine shrimp farming.

2. Material and methods

Interviews with shrimp farmers were conducted April–June 2000 with the help of a Thai interpreter. Farms were selected as randomly as possible within each area. The informants were farm owners or the responsible farm

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[1] At exchange rates year 2000: 1 USD = 40.2 THB, and 2001: 1 USD = 44.5 THB.

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managers (these were often one and the same). A questionnaire, covering information on basic production data and management practices, with a focus on use of chemicals and biological products, was used. Questions were open-ended and followed up when necessary. Altogether 76 farmers were interviewed in three major shrimp producing regions in Thailand. The three regions were eastern Thailand from Chachoengsao province to Chantaburi (30 farms), the Andaman coast from Trang to Krabi (24 farms), and the southern Gulf coast from Songkhla to Surat Thani (22 farms). The farms in the eastern Gulf coast area were located at about 12.5–13.5°N, in comparison with 7–8°N for the Andaman coast area, and 7–9°N for the southern Gulf coast area. One third of the farms on the eastern Gulf coast used trucks to transport sea water to their farms, whereas the other farms used salt water pumped from the sea, a khlong (canal or river), or ground water. All farms cultured the black tiger shrimp, *Penaeus monodon*, in marine or brackish water. As many as 69 of the farms fulfilled the criteria for intensive farms used by Primavera (1998), or were even more intensive. Two of the remaining farms had a lower production rate, and for classification of the remaining five farms there was insufficient information available. All farmers in the study relied on pelleted feed, but such formulated feed were not included in the figures presented here. However, products distributed to shrimps by adding them to the feed are included, both e.g. antibiotics, vitamins, and other feed additives such as mussels or bananas. The chemicals and biological products documented in the survey were sorted into the following major groups: fertilisers, pesticides and disinfectants, antibiotics, microorganisms, vitamins, immunostimulants, other soil and water treatment compounds, other feed additives, and an "uncertain group" of compounds that could not be classified. Some products were identified with respect to chemical formula of active ingredient (e.g. norfloxacin was the active ingredient of a number of products), whereas others were identified merely as a certain type of product (e.g. vitamins were grouped into one type; immunostimulants as another).

2.1. Statistical analyses

Differences between areas in average (median) number of products used per farm were analysed with Kruskal–Wallis test, followed by Mann–Whitney U-test (SPSS for Windows, 10.0) with limit for significance $p = 0.017$ (Bonferroni correction $p = 0.05/3$ where 0.05 is normal limit, 3 is number of tests performed). Indications of relationships between number of products used per farm and location or a number of farm management variables were studied through a stepwise multiple regression (SPSS for Windows, 10.0). The number of observations after excluding farms where information was lacking for one or several parameters was 60 in the first multiple regression (eastern Gulf coast: $n = 23$; Andaman coast $n = 19$; southern Gulf coast $n = 18$) and 56 in the second (21; 16; 19).

3. Results and discussion

3.1. Use of chemicals and biological products

More than 70 different substances or types of products were identified in the present study (Table 1). The same active ingredient was in many cases represented by different brands (e.g. Per-zoo and O-lan are both brand names of trifluralin products). Some of these were products seemingly very similar to each other, whereas some differed, for example in percentage of active ingredient. The substances or types of products were divided into major groups, with sub-groups where appropriate.

3.1.1. Proportion of users and purpose

Soil and water treatment compounds were used by all farmers in the study (Fig. 1). Thereafter the most commonly used groups of products, in order of frequency of farmers using them, were pesticides and disinfectants, microorganisms, other feed additives, vitamins, antibiotics, fertilisers, and immunostimulants.

3.1.1.1. Soil and water treatment compounds. All of the interviewed farmers used some kind of soil and water treatment compound in the pond management. The most commonly used substances were liming compounds, which were used by all but one of the farmers. A majority of these farmers used them to adjust pH, but at least one third additionally used them as disinfectants, to kill pathogens or plankton. Shrimp farms are often located in acid sulfate soil areas, e.g. former mangrove areas, where liming may be of particular importance (GESAMP, 1997). Zeolite products, i.e. hydrated alkali–aluminium silicates, were also used by a majority (57%) of the farmers. Most of the farmers used zeolites to decrease turbidity, whereas only a few used them to remove ammonia. Removal of ammonia is previously known as one of the main purposes of zeolite use in shrimp ponds, a practise that has been questioned (Boyd, 1995). Two farmers used cement to cover pond bottom before ponds were filled with water at the beginning of a culture cycle.

3.1.1.2. Fertilisers. Fertilisers were used to increase plankton growth in pond water, both to improve the general environment in the ponds and to increase food supply for the cultured shrimp. Forty eight of the interviewed farmers (63%) used some kind of fertiliser in the pond management. In the group of 27 farmers who

Table 1
Chemicals and biological products used by shrimp farmers in the survey. The number indicates how many farmers that were using one or several products of that particular category

Soil and water treatment compounds 76	Liming compounds 75	Dolomite 54
		Calcium carbonate 38
		Unidentified liming compounds 51
	Calcium 5	
	Zeolite 43	
	Sodium bicarbonate 1	
	Acetic acid 2	
	Cement 2	
	Unidentified soil and water treatment compounds 7	
Fertilisers 48	Inorganic fertilisers 27	N-fertiliser 9
		NP-fertiliser 5
		NPK-fertiliser 16
		PK-fertiliser 1
		P-fertiliser 1
		$SiO_2 + AlO_3$ 1
		Unidentified inorganic fertiliser 1
	Organic fertilisers 26	Chicken manure 11
		Cow manure 4
		Unidentified manure 3
		Molasses 5
		Dry leaves 1
		Fish 4
		Rice shell 3
		Pig feed 2
		Unidentified organic fertilisers 1
	Unidentified fertilisers 9	
Pesticides and disinfectants 73	Chlorine 51	Calcium hypochlorite 7
		Unidentified chlorine compounds 44
	Iodophores 28	
	Hydrogen peroxide 23	
	Potassium permanganate 7	
	Ozone 1	
	Formalin/formaldehyde 33	
	Quaternary ammonium compounds 32	Benzalkonium chloride 29
		Didecyl dimethyl ammonium chloride 1
		Unidentified quat. amm. comp. 2
	Detergents 9	
	Typical synthetic organic pesticides 25	Organophosphates 17
		Trichlorfon 17
		Dichlorvos 1
		Pyrethroids 1
		Trifluralin 7
		Endosulfan 2
		Niclosamide 1
	Malachite green 4	
	Troclosene sodium 1	
	Teaseed/saponin 64	
	Copper compounds 4	Copper sulfate 1
		Copper chloride 1
		Unidentified copper compounds 2
	Unidentified pesticides or disinfectants 36	
Antibiotics 56	Sulfonamides 10	Sulfamethazine 1
		Unidentified sulfonamides 9
	Fluoroquinolones 34	Norfloxacin 28
		Enrofloxacin 9
		Ciprofloxacin 2
		Perfloxacin 1
	Non-fluorinated quinolones 2	Oxolinic acid 2
	Unidentified quinolone 1	
	Tetracyclines 6–20	Oxytetracycline 3–17[a]

(*continued on next page*)

Table 1 (*continued*)

		Chlortetracycline 1
		Tetracycline 2
	Chloramphenicol 1–2[a]	
	Gentamicin 3	
	Trimethoprim 1	
	Tiamulin 1	
	Unidentified antibiotics 13–25[b]	
Microorganism products 65	*Bacillus* products 11	
	Unidentified microorganism products 56	
Immunostimulants 5		
Vitamins 58		
Feed additives 59	Animal based feed additives 37	Chicken egg 2
		Duck egg 1
		Unidentified egg 3
		Fish 22
		Mussels 2
		Oyster 1
		Shellfish 2
		Squid oil 8
		Fish oil 1
	Vegetable based feed additives 15	Banana 13
		Pineapple 1
		Unidentified fruit 1
		Garlic 5
		Lecithin 1
		Soybean sauce 1
	Other feed additives 3	Amino acid and yeast 1
		Calcium 2
	Unidentified feed additives 28	
Uncertain group 4	Tapioka starch 1	
	Unidentified compounds 3	

Major groups are listed in the left column. Product groups or substances in the right columns are subordinate to the major groups.

[a] The number depending on interpretation of product names. The lowest number corresponds to the highest number for unidentified antibiotics.

[b] The number depending on interpretation of product names. The lowest number corresponds to the highest number for oxytetracycline and chloramphenicol.

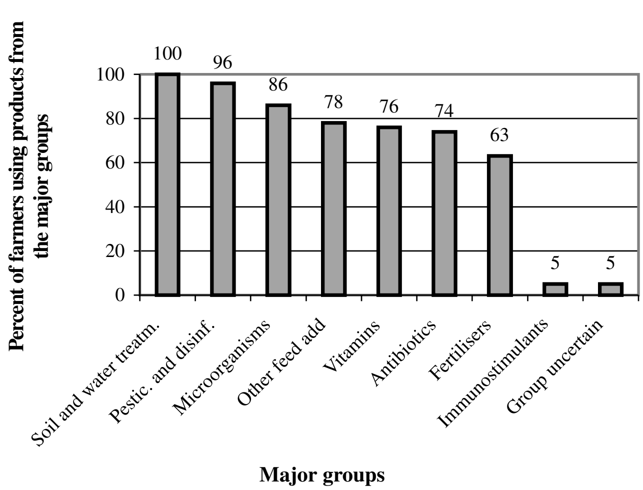

Fig. 1. Proportion of all farms in the study that used one or several chemical and biological products from the major groups.

used inorganic fertiliser, NPK-fertiliser was the most commonly used product. Among the 26 farmers who used organic fertiliser, chicken manure was most common. At least 10 farmers used both inorganic and organic fertilisers. Apparently, even though all farmers in the survey used pelleted feed in the farm management, many farmers additionally chose to use fertilisers to provide natural feed as a complement.

3.1.1.3. Pesticides and disinfectants. Most farmers (96%) used at least one kind of pesticide or disinfectant in the shrimp pond management. Commonly used products were chlorine, formalin, quaternary ammonium compounds, iodophores and hydrogen peroxide. Chlorine was used by 67% of the farmers, formalin by 43%, quaternary ammonium compounds (e.g. benzalkonium chloride) by 42%, iodophores by 37%, and hydrogen peroxide by 30%. These compounds were often used for several purposes, for example, to kill both algae, bacteria and parasites. Teaseed was the most commonly used organic pesticide, used by 84% of the farmers, mainly as piscicide. Frequently encountered were also the synthetic organic pesticides trichlorfon and trifluralin, used by 22% and 9% respectively; the former to kill wild crustaceans, and the latter as an algaecide and to prevent and eliminate *Zoothamnium* parasites. Seven farmers used potassium permanganate, four farmers used copper compounds, and four used malachite green. As mentioned above, liming compounds were also frequently used with the purpose of disinfection. There was also a large number of disinfectants and/or pesticides that could not be identified to their content.

3.1.1.4. Antibiotics. Fifty six of the farmers (74%) used one or several types of antibiotics in the farm. The use of at least 13 different kinds of antibiotics was documented. The most commonly used group was fluoroquinolones, followed by tetracyclines and sulfonamides. Antibiotics were used to prevent and to treat *Vibrio* infections, but also in the belief that they could prevent and treat viral infections such as white spot disease (discussed further by Holmström et al., in press). The antibiotics were generally distributed to the shrimps mixed with the feed. During a prevention effort, or treatment, antibiotics were typically given to the shrimps several times a day for 7 days.

3.1.1.5. Microorganisms. Products containing microorganisms were used by 65 farmers (86% of all farmers). These were either used to treat the water or sediment, or given directly to the shrimps by mixing the product (in this context often called probiotics) with the feed. Some of the products used as feed additives also contained enzymes and other nutrients. At least 11 farmers used microorganism products containing *Bacillus* spp. The products administered in the feed were used to enhance shrimps' digestion, while the purpose of treating water or sediment was mainly to increase decomposition of organic matter and to out compete pathogenic bacteria. Several farmers pointed out that they regarded microorganism products to be a more environmentally friendly alternative to chemicals.

3.1.1.6. Vitamins. A majority of the interviewed farmers (76%) used vitamins to mix with the shrimp feed, with the purpose to enhance growth, and prevent disease outbreaks. Most of these were C-vitamin products.

3.1.1.7. Other feed additives. Most farmers (78%) added different products to the feed in order to increase the nutrient content. Fish and shellfish products, and banana was common. 37% of the farmers used one or several feed additives that could not be identified. It is possible that some of these were microorganisms, immunostimulants or antibiotics.

3.1.1.8. Immunostimulants. Five farmers in the survey used an immunostimulant product, three farmers in the east, and one each on the southern Gulf coast and Andaman coast. The products were mixed with shrimp feed, with the purpose of preventing disease outbreaks. Immunostimulants are products containing elements that stimulate the non-specific immuno system in shrimp (Sakai, 1999). The content of the three different brands of immunostimulants used in this study was not quite clear. However, one of the products mainly contained glucan, mannan oligosaccharide and peptidoglycan, and one of the others contained agglutinin and peptidoglycan.

3.1.2. Products used by an average shrimp farm

Farmers in the present study used on average 13 chemicals and biological products in the shrimp pond management (Fig. 2). A farm on the eastern Gulf coast used on average 10 products, on the Andaman coast 13.5, and on the southern Gulf coast 15.5. The data were compared with Kruskal–Wallis test and Mann–Whitney U-test which showed that these differences in average were statistically significant between all three areas. Many farmers used several products from the same

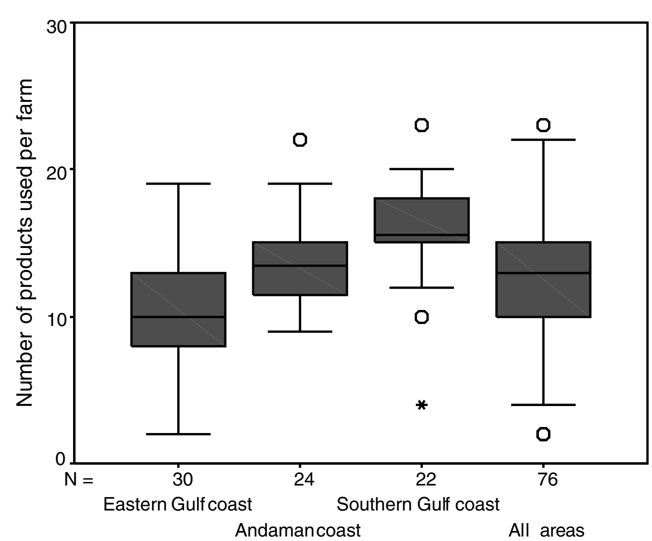

Fig. 2. Total number of chemicals and biological products used per farm. Median for each area, and for all areas together. The whiskers are highest and lowest values, excluding outliers. Circles are outliers, star is extreme value. Total number of products used on average: Eastern Gulf coast: 10; Andaman coast: 13.5; Southern Gulf coast: 15.5; Total for all farms: 13. There was a significant difference between the average number of products used in the three areas, between all areas. Kruskal–Wallis test: $p < 0.0001$; Mann–Whitney U-test: Eastern Gulf coast vs Andaman coast $p = 0.005$; Eastern Gulf coast vs Southern Gulf coast $p < 0.001$; Andaman coast vs Southern Gulf coast $p = 0.007$.

major group, for example both dolomite and calcium carbonate, or both chicken dung and an inorganic NPK-fertiliser. Examples include a farm on the Andaman coast where 10 different pesticides and disinfectants were used (chlorine, formalin, a iodophore, hydrogen peroxide, benzalkonium chloride, trichlorfon, dichlorvos, teaseed, trifluralin and one unidentified pesticide named alphacide), and another farm in the same area where five different types of antibiotics were used (oxytetracycline, oxolinic acid, norfloxacin, enrofloxacin and a sulfonamide). Farmers in this study used on average about 4 pesticide and disinfectant products, 3 soil and water treatment compounds, 1 other feed additive, 1 antibiotic, 1 fertiliser, 1 microorganism product, and 1 vitamin product, with some variations in the different areas (Table 2). A farmer in the southern Gulf coast area on average used a larger number of pesticides, disinfectants and fertilisers than an average farmer on the Andaman coast, who in turn used a larger number of these major groups of products than an average farmer in the eastern Gulf coast area.

3.1.3. Relations with location and management practices

Indications of relationships between the number of chemicals and biological products used per farm and a number of management practice variables were studied by conducting a multiple regression. The number of products used per farm was the dependent variable, and the following were the independent variables: area, farm age, number of ponds per farm, individual pond area, production per crop, number of crops per year, and stocking density ($n = 60$). In a second analysis, experienced disease problems and experienced pest problems were included ($n = 56$). Similarly to the results of the non-parametric statistics conducted, both analyses indicated that there was a relation between the number of products that were used and the area a farm was located in, mainly that farmers in the eastern Gulf coast area used a lower number of products than farmers in the other areas. Within the eastern Gulf coast area there was a weak indication of a negative relationship between number of products used per farm and stocking density. However, the main reason for the differences in levels of products used by farmers in the different areas was rather one or several factors not included in the analysis.

3.2. Market for chemicals and biological products

At the time of the survey, there obviously was a large number of chemicals and biological products available for Thai shrimp farmers on the market. There was a total of at least 290 different chemicals and biological products (excluding pelleted feed) that were used among the 76 farmers, considering similar products with different brand names and/or manufacturers as separate products. More than 60 different companies were documented as manufacturers of these products. Apparently, the market in Thailand for shrimp farming chemicals and biological products was very diverse at the time of the study. Information on product labels was often insufficient, for example, leaving out name of active ingredient, percentage active ingredient, safety instructions, and efficient use of the product. Many labels were in Thai, however, that is not of much help to the farmers when essential information is lacking. It is necessary that suppliers of chemicals and biological products for use in shrimp farming provide farmers with essential basic information so that the farmers have the possibility to make relevant choices of which products to use, and how to use them safely and efficiently.

3.3. Regulations

Thailand has no specific legislation on the use of chemicals in aquaculture (Tonguthai, 2000). However, many of the products used in shrimp farming are also used for other purposes, and the use of some of them are regulated in those contexts. The Ministry of Agriculture and Cooperatives is responsible for agricultural chemicals, and the Ministry of Public Health is responsible for drugs also used in human medicine. Regarding use of antibiotics, the use of chloramphenicol in animal feed is

Table 2
Number of chemicals and biological products used per farm on average

	Eastern Gulf coast	Andaman coast	Southern Gulf coast	All areas
Pesticides and disinfectants	3 (1–4)	4 (3.75–6)	5.5 (5–6.75)	4 (3–6)
Soil and water treatment products	3 (2–4)	3 (2–3.25)	3 (2–3)	3 (2–4)
Antibiotics	1 (0–1)	1 (1–2)	1 (1–2)	1 (0–2)
Other feed additives	1 (1–1.75)	1 (0–1.25)	1 (1–2)	1 (1–2)
Fertilisers	0.5 (0–1)	1 (0–2)	1.5 (1–2)	1 (0–2)
Microorganisms	1 (0–1)	1 (1–2)	1 (1–2)	1 (1–1)
Vitamins	1 (0–1)	1 (1–1)	1 (1–1)	1 (1–1)
Immunostimulants	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Group uncertain	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
All products	10 (8–13)	13.5 (11.8–15)	15.5 (15–17.8)	13 (10–15)

Averages described by medians, with first and third quartiles within brackets.

prohibited in Thailand (Thai Ministry of Public Health, personal communication). The Thai Department of Fisheries (DoF, under Ministry of Agriculture and Co-operatives) has presented a list of 12 chemicals commonly used in aquaculture, that must be registered with the DoF when imported. These chemicals are acetic acid, benzalkonium chloride, calcium hypochlorite, chlorine, fentin acetate, formaldehyde, hydrochloric acid, rotenone, sodium hydroxide, sodium hypochlorite, trichlorfon and trifluralin (Tonguthai, 1996). Regarding malachite green, DoF does not advise farmers to use it, and it can not be registered for use in aquaculture (Tookwinas, personal communication).

The DoF has, together with Thai Marine Farmers Association and other stakeholders from the private sector, developed a Code of Conduct with overall recommendations and guidelines for the Thai marine shrimp industry. To facilitate the implementation of the code, operating guidelines for shrimp farms have been developed by Tookwinas et al. (1999). Regarding therapeutic agents and other chemicals it is stated, "Shrimp farm health management should thus focus on disease prevention through good nutrition, sound pond management, and overall stress reduction rather than disease treatment". More than half of the farmers in this survey were asked about the Thai Code of Conduct. Only seven out of 46 respondents had heard of the Code, and knew that it includes policies to decrease impacts on the environment.

3.4. Potential risks

The chemicals and biological products documented in the study could have negative effects on the health of the cultured shrimps, represent food safety and occupational health hazards, and pose a risk for negative effects on adjacent ecosystems. Regarding the health of cultured shrimp, there is a general risk that exposure to chemicals can increase their stress levels, and thereby decrease growth and/or increase their susceptibility to infections (Reyes et al., 1999; Le Moullac and Haffner, 2000). Bainy (2000) argues that disinfectants, antibiotics, pesticides, fertilisers and different feed additives used in shrimp farming all have a potential to cause toxic effects to the cultured shrimp.

Some of the products used by farmers in the present study, e.g. endosulfan and several antibiotics, can remain in the shrimp after harvest, and pose hazards for food safety (Reyes et al., 1999; Holmström et al., in press). A number of the oxidants used in this study, particularly chlorine, hydrogen peroxide, and potassium permanganate pose a hazard for the health of farmers or workers handling the products (Boyd and Massaut, 1999; ILO, 2002). Other chemicals with occupational health hazards are formalin, the typical organic synthetic pesticides, and malachite green (Alderman et al., 1994; Boyd and Massaut, 1999; ILO, 2002). Only about half of the interviewed farmers used gloves and sometimes also a mask when handling some of these products. Ten of the farmers stated that handling chemicals had caused health problems, e.g. nausea, burns and rashes, as well as irritation to eyes and respiratory tract.

Pesticides and disinfectants are used for their toxic properties, and many of them may have negative impacts on the environment. This is pronounced for the synthetic organic pesticides, malachite green, and the copper compounds. These may persist or leave toxic residues in the pond environment, and be released with pond water or sediment to nearby ecosystems (Gräslund and Bengtsson, 2001). Other products that have a potential to have negative impacts on the environment are the oxidants, through formation of oxidation byproducts (Boyd and Massaut, 1999; Gräslund et al., 1999; Gräslund and Bengtsson, 2001), and teaseed (Primavera et al., 1993). Hazards related to the individual pesticides and disinfectant products used in the survey are discussed in detail by Wahlström (2001).

The use of antibiotics in shrimp farming can potentially be a risk to farm workers, health of cultured shrimp, local and regional human medicine, and the environment. This is thoroughly discussed by Holmström et al. (in press). The widespread use of antibiotics in this study, and the common practise of preventive usage, is a risk for development of resistance (American Academy of Microbiology, 1999; Wegener et al., 1999; Inglis, 2000). Resistance may cause difficulties to treat bacterial infections in the cultured shrimp, and additionally difficulties to treat humans who have been exposed. The common use of fluoroquinolones in the present study should be given special attention, since resistance may develop, and these drugs are of great importance in treatment of a broad range of human pathogens (WHO, 1998). Farmers often mixed antibiotic powder with shrimp feed using their bare hands, a process that exposes both skin and respiratory tracts to the antibiotic. Handling antibiotics can have severe health effects, such as skin dermatitis from sulfonamide exposure, or aplastic anaemia from exposure to chloramphenicol (Rang and Dale, 1987; Brown, 1989; Rice and Cohen, 1996). Antibiotics are in general not well investigated from an ecotoxicological perspective, but recent studies show that many of them are moderately to highly toxic to aquatic life (Holten Lützhøft et al., 1999; Halling-Sørensen, 2000; Halling-Sørensen et al., 2000; Wollenberger et al., 2000).

Fertilisers could contribute to eutrophication in adjacent waters; however, they are likely to have a smaller impact than nutrients coming from pelleted feed (Funge-Smith and Briggs, 1998). The same probably applies to animal and vegetable feed additives. Certain inorganic fertilisers may be a health hazard for people handling the products (Boyd and Massaut, 1999). Microorganism products used in shrimp farming may not always be produced under controlled conditions, and it is possible that they sometimes contain cells with acquired antibiotic resistance. Using such products would introduce resistance into the pond environment, and potentially spread to, for example, shrimp pathogens (Wongtavatchai, personal communication).

3.5. Discussion

It must be questioned whether it is possible to efficiently use on average as many as 13 chemical and biological products in a shrimp farm (Fig. 2, Table 2). Actions of single products are usually complicated, sometimes not well known, and often influenced by a number of factors, such as pH and temperature. Trying to understand and control the combination of up to more than 20 different products (many for which there was no or limited information regarding content), their individual and combined fate and effects in a shrimp pond environment is likely to cause a headache even for the most experienced shrimp farmer, or qualified chemist.

The average number of products used per farm differed significantly between the three areas, with farmers on the southern Gulf coast using the highest number of products, and farmers on the eastern Gulf coast using the lowest number of products. There was no apparent explanation for the difference to be found in the information about other management practices collected during the interviews. For example, there seemed to be a lack of relation between number of products used and production level, size of farm or age of farm. However, the results indicate that there were differences between the three areas that had influenced shrimp farmers in their choices to use certain chemicals and biological products. Some farmers relied on other farmers' experience and recommendations, and a local exchange of information among farmers may partly explain differences between areas.

There seemed to be a more active presence of the Thai Department of Fisheries (DoF) in the eastern Gulf coast area than in the other two areas. The DoF conducts information activities and consultancy for shrimp farmers, activities that in the two southern areas to a larger extent seemed to be conducted by private companies. Some farmers in the present study pointed out that advisory services provided by companies often resulted in recommendations to use expensive treatment products. The stronger presence of private companies in the two regions in the south may partly explain the larger number of products used per farm in these areas. Tonguthai (2000) recognises that the aggressive promotion of drugs and chemicals by salesmen has partly led to an increased use of such products by farmers.

Many products documented in the survey were used with the purpose of preventing, treating, or mitigating disease outbreaks, and the number of products used by a farmer may have been influenced by the presence, or immediate risk of disease outbreaks. Could there have been a lower risk for disease outbreaks in the eastern Gulf coast area than in the other two areas? A slightly larger portion of farmers in the two southern areas had experienced problems with viral or bacterial infections and pests, than farmers in the eastern Gulf coast area. However, there was no indication of such a relation in the multiple regression. It may be that the frequency and intensity of the experienced problems had been higher in the two areas in the south, but those parameters were not documented during the survey. There was no obvious explanation for the weak indication that farmers within the eastern Gulf coast area with a higher stocking density used fewer products than farmers with a lower stocking density, and this was not the case for the other two areas. It is possible that farmers with less serious disease problems in general had higher stocking densities and simultaneously less need for chemical and biological products. A more detailed analysis of the use of antibiotics is provided by Holmström et al. (in press), and a thorough analysis of the use of pesticides and disinfectants, including volumes, has been conducted by Wahlström (2001).

A similar study was performed 10 years earlier in the Philippines. Primavera et al. (1993) conducted a survey of the use of chemicals and biological products in shrimp farms in Western Visayas and Northern Mindanao in 1990. Some notable differences were found when comparing their results to the present study. Compounds that were used to a clearly larger extent in the present study were chlorine, formalin, hydrogen peroxide, synthetic organic pesticides, fluoroquinolones, sulfonamides and immunostimulants. On the other hand, some products were obviously used by a smaller portion of farmers in the present study than in the ten year older Philippine study, namely zeolite, inorganic fertilisers, quaternary ammonium compounds and chloramphenicol. Another difference was the way of using microorganism products in the farm management. In both studies they were widely used to decompose organic matter in the pond, whereas in the present study microorganism products (often called probiotics) were additionally widely administered mixed with the feed, directly aiming at improving shrimp health. The two studies concern two different countries and were made 10 years apart, so it is not possible to draw any firm conclusions from this comparison. Fluoroquinolones seem to have become available for shrimp farmers during the 1990s, and it is not surprising that they were not documented during the older study. Other differences could be due to a number of factors, such as differences in availability of products, promotion by retailers, trends among farmers, and recommendations from authorities or associations. Different needs depending on local factors (soil or water quality, type of diseases etc.), as well as regulations may also have played a role.

It is possible that the present survey in some instances has documented fewer or more products than were actually in use. Additionally, the lack of information on some products should be kept in mind. For example, some of the unidentified feed additives may have been microorganism products, immunostimulants, vitamins or antibiotics. Thus the group "other feed additives" may have been overestimated while other groups may have been underestimated. Hence, the actual numbers presented here should be considered approximate. It was difficult to document volumes and frequencies of usage of the products, and such information would have added considerable value to the results. It is of course possible that a farmer using many products may have used them rarely and carefully, while a farmer using few products may have used them indiscriminately, and thereby created larger hazards to himself and the environment. Still, number of products used at a farm says at least something about the tendency to use chemicals and biological products to improve culture conditions. Collection of information through interpreted interviews may have caused minor errors. However, this risk has been carefully considered throughout the study, and is not likely to have had an impact on its general outcome. While analysing the collected information, the need to investigate further parameters became clear, for example, regarding the influence of profit-driven companies on the use of chemicals and biological products that are used in a shrimp farm.

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