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Chemicals and biological products used in south-east Asian shrimp farming, and their potential impact on the environment — a review

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Abstract

A wide variety of chemicals and biological products are used to treat the water and sediment of ponds in semi-intensive and intensive south-east Asian shrimp farming. These products are also often used in shrimp hatcheries and to disinfect equipment for shrimp pond management. In spite of the size and importance of the shrimp farming industry in several south-east Asian countries, documentation of the quality and quantity of chemicals and biological products used during farming is scarce. This paper is a compilation of the literature available on substances used in shrimp farming, and the possible environmental effects of these products are analysed to the extent allowed by the limited information. The role of shrimp farm managers, the chemical industry, governments, inter-governmental organisations and scientists in the development of a sustainable practice is discussed. It is concluded that shrimp farmers should reduce the use of chemicals and biological products because of the risks to the environment, human health and to production, and also, because many chemicals and biological products used in pond management have not been scientifically shown to have a positive effect on production. Clearly, the use of some chemicals, i.e. certain antibiotics, poses a risk of danger towards human health. Some chemicals used in shrimp farming, such as organotin compounds, copper compounds, and other compounds with a high affinity to sediments leave persistent, toxic residues, and are likely to have a negative impact on the environment. However, to assess the reality of these risks, substantial new information about the quantity of chemicals used in marine south-east Asian shrimp farming is needed. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Aquaculture; Shrimp; South-east Asia; Disinfectants; Antibiotics; Pesticides

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1. Introduction

There has been a rapid expansion in the culture of shrimps over the last 20 years in southern and eastern Asia, Latin America and other tropical regions. In south-east Asia, the production of cultured crustaceans increased by over 500% between 1984 and 1995 (FAO, 1997a). By 1998, the total shrimp aquaculture production in this region was 580 000 tonnes, i.e. slightly more than the quantity of shrimps caught in the wild (P. Sabatini, FAO, personal communication). The value of shrimp exports (not discriminating between cultured and wild-caught shrimps) from the south-east Asian countries was approximately US $4 billion the same year (P. Sabatini, FAO, personal communication). There is no doubt that the marine shrimp culture is a very important economic factor for many of these countries. In the shadow of the value of the shrimp farming sector, much attention has been paid to several negative environmental and socio-economic impacts of the industry. The main concerns have been the destruction of mangroves and other wetlands for the construction of shrimp farms (Hopkins et al., 1995), salinisation of the soil (Bangkok Post, 1998a; Flaherty et al., 2000), biological pollution of native shrimp stocks (Hopkins et al., 1995; Kautsky et al., 2000; Naylor et al., 2000), depletion of wild fish populations through large inputs of fish meal and fish oil in commercial shrimp feed (Naylor et al., 2000), eutrophication (Hopkins et al., 1995; Boyd and Clay, 1998; Kautsky et al., 2000); and the dispersion of chemicals in the environment (Hopkins et al., 1995; Kautsky et al., 2000). Similar concerns have been expressed for other types of marine aquaculture, primarily salmon culture (Naylor et al., 2000). Some of these issues have given the shrimp farming industry a negative image in countries that import shrimps, and among environmentalists within the producing countries. There is an increasing interest in an environmentally friendly shrimp culture within the shrimp farming industry, and efforts to reach a sustainable production are being made.

The aim of this review was to present the available material on the potential impact of the chemicals used in shrimp farming on the environment. A summary of the current use of chemical and biological products used in marine shrimp farming in south-east Asia is given and basic information about the potential environmental impact of these substances is discussed. The shrimp farming industry and farm management in south-east Asia is also briefly introduced.

2. Material studied

This paper is based on the available literature which includes scientific technical reports and reviews, publications from international organisations, and our own observations. Intensive shrimp farming is a highly changeable sector with practices changing rapidly and repeatedly due to disease, trends, the manufacturers' influence, and legislation. The literature reflects the use of chemicals and biological products mainly during the 1990s. In this review, south-east Asia corresponds to the ASEAN members, namely Indonesia, Thailand, the Philippines, Vietnam, Cambodia, Malaysia, Myanmar, Brunei Darussalam, Laos and Singapore. The first four countries seem to dominate the literature. However, several of the other countries, e.g. Cambodia, Malaysia, and Myanmar, also have a shrimp farming industry. Products used in ponds are the issue in this review, but information about chemical use in hatcheries is presented when available. This report is mainly relevant to intensive and semi-intensive management systems. It covers marine and brackish water shrimp farming, which, in the text, is referred to as marine shrimp farming. Feed and feeding practices and their effects on the environment are wide-ranging issues that are not within the scope of this review, but are briefly mentioned in connection with eutrophication. For an analysis of the effects of aquaculture feeding practices on world fish supplies, see Naylor et al. (2000). Chemicals and biological products that are reported to be, or have been, used in shrimp farming are encompassed, but information about products that are available on the market are not included. References from other types of aquaculture, or from shrimp farming in other parts of

Table 1
Production of cultured shrimp in the countries dominating the South-east Asian shrimp farming industry[a]

Year	Thailand	Indonesia	Vietnam	Philippines
1995	220 000	80 000	50 000	30 000–50 000
1997	150 000	80 000	30 000	10 000
1999	200 000–210 000	100 000	40 000	40 000

[a] Figures in metric tons. After Kongkeo (1997) and Rosenberry (1995, 1997, 1999).

the world have been included where data is very scarce. The purpose of such comments is not to infer that the same practice is being undertaken in south-east Asian shrimp farming, but to facilitate further investigations in the field.

3. Shrimp farming in south-east Asia

The countries dominating the production of cultured marine shrimp in south-east Asia are Thailand, Indonesia, Vietnam and the Philippines (see Table 1).

The most important markets for south-east Asian farmed shrimps are Japan, the United States and Europe (Rosenberry, 1999). Smaller volumes are exported to other Asian countries, e.g. South Korea, Malaysia, Taiwan, China, Singapore and Hong Kong, and some is consumed within the producing countries. Part of the trade is not official, e.g. Rosenberry (1999) indicates that China is the third largest importer of Thai shrimps, but that little is registered in order to avoid duty fees. The species dominating the marine shrimp culture in south-east Asia are penaeid shrimp, especially *Penaeus monodon*, commonly known as the black tiger shrimp, or the giant tiger shrimp.

The management systems used in marine shrimp farming can be separated into three types: extensive, semi-intensive and intensive (see Table 2). The extensive farming system has low shrimp densities in the ponds; usually juveniles from wild populations brought into the ponds with the inlet water (Weidner and Rosenberry, 1992). In the extensive method, either no chemicals are used at all, or fertilisers are added to promote the growth of algae as a natural food (Boyd and Clay, 1998). Semi-intensive farms have medium-sized ponds and stocking densities, the juveniles are either from the wild or from hatcheries, and natural food is used and/or artificial feed is added. Intensive farms are typically small and have high densities of hatchery produced juveniles. The production relies on heavy feeding and aeration (Weidner and Rosenberry, 1992). Primarily intensive farms, but also semi-intensive farms use a wide array of chemicals and biological products to enhance the production.

Thailand produces more cultured shrimps than any other country in the world (FAO, 1999). The estimated total area of productive Thai shrimp farms are presently 80 000 hectares, which are managed by 20 000 farmers (Rosenberry, 1999). Since 1992, the country has annually produced 150 000–220 000 tons of cultivated shrimp, of

Table 2
Characteristics of different shrimp farming methods used in south-east Asia[a]

Method	Pond size (ha)	Stocking density (number of juveniles/ha)	Production capacity (kg/ha/year)
Extensive	1–10	10 000–30 000	600–1500
Semi-intensive	1–2	30 000–100 000	2000–6000
Intensive	0.1–1	100 000–500 000	7000–15 000

[a] After Primavera, 1998.

which 90% are exported (Rosenberry, 1996; Kongkeo, 1997; Bangkok Post, 1998b; Rosenberry, 1998). *P. monodon* constitutes 90% of the cultured shrimps in Thailand (Rosenberry, 1998). The shrimp export is of great significance to the Thai economy; since 1992, shrimp export competes with rice as the agricultural product that brings most foreign currency in to the country (Fish Farming International, 1994). During the 1990s, the majority of Thai shrimp farms were managed as intensive systems. However, the most recent figures show that semi-intensive systems are becoming more frequent while the proportion of intensively managed farms is decreasing (Rosenberry, 1999), possibly as a response to the disease and water quality problems often associated with a farm's level of intensity.

Shrimp farming in the Philippines is dominated by semi-intensive systems, whereas Indonesia and Vietnam are dominated by extensive farming systems (see Table 3).

In intensively managed shrimp ponds, there is a high risk of disease outbreaks caused by virus, bacteria, fungi and other pathogens. The following viral diseases have had an impact on south-east Asian shrimp farming during the 1990s (Flegel, 1997; Lightner and Redman, 1998; Rosenberry, 1999):

- white spot syndrome or red body and white spot disease (caused by a virus in the WSSV group, e.g. WSBV or systemic ectodermal and mesodermal baculo virus, SEMBV);
- yellowhead disease (caused by YHV);
- monodon baculo virus disease (caused by MBV);
- hepatopancreatic parvo (or parvo-like) virus disease (caused by HPV); and
- infectious hypodermal and hematopoetic necrosis disease (caused by IHHNV).

Viral infections have caused severe economic losses in south-east Asia, e.g. during the heavy outbreak of SEMBV in Thailand in 1996 (Kongkeo, 1997). Besides viral disease outbreaks, bacterial infections have also had severe consequences to shrimp farming in the region. Luminous vibriosis caused by the bacteria *Vibrio harveyi* has resulted in major production losses in the Philippines (Barg and Lavilla-Pitoga, 1996; in FAO, 1997a), and in other south-east Asian countries (Rosenberry, 1999).

Intensively farmed shrimp ponds are often abandoned after 2–10 years due to environmental and disease problems caused by the accumulation of nutrients, declined access to clean water, etc. or simply because of lowered yields or profits (Flaherty and Karnjanakesorn, 1995; Barraclough and Finger-Stich, 1996; Dierberg and Kiattisimkul, 1996; Sansanayuth et al., 1996).

In the 1990s, there was a rapid development of saltwater shrimp farming in freshwater areas of Thailand. This practice depends on the transportation of seawater to ponds inland, where it is diluted with freshwater to relatively low salinities tolerable for *P. monodon*. In 1998, the Thai government banned saltwater shrimp farming in in-

Table 3
Percentage of different management systems practised in the countries dominating the south-east Asian shrimp farming industry

	Extensive (% of farms)	Semi-intensive (% of farms)	Intensive (% of farms)	Year	References
Thailand	5	10	85	1994	Kongkeo, 1997
	5	70	25	1999	Rosenberry, 1999
Philippines	35	50	15	1994	Kongkeo, 1997
	30	60	10	1999	Rosenberry, 1999
Indonesia	80	10	10	1994	Kongkeo, 1997
	50	25	25	1999	Rosenberry, 1999
Vietnam	90	No data	No data	1992	Weidner and Rosenberry, 1992
	85	15	0	1999	Rosenberry, 1999

Table 4
A selection of chemicals used in shrimp farming or shrimp hatcheries

Substance	Molecular formula	Examples of other names/ commercial products	Chemical Abstract Service reg.no.	References
Azinphos-ethyl	$C_{12}H_{16}N_3O_3PS_2$	Gusathion A	2642-71-9	Baticados and Tendencia, 1991 Budavari, 1996 Richardson, 1992
Benzalkonium chloride	$C_{17\text{-}27}H_{30\text{-}50}NCl$	*n*-alkyl(C_8–C_{18}) dimethyl-benzylammonium chloride, BKC	8001-54-5	Primavera et al., 1993 Richardson, 1992
Calcium carbonate	$CaCO_3$	calcite	1317-65-3	Primavera, 1993 GESAMP, 1997 Richardson, 1992
Calcium hydroxide	CaH_2O_2	hydrated lime, slaked lime	1305-62-0	Primavera et al., 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Calcium hypochlorite	$CaCl_2O_2$	high test hypochlorite, HTH	7778-54-3	Primavera et al., 1993 Dierberg and Kiattisimkul, 1996 Funge-Smith and Briggs, 1998 Richardson, 1992 Budavari, 1996
Calcium oxide	CaO	burnt lime, quick lime	1305-78-8	Boyd, 1995 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Calcium sulfate or calcium sulfate dihydrate	CaO_4S resp. CaH_4O_6S	gypsum	7778-18-9 resp. 10101-41-4	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Chloramphenicol	$C_{11}H_{12}Cl_2N_2O_5$		56-75-7	Primavera et al., 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Chlorpyrifos	$C_9H_{11}Cl_3NO_3PS$	Dursban	2921-88-2	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Copper sulfate	CuO_4S	cupric sulfate	7758-98-7 7758-99-8 (pentahydrate)	Primavera, 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996

Table 4 (*Continued*)

Substance	Molecular formula	Examples of other names/ commercial products	Chemical Abstract Service reg.no.	References
Diazinon	$C_{12}H_{21}N_2O_3PS$	dimpylat	333-41-5	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Dichlorvos	$C_4H_7Cl_2O_4P$	DDVP, Nuvan	62-73-7	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Didecyl dimethylammonium bromide	$C_{22}H_{48}NBr$		2390-68-3	Primavera et al., 1993 European Chemicals Bureau, 2000
EDTA (ethylenediaminetetra-acetic acid)	$C_{10}H_{16}N_2O_8$	edetic acid	60-00-4	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Endosulfan	$C_9H_6Cl_6O_3S$	Thiodan	115-29-7	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Enrofloxacin	$C_{19}H_{22}FN_3O_3$		93106-60-6	GESAMP, 1997 Budavari, 1996
Erythromycin	$C_{37}H_{67}NO_{13}$		114-07-8	Primavera, 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Formaldehyde	CH_2O		50-00-0	Primavera et al., 1993 Dierberg and Kiattisimkul, 1996 GESAMP, 1997 Funge-Smith and Briggs, 1998 Richardson, 1992 Budavari, 1996
Furazolidone	$C_8H_7N_3O_5$		67-45-8	Primavera, 1993 GESAMP, 1997 Budavari, 1996
Glutaraldehyde	$C_5H_8O_2$		111-30-8	Boyd, 1995 Richardson, 1992 Budavari, 1996
Malachite green	$C_{23}H_{25}ClN_2$	C.I. Basic Green 4	569-64-2	Primavera et al., 1993 Dierberg and Kiattisimkul, 1996 Funge-Smith and Briggs, 1998 Richardson, 1992 Budavari, 1996

Table 4 (*Continued*)

Substance	Molecular formula	Examples of other names/ commercial products	Chemical Abstract Service reg.no.	References
Malathion	$C_{10}H_{19}O_6PS_2$		121-75-5	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Nicotine	$C_{10}H_{14}N_2$	tobacco dust	54-11-5	Chua et al., 1989 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Nifurpirinol	$C_{12}H_{10}N_2O_4$	Prefuran	13411-16-0	Baticados et al., 1990 GESAMP, 1997 Budavari, 1996
Norfloxacin	$C_{16}H_{18}FN_3O_3$		70458-96-7	GESAMP, 1997 Budavari, 1996
Ormetoprim	$C_{13}H_{16}N_4O_2$		6981-18-6	GESAMP, 1997 European Chemicals Bureau, 2000
Oxolinic acid	$C_{13}H_{11}NO_5$		14698-29-4	GESAMP, 1997 Budavari, 1996
Oxytetracycline	$C_{22}H_{24}N_2O_9$		79-57-2	Primavera et al., 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Ozone	O_3		10028-15-6	Primavera et al., 1993 Dierberg and Kiattisimkul, 1996 GESAMP, 1997 Funge-Smith and Briggs, 1998 Richardson, 1992 Budavari, 1996
Potassium permanganate	$KMnO_4$		7722-64-7	Primavera, 1993 Boyd and Massaut, 1999 Richardson, 1992 Budavari, 1996
Povidone iodine		polyvinyl-pyrrolidone iodine complex	25655-41-8	GESAMP, 1997 Funge-Smith and Briggs, 1998 Budavari, 1996
Rifampicin	$C_{43}H_{58}N_4O_{12}$	rifampin	13292-46-1	Primavera, 1993 Richardson, 1992 Budavari, 1996

Table 4 (*Continued*)

Substance	Molecular formula	Examples of other names/ commercial products	Chemical Abstract Service reg.no.	References
Rotenone	$C_{23}H_{22}O_6$	derris root	83-79-4	GESAMP, 1997 Kongkeo, 1997 Richardson, 1992 Budavari, 1996
Sodium hypochlorite	ClNaO	bleach	7681-52-9	Chang et al., 1998 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Sulfadiazine	$C_{10}H_{10}N_4O_2S$		68-35-9	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Sapogenin glycosides	variable	tea seed, saponin		Primavera, 1993 GESAMP, 1997 Kongkeo, 1997 Boyd and Massaut, 1999 Budavari, 1996
Trichlorfon	$C_4H_8Cl_3O_4P$	Neguvon, Dipterex	52-68-6	Tonguthai, 1996 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Trifluralin	$C_{13}H_{16}F_3N_3O_4$	Treflan	1582-09-8	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Trimetoprim	$C_{14}H_{18}N_4O_3$	trimethoprim	738-70-5	GESAMP, 1997 European Chemicals Bureau, 2000
Triphenyltin acetate	$C_{20}H_{18}O_2Sn$	fentin acetate, Brestan	900-95-8	GESAMP, 1997 Richardson, 1992 Budavari, 1996
Triphenyltin chloride	$C_{18}H_{15}ClSn$	fentin chloride, Aquatin	639-58-7	Baticados et al., 1986 GESAMP, 1997 Richardson, 1992
Vitamin B12	$C_{63}H_{88}CoN_{14}O_{14}P$		68-19-9	Primavera et al., 1993 Richardson, 1992 Budavari, 1996
Vitamin C	$C_6H_8O_6$	ascorbic acid	50-81-7	Primavera et al., 1993 GESAMP, 1997 Richardson, 1992 Budavari, 1996
Vitamin E	$C_{29}H_{50}O_2$		59-02-9	GESAMP, 1997 Richardson, 1992 Budavari, 1996

land areas classified as freshwater zones, but the practice continues and there is an ongoing debate over the potential environmental impact of inland shrimp farming (Bangkok Post, 1998c; Flaherty et al., 2000).

South-east Asian shrimp farmers rely on wild shrimp for the production of seed stock. Gravid females are either captured in the wild or matured in a hatchery. Small-scale hatcheries have been very successful, e.g. in Thailand, Indonesia and the Philippines (Rosenberry, 2000). In 1999, there were approximately 1000 hatcheries in Thailand. Of these hatcheries, 80% were small-scale. In the same year, there were approximately 300 hatcheries in Indonesia, 85% of them small-scale, 1000 hatcheries in Vietnam, of which 90% were small-scale, and 120 hatcheries in the Philippines, of which 90% were small-scale (Rosenberry, 1999).

4. Chemicals and biological products used in shrimp farming

Large amounts of chemicals are used in south-east Asian shrimp farming. In 1995, approximately US $100 million was spent on chemicals for use in shrimp farming in Thailand alone (Tonguthai, 1996). Major reasons for the use of chemicals and biological products in shrimp farming are water quality problems, and the high risk of disease. Some of the products are produced biologically, organic fertilisers, rotenone and several of the antibiotics for example, but many of these natural control agents are just like the synthetic chemicals produced commercially.

The most common products used in pond aquaculture are fertilisers and liming material. Disinfectants, antibiotics, algaecides, herbicides, and probiotics are also used to improve the production (Boyd and Massaut, 1999). There is no clear distinction between the different groups of substances, for example, chlorine, which is used as a disinfectant to kill bacteria and viruses, can also be used as an algaecide, a herbicide, or to regulate the pH of the pond water. A farmer might also use a product differently than intended by the producer. The frequent use of numerous common names and brand names for the same chemical, even within a country, makes it difficult to summarise the scarce information available. A selection of the chemicals discussed below is presented in Table 4.

The toxicity criteria used in the text are based on the hazard classification system of OECD (1998) (Table 5). Class Acute I corresponds to highly acute toxic in the text, II to moderately toxic, and III to slightly toxic. In addition to the EC_{50} (48 h) values for crustaceans, data on LC_{50} (48 h) for crustaceans are considered acceptable for the ranking used in the text. Toxicity data that are of interest, but do not fit into this classification system, are also presented. The toxicity data that is referred to, as well as some additional information, are presented in Table 6.

Table 5
From the OECD harmonised system for the classification of chemicals which are hazardous to the aquatic environment (1998)[a]

Acute I	LC_{50} (96 h) for fish	≤ 1 mg/l and/or
	EC_{50} (48 h) for crustacea	≤ 1 mg/l and/or
	EC_{50} (72 or 96 h) for aquatic plants	≤ 1 mg/l
Acute II	LC_{50} (96 h) for fish	$> 1- \leq 10$ mg/l and/or
	EC_{50} (48 h) for crustacea	$> 1- \leq 10$ mg/l and/or
	EC_{50} (72 or 96 h) for aquatic plants	$> 1- \leq 10$ mg/l
Acute III	LC_{50} (96 h) for fish	$> 10- \leq 100$ mg/l and/or
	EC_{50} (48 h) for crustacea	$> 10- \leq 100$ mg/l and/or
	EC_{50} (72 or 96 h) for aquatic plants	$> 10- \leq 100$ mg/l

[a] The same criteria are used for chronic acute toxicity if the substance is not rapidly degradable and/or the log $K_{ow} \geq 4$ (unless the experimentally determined BCF < 500), and unless the chronic toxicity NOECs are > 1 mg/l.

Table 6
Data on toxicity of selected chemicals used in shrimp farming or shrimp hatcheries

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Copper sulfate	rainbow trout, harlequin fish, goldfish and eel			LC_{50} (96 h)	0.1–2.5 mg/l	Richardson, 1992
Copper sulfate	freshw. crustacean *Daphnia magna*			EC_{50} (48 h)	24 μg/l	Richardson, 1992
Copper sulfate	freshwater crustaceans *Asellus aquaticus* and *Crangonyx pseudogracilis*			EC_{50} (96 h)	1.3–9.2 mg/l	Richardson, 1992
Copper sulfate	freshwater snail *Viviporus bergalersis*			LC_{50} (96 h)	2.4 mg/l	Richardson, 1992
Cu^{2+}	green freshwater micro alga *Selenastrum capricornutum*		24°C	EC_{50} (96 h)	66–70 μg/l	St-Laurent and Blaise, 1992
Cu^{2+}	marine brown macro alga *Laminaria saccharina*		10°C	Inhib. sporophyte growth	10 μg/l	Chung and Brinkhuis, 1986
Formalin	aquatic life, not specified			LC_{50} (96 h)	1 to 1000 μg/l	GESAMP, 1997
Formalin	marine brown macro alga *Phyllospora comosa*	34 ppt	15°C	Decr. germination rates in 48 h exp.	0.1 mg/l	Burridge et al., 1995
Malachite green	freshwater fishes *Claris macrocephalus* and *Tilapia nilotica*			LC_{50} (96 h)	0.066–0.425 mg/l	Richardson, 1992
Malachite green	freshwater catfish *Heteropneustes fossilis*		21°C	LC_{50} (96 h)	1.0 mg/l	Srivastava et al., 1995
Malachite green	saltwater crustacean *Penaeus stylirostris*, nauplii			Metamorphosis inhib. in 12 and 24 h exp.	80 μg/l	Richardson, 1992

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Malachite green	saltwater crustacean Penaeus *stylirostris*, nauplii			NOEC 12 and 24 h	16 μg/l	Richardson, 1992
Benzalkonium chloride	embryos of *Crassostrea gigas* (Japanese oyster)	30 ppt	24°C	EC_{50} (24 h)	138 μg/l	His et al., 1996
Benzalkonium chloride	nine marine diatom species			Non-viable after 7 days exp.	10 mg/l	Beveridge et al., 1998
Trifluralin	carp *Cyprinus carpo*		20°C	LC_{50} (96 h)	45 μg/l	Poleksic and Karan, 1999
Trifluralin	7 fish species			wet weight based BCF	400–15 500	Schultz and Hayton, 1999
Trifluralin	duckweed *Lemna minor*		25°C	EC_{50} (96 h)	170 μg/l	Fairchild et al., 1997
Trifluralin	freshwater green micro alga *Selenastrum capricornutum*		25°C	EC_{50} (96 h)	673 μg/l	Fairchild et al., 1997
Trifluralin	freshwater green micro alga *Scenedesmus vacuolatus*			EC_{50} (24 h)	24 μg/l	Schmitt et al., 2000
Nicotine	fry of *Oncorhyncus mykiss* (rainbow trout)			LC_{50} (60 days)	5.0 mg/l	Passinoreader et al., 1995
Azinphos-ethyl	saltwater crustacean *Penaeus monodon*, juveniles	30–33.5 ppt	26–28°C	LC_{50} (96 h)	0.12 μg Gusathion A/l	Baticados and Tendencia, 1991
Azinphos-ethyl	saltwater crustacean *Penaeus monodon*, juveniles	30–33.5 ppt	26–28°C	96 h exp. to 0.002–0.2 μg Gusathion A/l	Shell-softening in 27–53% of the shrimp	Baticados and Tendencia, 1991

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Diazinon	freshwater fish *Oryzias latipes*		18°C	wet weight based BCF	49	Tsuda et al., 1997
Diazinon	freshwater fish *Oryzias latipes*		22°C	LC_{50} (48 h)	4.4 mg/l	Tsuda et al., 1997
Diazinon	freshwater fish *Oryzias latipes*		17°C	wet weight based BCF	28	Tsuda et al., 1995
Diazinon	bluegill sunfish, rainbow trout, carp and fathead minnow			LC_{50} (96 h)	0.1–16 mg/l	Richardson, 1992
Diazinon	estuarine crustacean *Mysidopsis bahia*, juveniles	25 ppt	25°C	LC_{50} (96 h)	8.5 μg/l	Cripe, 1994
Diazinon	saltwater crustacean *Penaeus duorarum*, postlarvae	25 ppt	25°C	LC_{50} (96 h)	21 μg/l	Cripe, 1994
Diazinon	freshwater crustacean *Ceriodaphnia dubia*			LC_{50} (96 h)	0.41–0.47 μg/l	Bailey et al., 1996
Trichlorfon	estuarine fish *Cyprinodon variegatus* (sheepshead minnow)	15–30 ppt	17–27°C	LC_{50} (96 h)	13–19 mg/l 1994	Brecken-Folse et al.,
Trichlorfon	estuarine fish *Cyprinodon variegatus* (sheepshead minnow)	15–30 ppt	17–27°C	wet weight based BCF	0.002–0.11	Brecken-Folse et al., 1994
Trichlorfon	*Onchorynchus mykiss* (rainbow trout)	freshwater pH 6.5	17°C	LC_{50} (96 h)	2.5 mg/l	Howe et al., 1994

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Trichlorfon	*Onchorynchus mykiss* (rainbow trout)	freshwater pH 9.5	17°C	LC_{50} (96 h)	0.33 mg/l	Howe et al., 1994
Trichlorfon	crustacean *Gammarus pseudolimnaeus*	freshwater pH 6.5	17°C	LC_{50} (96 h)	0.14 mg/l	Howe et al., 1994
Trichlorfon	crustacean *Gammarus pseudolimnaeus*	freshwater pH 9.5	17°C	LC_{50} (96 h)	0.02 mg/l	Howe et al., 1994
Trichlorfon	estuarine crustacean *Palaemonetes* spp. (grass shrimp)	15–30 ppt	17–27°C	LC_{50} (48 h)	9–25 μg/l	Brecken-Folse et al., 1994
Trichlorfon	estuarine crustacean *Palaemonetes* spp. (grass shrimp)	15–30 ppt	17–27°C	LC_{50} (96 h)	6–11 μg/l	Brecken-Folse et al., 1994
Trichlorfon	estuarine crustacean *Palaemonetes* spp. (grass shrimp)	15–30 ppt	17–27°C	wet weight based BCF	28–186	Brecken-Folse et al., 1994
Trichlorfon	crab *Cancer pagurus*	30 ppt	9°C	24h exp. to 10 ppm Neguvon	2 of 3 died	Egidius and Møster, 1987
Trichlorfon	crab *Cancer maenas*	30 ppt	9°C	17 h exp. to 10 ppm Neguvon	all survived	Egidius and Møster, 1987
Trichlorfon	lobster *Homarus gammarus*	30 ppt	9°C	24 h exp. to 0.5 ppm Neguvon	all died	Egidius and Møster, 1987
Trichlorfon	blue mussel *Mytilus edulis*	30 ppt	9°C	24 h exp. to 10 ppm Neguvon	all died	Egidius and Møster, 1987
Chlorpyrifos	freshwater fish *Lepomis macrochirus* (bluegill sunfish)			IC_{25}	0.4–1.9 μg/l	Giddings et al., 1997

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/study	Result	Reference
Chlorpyrifos	three-spined stickleback *Gasterosteus aculeatus*	freshwater	20°C	lipid based BCF	21 000	Deneer, 1994
Trichlorfon	*Onchorynchus mykiss*	freshwater pH 9.5	17°C	LC_{50} (96 h)	0.33 mg/l	Howe et al., 1994
Chlorpyrifos	freshwater fish *Oryzias latipes*	freshwater	25°C	LC_{50} (48)	0.25 mg/l	Rice et al., 1997
Chlorpyrifos	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (48 h)	5.2–6.5 μg/l	Leight and Van Dolah, 1999
Chlorpyrifos	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (96 h)	0.2–0.3 μg/l	Leight and Van Dolah, 1999
Chlorpyrifos	freshwater crustacean *Ceriodaphnia dubia*			LC_{50} (96 h)	0.06 μg/l	Bailey et al., 1996
Chlorpyrifos	*Mytilus galloprovincialis* (Mediterranean mussel)	38 ppt	18°C	lipid based BCF	400	Serrano et al., 1997
Dichlorvos	herring *Clupea harengus*, larvae	34 ppt	10°C	LC_{50} (96 h)	122 μg/l	McHenery et al., 1991
Dichlorvos	crab *Cancer pagurus*	30 ppt	9°C	24 h exp. to 1 ppm Nuvan	1 of 4 died	Egidius and Møster, 1987
Dichlorvos	crab *Cancer maenas*	30 ppt	9°C	10 h exp. to 1 ppm Nuvan	all survived	Egidius and Møster, 1987
Dichlorvos	lobster *Homarus gammarus*	30 ppt	9°C	24 h exp. to 0.1 ppm Nuvan	all died	Egidius and Møster, 1987
Dichlorvos	blue mussel *Mytilus edulis*	30 ppt	9°C	24 h exp. to 0.1 ppm Nuvan	all survived	Egidius and Møster, 1987

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Dichlorvos	lobster *Homarus gammarus*, larvae	34 ppt	10°C	EC_{50} (48 h)	7.3 μg/l	McHenery et al., 1991
Dichlorvos	lobster *Homarus gammarus*, larvae	34 ppt	10°C	EC_{50} (48 h)	7.3 μg/l	McHenery et al., 1991
Dichlorvos	lobster *Homarus gammarus*, larvae	34 ppt	10°C	LC_{50} (96 h)	5.7 μg/l	McHenery et al., 1991
Dichlorvos	marine crustacean *Tigriopus brevicornis*	35 ppt	20°C	LC_{50} (96 h)	0.9–4.6 μg/l	Forget et al., 1998
Malathion	freshwater fish *Oryzias latipes* (killifish)		18°C	wet weight based BCF	11	Tsuda et al., 1997
Malathion	freshwater fish *Oryzias latipes* (killifish)		22°C	LC_{50} (48 h)	1.8 mg/l	Tsuda et al., 1997
Malathion	marine crustacean *Tigriopus brevicornis*	35 ppt	20°C	LC_{50} (96 h)	7.2–24.3 μg/l	Forget et al., 1998
Malathion	estuarine crustacean *Mysidopsis bahia*, juveniles	25 ppt	25°C	LC_{50} (96 h)	11 μg/l	Cripe, 1994
Malathion	estuarine crustacean *Penaeus duorarum*, postlarvae	25 ppt	25°C	LC_{50} (96 h)	12 μg/l	Cripe, 1994
Malathion	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (48 h)	1.2–26.0 mg/l	Leight and Van Dolah, 1999
Malathion	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (96 h)	2.3–4.7 μg/l	Leight and Van Dolah, 1999

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Malathion	9 species freshwater mussels, juveniles	freshwater	25–32°C	LC_{50} (96 h)	24–219 mg/l	Keller and Ruessler, 1997
Malathion	9 species freshwater mussels, glochidia and juv.	freshwater	25–32°C	LC_{50} (48 h)	7–365 mg/l	Keller and Ruessler, 1997
Malathion	3 species freshwater mussels, adults	freshwater	25–32°C	LC_{50} (96 h)	> 350 mg/l	Keller and Ruessler, 1997
Endosulfan	golden orfe and rainbow trout			LC_{50} (96 h)	0.3–2 μg/l	Richardson, 1992
Endosulfan	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (48 h)	2.3–5.6 μg/l	Leight and Van Dolah, 1999
Endosulfan	estuarine crustacean *Gammarus palustris*	15 ppt	20°C	LC_{50} (96 h)	0.4–0.5 μg/l	Leight and Van Dolah, 1999
Triphenyltin acetate	*Danio rero* (zebrafish), embryos and larvae	freshwater	28°C	LC_{50} (96 h)	40 μg/l	Strmac and Braunbeck, 1999
Triphenyltin acetate	*Danio rero* (zebrafish), embryos and larvae	freshwater	28°C	96 h exp. to 0.5 μg/l and above	delayed hatching	Strmac and Braunbeck, 1999
Triphenyltin acetate	*Danio rero* (zebrafish), embryos and larvae	freshwater	28°C	96 h exp. to 25 μg/l and above	increased mortality	Strmac and Braunbeck, 1999
Triphenyltin acetate	marine diatom *Skeletonema costatum*	30 ppt	20°C	EC_{50} (72 h)	0.9 μg/l	Walsh et al., 1985
Triphenyltin acetate	marine diatom *Thalassiosira pseudonana*	30 ppt	20°C	EC_{50} (72 h)	1.1 μg/l	Walsh et al., 1985

Table 6 (*Continued*)

Substance	Species	Water	Temperature	Endpoint/ study	Result	Reference
Triphenyltin chloride	saltwater crustacean *Peneus monodon*	sea water		96 h exp. to 0.02–0.5 mg Aquatin/l	Shell–softening in 47–60% of the shrimp	Baticados et al., 1986
Triphenyltin chloride	3 species marine gastropods	sea water	20°C	LC_{50} (48 h)	1.4–4.6 μg/l	Horiguchi et al., 1998
Triphenyltin chloride	marine diatom *Skeletonema costatum*	30 ppt	20°C	EC_{50} (72 h)	0.9 μg/l	Walsh et al., 1985
Triphenyltin chloride	marine diatom *Thalassiosira pseudonana*	30 ppt	20°C	EC_{50} (72 h)	1.3 μg/l	Walsh et al., 1985
Potassium permanganate	milkfish, bluegill sunfish and channel catfish			LC_{50} (96 h)	1.5–18 mg/l	Richardson, 1992
Rotenone	rainbow trout, carp, goldfish			LC_{50} (48 h)	26–33 μg/l	Richardson, 1992
Rotenone	crustacean *Simocephalus serrulatus*			LD_{50} (48 h)	190 μg/l	Richardson, 1992
Saponin	saltwater crustavean *Penaeus japonicus*, juveniles	34 ppt	27°C	LC_{50} (48)	21 mg/l	Chen et al., 1996
Saponin	saltwater crustavean *Penaeus japonicus*, juveniles	34 ppt	27°C	Shortened time to first moult etc.	0.5 mg/l	Chen et al., 1996

5. Soil and water treatment compounds

Aluminium sulfate ($Al_2[SO_4]_3(14H_2O)$ or aluminium potassium sulfate ($AlK[SO_4]_3(14H_2O)$ (alum) is used at concentrations of 10–20 mg/l in shrimp ponds to coagulate suspended colloids so that they will settle from the pond water (Boyd, 1995; GESAMP, 1997). It provides dissolved aluminium ions, which neutralise the negatively charged suspended colloids and allows particles to coagulate and settle. Alum can also be used to remove phosphorus from aquaculture ponds. However, there are naturally plenty of ions in saltwater that enhance the sedimentation of particles and limit phosphate availability (Boyd, 1995).

EDTA (ethylenediaminetetraacetic acid) reduces the bioavailability of for example, the heavy metal ions and is used in larval rearing water in some shrimp hatcheries in south-east Asia and Latin America (GESAMP, 1997).

Calcium sulfate, or gypsum ($CaSO_4 \cdot 2H_2O$), is used at concentrations of 250–1000 mg/l as a coagulant in shrimp ponds (Boyd, 1995; GESAMP, 1997). It is also used as a highly available source of calcium and sulfate in commercial fertilisers (Boyd, 1995).

Liming materials are used as amendments to shrimp ponds all over south-east Asia to neutralise the acidity of the soil and water, and to increase the total alkalinity and total hardness (Primavera et al., 1993; Boyd, 1995; GESAMP, 1997; Kongkeo, 1997). The most common liming materials are agricultural limestone (calcium carbonate, $CaCO_3$, dolomite, $CaCO_3 \cdot MgCO_3$, or calcium magnesium carbonate with another composition, $[CaCO_3]_{2-x}([MgCO_3]_x)$, calcium oxide (CaO) and calcium hydroxide ($Ca[OH]_2$) (Primavera et al., 1993; Boyd, 1995; GESAMP, 1997; Boyd and Massaut, 1999). Lime is added to the pond bottom during preparation, at doses of 100–8000 kg/ha or to the water during the rearing period at 10–500 kg/ha (Gräslund, unpublished; GESAMP, 1997). Liming is practised (using different procedures) to neutralise the acid sulfate which results from the oxidation of pyrite in ponds constructed in the mangrove areas of south-east and south Asia. Burnt lime is used at 50–100 g/m^2 in conjunction with ammonium phosphate to kill pests and predators (GESAMP, 1997). Liming also increases the microbial activity in the pond sediment. After harvest, farmers often leave the pond fallow for 2–4 weeks to enhance the decomposition of organic matter before it is re-stocked (Boyd, 1995). Decomposition takes place partly by chemical oxidation (Hopkins et al., 1995) and by microbial activity, the latter process being most effective at pH 7.5–8.5. If the pond soil is acidic, liming can be used to improve the conditions for microbial activity (Boyd, 1995). Some Thai shrimp farmers apply lime to the pond edges to neutralise rain (which is supposedly acidic).

Zeolites are aluminosilicate clay minerals which have a strong capacity to adsorb or desorb molecules in internal cavities, and to exchange cations (Boyd, 1995). In south-east Asia, zeolite is added to shrimp ponds at 100–500 kg/ha to remove hydrogen sulfide and carbon dioxide through adsorption, and to remove ammonia through ion exchange (Primavera et al., 1993; Boyd, 1995; GESAMP, 1997). The efficiency of this practice in saltwater has been questioned, for example, it has been shown that NH^{4+} adsorption is clearly repressed by cations in the water (Boyd, 1995; GESAMP, 1997).

6. Fertilisers

Fertilisers have a wide-spread use in shrimp ponds to increase the growth of natural food (GESAMP 1997; Boyd and Massaut, 1999). There is normally no need to fertilise ponds if the shrimps are given commercial feed, and there is an inverse relation between the amount of feed added, and the amount of fertiliser used (Boyd, 1995; GESAMP, 1997). Although the addition of fertilisers can increase shrimp production, it may also cause soil and water conditions to deteriorate if applied indiscriminately (GESAMP, 1997). There are two groups of fertilisers, i.e. organic and inorganic.

The organic fertilisers used in south-east Asian shrimp farming are mainly chicken manure, but cow, water buffalo (carabao) and pig manure are also used (Primavera et al., 1993; GESAMP, 1997).

A combination of inorganic fertilisers, i.e. ammonium phosphate (percentage N/P/K = 16:20:0) (Primavera et al., 1993) or (11:48:0) and urea (46:0:0) is commonly used in shrimp ponds (Boyd, 1995; GESAMP, 1997). Other inorganic fertilisers which are used are diammonium phosphate (18:46–48:0) (Primavera et al., 1993), complete fertiliser of the composition (14:14:14), solophos or superphosphate (0:18–20:0) (Primavera et al., 1993), ammonium sulfate (20–21:0:0), calcium nitrate (15:0:0) and calcium sulfate (20–21:0:0; see under Section 5) (Boyd, 1995; GESAMP, 1997). The remaining percentage of fertiliser product is a filler, usually agricultural limestone (Harrell and Webster, 1999).

7. Pesticides and disinfectants

The word ‘pesticide’ can be used in a broad sense to include disinfectants, or more specifically, for chemicals which target a certain group of organisms. The more specific pesticides can be used in shrimp ponds to kill organisms such as fish, crustaceans, snails, fungi, and algae. Algaecides are widely used to control weed growth in freshwater aquaculture, but have less use in marine aquaculture (GESAMP, 1997). Disinfection, in the meaning of elimination of pathogens, can be obtained by heating, UV-radiation and a large number of chemical compounds. Disinfectants can also be used to control phytoplankton or to oxidise the bottom soil. Great quantities of disinfectants are used in intensive shrimp farming, both in hatcheries and in grow-out ponds. They are used for site and equipment disinfection and sometimes to treat disease (GESAMP, 1997).

Ammonia/ammonium fertiliser is sometimes used in shrimp culture to kill fish before pond stocking (see also Section 6) (GESAMP, 1997; Boyd and Massaut, 1999).

Calcium hypochlorite ($Ca[OCl]_2$) and sodium hypochlorite (NaOCl) are the most commonly used disinfectants in south-east Asian shrimp farming (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). The application of hypochlorite is widely used in south-east Asia for viral control, either to disinfect incoming sea water before it is used in hatcheries, or to disinfect water or sediment in grow-out ponds (GESAMP, 1997). Frequently used concentrations of calcium hypochlorite in the pond water prior to stocking are 20–30 mg/l (Boyd, 1995) or 1–18 mg/l (Gräslund, unpublished). Concentrations of 10–20 mg/l (Boyd, 1995) or 0.5–1.5 mg/l (Gräslund, unpublished) are often added to ponds stocked with shrimps. Some Thai *P. monodon* farmers pump the inlet water through a bag of calcium hypochlorite before letting it into the pond. One Thai shrimp farmer adds calcium hypochlorite into the pond water to decrease the amount of organic matter in the water. Hypochlorite is highly toxic to aquatic organisms. It is quickly transformed, and the by-products which form can have a negative effect on the environment (see under Disinfection by-products).

Copper compounds have been used to eliminate external protozoans and filamentous bacterial diseases in post-larval shrimps. They are also used to inhibit phytoplankton growth and to induce moulting in shrimps (Boyd, 1995; GESAMP, 1997). Aquatrine is one of the copper compounds used in pond aquaculture (GESAMP, 1997) [identical to Cutrine-Plus, a copper II alkanol amine complex (PMEP, 1999; Applied Biochemists, 2000)]. Primavera et al. (1993) reported the use of copper compounds in shrimp farming in the Philippines in 1990. It is the cupric ion (Cu^{2+}) which is toxic to algae, and the most widely used products are copper sulfate ($CuSO_4$) and chelated copper (Boyd, 1995), which release the cupric ion into the water at different rates. Copper is moderately to highly acutely toxic to aquatic life (St-Laurent and Blaise, 1992; Richardson, 1992). Inhibitory effects on the sporophytes of a marine alga have been recorded at Cu-levels from 10 μg/l (Chung and Brinkhuis, 1986).

Formalin (or formaldehyde solution) which is 37 wt.% formaldehyde gas in water (Budavari, 1996) is used world-wide in aquaculture (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). It is used as an antifungal agent and in the control of ectoparasites, primarily in hatchery systems, but also as a piscicide (GESAMP, 1997; Boyd and Massaut, 1999). Formalin has been successfully used against MBV in nauplii washing in a Thai hatchery (Rosenberry, 1999). Treatment is often 15–250 μl/l for fish and crustaceans, and up to 2000 μl/l for the control of fungi on eggs (GESAMP, 1997). Formalin is sometimes added to south-east Asian shrimp ponds to remove ammonia (Boyd, 1995). In some Thai shrimp farms, it is used in the grow-out ponds at a rate of 120–3200 μl formalin/l, typically 3 days before stocking (Gräslund, unpublished). Formalin is highly acutely toxic to aquatic life (96 h LC_{50} range from 1 to 1000 μl/l, depending on species) (GESAMP, 1997). The compound has a relatively low persistence with a half-life of 36 h (GESAMP, 1997).

Glutaraldehyde is used by shrimp farmers as a bactericide (Boyd, 1995). It has been reported to cause skin and upper respiratory irritation, headache and nausea, etc. dose-dependently in exposed hospital workers (Richardson, 1992). No information about the toxicity to aquatic organisms has been found.

Iodophores are used world-wide as a disinfectant for equipment used in aquaculture and for the disinfection of water in grow-out ponds (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). The term iodophore can be used for any product in which surface active agents act as carriers and solubilising agents for iodine (Budavari, 1996). They are effective against a wide range of bacteria and viruses (GESAMP, 1997). Povidone iodine [polyvinyl–pyrrolidone iodine (Boyd, 1995)] is a form of iodophore used in south-east Asian shrimp farming. Rosenberry (1999) reports the use of iodophore in nauplii washing to reduce MBV infections in Thai hatcheries. Thai *P. monodon* farmers have been reported to use povidone iodine in grow-out ponds at a concentration of 3 l/ha/week.

Lime (see under Section 5) can be used as a piscicide (Boyd and Massaut, 1999).

Malachite green has been widely used in south-east Asian shrimp farming (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). It is used as an antifungal and antiprotozoal bath in the culture of shrimps, primarily in the hatcheries (GESAMP, 1997). It is prohibited in some south-east Asian countries such as Thailand, the USA and the European Union, due to its role as a respiratory enzyme poison (GESAMP, 1997). Malachite green is highly acute toxic to fish (Richardson, 1992; Srivastava et al., 1995). *P. stylirostris* nauplii exposed to malachite green exhibited metamorphosis inhibition at 80 μg/l (Richardson, 1992). It has persistent residues (GESAMP, 1997).

Nicotine (tobacco dust) is used in south-east Asian shrimp ponds before stocking to kill snails (Chua et al., 1989; GESAMP, 1997). Commercial nicotine is a by-product from the tobacco industry. It is extracted from leaves of the tobacco plants *Nicotiana tabacum* or *N. rustica* (Budavari, 1996). The LC_{50} (60 days) of nicotine was determined to 5.0 mg/l for rainbow trout fry (Passinoreader et al., 1995).

Organochlorine compounds, in particular endosulfan (Thiodan), have been used in south-east Asian shrimp farming (GESAMP, 1997). Thiodan is still used occasionally in Thai marine shrimp farming. Endosulfan is highly acute toxic to aquatic fauna (Richardson, 1992; Leight and Van Dolah, 1999) and has been recorded to reduce the growth rate of the marine red macro alga *Champia parvula* exposed for 14 days to the lowest tested concentration, i.e. 47 μg/l (Thursby et al., 1985). In a Jamaican study, hydrolysis of endosulfan at 30°C resulted in a half-life of 24–28 days and photolysis in sunlight gave a half-life of 11–13 sun days (during 32–40 days) at a day temperature of 29–39°C (Singh et al., 1991). Endosulfan degradation increases with increasing temperature and pH, and is higher in water than in soil (Kaur et al., 1998). Thiodan is not an organotin product as indicated by GESAMP (1997).

Organophosphates are acetylcholinesterase inhibitors used as insecticides. Organophosphates that have been used in south-east Asian shrimp farming are azinphos-ethyl (Gusathion A), diazinon, and trichlorfon (Dipterex) (Baticados and Tendencia, 1991; Tonguthai, 1996; GESAMP, 1997). According to GESAMP (1997), other organophosphates used in marine aquaculture are chlorpyrifos (Dursban), Dichlorvos, Demerin and Malathion. Azinphos-ethyl was once used in the Philippines to remove molluscs in shrimp ponds, but it has now been banned. Diazinon is applied to Indonesian shrimp ponds to kill mysids. Organophosphates are used in shrimp hatcheries to control monogenetic trematode infections in shrimps (GESAMP, 1997).

The effects on non-target crustaceans are a major concern for all the organophosphates (GESAMP, 1997). LC_{50} (96 h) values for azinphos-ethyl, chlorpyrifos, diazinon, dichlorvos, malathion and trichlorfon imply that these substances are all highly acute toxic to crustaceans (Baticados and Tendencia, 1991; McHenery et al., 1991; Cripe, 1994; Howe et al., 1994; Bailey et al., 1996; Forget et al., 1998; Leight and Van Dolah, 1999). Dichlorvos is highly acute toxic to fish (McHenery et al., 1991) and trichlorfon and diazinon are slightly to highly acute toxic to fish (Brecken-Folse et al., 1994; Howe et al., 1994; Richardson, 1992). LC_{50} (48 h) of chlorpyrifos to fish was 0.25 mg/l (Rice et al., 1997). Malathion is practically non-toxic to slightly acute toxic to mussels (Keller and Ruessler, 1997).

Lipid-based BCF of chlorpyrifos in fish has been reported as 21 000 (Deneer, 1994) which corresponds to a wet weight-based BCF of approximately 1000. Deneer also refers to five other studies on BCF of chlorpyrifos in different fish species, all with comparable results. These high BCF-values, together with the toxicity data presented above, indicate that chlorpyrifos is highly chronic toxic to aquatic organisms. Half-lives in water range from 1.2 to 6.3 days for trichlorfon via dichlorvos, malathhion and chlorpyrifos, to 8–11 days for diazinon at pH 7–8, 4.5–15°C in water of 20 ppt to marine salinities (Samuelsen, 1987; Lacorte et al., 1995). Trichlorfon degrades to dichlorvos when hydrolysed (Samuelsen, 1987).

Organotin compounds [e.g. triphenyltin acetate (Brestan), triphenyltin chloride (Aquatin) (Budavari, 1996; Richardson, 1992)] were widely used in south-east Asia to remove molluscs before the stocking of shrimp ponds, but are now banned in the Philippines and Indonesia (GESAMP, 1997). Triphenyltin acetate is highly acute toxic to fish and marine diatoms (Walsh et al., 1985; Strmac and Braunbeck, 1999). Corresponding data on triphenyltin chloride toxicity to fish have not been found, but Walsh et al. (1985) have shown that it is highly acute toxic to marine phytoplankton. 47–60% of *P. monodon* exposed to Aquatin for 96 h exhibited soft-shelling at levels of 15 μg/l and above (Baticados et al., 1986). The reported toxicity of triphenyltin chloride to three marine gastropods is LC_{50} (48 h) 1.4–4.6 μg/l (Horiguchi et al., 1998). The half-life of triphenyltin acetate in soil has been determined as 47–140 days with an increasing half-life with increasing carbon content of the soil (Loch et al., 1990).

Ozonation (ozone, O_3) is a disinfection technique often used in aquaculture (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). Ozonation is sometimes used to disinfect hatchery water, but less frequently to disinfect water in grow-out ponds (GESAMP, 1997). The technique requires relatively large investments and is therefore more frequently used in the larger farms.

Potassium permanganate ($KMnO_4$) is used as a piscicide (Boyd and Massaut, 1999) or as a general disinfectant. It is slightly to moderately toxic to marine and freshwater fish (Richardson, 1992).

Quaternary ammonium compounds are commonly used to disinfect water in shrimp ponds (Primavera et al., 1993; Dierberg and Kiattisimkul, 1996; Boyd, 1997; GESAMP, 1997; Boyd and Clay, 1998; Chang et al., 1998; Funge-Smith and Briggs, 1998). Examples of this group of compounds used in south-east Asian shrimp farming are *n*-alkyl (C_8–C_{18}) dimethyl-benzylammonium chloride or benzalkonium chloride (BKC) and didecyl dimethylammonium bromide (Primavera et al., 1993; Richardson, 1992). Quaternary ammonium compounds are used as bactericides and fungicides in shrimp hatcheries and to control infections in shrimp ponds (GESAMP, 1997). Several Thai *P. monodon* farmers use BKC to kill both phyto- and zooplankton, typically at a concentration of 6–20 l/ha. The EC_{50} (24 h) for embryos of Japanese oysters was 138 μg/l (His et al., 1996). The nine marine diatom species studied by Beveridge et al. (1998) were non-viable at the BKC concentration of 10 mg/l after 7 days exposure.

Rotenone is derived from certain legumes, in south-east Asia primarily from *Derris elliptica*, where it is used to remove fish before stocking the shrimp ponds (GESAMP, 1997; Kongkeo, 1997; Boyd and Massaut, 1999). It works by paralysing the gills of the fish (Wingard and Swanson, 1992). Rotenone can cause respiratory paralysis to humans and its use is thus strictly controlled in many countries, e.g. in the European Union (Richardson, 1992; GESAMP, 1997). Examples of published toxicity data are an LC_{50} (48 h) for rainbow trout, carp and goldfish of 26–33 $\mu g/l$, and an LD_{50} (48 h) for the crustacean *Simocephalus serrulatus* of 190 $\mu g/l$. Decomposition has been shown to follow a first order decay curve, with a half-life in cold water of 10.3 days, and in warm water of 0.94 days (Richardson, 1992).

Teaseed cake/meal or saponin is often used in south-east Asia as a piscicide (Primavera et al., 1993; GESAMP, 1997; Kongkeo, 1997; Boyd and Massaut, 1999) and in Thailand and the Philippines to induce moulting in shrimps (GESAMP, 1997). Teaseed is reported to be used in the water before stocking by Thai *P. monodon* farmers as a piscicide at a concentration of 60 kg/ha, and in already stocked ponds to induce moulting at concentrations of 60–80 kg/ha. Saponins are a type of glycoside (sapogenin glycosides) that are widely distributed in plants (Budavari, 1996). Saponin is slightly toxic to *P. japonicus* juveniles (Chen et al., 1996). The same study showed that exposure levels of 0.5 mg/l shorten the time to the first moult and thereafter, decrease the moulting frequency.

Trifluralin (e.g. Treflan) is a nitroaromatic compound that is used as a fungicide in shrimp hatcheries (GESAMP, 1997). In other contexts, the main use of trifluralin is as a herbicide (Budavari, 1996; Richardson, 1992). Trifluralin is highly acute toxic to fish and aquatic flora (Fairchild et al., 1997; Poleksic and Karan, 1999) and can be highly chronic toxic to fish, at wet weight based bioconcentration factors (BCF) ranging from 400 to 15 500 (Schultz and Hayton, 1999). Degradation studies have shown that the half-life of trifluralin in soil is between 21 and 50 days, and that possibly degradation is slower in loam than in sandy soil (Richardson, 1992).

8. Antibiotics

In many countries there is a widespread prophylactic use of antibiotics in shrimp hatcheries (GESAMP, 1997). In the text, the word antibiotics refers to biologically and synthetically produced substances.

Macrolides is a group of antibiotics effective against Gram-positive (and a few Gram-negative) bacteria that work by inhibiting the bacterial protein synthesis (Rang and Dale, 1987). Erythromycin is a macrolide that is used in some shrimp hatcheries in south-east Asia (Primavera, 1993; GESAMP, 1997). Resistance may occur and is plasmid-controlled (Rang and Dale, 1987).

Nitrofurans. Furazolidone and nifurpirinol belong to this group of synthetic agents. They are effective against Gram-negative and Gram-positive bacteria. They also have antiprotozoal activity. The mechanism of action is not known (Rang and Dale, 1987). Nitrofurans have been extensively used in shrimp farming (GESAMP, 1997). Baticados et al. (1990) reported that nifurpirinol was one of the most commonly used drugs in shrimp hatcheries in the Philippines. The nitrofurans are suspected carcinogens and therefore prohibited for use on food animals in the European Union (GESAMP, 1997).

Chloramphenicol is a broad spectrum antibiotic effective against gram positive and gram negative bacteria by inhibiting protein synthesis (Rang and Dale, 1987). The use of chloramphenicol in shrimp farms and hatcheries has been reported from the Philippines (Baticados et al., 1990; Primavera et al., 1993). In human medicine, chloramphenicol is used to treat meningitis and typhoid, for example. It may cause severe adverse affects such as aplastic anaemia (Rang and Dale, 1987; GESAMP, 1997). Resistance may occur, but this develops rather slowly (Rang and Dale, 1987). No residue levels in food products are tolerated in Europe and USA (GESAMP, 1997).

Quinolones are commonly used in Asian aquaculture (GESAMP, 1997). Oxolinic acid and norfloxacin are two quinolones that are used in Thai *P. monodon* farms. Other substances that belong to this group of synthetic antibiotics are nalidixic acid, flumequine, enrofloxacin, and sarafloxacin (GESAMP, 1997). Oxolinic acid, nalidixic acid and flumequine are mainly used against Gram-negative bacteria, while the others have a wider spectrum of action. The quinolones act against DNA-metabolism and repair attempts by the bacteria can lead to the formation of resistant mutants, a process that has already been documented. Microbial degradation of quinolones does not take place, but photodegradation is possible for substances exposed to light (i.e. less likely for residues in sediment) (GESAMP, 1997).

Rifampicin is effective against mycobacteria. In human medicine, it is mainly used in the treatment of tuberculosis and leprosy. It inhibits the bacterial RNA polymerase and resistance can develop rapidly (Rang and Dale, 1987). It has been used in shrimp hatcheries in the Philippines (Primavera, 1993).

Sulfonamides are commonly used in aquaculture in combination with a diaminopyrimidine, e.g. trimetoprim or ormetoprim, to control vibriosis for example (GESAMP, 1997). The use of sulfadiazine potentiated with trimetoprim has been reported in Thai shrimp farms. Sulfadiazine and trimetoprim are efficient against Gram-positive and Gram-negative bacteria, the first by inhibiting the tetrahydrofolat synthesis and the second by inhibiting dihydrofol acid reductase. Sulfonamides commonly induce plasmid-mediated resistance (Rang and Dale, 1987).

Tetracyclines are broad-spectrum antibiotics which include oxytetracycline, probably the most widely used antibacterial in aquaculture. It is effective against a wide range of Gram-positive and Gram-negative bacteria, including the Gram-negative *Vibrio* spp. (GESAMP, 1997). Its use has been reported from *P. monodon* farms in the Philippines (Primavera et al., 1993) and in Thailand. It is commonly used in Philippine shrimp hatcheries (Baticados et al., 1990). Commercial shrimp feeds are commonly enriched with oxytetracycline or other antibiotics (Flaherty et al., 2000). The tetracyclines act by inhibiting protein synthesis. Resistance is plasmid transmitted and may cause resistance to several other antibiotics simultaneously (Rang and Dale, 1987). Resistance against oxytetracycline is increasing, and therefore treatment is often inefficient (GESAMP, 1997).

9. Probiotics

Live bacteria inocula and fermentation products rich in extracellular enzymes are used in aquaculture (Boyd and Massaut, 1999). The reasons for using probiotics include the prevention of an off-flavour, reduce the proportion of blue–green algae, less nitrate, nitrite, ammonia, and phosphate; more dissolved oxygen, and an enhanced rate of organic matter degradation (Boyd, 1995). Selected strains of *Bacillus* have been used experimentally to control infectious *Vibrio* species (Moriarty, 1998; Rengpipat et al., 1998). It has been reported that *P. monodon* farmers in the Philippines use bacteria and enzyme preparations as organic matter composers (Primavera et al., 1993). Shrimp farmers on the Thai Gulf coast use bacterial amendments, e.g. a product called 'effective micro-organism' at a rate of approximately 400 g/ha. The efficiency of bacterial and enzymatic amendments has been questioned (Boyd, 1995). However, both Moriarty (1998) and Rengpipat et al. (1998) show that probiotics can have an effect against luminous *Vibrio* species. The mechanisms involved could be a combination of competition between the bacteria and of the different antibiotic compounds produced by *Bacillus* that are used in the treatment.

10. Vaccines

Virus vaccines cannot be used for shrimps as the immune system of crustaceans is fairly non-specific, but a similar treatment uses immunostimulants (see under Section 11).

11. Feed additives

The use of feed additives does not generally cause the cultured shrimp much stress. GESAMP (1997) states that pigments, vaccines and immunostimulants have been successfully applied as feed additives for crustaceans. What is meant by vaccines is not explained further, but it is possible that it refers to immunostimulant treatment since the word vaccine is sometimes used in this context (see Sakai, 1999).

Immunostimulants (e.g. yeast glucan, peptidoglycans, lipopolysaccharids and *Vibrio* bacteria) have an increasing use globally to stimulate the non-specific immune system in shrimps (GESAMP, 1997). Immunostimulants mainly work by increasing the bactericidal activities of the phagocytic cells. Treatment has been shown to have an immunostimulating effect or an effect against infection by *Vibrio* and YHV, in *P. monodon* (Rukyani et al., 1999; Sunarto et al., 1999; Sakai, 1999). Immunostimulants are used prophylactically. However, the response is likely to be of short duration (Sakai, 1999).

Vitamin B12. The use of vitamin B12 as a feed additive is reported from the Philippines (Primavera et al., 1993)

Vitamin C (ascorbic acid). Vitamin C is often added to shrimp feed, since it is documented that ascorbic acid deficiency in tiger shrimps is associated with moulting incompetence, malformation of the carapace, disorders of the gills, and high mortality rates (GESAMP, 1997). The addition of vitamin C to shrimp feed has been reported to be common in the Philippines (Primavera et al., 1993) and in Thailand.

Vitamin E is reported to enhance disease resistance. It is widely used as a feed additive during all stages of the production cycle of the tiger shrimp (GESAMP, 1997).

Feeding attractants are used as a 'start-feeding' stimulant for shrimp larvae (GESAMP, 1997). Specific compounds that are present in prey species, or in their release products, can be used to attract cultured shrimps to artificial feed. Coman et al. (1996) showed that *P. monodon* were attracted to glutamine, taurine, betaine and a mixture of amino acid and betaine.

Other feed additives reported from *P. monodon* farming in the Philippines are fatty acids, calcium compounds and binders (chicken egg) (Primavera et al., 1993).

12. Non-intentional chemical contamination in ponds

Pollutants originating from industrial activities, dumps or human settlements near shrimp farms, as well as pollutants from non-point sources such as pesticides from agricultural run-off can have a negative impact on shrimp health and farming (Chua et al., 1989; S. Jensen, personal communication). Insecticides, heavy metals, fuels and lubricants can be present in the ponds, usually due to non-intentional contamination (Boyd and Massaut, 1999). Structural materials, e.g. plastic, contain a variety of additives such as stabilisers, pigments, antioxidants, UV absorbers, flame retardants, fungicides and disinfectants, which can have an adverse effect on aquatic life if leached from plastic constructions (GESAMP, 1997).

13. Potential impact on the environment

Concern is being expressed regarding the potential impact of aquaculture chemicals on the aquatic environment, adjacent terrestrial ecosystems and human health (Redshaw, 1995; FAO, 1997b; Bangkok Post, 2000). There is a lack of information about the quantities of chemicals used in shrimp farming in the different south-east Asian countries. The absence of such quantitative information makes it very difficult to assess the impact of shrimp farming chemicals on the environment. However, with the available information on the types of chemicals that are used, the main aspects regarding their environmental fate may be discussed. There are three main groups of substances used in shrimp farming that can affect the environment in different ways, i.e. toxic chemicals, antibiotics and nutrients. Chemicals spread in the environment as a result of their use in aquaculture can be acutely toxic, mutagenic or have other negative sub-lethal effects on the wild flora and fauna. The dispersion of antibiotics after treatment in shrimp ponds or hatcheries can cause resistance among the pathogens, and a changed micro-organism composition in the aquatic environment. Effluents with high nutrient content can cause local or regional eutrophication.

14. Ecotoxicology in tropical ecosystems

In order to evaluate the available ecotoxicological data given in this paper regarding potential pollution from marine shrimp farming, the characteristics of tropical coastal ecosystems should be considered. The impact of a pollutant can be very different in a tropical environment than in a temperate one, primarily due to the different temperature and light conditions, but also due to variations in rainfall and biomass content (Castillo et al., 1997). However, the infrequency of studies from tropical systems often makes it necessary to refer to studies conducted in a temperate climate.

No general statement can be made about differences in sensitivity to pollutants between temperate and tropical aquatic species in their respective natural environment. However, a single species exposed to a chemical at different temperatures can exhibit a changed sensitivity to the chemical at higher temperatures. This phenomenon was studied by Mayer and Ellersieck (1988), who concluded that the toxicity of most chemicals (including, e.g. chlorpyrifos, malathion, trichlorfon and trifluralin) to freshwater fish increased 2–4-fold per 10°C change, while the toxicity of a few chemicals was negatively correlated with temperature. Differences in toxicity as a result of temperature change could be due to differences in the respiratory rate, chemical absorption, and excretion and detoxification of chemicals. While a temperature increase often increases toxicity, it may also increase detoxification and elimination (Cairns et al., 1975). Increased temperature also influences persistence as discussed below, and increases volatilisation rate.

Most available data on toxicity to aquatic life are from studies of freshwater organisms. A major concern regarding pollution from shrimp farms is the possible contamination of marine and brackish water ecosystems. However, freshwater can also be affected, both in coastal areas and in those inland areas where shrimp ponds are situated. Hutchinson et al. (1998) compared the toxicity of chemicals to freshwater versus saltwater organisms. They concluded that the sensitivity (EC_{50}) of freshwater and saltwater fish was within a factor of 10 for 91% of all 22 substances, and for invertebrates the corresponding figure was 33% of all 12 chemicals studied. More data was considered necessary in order to derive a firmer conclusion. For the substances discussed in this paper, e.g. chlorpyrifos was more toxic to saltwater than to freshwater fish (EC_{50} ratio for freshwater vs. saltwater fish was 26), and endosulfan was clearly more toxic to saltwater than to freshwater invertebrates (ratio 243) (ratio 0.05–2 was considered as being equal). A reason for saltwater fish being more sensitive than freshwater fish to certain chemicals could be that they are not only exposed to contaminants in the water by way of the gills and skin, but also through osmoregulation by drinking the sea water. Some of the results pointing at a higher sensitivity for saltwater species included in the comparison could be inaccurate, since saltwater species used in toxicity tests are often collected from the wild in contrast to freshwater organisms, and, hence, may be subject to higher stress levels and infections (Hutchinson et al., 1998). According to OECD (1998), freshwater and marine species toxicity data can be considered as equivalent data for application of their harmonised system for the classification of chemicals which are hazardous to the aquatic environment. Another aspect of the impact of salinity on toxicity is that a certain species can be more or less sensitive to a certain pollutant at higher salinities. For example, the toxicity of trichlorfon to grass shrimp and sheepshead minnow increased slightly with increased salinity, whereas the two nitrophenols tested were less toxic with increased salinity (Brecken-Folse et al., 1994).

15. Disinfection by-products

Disinfection using chlorine (usually calcium or sodium hypochlorite) is a widely used and recommended disease preventing measure in south-east Asian shrimp farming (see, e.g. Kongkeo, 1997; Rosenberry, 1998). In Thailand alone, approximately 50 000 tons of chlorine is used annually for disinfection in shrimp farms (C.K. Lin, personal communication).

Chlorine added to natural waters can react with different organic substances and result in significant concentrations of halogenated hydrocarbons (Christman et al., 1983; Urano et al., 1983; Fam and Stenstrom, 1987; Bauman and Stenstrom, 1990; Kristiansen et al., 1992; Jimenez et al., 1993; Kristiansen et al., 1994; Bull et al., 1995; Nordic Council of Ministers, 1997; Abia et al., 1998). Humic substances and bromine are significant precursors in this process (Hanna et al., 1991; Italia and Uden, 1992; Kristiansen et al., 1992; Xie and Reckhow, 1993; Kristiansen et al., 1994; Peters et al., 1994; Tretyakova et al., 1994; Bull et al., 1995; White, 1998). Substances found in chlorinated drinking water, or which have been observed to form after the experimental chlorination of water, are chlorinated and brominated trihalomethanes and haloacetates, chloral hydrate, benzaldehyde, trichlorophenols, halogenated furanones, haloacetonitriles, halogenated fatty acids, organic chloramines and many more (Christman et al., 1983; Urano et al., 1983; Bauman and Stenstrom, 1990; Kristiansen et al., 1992; Jimenez et al., 1993; Kristiansen et al., 1994; Bull et al., 1995; Nordic Council of Ministers, 1997; Abia et al., 1998). Several of the halogenated hydrocarbons that are found in chlorinated drinking water are well-known carcinogens, some are known to have a high acute toxicity, some have short-term toxic effects, while others still need to be examined for their toxicity (Capuzzo, 1977; Szal et al., 1991; Jimenez et al., 1993; Bull et al., 1995; Boyd, 1996; Klaassen, 1996; Nordic Council of Ministers, 1997). Marine aquaculture ponds contain a considerable amount of organic substances and ions such as bromide. It can be concluded that there is a clear risk that toxic chlorinated and brominated hydrocarbons form following the chlorination of shrimp ponds.

Chlorate is an inorganic by-product found in drinking water disinfected with chlorine dioxide. Small quantities are also present in water treated with hypochlorite (Bolyard et al., 1992; White, 1998). Chlorate is highly toxic to the marine macro brown algae, but non-toxic to other groups of investigated aquatic organisms (van Wijk and Hutchinson, 1995).

The formation of disinfection by-products from oxidising agents other than chlorine has not been as thoroughly studied. However, all oxidising agents that are effective in water treatment will create oxidant by-products that are potentially toxic (Trussel, 1999). For example, the ozonation of water with a high content of bromine and organic matter will cause the formation of disinfection by-products (White, 1998).

After disinfection of a shrimp pond, the oxidising agent itself can disappear from the pond water within a few hours whilst the by-products that form may be persistent.

16. Persistence of residues

The persistence of residues strongly depends on the environmental conditions. Major factors influencing the degradation are temperature, pH, the level of dissolved oxygen, light intensity and the presence of micro-organisms. Different substances respond in different ways to specific environmental conditions. Generally, there is a higher degradation rate at higher temperatures and higher light-intensities. Residues in sediment tend to remain for longer periods than residues in water, especially if there are anaerobic conditions and a lower likelihood of photodegradation (GESAMP, 1997). On the other hand, some substances degrade more rapidly under anaerobic than aerobic conditions, e.g. chloramphenicol (Chien et al., 1999).

The persistence of aquaculture chemicals in the tropical environment has not been thoroughly studied, and is likely to differ from persistence in temperate regions (GESAMP, 1997). Degradation under tropical conditions of some aquaculture chemicals used in agriculture is documented in the literature, e.g. endosulfan degradation in a tropical environment is described by Singh et al., 1991 (see under Section 7). Higher temperatures and light-intensities in tropical regions suggest more rapid degradation in these regions. Studies of DDT in aquatic systems indicate that there is a lower persistence for this specific insecticide in tropical regions than in temperate regions (Berg et al., 1992) and it is possible that similar patterns will be found for aquaculture chemicals. Additionally, the rate of biodegradation by micro-organisms roughly doubles every 10°C between 10 and 30°C (De Henau, 1998).

Many aquaculture chemicals persist for very short time periods. For example, formalin has a half-life in water of 36 h (GESAMP, 1997) and the antibacterial furazolidone has a half-life of 18 h in marine sediment at 4°C (Samuelsen et al., 1991).

Organophosphates are extensively used in aquaculture, partly because they typically degrade faster than, for example the chlorinated pesticides. Their rate of hydrolysis generally increases with increased pH and temperature (Brecken-Folse et al., 1994). Whereas most organophosphates degrade to less toxic products, trichlorfon is an important exception. Trichlorfon hydrolyses to the more toxic (2.6–350 times) and more stable dichlorvos (Samuelsen, 1987; Mayer and Ellersieck, 1988). Degradation of organophosphates bound onto sediments can be considerably slower than degradation in water, a situation of interest regarding chlorpyrifos (log $K_{ow} = 5.11$) and other substances with relatively high log K_{ow}-values. Readman et al. (1992) concluded that chlorpyrifos originating from agriculture in a tropical environment can be sufficiently stable to contaminate marine sediments, due to its high affinity to sediment.

Other chemicals have a very long half-life, keeping their toxic properties for many months. Organotin compounds are likely to be quite persistent in sediments. Copper (applied to ponds as copper sulfate or chelated copper) will, being an element, remain in the environment. The cupric ion easily adsorbs to suspended particles, or forms organic complexes with dissolved organic matter, the form decided by many factors including pH (Shi et al., 1998). Concerning organochlorines, endosulfan is generally less persistent than other chlorinated pesticides due to its high level of oxygenation (Alloway and Ayres, 1997).

Several antibiotics, e.g. oxytetracycline, oxolinic acid and flumequine, have been found in sediments 6 months after treatment (Samuelsen, 1989; Weston, 1996; GESAMP, 1997). According to Chien et al. (1999), the degradation rate of chloramphenicol decreased with increasing salinity and chloramphenicol degraded at a higher rate under anaerobic conditions than under aerobic conditions. The half-life was between 0.4 days in freshwater under anaerobic conditions and 18.4 days at a salinity of 36 ppt under aerobic conditions. The half-life of oxytetracycline was estimated to be 10 weeks in anoxic sediment (at 4–8°C) in a model of a fish farm bottom (Jacobsen and Berglind, 1988). They also found oxytetracycline in real fish farm sediments that caused antimicrobial effects 12 weeks after administration. It has been suggested that the decomposition of oxytetracycline in sediments is minimal and that the observed decline could be explained by diffusion and wash-away with water currents from the sediment (Samuelsen, 1989; Björklund et al., 1991). Oxytetracycline and oxolinic acid levels in fish farm sediments was reported to decline rapidly for 10–20 days, where after they remained on a nearly constant level (Björklund et al., 1991). In the same study, there was no oxolinic acid antibacterial effect in the sediment after 10 days, whereas the oxytetracycline antibacterial effect remained for at least 77 days. The degradation of oxytetracycline increases with increased temperature and light intensity, and decreases with increased sedimentation rate (Samuelsen, 1989).

Persistence is of major importance for the environmental effects of aquaculture chemicals. A significant persistence of a chemical, or its byproducts, can influence organisms living in contact with the ponds and organisms in other ecosystems through bioaccumulation, biomagnification or physical transport through air, water or soil.

17. Effects on micro-organisms, sediment and water

The presence of antibiotics in the bottom sediments may affect the natural bacterial composition and activity, and thereby change the ecological structure of benthic microbial communities. The accumulation of antibiotics in pond sediment can lead to decreased or inhibited microbial activity in the sediment, which in turn can lead to anaerobic conditions. Aerobic degradation of organic matter by bacterial activity produces less toxic by-products, such as carbon dioxide and nitrates, than anaerobic degradation, which results in more toxic by-products such as sulfides and ammonia. Additionally, it reduces the rate of organic matter degradation. Accordingly, antibacterial residues in the sediment can negatively affect the water quality of the shrimp ponds (GESAMP, 1997). On the other hand, anaerobic conditions can favour the degradation of chloramphenicol (Chien et al., 1999), for example, and cannot exclusively be seen as negative.

Antibiotics and other products added to feed often end up on the pond bottom since some of the feed is not consumed by the shrimps. Denitrification may be disturbed by chloramphenicol residues and thereby decrease the water quality (Chien et al., 1999). Jacobsen and Berglind (1988) showed that deposition of feed impregnated with chloramphenicol increased sulfide ion activity in their model of a fish farm bottom. The same was shown for furazolidone and sulfadiazine/trimetoprim. When soils are acidic, hydrogen ions and sulfide ions can form complexes of bisulfide ions and hydrogen sulfide. Relative to other benthic invertebrates, crustaceans generally have a low tolerance to hypoxia and sulfide (Bagarinao, 1992). Sulfide toxicity is considered very difficult to determine (Wang and Chapman, 1999) and no data on the toxicity of sulfide to *Penaeus* species have been found.

If persistent residues from chemicals applied to shrimp ponds accumulate in the sediment, it is likely that these substances will also be present at the bottom of abandoned ponds. Factors influencing the presence of these substances would, besides formation and accumulation, be degradation rate, bioaccumulation in organisms living or foraging in the ponds and management routines concerning sediment removal while the ponds are still being used (a possibility of dispersion of residues).

In eastern Thailand, sediment removed from intensive *P. monodon* farms is sometimes used as fertiliser, e.g. in fruit orchards. The sediment is treated with micro-organisms, water and aeration etc. before it is considered suitable as fertiliser. It is possible that such fertiliser contains antibacterial or other potentially toxic residues from aquaculture chemicals even after the treatment.

18. Eutrophication

Nutrient input to shrimp ponds by adding fertiliser and feed can result in the eutrophication of waters receiving the shrimp pond effluents (Chua et al., 1989; Sansanayuth et al., 1996; GESAMP, 1997; Funge-Smith and Briggs, 1998). Coastal shrimp farms are often located in areas with coral reefs and sea-grass beds, ecosystems that are particularly sensitive to eutrophication (GESAMP, 1997). Feed has been shown to be the major source of nitrogen and phosphorous in shrimp pond water in Thai intensive shrimp farming systems whereas fertiliser addition only accounts for a small portion of the nutrients (Funge-Smith and Briggs, 1998). Robertson and Phillips (1995) compiled data on nutrient and particle concentrations in the pond effluent from intensive shrimp cultivation. They concluded that levels of ammonia, chlorophyll a and bacterial cell densities were higher in effluent water than in pristine mangrove waterways. Elevated levels of dissolved organic nitrogen, dissolved organic phosphorous, total dissolved nitrogen, total suspended solids and chlorophyll a were observed in a creek receiving shrimp farm discharge (Wolanski et al., 2000). Shrimp culture can contribute to coastal eutrophication, but in some cases the contribution is much less than from other human activity (Beveridge et al., 1997). Eutrophication is often mentioned as an important negative impact of shrimp farming on the environment (Hopkins et al., 1995; Boyd and Clay, 1998; Kautsky et al., 2000; Naylor et al., 2000). However, studies showing the connection between shrimp farming, eutrophication and changes in the ecological community structure have not been found in international journals. Data from such studies would be very valuable.

19. Residues in shrimps and other organisms

In 1991, the Japanese Health Authority found unacceptable levels of oxytetracycline in farm-raised shrimps imported from Thailand. The authorities were forced to create an inspection programme for all shrimps imported from Thailand

and other countries in south-east Asia (Weidner and Rosenberry, 1992). In 1993, the Thai Medical Sciences Department found that 24% of shrimps for export contained tetracycline residues. Four years later, another study showed that the number had fallen to 5%. Whereas antibacterial residues have decreased in exported shrimps, concern is being raised in Thailand since few analyses have been made on shrimps for the domestic market (Bangkok Post, 2000). However, Saitanu et al. (1994) examined 1461 of cultured *P. monodon* bought from markets in Bangkok for antibacterial residues. Antibiotics were present in more than 8% of the shrimps included in the study. The Swedish National Food Administration has occasionally carried out analyses for tetracyclines, sulfonamides and quinolones in imported shrimps. None of these antibiotics have been found in the investigated consignments from China, Indonesia and Thailand (Nordlander, 1998). It is, however, not clear whether the tests were done on cultured or wild-caught shrimps.

Theoretically, chemicals other than antibiotics that are added to the shrimp ponds, or by-products from the applied substances, that have a bioaccumulation potential, could be found as residues in the shrimps. The accumulation of lipophilic substances is most likely to take place in the large hepatopancreas, and, considering its lower fat content, the muscle is less likely to contain significant levels of lipophilic toxic substances. However, little attention has been paid to the risk of residues other than antibiotics in farmed shrimps, and no data from such investigations have been found.

Triphenyltin (TPT) contamination from the use of Brestan has been studied in two milkfish (*Chanos chanos*) brackish water ponds in the Philippines (Coloso and Borlongan, 1999; I. Borlongan personal communication). Brestan was last applied to the ponds at a dose of 1 kg/ha, 6 and 12 months, respectively, before the study took place. Approximately 3–4-month-old fish from the ponds were investigated, and were shown to contain 0.3–0.4 and 0.6–0.7 mg TPT-Sn/kg dry matter, respectively. The values are comparable with FAO/WHO's recommended level for the acceptable daily intake of 0.5 μg Sn/kg body weight. This study shows that organotin pesticides are persistent enough to be present in fish 6–12 months after application, at levels that could have a negative effect on the humans consuming the fish.

There is a risk that the use of chemicals in shrimp ponds can result in the uptake of residues by filter-feeding molluscs, fish, crustaceans, birds, micro and meiofauna, algae and other vegetation in the surrounding environment. This risk is likely to be greater as the level of water exchange in the management system increases. Potential effects to human health should be considered if, for example, filter-feeding molluscs are harvested for human consumption adjacent to semi-intensive or intensive shrimp farms. A problem is that it is possible to specify the removal time of a chemical, e.g. a certain antibacterial, but it is hardly feasible to stop people from collecting contaminated seafood from areas affected by the shrimp pond effluent during the time period in question.

Fish generally have a higher lipid content than crustaceans and can therefore be expected to bioconcentrate more. On the other hand, they may be able to metabolise and depurate pollutants more rapidly and hence bioconcentrate less than the crustaceans (Brecken-Folse et al., 1994).

20. Toxicity to cultured shrimps and other non-target species

Pesticides and other products used in shrimp farming for their toxic properties can pose a risk to wild flora and fauna, but also to the health of the shrimp cultures (Baticados et al., 1986). Many of the chemicals included in this review are slightly to highly toxic to aquatic animals. Their potential effect on non-target organisms depends on toxicity and on the degradation rate and dispersion, i.e. the actual concentration the organism is exposed to. The toxicological mechanisms of pollutants cause different stress levels to different groups of organisms and can potentially change the community structure of marine sediments (Readman et al., 1992).

The discharge of shrimp pond water treated with teaseed has been associated with mass fish kills in adjacent mangrove areas (Primavera, 1993). Organophosphates that are used against trematodes or mysids pose a major threat to exposed non-target crustaceans (GESAMP, 1997). Tonguthai (1996) reported that considerable amounts of insecticides such as the organophosphate Dipterex (active ingredient: trichlorfos) have been used in Thai shrimp farming systems to kill disease vectors such as crabs and small shrimps, thus posing a threat to the environment. In a Norwegian study, Egidius and Møster (1987) demonstrated that Neguvon (active ingredient: trichlorfos) treatment in salmon farms was the likely agent that caused the death of lobsters and the disappearance of crab populations adjacent to salmon farms. In another study, acetylcholinesterase activity in mussels growing close to salmon farms was shown to be related to previous in situ exposure to dichlorvos (McHenery et al., 1997); the research group found a positive correlation between previous exposure and sensitivity to dichlorvos. These studies are interesting, but differences in methods for cage and pond cultures and the climate should be taken into account when comparing studies from salmon and shrimp culture. When relatively short-lived chemicals are used in cage culture, they will reach the surrounding environment more rapidly than when used in pond aquaculture. At the same time, the dispersion and dilution rates of chemicals may be higher near cage cultures than for coastal shrimp pond effluents.

21. Antibiotic resistance

There is a significant use of antibiotics in aquaculture, either to treat infections or as prophylactic therapy. In many countries, there is a widespread prophylactic use of antibiotics both in shrimp hatcheries and in ponds. This practice is likely to cause the dispersion of antibiotics to the local environment, and might contribute to resistance among bacteria (GESAMP, 1997). One of the major factors causing a collapse in the Taiwan shrimp farming industry in 1988 was the indiscriminate use of antibiotics, resulting in the resistance of pathogens (Lin, 1989). Resistance towards some of the antibiotics commonly used in south-east Asian shrimp farming, e.g. chloramphenicol and tetracycline, is already developing in human, as well as shrimp pathogens in the region (resistance in human pathogens has been documented in Indonesia, Thailand, the Philippines, Vietnam, Cambodia, Malaysia, Brunei Darussalam, and Singapore) (GESAMP, 1997; WHO, 2000). Baticados et al. (1990) concluded that the likelihood of controlling luminous vibriosis among shrimp larvae with antibiotics is limited by the prospect of resistance development and the limited tolerance of shrimp larvae to the drugs. The consequences of resistance development include (GESAMP, 1997; WHO, 1999):

- An increase in the prevalence of resistant bacteria in the target animal.
- An increased potential for the transfer of resistant pathogens to humans by direct contact with animals or by the consumption of contaminated food or water. For example, cholera strains of *Vibrio cholerae* and at least three other *Vibrio* species have been observed to cause infections in humans after the consumption of shellfish, after sea bathing, and after minor injuries while cleaning crabs, etc. (Brown, 1989). Cholera infections can be treated e.g. with tetracycline (the treatment is however often not used, partly because of tetracycline's high cost).
- The transfer of resistant DNA or RNA from target animal pathogens to human pathogens. Theoretically, excess use of antibiotics in aquaculture could affect practices in human medicine by the transfer of resistant DNA or RNA to human pathogens, even though the evidence for such pathways has not been shown (GESAMP, 1997).

Several of the antibiotics used in shrimp farming are crucial in human medicine. For example, phenicols are the only accessible potent cure for meningitis in poor countries. Rifampicin is efficient against a wide range of bacterial infections, but it should not be used against anything but tuberculosis and leprosy, except in emergency cases, due to the risk for rapid development of resistance (Kindmark, C.O., personal communication).

22. Health risks for farm workers

Some substances used in shrimp farm management pose an acute risk to the health of farm workers, even when handled according to the manufacturers instructions. WHO regularly issues a guideline for the classification of pesticides according to the hazard (WHO, 1998). For example, azinphos-ethyl, dichlorvos and nicotine are classified as highly hazardous, whereas trifluralin is considered unlikely to present an acute hazard to a person handling the product correctly. Other useful documents regarding pesticide management are produced by FAO (1998). GESAMP (1997) and Boyd and Massaut (1999) discuss the available information on the risks of aquaculture chemicals towards farm workers. However, this is an area where further studies and documentation are needed.

23. Role and responsibility of different stakeholders

According to the 1996 Expert Meeting on the Use of Chemicals in Aquaculture in Asia, many of the chemicals that are used are essential for successful and efficient aquaculture production, and do not appear to have adverse effects on human health or the environment if applied properly (Barg and Lavilla-Pitoga, 1996). The meeting also found that the safe and effective use of chemicals in aquaculture is inhibited by the lack of a trained work-force, misapplication of some chemicals (e.g. due to lack of information to farmers, lack of alternatives, promotion by salesmen), insufficient understanding of the mode of action, especially under tropical conditions, and vague legal and institutional frameworks.

According to Boyd (1995), some products used to treat the water or soil in shrimp ponds can correct specific conditions when used properly (e.g. fertilisers, liming materials and algaecides). Some chemicals are potentially useful, but optimal application practices have not yet been found (e.g. oxidising agents and products to remove phosphorous). Yet other products are used in shrimp ponds, even though there are no scientific data that supports their efficiency (e.g. zeolite) (Boyd, 1995). Favourable conditions for shrimp culture can be obtained by improved management practices. Chemicals should be used as a last resort, and only those products that have been shown to have a clear positive effect should be used.

Relevant practice regarding the use of chemicals and biological products in shrimp farming is clouded by anecdotal information exchanged between pond managers, and misleading advertising claims propagated by sales agents. The farm managers are often easily influenced by vendors and advertisements, partly due to their usually limited knowledge of water chemistry. It has been reported that much of the application of chemicals is beyond rational explanation, as the dosage often exceeds recommended limits and the efficacy of the treatments in some cases is questionable (Boyd, 1995; P.J. Miller, personal communication). Some logic in such ‘irrational’ treatments can, however, be found in the fear of major economic losses, making farmers prepared to try all means to avoid crop failure. Additionally, recommended dosage and other crucial information are often absent from product labels, making it difficult for farm managers to know how the product should be used.

Important work on the development of policies and global and regional recommendations for sustainable aquaculture is done by inter-governmental organisations, e.g. Food and Agriculture Organization of the United Nations (FAO), Network of Aquaculture Centres in Asia-Pacific (NACA) and South-East Asian Fisheries Development Center (SEAFDEC). FAO has developed a Code of Conduct for Responsible Fisheries (CCRF), which was adopted by the FAO Conference in 1995 (FAO, 1995), and technical guidelines to support the implementation of the code. Aquaculture development, including the use of therapeutants and other chemicals, is analysed in article 9 of CCRF and no. 5 of the technical guidelines (FAO, 1997b). The following points are discussed in these documents:

- 'Safe, effective and minimal use of therapeutants, hormones and drugs, antibiotics and other disease control chemicals should be ensured. (FAO, 1995 art. 9.4.4)'.
- Use of such material should preferably be under veterinary supervision (FAO, 1997b, p. 30)
- Marketing and use of drugs, which have not been certified for aquatic use, should be strictly regulated, if not prohibited. (FAO, 1997b, p. 30)
- Preventive use of antibiotics should be avoided as far as possible (FAO, 1997b, p. 30)
- 'States should regulate the use of chemical inputs in aquaculture which are hazardous to human health and the environment.' (FAO, 1995 art. 9.4.5)

SEAFDEC is facilitating the implementation of CCRF in south-east Asian countries by the development of regionally adapted technical guidelines (SEAFDEC, 1999). The Conference on Aquaculture Development in the Third Millennium 2000 organised by NACA and FAO resulted in the Bangkok Declaration and Strategy (NACA/FAO, 2000). Chemical use in aquaculture is mentioned in the document, but not discussed in detail.

Governmental authorities have the responsibility to regulate the use of chemicals and biological products in shrimp farming. Before any substance is approved for use, its hazards should be assessed and the risks to aquatic and terrestrial life should be determined before deciding whether the substance is safe (Redshaw, 1995; Tonguthai, 1996). The predicted no effect concentration (PNEC) of the substance in a certain environment should be assessed and compared to the highest predicted environmental concentration (PEC). The PEC can be estimated from data on the physical and chemical properties of the substance and information on the quantities and patterns of its use (Redshaw, 1995). Use of antibiotics should be regulated by governments, so that the risk for the development of resistant bacteria is decreased (Boyd and Clay, 1998). Governmental agencies should increase the awareness of the shrimp farmers on the impact of chemical use on the environment and public health (Tonguthai, 1996). Governments and representatives from aquaculture and the drug and chemical industry should jointly develop regulations for the labelling of all chemical and biological products approved for use. However, the situation is not improved if the drug and chemical industry and shrimp farm managers do not comply with it. It is the responsibility of the governments to enforce existing legislation.

An example of national regulations for chemicals used in aquaculture is the situation in Thailand. The Thai Department of Fisheries partly regulates 12 chemicals commonly used in aquaculture (acetic acid, benzalkonium chloride, calcium hypochlorite, chlorine, fentin acetate, trichlorfon, formaldehyde, hydrochloric acid, rotenone, sodium hydroxide, sodium hypochlorite, and trifluralin). The importing of these substances must be registered at the Department of Fisheries (Tonguthai, 1996). Additionally, the product labels must declare all relevant information in Thai, a regulation that is not fully implemented. The Ministry of Public Health is responsible for the human drugs (as most of the listed antibiotics in this review are), whilst the Ministry of Agriculture and Cooperatives is responsible for agricultural chemicals.

Governmental work aside from regulations can be exemplified by the initiative of the Thai Department of Fisheries. The Department of Fisheries has, together with Thai Marine Farmers Association and other industrial stakeholders, developed a code of conduct with overall recommendations and guidelines for the Thai marine shrimp industry to follow. 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'. The code is relatively progressive and commendable, but until now, many Thai farmers are not familiar with its existence.

Shrimp farm managers have the responsibility to be restrictive with the application of amendments to shrimp ponds. The main reasons for the use of chemical and biological products in shrimp ponds are water quality problems and the high risk for disease outbreaks. Water quality problems are mainly caused by excessive feed inputs, acidic soil or external water pollution (Boyd, 1995). The first problem can easily be avoided, whilst the two latter can be prevented by the proper selection of a pond site. According to the precautionary principle, chemicals should not be used if their potential impact on the environment is unknown. Additionally, products that do not clearly have the intended effect should not be used.

When using chemicals, it is important that farmers follow the information on the product labels regarding dosage, proper use, storage and other constraints. Treatment should comply with national and international recommendations. Farmers should keep records of the chemicals and biological products used at their farm. When potentially toxic or bioaccumulative chemicals are used in ponds, the water should not be discharged until the compounds have decomposed to non-toxic forms. Alternative techniques may be appropriate in some cases, for example, the killing of disease vectors and pathogens to a variable extent can be achieved by drying the ponds and equipment, and drenching the equipment in hot water.

A number of technical and ecological measures can increase the chances of good water quality in ponds and diminish the risk of infectious diseases in cultured shrimps. Poor environmental conditions cause stress to the cultured shrimp. Stress is an important factor that makes the shrimp more susceptible to disease (Clay, 1997; LeMoullac et al., 1998). The following steps are likely to improve the environmental conditions and thereby improve the chance for healthy shrimps and decrease the need for chemicals and biological products.

- Sites with suitable soil and water for shrimp farming should be selected (Boyd, 1995). Mangroves and tidal wetlands are unsuitable for sustainable pond culture, since they often have acidic soil that creates too low a pH in the pond water (Boyd and Clay, 1998), and a high organic load contributing to water quality problems and thereby disease outbreaks (Kongkeo, 1997). Therefore, besides the environmental conservation aspects on mangrove destruction, shrimp ponds should not be established in such areas.
- Ponds should be designed and constructed properly. Ponds that are too shallow might be invaded by macrophytes. Where ponds are too deep, the water can stratify, causing water quality problems, e.g. oxygen depletion (Boyd, 1995). Large buffer zones around the ponds should be created (Kautsky et al., 2000).
- Sedimentation ponds should be used for inlet water if the water supply contains heavy sediment loads (Boyd, 1995).
- Species should be chosen that are native to the locality, and suitable for the local climate and salinity (Boyd, 1995). This reduces the risk for disease outbreaks and biodiversity depletion, which can be caused through escapement of cultured stocks and competition, predation and possibly inter-breeding with wild species or varieties.
- Stocking densities should be reduced (Boyd, 1995; Kautsky et al., 2000). Exceedingly high densities of shrimp in the ponds will increase the risk for disease outbreaks, partly by causing oxygen depletion in the ponds.
- High quality feed and fertilisers should be used restrictively (Boyd, 1995). Here high quality feed refers to feed with low contamination risk, i.e. fresh, properly stored, and with a relevant nutrition content.
- Aeration and water exchange can be used to increase water conditions, but it cannot compensate for excessive stocking densities, excess fertiliser or feed input (Boyd, 1995).
- Water exchange between shrimp ponds and adjacent water bodies should be reduced or eliminated (Hopkins et al., 1995; Kongkeo, 1997; Boyd and Clay, 1998). A restricted water exchange management will lower the risk for sudden changes in biological, chemical and physical water quality, and thereby decrease shrimp mortality. It will also reduce the intro-

duction of viruses and other pathogens (Kongkeo, 1997).

- Systems for effluent treatment should be integrated in the farming (Kautsky et al., 2000). Treatment ponds should be used for water drained after harvest to encourage sedimentation, denitrification and the removal of other pollutants associated with suspended solids, before the water is reused or let out to the surrounding environment (Boyd and Clay, 1998). Water should not be discharged until the potentially toxic substances have decomposed to non-toxic forms.

The chemical and drug producers and retailers should base their work on scientific data and ethic values. They have the responsibility of only promoting products that have a scientifically proven effect on the proposed use. These groups must provide shrimp farm managers with accurate information about their products. A declaration label should always specify the chemical formulae of the active ingredient and other substances included in the product and the percentage of active ingredient. The intended use, route of treatment, dose, frequency of treatment, environmental and health hazards, species and life stage to be treated, storage conditions, expiration dates and disposal recommendations should also be declared on the product label (GESAMP, 1997). The information should be in the local language. Products should not be repacked without accurate labelling.

As pointed out by Redshaw (1995), further research is necessary to clarify the fate and biological effect of chemicals used in the aquatic environment. There is a general lack of literature on chemical use in pond aquaculture. Published firsthand information that summarises the chemicals used in different types of aquaculture in different regions is scarce, but crucial. It is also important to intensify the documentation of the frequency, severity and spatial extent of the environmental impact caused by chemical use in aquacultural activities (GESAMP, 1997). Little is known about the degradation and environmental effect of aquaculture chemicals, specifically in tropical marine environments, and studies in this field are needed. Furthermore, scientists also have the responsibility of disseminating information obtained from their research to the farmers as soon as possible, and to make findings available to governmental authorities in the purpose of facilitating their work (Tonguthai, 1996).

24. Conclusions

It is necessary to collect more information about the types of chemicals and the quantities used in order to make accurate environmental risk assessments of chemical usage in shrimp farming. Without this, it is impossible to draw any conclusions on impact on the environment. Another field that needs to be investigated further is the environmental fate and biological effects of the substances, more specifically under the conditions prevalent in marine aquaculture ponds and in a tropical environment. The literature on degradation and environmental effects of aquaculture chemicals is dominated by studies on antibiotics. Other groups of chemicals, primarily disinfectants and pesticides clearly need to be studied further.

The use of antibiotics is a major problem in shrimp farming, with a significant potential to have a negative impact on human health, locally and regionally. Some of the less investigated substances might have an important impact on the environment in regions where shrimp farming facilities are located. For example, copper compounds, some organotin compounds and certain other substances with a high affinity to sediment leave persistent, toxic residues, and may have a negative effect on the environment. The actuality of such an effect depends on the currently unknown quantities of the substances that are spread throughout the environment.

Both scientists and inter-governmental organisations recommend that pond aquaculture managers should be restrictive in the use of chemicals and biological products. This point of view is in line with the concept of risk for environmental effects from the excessive chemical use and hence the precautionary principle, the risk for decreased production, e.g. through antibacterial resistant shrimp pathogens, and the reality that many chemicals and biological products have not been shown scientifically to affect shrimp culture. Governments, shrimp farm managers and the chemical industry all have the responsibility to promote and inaugurate restrictive and relevant use of chemicals in shrimp farming.

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