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Management measures to control diseases reported by tilapia (*Oreochromis* spp.) and whiteleg shrimp (*Litopenaeus vannamei*) farmers in Guangdong, China

Kang Li [a,b], Liping Liu [a,*], Jesper Hedegaard Clausen [b], Maixin Lu [c], Anders Dalsgaard [b]

[a] Key Laboratory of Freshwater Fishery Germplasm Resources, Ministry of Agriculture, Shanghai Ocean University, Shanghai 201306, China
[b] Department of Veterinary Disease Biology, Faculty of Health and Medical Sciences, University of Copenhagen, Stigbøjlen 4, DK 1870 Frederiksberg C, Denmark
[c] Pearl River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Guangzhou 510380, China

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ABSTRACT

Culture of tilapia (*Oreochromis* spp.) and whiteleg shrimp (*Litopenaeus vannamei*) has intensified during the last decade in China with increased production, meanwhile it has also brought some problems, including diseases, increased use of antimicrobials and other chemicals for disease control and pond water quality management. This study investigated the knowledge, practices and challenges of tilapia and whiteleg shrimp farmers when preventing and controlling diseases through the use of antimicrobials and other compounds in Guangdong province, which is the most important shrimp and tilapia production area in China. Tilapia farmers (25) mainly reported streptococcosis (9) and exophthalmia disease (9) which often was treated with sulfadiazine, florfenicol and vitamins or rhubarb (*Rheum rhabarbarum*) extract, although farmers thought the effectiveness of antimicrobial treatment has decreased in recent years. Shrimp farms (30) mainly experienced outbreaks of red body disease (19) and white spot syndrome (5), both viral diseases, and so-called "secret death disease" (5) which farmers controlled by application of a variety of disinfectants, probiotics and vitamins. Most of the farmers reported they did not use antimicrobials to treat shrimp disease. All farmers applied disinfectants and probiotics to control pond water quality although the efficacy of such use was not known. Farmers prepared their own medicated feed through mixing antimicrobial water-based solutions into the feed pellets with bare hands with small and medium scale farmers having little awareness of associated occupational health hazards. This practice together with inferior drug quality will lead farmers to administer sub-therapeutic antimicrobial concentrations with the subsequent risks of treatment failure and resistance development. Farmers stated lower costs and stricter regulation on antimicrobial usage as reasons for the popularity of probiotics. Farmers also reported the use of herbal extracts for disease control and water quality improvements, partly because of the low number of reported negative side effects and no antimicrobial residue problems. Local chemical supply shops, with representatives often visiting the farms, were important sources of information that farmers used when diagnosing and treating diseases. Farmers also relied on their own experience and current practices of chemical use do not seem cost-effective. Thus, government, academia, and the private sector should cooperate, e.g. in private–public partnerships, to improve advisory services and offer training to farmers, in particular on prudent and efficient use of antimicrobials and other compounds. Approval procedures and legislation of products used in aquaculture should be strengthened and enforced ensuring farmers' access to quality and efficient agents for disease control.

Statement of relevance: This study reports the knowledge, practices and challenges of tilapia and white leg shrimp farmers in China when preventing and controlling diseases through the use of antimicrobials and other compounds. Farmers lack sufficient knowledge and access to advisory services to prudently use antimicrobials and other compounds in aquaculture. Innovative private–public partnerships may provide such services.

1. Introduction

Aquaculture is one of the fastest growing food producing sectors because of increased demand for fish and seafood worldwide (Rivera-Ferre, 2009), with China being the largest producer (Cao et al., 2007; Xie and Yu, 2007; Ponte et al., 2014). Tilapia (e.g. *Oreochromis niloticus*) originated in Africa and the Middle East and has become one of the most cultured and internationally traded food fish in the world (Dey et al., 2000; Gupta and Acosta, 2004; FAO, 2012). Whiteleg shrimp (*Litopenaeus vannamei*) is a valuable and favoured species among Asian shrimp producers and accounted

* Corresponding author.
E-mail address: lp-liu@shou.edu.cn (L. Liu).

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for 77% of the 2013 total shrimp production in China (Zhong et al., 2014).

The intensification of aquaculture has increased the risk of diseases due to high stocking densities and rates of feeding that lead to adverse changes in water quality and increased incidence of disease with subsequent application of antimicrobials and other chemicals (Gräslund and Bengtsson, 2001; Miao and Liang, 2007; Xie and Yu, 2007; Qi et al., 2009). The main diseases of tilapia in Asia include bacterial diseases such as streptococcosis caused by *Streptococcus iniae* and *Streptococcus agalactiae*, whereas those in whiteleg shrimp include red body disease (Taura syndrome virus, TSV); white spot disease (white spot syndrome virus, WSSV); and Early Mortality Syndrome disease (EMS), the latter possibly caused by a phage-encoded toxin produced by *Vibrio parahaemolyticus*; and yellow head virus (YHV) (Nielsen et al., 2005; Zhou et al., 2008; Chen et al., 2012; Flegel, 2012; Lightner et al., 2012; Liu et al., 2014). Farmers treat and attempt to prevent diseases with a variety of chemicals including antimicrobials that may subsequently accumulate in the cultured fish and shrimp, lead to antimicrobial resistance as well as negatively affecting the aquatic environment (Cabello, 2006; Sapkota et al., 2008; Labella et al., 2013).

Antimicrobial residues in fish and shrimp constitute a food safety hazard as some consumers may experience serious allergic reactions when exposed to specific antimicrobials (Dewdney et al., 1991; Dayan, 1993; Heuer et al., 2009). Most Asian countries, including China, have experienced commodity rejection or other types of alerts when the importing countries have detected banned antimicrobial residues in products (Xie and Yu, 2007; Love et al., 2011). Such alerts and rejections have caused significant economic loses for farmers and other stakeholders (Cato and Dos Santos, 1998; Holmström et al., 2003; Neela et al., 2013). Farmers have therefore increasingly turned to use other means of disease control because of problems with residues and limited effect of antimicrobial usage, e.g. probiotics, herb extracts and water disinfectants, although little information is available about such alternative use practices.

The knowledge and capacity of aquaculture farmers are central when decisions are taken on the use of antimicrobials and other compounds to attempt to prevent and control diseases at the farm, in particular in less developed countries where veterinary services are often poor or lacking. There is little information about farmers' knowledge and practices on disease management control measures, including their capacity to correctly diagnose diseases and from what sources they do obtain information regarding the prudent use of antimicrobials and other compounds. The objective of this study was to investigate the knowledge, practices and challenges of Chinese tilapia and whiteleg shrimp farmers in Guangdong province, China in preventing and controlling diseases through the use of antimicrobials and other compounds.

2. Materials and methods

2.1. General description of study area

Guangdong province located in southern China produces nearly 0.6 million tons tilapia, which is almost half of the country's tilapia (*Oreochromis* spp.) production with Maoming district accounting for 25% of the total production in 2010 (Gupta and Acosta, 2004; Anonymous, 2010; Wang et al., 2010; Li et al., 2013). Zhanjiang district (Fig. 1) is located in the western part of Guangdong province and the largest production area of whiteleg shrimp in China with a production of 0.25 million tons in 2010 (Zhang et al., 2012).

2.2. Selection of farms and questionnaire interviews

A cross-sectional survey of Maoming and Zhanjiang districts selected as study areas was conducted using semi-structured questionnaire-based interviews from July to September in 2011 to collect information about diseases and their attempted prevention and control measures as reported by tilapia and whiteleg shrimp farmers. The individual responsible for the overall management of the farm, i.e. the owner or an employed manager, was interviewed. A total of 25 tilapia and 30 whiteleg shrimp farms were randomly selected in Maoming and Zhanjiang, respectively from a database established by the EU-funded SEAT project (Sustaining Ethical Aquaculture Trade, www.seatglobal.eu). Farms were divided into three groups (Table 1); small, medium and large scale depending on pond size, employed labour, farm ownership and farm management procedures (Murray et al., 2013). All shrimp ponds studied used plastic lining due to easier pond management and as protection against water seepage. Among the 25 tilapia farms, 12 small and 5 medium scale farms were integrated tilapia–pig farms.

Data were collected about the occurrence of disease and how farmers diagnosed it as well as their preventive and control measures, i.e. use of disinfectants, antimicrobials, probiotics and other compounds, within the last 12 months. Details were also collected about handling practices of chemicals and preparation of medicated feed. Additional information was collected through open-ended questions, e.g. general disease management practices. On-farm observations were made, e.g. of stored chemicals and other compounds, and were documented by photographs taken at the farm. Two interviewers were present at each interview, with one posing questions and the other making notes of the answers. Farmers participating in the survey were informed about the study objectives and gave informed consent orally. Summary data on the use of chemicals and other compounds by the tilapia and shrimp farmers studied have been partly reported by Rico et al. (2013b).

The collected data were entered into Microsoft® Excel 2010 (Microsoft Inc., WA, USA) and descriptive analysis was done after the quality of entered data was assured.

3. Results

3.1. Characteristics of tilapia and shrimp farms

The total pond area of each of the 25 tilapia farms ranged from 0.3 to 20.0 ha, including small (1.1 ± 0.6 ha, n = 15), medium (2.6 ± 0.9 ha, n = 8) and large scale (17.5 ± 2.5 ha, n = 2) farms. All farms practised intensive pellet-fed culture with an overall mean stocking density of 3.1 ± 0.7 tilapia/m^2 with a lower density of small scale farms (2.8 ± 0.7 tilapia/m^2) and slightly higher density seen on medium (3.5 ± 0.7 tilapia/m^2) and large scale farms (3.5 ± 0.5 tilapia/m^2). In addition to tilapia, all farms irrespective of size also stocked various carp species which made up less than 5% of the total number of stocked fingerlings.

The 30 shrimp farms studied each had a total pond area ranging from 0.2 to 26.7 ha, with an average of 0.7 ± 0.3 ha for small scale (n = 13), 1.6 ± 0.7 ha for medium scale (n = 15) and 23.3 ± 3.3 ha for large scale (n = 2) farms. The stocking density varied from 45 to 300 shrimp/m^2, and the small and medium scale farms had the highest stocking densities, with some of which performed partial harvests.

Most of shrimp and tilapia farm managers had basic school education with only one large scale and two medium scale tilapia farms having a bachelor degree in aquaculture. Tilapia farmers had an average of more than 10 years of working experience (14.7 ± 5.9) in aquaculture, whereas the shrimp farmers had fewer years of experience (11.5 ± 6.9). Less than half of the farmers had received specific training in aquaculture management, with more shrimp farm managers (11/30) having received training than tilapia farm managers (4/25). Farmers mentioned that chemical supply shops and private feed companies were the main organisers of training workshops on how to diagnose and treat fish diseases. Chemical supply shops often had branches located in towns close to the main aquaculture areas. Several farmers stated that they obtained advice and different services from the shops free of cost such as routine visits, especially during the summer season where most disease outbreaks occur. Microscopic examination of diseased shrimp and tilapia as well as water quality analysis were among the services provided.

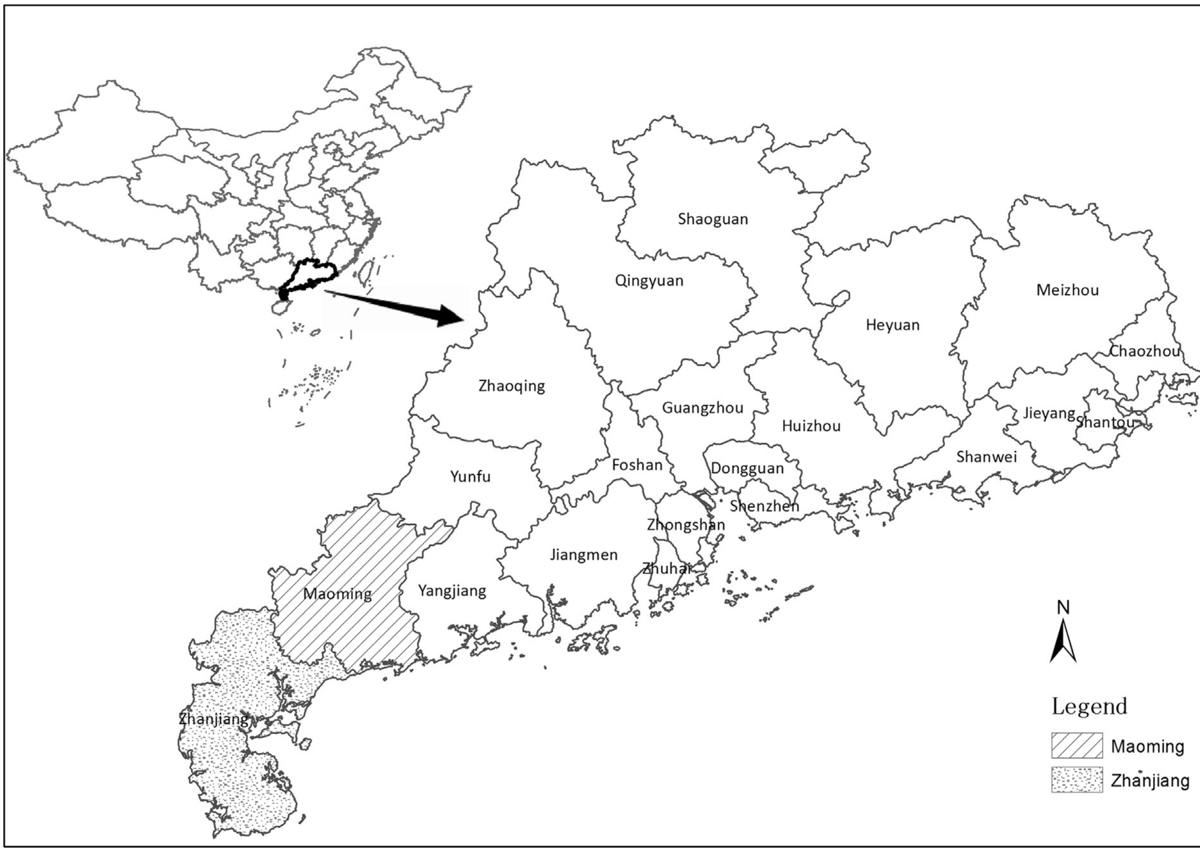

Fig. 1. The location of Maoming and Zhanjiang city, China.

Staff from the local governmental technical extension station in Maoming district provided regular monthly visits where farms experiencing diseases could have samples collected and tested free of charge. Farmers seemed less aware of the possibility to obtain individual services from the extension staff such as testing for pathogens and advice on treatment, including which approved antimicrobials should be used, during disease outbreaks. Large scale farms had typically employed technical experts with a bachelor degree in aquaculture which includes formal training in disease management and control.

3.2. Diseases reported by tilapia farmers

The main diseases and clinical manifestations reported by tilapia farmers are shown in Table 2. Streptococcosis, mainly caused by *S. iniae* and *S. agalactiae*, was well-known to most tilapia farm managers. This apparently was mainly due to a large streptococcosis outbreak that was ongoing when the farmers were interviewed with 9/25 farms having experienced the disease within the last 12 months (Table 2). Farmers reported that streptococcosis mainly appeared in the summer, i.e. from May to September, when water temperatures were high, i.e. 25–37 °C. The most prominent sign reported was “pop-eye” (unilateral or bilateral exophthalmia). Some farmers thought that “pop-eye” was caused by *Streptococcus* spp. and that inbreeding of purchased fingerlings as well as pollution of pond water sources was associated with the disease. About half of the small scale farm owners reported another phenotype of “pop-eye” disease, with ulcers in the abdomen and enlargement of the liver (Table 2) and no visible haemorrhages in the eyes and muscle.

3.3. Diseases reported by shrimp farmers

Red body disease was reported by more than half (19/30) of the small and medium scale farm managers with most managers reporting that it was caused by Taura syndrome virus (TSV, Table 3). Farmers reported that diseased shrimp lost appetite, had slow movements and appeared lethargic, with pale, reddish coloured appendages. Black spots were seen on the shrimp body and farmers reported the gut to be swollen and reddish when inspected. Most shrimp died within 3–5 days and

Table 1
Characteristics and classification of small, medium and large scale shrimp and tilapia farms[a].

Type of farm	Characteristics	Farm scale		
		Small	Medium	Large
Shrimp	Fulltime workers[b]	≤2	≥1–<7	≥7
	Total pond area	≤1 ha	>1 ha–<6 ha	≥6 ha
Tilapia	Paid fulltime workers	≤2	≤3	≥3
	Total pond area	<3 ha	≥3 ha	≥14 ha
Shrimp/tilapia	Farm management	Owner	Owner or workers	Owner or workers
	Ownership	Leased/owned by family	Leased/owned by family	Corporately owned

[a] Data presented were obtained from Murray et al. (2013).
[b] Paid workers and family members.

Table 2
Diseases, clinical manifestations and treatments reported by tilapia farmers in Guangdong province.

Disease	Clinical manifestation	Aetiology	Small (n = 15)	Medium (n = 8)	Large (n = 2)	Medicated feed
Streptococcosis	Uni- or bi-lateral exophthalmia, haemorrhages in eyes, liver enlargement	*Streptococcus*	5	3	1	Sulfadiazine + trimethoprim (TMP): 3S[a] + 2M[a]; amoxicillin + florfenicol + vitamin C, E: 2S[a] + 1M[a]; *Rheum rhabarbarum* + *Radix astragali*: 1L[a]
Exophthalmia disease	Exophthalmia, ulcers in abdomen, enlarged liver		8	1	0	Sulfadiazine + vitamin C, K: 4S[a] + 1M[a]; florfenicol: 3S[a]; aminocinnamic acid hydrochloride + glucose: 1S[a]
Enteritis	Lethargic swimming, distended abdomen, intestine filled with yellow mucus	*Aeromonas hydrophila*	2	1	0	*Andrographis paniculata*: 1S[a]; sulfadiazine + oxytetracycline: 1S[a]; sulfadiazine: 1M[a]
Unknown	Exophthalmia and liver enlargement		0	3	0	Florfenicol: 2M[a]; *R. rhabarbarum*: 1M[a]

[a] The different scales of farms, S — mall scale farm, M — medium scale farm, L — large scale farm.

the disease, according to the farmers, caused substantial economic losses.

Another disease that caused substantial economic losses in shrimp culture was white spot disease, caused by white spot syndrome virus (WSSV), which had occurred on five farms (Table 3) within the previous 12 months. Farmers diagnosed WSSV when white spots appeared on the cephalothorax and abdominal exoskeleton and the shell was easy to peel off. Immediately after a WSSV disease outbreak, most farmers did an early harvest as the shrimp would usually die within a few days.

The so-called "secret death disease" was reported by 5/30 shrimp farmers. The shrimp initially decreased or ceased their feed intake which was quickly followed by high mortalities around one month post-stocking (Table 3). Farmers found it difficult to diagnose "secret death disease" which typically occurred within 30–60 days after stocking with subsequent mortalities of around 70%.

3.4. Use of chemicals and other compounds for disease treatment

A wide range of antimicrobials, disinfectants, probiotics and other compounds were used by the tilapia and shrimp farmers to treat pond water in an attempt to prevent and control disease (Tables 4 and 5). None of the farmers reported using, or were observed to keep, chemicals and other compounds banned for use by the Chinese authorities in aquaculture, e.g. malachite green and chloramphenicol. Although the number of farms sampled was small, there were no differences in the number of diseases reported and chemicals used between integrated and non-integrated small- and medium scale farms.

3.4.1. Preparation of medicated feed

Of the antimicrobials and Chinese herbs that were used, most were applied as medicated pelleted feed on both tilapia and shrimp farms. Farmers mainly purchased these compounds in the chemical supply shops or from salesmen visiting the farm. Some medium and large scale tilapia farms used a portable sprayer to apply the compound solution. Several shrimp farmers added seaweed extract to enhance the binding of compounds to the feed pellets, because shrimp, unlike tilapia that readily consume feed, require a much longer time of up to 2 to 5 h to consume the feed with the risk that the added compound would dissolve into the pond water. Only one manager reported spraying antimicrobial solutions directly into the pond water. Around half of the tilapia (14/25) and shrimp (13/30) farm managers adjusted the chemical compound (antimicrobials, disinfectants and anti-parasitic drugs) dosage based on the cultured species mass and dosage instructions on the package labels. On the large scale farms, medicated feed was prepared by workers under the supervision of the technical manager. Six out of 25 (three small, one medium and two large scale) tilapia farms kept written records of their chemical use as compared to 12 of 30 shrimp farms (four small, six medium and two large scale farms).

3.4.2. Antimicrobial treatment of disease

Sulfadiazine and florfenicol were frequently used by tilapia farmers to treat fish diseases (Table 2). Streptococcosis and exophthalmia disease were typically treated with antimicrobials together with vitamins or rhubarb (*Rheum rhabarbarum*) extract; a combination that was thought to have a synergistic curative effect. Some farmers increased the initial antimicrobial dosage when prolonged symptoms and increased mortality were observed. Several farmers stated that the effectiveness of sulfadiazine, and also amoxicillin and florfenicol, in treating streptococcosis was reduced compared with the efficacy seen a few years ago, even at increased dosage. Water disinfectants were occasionally applied to the pond water during disease outbreaks, e.g. quick lime

Table 3
Diseases, clinical manifestations and treatment reported by shrimp farmers in Guangdong province.

Disease name/local name	Clinical manifestations	Aetiology	Small (n = 13)	Medium (n = 15)	Large (n = 2)	Type of treatment
Red body disease	Red chromatophores in body shell and appendages	Taura syndrome virus (TSV); white spot syndrome virus (WSSV)	7	10	2	$ZnSO_4 \cdot 7H_2O$: 1M[b]; *Andrographis paniculata*: 1S[b]; dimethylhydantoin: 3S[b] + 6M[b] + 1L[b]; chlorine dioxide: 2S[b] + 3M[b] + 1L[b]; bleaching powder: 1S[b]
White spot disease/white spot syndrome disease (WSSV)	White spots on exoskeleton and epidermis, fragile carapace, rapid and massive mortality	WSSV	1	4	0	Chlorine dioxide + vitamin C: 1S[b] + 1M[b]; allicin (garlic extract) + vitamin + choline: 1M[b]; $Na_2S_2O_3$ + probiotics + lime: 1M[b]; DBDMH: 1M[b]
Early Mortality Syndrome/"secret death disease"	Reduced feed intake; mass mortality and dead shrimp found at the pond bottom	Yellow head virus (YHV), covert mortality nodavirus (CMNV), acute hepatopancreatic necrosis syndrome (AHPNS)	2	3	0	Disinfectants
Empty stomach disease	Shrimp become anorexic, empty intestine and stomach	Unknown	4	4	0	Povidone iodine + rhubarb: 3M[b] + 1S[b]; *Radix isatidis*: 1S[b]; bleaching powder + chlorine dioxide: 1M[b] + 2S[b]

[a] Disinfectants listed were used for water treatment and other compounds were used as feed additives.
[b] The different scales of farms, S — small scale farm, M — medium scale farm, L — large scale farm.

Table 4
Antimicrobials, disinfectants and anti-parasitic compounds observed in use on the different tilapia and shrimp farms used in this study.

Name	Tilapia			Shrimp		
	Small (n = 15)	Medium (n = 8)	Large (n = 2)	Small (n = 13)	Medium (n = 15)	Large (n = 2)
Antimicrobials						
Allicin (garlic extract)	0	0	0	1	0	0
Amoxicillin	1	0	0	0	0	0
Enrofloxacin	0	0	0	0	1	0
Florfenicol	2	1	0	0	1	0
Oxytetracycline	1	0	0	0	0	0
Sulfadiazine	4	0	0	0	0	0
Disinfectants						
Benzalkonium bromide	0	0	0	1	0	0
Bleaching powder	0	1	0	3	0	0
Calcium peroxide	0	0	0	2	0	0
Carbolic acid (phenol)	1	0	0	0	0	0
Chlorine dioxide	2	3	0	2	1	1
DBDMH (1,3-dibromo-5,5-dimethylhydantoin)	0	0	0	2	5	2
Glutaraldehyde	0	0	0	0	0	1
Lime	4	1	0	0	1	0
Potassium permanganate	1	1	0	0	1	0
Povidone iodine	1	0	0	1	2	0
Sodium chlorite	0	0	0	0	0	1
Antiparasitics						
Mebendazole	0	0	0	0	1	0
$ZnSO_4$	0	0	0	2	2	0

and chlorine dioxide, as this was thought by some farmers to kill the pathogens. Some farm managers reported that they reduced the seed stocking density and feed intake to improve water quality and prevent disease. In cases when farmers were uncertain about aetiology of the disease, two out of three farms applied medicated feed with florfenicol to treat disease (Table 2). On-farm observations revealed that four small scale tilapia farms had stocks of sulfadiazine, florfenicol, oxytetracycline and amoxicillin packages.

Most of the shrimp farmers reported that they did not use antimicrobials to treat disease, including viral diseases like red body disease and white spot syndrome disease (Table 3). When farmers were not able to diagnose a disease, 3/4 small shrimp farms used sulfadiazine for

Table 5
Observation of Chinese herb extracts, probiotics, nutritional supplements and other compounds kept on tilapia and shrimp farms.

Name	Tilapia			Shrimp		
	Small (n = 15)	Medium (n = 8)	Large (n = 2)	Small (n = 13)	Medium (n = 15)	Large (n = 2)
Chinese herb extracts (12)						
Artemisia carvifolia	0	0	0	0	2	1
Andrographis paniculata	1	0	0	0	0	0
Bupleurum chinense	0	0	0	1	0	0
Curcuma aromatica	0	0	0	0	0	1
Forsythia suspensa	0	0	0	0	0	1
Folium isatidis	0	0	1	1	2	0
Glycyrrhiza uralensis	0	0	0	0	1	0
Lonicera japonica	0	0	0	1	0	0
Radix isatidis	0	0	0	1	1	0
Rheum rhabarbarum (rhubarb)	0	1	1	0	1	1
Probiotics (5 to 8 products)						
Probiotics (declared bacteria included *Bacillus* spp., photosynthetic bacteria, and enzymes)	2	3	0	10	8	2
Yeast	0	0	0	0	0	1
Nutritional supplements (7 to 10 products)						
Amino acid mixture	0	0	0	2	5	1
Glucose	0	1	0	1	1	1
Minerals	0	0	0	2	2	0
Organic acid mixture	0	1	0	0	2	1
Seaweed polysaccharide	0	0	0	1	0	0
Vitamins	1	0	0	1	6	1
Other compounds (6)						
Activated carbon	0	0	0	1	0	0
Cinnamon amino acid salt	0	0	0	0	1	0
Citric acid	0	0	0	1	0	0
Humic acid sodium	0	0	0	2	4	0
$Na_2S_2O_3$	0	0	0	0	1	0
Sodium percarbonate	0	0	0	0	2	0

undiagnosed diseases treatment. Two small shrimp farms used sulfadiazine to treat yellow-gill disease.

3.4.3. Use of disinfectants

Almost all tilapia and shrimp farms applied disinfectants to treat pond water and sediment irregularly throughout the production cycle, including during periods of disease where the disinfectants were thought to kill and prevent the spread of pathogens between ponds. Observations on tilapia farms showed that they mainly used lime and chlorine dioxide (Table 4), not only to disinfect pond water and sediment but also to kill wild fishes in the ponds before stocking of fingerlings. During disease outbreaks, both tilapia and shrimp farmers also used disinfectants, even when the disease causing pathogens were unknown, because of their low cost and anticipated limited side effects. Ten different disinfectants were observed on stock at shrimp farms (Table 4). DBDMH (1, 3-dibromo-5,5-dimethylhydantoin) was the most commonly used disinfectant which farmers found effective and with low side-effects; chlorine dioxide was often applied during red body and white spot disease outbreaks. Disinfectants were generally applied during pond preparation (e.g. lime) and to disinfect pond water before stocking. Compared to tilapia farms, shrimp farm managers preferred to do an early partial harvest rather than use antimicrobials to reduce economic loss. Given the fast spread of viral diseases, most shrimp farm managers reported that antimicrobials were not effective in treating such diseases and preventing the transmission of pathogens to other ponds.

3.4.4. Use of probiotics, Chinese herb extracts and other compounds

Tilapia and shrimp farmers used different probiotics (Table 5) to improve water quality, but also to maintain appetite and weight gain and a general strengthening of the intestinal microbial balance which was thought to increase the host animal's resistance towards diseases. Among the probiotics, products marketed as so-called “Effective Microorganisms (EM)”, typically containing lactic acid bacteria, photosynthetic bacteria and yeasts, were commonly used by farmers. The quality of pond water was assessed by farmers using water quality kits, e.g. to measure ammonia, nitrogen and pH; and by visual inspection, e.g. of water colour and transparency. Staff from chemical companies and aquaculture supply shops visited farmers regularly to sell their products, and to provide water testing and advisory services on the use of probiotics and other chemicals, e.g. on how to improve water quality.

Chinese herb extracts were reported used by three tilapia farms and five shrimp farms, e.g. *R. rhabarbarum*, *Radix astragali*, *Radix isatidis* and *Andrographis paniculata* (Table 5). Herb extract commercial products were purchased as powder or as a liquid solution and farmers preferred to apply the herbs mixed with feed, although some extracts were sprayed into the pond water as a bath treatment. Rhubarb was also used in combination with sulfadiazine to treat streptococcosis in tilapia. Furthermore, few side effects and no antimicrobial residue problems were reasons given by farmers to use herbs because of its natural origin. If mortality continued to increase during a disease outbreak, farmers would change to or combine the use of herbs with antimicrobials such as oxytetracycline and sulfadiazine. During the survey, tilapia and shrimp farmers did not report the use of any vaccines.

3.5. Occupational hazards

Less than half of the small and medium scale, but all the large scale, tilapia and shrimp farm managers were informed about health and environmental risks associated with using chemicals (Table 6). Sources of information about such risks included aquaculture training (3/23) and the press media (4/23) but most managers acquired information in other ways, e.g. from aquaculture counterparts and chemical supply shops. More than half of the small and medium farm managers were informed about what antimicrobials and other chemical were banned for use in aquaculture, mainly through printed information material provided by local governmental fishery extension services. Shrimp and tilapia farm managers mainly relied on advice from aquaculture supply shop staff for information on chemical use as well as their own experience, although most shrimp farm managers also acquired information through safety instructions provided on product labels (Table 6). Most tilapia (13/25) and shrimp (23/30) farm workers on small and medium, but not large scale, farms had direct skin contact to chemicals, e.g. the hands when preparing chemical solutions from liquid and powder products. In contrast to large scale farm workers, few workers on small and medium scale farms used protective measures, e.g. gloves and masks, when preparing, e.g. mixing antimicrobials with pelleted feed, and applying chemicals. Workers from three farms reported skin problems on hands and arms when preparing and applying disinfectants without any protective measures, e.g. gloves (Table 6).

4. Discussion

4.1. Farmers' capacity to diagnose disease

Knowledge on disease diagnosis, prevention and control is central when aquaculture farmers take decisions on the use of antimicrobials, other chemicals and general farm management practices. Most tilapia and shrimp farmers in our study had several years of working extensive experience in aquaculture but few, only managers at large scale farms, had any formal education and training in aquaculture. This lack of formal training seems a main limiting factor in correct disease diagnosis and subsequent treatment, in particular when new diseases emerge, e.g. streptococcosis in tilapia (Amal and Zamri-Saad, 2011; Zhang

Table 6
Management and safety of chemicals used on tilapia and shrimp farms.

	Tilapia			Shrimp		
	Small (n = 15)	Medium (n = 8)	Large (n = 2)	Small (n = 13)	Medium (n = 15)	Large (n = 2)
Managers had knowledge about the health and environmental risks associated with use of chemicals	4	6	2	4	5	2
Managers were informed about banned chemicals	7	7	2	8	8	2
Chemical management done according to:						
Labelled safety instruction	1	2	0	12	11	1
Advice from aquaculture supply shop staff/technician	10	2	1	3	3	0
Advice by extension staff	0	0	0	1	1	0
Farmer experience	5	6	1	7	7	0
Advice by friends/others	4	2	0	0	1	0
Use of protective measures during handling of chemicals	3	3	2	1	0	2
Direct skin contact when handling liquid and powder chemicals	9	4	0	10	13	0
Direct skin contact with pond water treated with chemicals	6	1	0	6	9	1
Cleaning equipment and tools after preparation of chemical solutions	11	7	2	13	15	2
Keeping record of chemical use	3	1	2	4	6	2
Skin problems on hands and arms when handling chemicals	1	0	0	1	1	0

et al., 2013a) and Early Mortality Syndrome disease (EMS) in shrimp (FAO, 2013; Tran et al., 2013). The pathogen of exophthalmia disease, e.g. *Vibrio* spp., *Edwardsiella* spp. or *Pseudomonas* spp., was also unknown to farmers. Farmers reported different diseases with similar symptoms, e.g. so-called "Unknown" disease was reported to have similar symptoms as exophthalmia disease (Table 2). Main diseases in tilapia were streptococcosis and viral diseases in shrimp. Early Mortality Syndrome (EMS) is a complex of different factors and pathogens that results in early mortality. EMS, has emerged and is causing significant losses not just in China, but also in other countries, e.g. Thailand, Malaysia and Mexico (Leaño and Mohan, 2012; Lightner et al., 2012; Lyon et al., 2013). The covert mortality nodavirus (CMNV), *V. parahaemolyticus* and yellow head virus (YHV) are all possible pathogens to EMS (Huang, 2012).

With the rapid development of the aquaculture sector in China, many companies have established so-called chemical supply shops in the main aquaculture production areas where farmers purchase disinfectants, probiotics, antimicrobials and other compounds. Our study documents that these shops are the most important sources of information for tilapia and shrimp farmers with regard to disease diagnosis and treatment, in particular for the small and medium scale tilapia farms. Shop representatives furthermore also often come to the farms where they may provide advisory services free of charge while at the same time promoting their products. Follow-up studies are needed to evaluate the quality of the advice that the chemical shops provide to farmers, including to what extent such advice is biased towards promotion of own products. Local governmental technical extension stations also pay visits to aquaculture farms and provide advisory services on disease diagnosis and treatment free of charge, however, the number of stations and staff is limited and as a result they pay less frequent visits to the farms compared to the chemical shop representatives. Farmers were little aware of the possibility to get free of charge advisory services with contacting the stations, but also to have the aetiology of diseased tilapia or shrimp diagnosed. As the private chemical shops are likely also in the future to play an important role in disease diagnosis and control together with the government stations, innovative combined efforts should be considered to improve advisory services to the farmers. As most farmers use smart phones there seems to be market opportunities for internet-based veterinary services to prevent and control diseases, e.g. atlas-based guides for initial diagnosis of diseases. However, any initiatives of such telemedicine should involve veterinarians, e.g. in the decisions on the use of antimicrobials and other chemicals.

4.2. Usage of antimicrobials and other chemicals

Streptococcosis and exophthalmia disease were the most common diseases in tilapia treated with antimicrobials, mainly sulfonamides and florfenicol. *S. iniae* and *S. agalactiae* are the main species causing disease in Chinese tilapia aquaculture (Chen et al., 2012; Wang et al., 2013). Resistance in these *Streptococcus* spp. has been reported to several antimicrobials, e.g. ampicillin, quinolones and tetracycline (Perera et al., 1994; Kawamura et al., 2003; Sapkota et al., 2006) although limited information seems available for China. Farmers in our study mentioned that treatment with amoxicillin and florfenicol was effective a few years ago, but those treatments were now less effective even when the antimicrobial dosage was increased. It should be noted that farmers using antimicrobials according to the instructions on product labels may in reality not administer a correct dosage. Our farmers mixed their own medicated feed using different methods adding antimicrobials to the feed pellets. It is likely that the added antimicrobials are not evenly distributed and adequately bound into the feed pellets and furthermore that inferior quality of antimicrobial products may contribute to admission of sub-therapeutic antimicrobial concentrations and subsequent risk of treatment failure and development of resistance (Gullberg et al., 2011). This was documented in a recent study in Vietnam where common antimicrobial products used in aquaculture contained lower antimicrobial concentrations than declared with some products even not containing declared compounds (Phu et al., 2015). Due to the limited effect of antimicrobial treatment of streptococcosis, some tilapia farmers have started to stock fingerlings at lower densities to prevent disease outbreaks (Segner et al., 2012; Garcia et al., 2013).

Herbal medicine has played an important role in traditional Chinese medicine. In the early days of aquaculture, Chinese aquaculture farmers prepared their own herbal extracts for disease control and although most farmers currently use antimicrobials our study documents that tilapia and shrimp farmers still use herbal extracts, often mixed with antimicrobial products, for disease control, as an immune stimulant and to enhance feed digestibility (Tables 2, 3 and 5). The ability of herbal extracts, e.g. *Galla chinensis* and *R. astragali*, to kill bacterial or other pathogens has typically been tested in laboratory experiments and only rarely in on-farm trials in ponds with diseased aquatic animals (Wang et al., 2006; Ardó et al., 2008; Zhang et al., 2013b). With the increase in antimicrobial resistant bacterial pathogens in aquaculture, e.g. *Streptococcus* spp. and *Edwardsiella* spp., and also food safety aspects of antimicrobial residues, there is a renewed interest in alternative therapeutics like herbal extracts. There does, however, appear to be a need for improved legislation and approval of herbal extract products to ensure farmers access to products with well-documented effect.

Probiotics were widely used by tilapia and shrimp farmers (Table 5) as they were perceived to strengthen the intestinal microbial population, enhance growth, and improve water quality (Qi et al., 2009). Farmers also thought that probiotics had few negative side effects in contrast to the residue problems associated with antimicrobial usage. Farmers also stated low costs and stricter regulation on antimicrobial usage as reasons for the popularity of probiotics. Production of the popular so-called EM ("Effective Microorganism") product reached 10,000 t in China alone in 2009 (Qi et al., 2009). For herbal extract products, however, there is also a need for improved legislation and approval of probiotic products for use in Chinese aquaculture. This need is stressed by a recent study in Vietnam where common probiotic products used in shrimp culture often did not contain any information on the specific bacterial strains included and often products did not contain the declared bacterial species (Noor Uddin et al., 2015). Although no farmers in this study used vaccines, it is likely that they will gain popularity in the future, e.g. against streptococcosis (Sun et al., 2012; Huang et al., 2014).

Disinfectants were widely used and in large quantities by tilapia and shrimp farmers who stated a number of reasons and purposes of such use. A recent study also conducted in our study area estimated that a total of 64 g and 665 g of disinfectants were used throughout the production cycle to produce 1 t of tilapia and shrimp, respectively (Rico et al., 2013b). At the same time, most farmers were not aware of the limitations when using disinfectants, e.g. limited effect when treating pond water with a high content of organic matter, and the associated environment risks, e.g. eco-toxicological impact on natural aquatic biota (Burridge et al., 2010; Rico et al., 2013a; Seier-Petersen et al., 2014). Also, the use of disinfectants has been shown to co-select for antimicrobial bacterial resistance, e.g. towards cephalosporins (Doyle et al., 2013).

Unlike the large scale aquaculture farms only less than half of the small and medium scale shrimp farmers and few tilapia farmers kept records of their chemical use. In the future it is expected that the numbers of large scale aquaculture farms increase and that these farms will be certified under different schemes, e.g. Global Gap (Hilbrands, 2008). In China, the CIQ (China Entry–Exit Inspection and Quarantine) authority is promoting a national certification scheme (CIQ) which is required by aquaculture farms if they want to export their products (AQSIQ, 2011). As certified farms are required to keep records of their use of different compounds, such data will be important for monitoring purposes, including ensuring the food safety of harvested products. It should also be noted that some tilapia farms used sulfadiazine and trimethoprim (Table 2), two compounds that were recently not approved for aquaculture use in e.g. the United States. Recently residues of these compounds have been found in imported frozen tilapia from China imported into the United States (http://www.accessdata.fda.gov/cms_ia/importalert_27.html).

4.3. Occupational and public health hazards

Workers at most small and medium, but not large, scale shrimp and tilapia farms did not wear protective measures and therefore had direct skin contact when handling, e.g. preparing medicated feed, disinfectants and other antimicrobials (Table 6). Large scale farms are employing workers in contrast to the small and medium scale farms where mainly family members are working. When employing workers a company must according to Chinese regulations provide adequate instructions and protective gear to workers on how they protect their health. Only skin problems were reported associated with this exposure by a few farmers. It is likely, however that more farmers experienced different and more severe health problems as farmers may not perceive their health problems to be caused by their occupational exposure to chemicals rather they see such problems as normal when working as an aquaculture farmer. It is well-documented that skin exposure and inhalation exposure to antimicrobials and disinfectants are associated with skin and respiratory problems, e.g. allergies (Holmström et al., 2003; Wooster et al., 2005; Sapkota et al., 2008; Moreau and Neis, 2009). Other main occupational health hazards at aquaculture farms include physical hazards during daily work, e.g. body injuries from operating equipment, accidents from falling on slippery surfaces, and infections due to punctures or cuts (Myers, 2010). Follow-up studies involving trained medical staff and social scientists are needed to assess perceived and actual occupational health risks at the studied farms. Such information can then find the basis for how relevant stakeholders, e.g. local extension stations, most effectively disseminate information to farm workers and owners on needed behavioural changes enabling them to prevent occupational health hazards. Although food safety concern of the antimicrobial and chemical use was not part of this study objective, it is likely that the current use patterns may lead to accumulation of antimicrobial residues in tilapia while less likely in shrimp as partial harvest rather than antimicrobial treatment is conducted when shrimp is diseased. Follow-up studies are needed to determine to what extent farmers adhere to stated antimicrobial withdraw periods and the associated food safety rules.

5. Conclusions

Our study shows that there is an urgent need to establish new means of training Chinese aquaculture farmers that build on farmers' current knowledge and experiences that are practical and will improve the farmers' capacity to diagnose and control aquatic animal diseases. Especially small and medium scale farms lack such capacity and do often not keep records of chemical usage.

Chemical supply shops and local technical extension stations were the main providers of advisory services to farmers on disease diagnosis and treatment. Governmental extension services paid limited visits to farmers in contrast to the private chemical companies and supply shops that mainly marketed their own products. It should be considered to identify new ways, e.g. internet-based, where governmental institutions and private companies share information and provide coordinated advisory services to aquaculture farmers on disease diagnosis and control. Furthermore, the quality of the antimicrobials used should be assured through adequate and enforced legislation.

A variety of occupational health hazards are associated with the handling of chemicals in aquaculture. The health effects from these hazards are often underestimated by farmers and there is an urgent need to improve knowledge about these hazards and how to protect against them in particular for small and medium scale farmers.

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