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An assessment of health management practices and occupational health hazards in tiger shrimp (*Penaeus monodon*) and freshwater prawn (*Macrobrachium rosenbergii*) aquaculture in Bangladesh

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ABSTRACT

Diseases have been recognized as the major obstacle to the shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*) aquaculture production in Bangladesh. This study provides an assessment of shrimp and prawn diseases/syndromes, health management practices, and occupational health hazards associated with the handling of chemical and biological products to prevent and treat shrimp and prawn diseases. A survey was conducted using a semi-structured questionnaire with 380 shrimp and prawn farmers in the southwest of Bangladesh during February and June of 2016. The farms were categorized on the basis of the three cropping patterns: shrimp polyculture, prawn polyculture, and shrimp and prawn polyculture. Eight different diseases and/or symptoms were reported by the surveyed farmers. The white spot disease and the broken antenna and rostrum symptom were the most common in shrimp and prawn species, respectively. In total, 35 chemical and biological products (4 antibiotics, 15 disinfectants, 13 pesticides, 2 feed additives and probiotics) were used to treat and/or prevent diseases in the all farm categories. The major constraints for disease management were limited access to disease diagnostic service, inadequate product application information and lack of knowledge on better management practices. Handling chemicals and preparation of medicated feed with bare hands was identified as a potential occupational health hazard. This study suggests improvements in farmers' knowledge and skill in disease diagnostics and health management practices, and appropriate handling of potentially hazardous chemicals.

1. Introduction

The shrimp sector plays an important role in the national economy of Bangladesh. It contributed approximately 84% to the USD 599 million frozen seafood export earnings in the financial year 2014–2015 (FRSS, 2016). The shrimp/prawn farming area and production has increased from 141,352 ha and 66,703 MT in 2002–2003 to 275,583 ha and 223,582 MT in 2014–2015, respectively (FRSS, 2016). The expansion of farming area has been unregulated and poorly coordinated (Alam, Lin, Yakupitiyage, Demaine, & Phillips, 2005; Paul & Vogl, 2011). The intensification of production systems leads to adverse changes in water quality and has increased the risk of diseases due to higher stocking densities and feeding rates (Nasrin, 2016). In recent years, the prevalence of known endemic diseases has increased and has been recognized as the major barrier to the development of the shrimp sector in Bangladesh (Hossain, Uddin, & Fakhruddin, 2013; Karim et al., 2012). The economic loss caused by diseases was estimated at USD 832 to 3928 ha^{-1} per year depending on the degree of intensification of the farming systems (Jahan, Belton, Ali, Dhar, & Ara, 2015).

Several studies have reported a wide range of diseases caused by viral and bacterial pathogens in shrimp farms in Bangladesh (Ali, Rico, Jahan, & Belton, 2016; Karim et al., 2012). The importance of farm level biosecurity and health management practices in reducing the impact of diseases has been well recognized (Hasan, Faruk, Anka, & Azad, 2013), but the actual implementation has not been always straightforward. A wide range of chemical and antimicrobial compounds are available in the

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market for the prevention and treatment of diseased fish species (Ali, Rico, Jahan & Belton, 2016; Rico et al., 2013). A major drawback is the that treatments sometimes occur without proper disease diagnosis and lack of consideration for environmental and food safety issues. Residues of potentially toxic substances such as pesticides or antimicrobials can accumulate in treated animals, resulting in potential hazards for consumers, and issues with marketing and export of aquaculture products (Heuer et al., 2009). Furthermore, the extensive use of antimicrobials in aquaculture can contribute to the development of antimicrobial-resistant pathogenic bacteria both inside and outside the aquaculture facilities (Sun et al., 2016), which can have severe consequences for the effective treatment of current and new bacterial diseases in the cultured organisms and ultimately for human health.

Several reports indicate that a large number of aquaculture farmers in south-east Asia use chemicals without protective handling measures (Ali, Rico, Jahan & Belton, 2016; Li, Liu, Clausen, Lu & Dalsgaard, 2016). Inappropriate use of chemicals can contribute to occupational health hazards and human health risks such as respiratory and skin problems, allergies, risk of intoxication and propagation of infectious diseases (Phu et al., 2016; Sumon et al., 2016). Zoonotic pathogens such as *Vibrio* spp., and *Aeromonas* spp., pose particular risks to both human and crustaceans (Watterson et al., 2012). To date, Bangladeshi shrimp farmers are not in general aware of occupational health hazards (Ali, Rico, Jahan & Belton, 2016; Ali, Rahman et al., 2016).

The implementation of proper disease management programs requires a study of the most important diseases and symptoms affecting the shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*) aquaculture, as well as the current management practices and associated potential problems. The present study assessed the range of aquatic animal health problems encountered and management practices adopted by shrimp and freshwater prawn farmers through a systematic survey. The ultimate goals of this study were to provide an evaluation of the health problems, disease management practices, occupational health hazards associated to shrimp and prawn aquaculture and to assess farmers' knowledge on disease prevention and treatment to promote appropriate private and public interventions.

2. Materials and methods

2.1. Study area and data collection

The study was conducted in nine sub-districts of Bagerhat, Khulna and Satkhira districts, in South-west Bangladesh (Fig. 1). In total 380 farms were surveyed between February and June of 2016 from a census list of 2015 farms. These farmers practiced either shrimp polyculture (SP), shrimp and prawn polyculture (SPP) or prawn polyculture (PP). A stratified random sampling strategy was followed to survey the farms as described earlier (Ali, Rahman et al., 2016). Briefly, the major production systems and most important farm groups in the sub-districts were identified and sampled to have a detailed representation of their production technologies and practices (Table 1).

The selected farms were categorized into small ($<$0.61 ha), medium (0.61–1.41 ha) and large ($>$1.41 ha) based on total operational farm area. The survey was used to obtain information regarding (i) respondents education and training, (ii) farm infrastructure, (iii) production characteristics (e.g. pond area, stocking density, production) and (iv) usage of chemical and biological products (e.g. active ingredients, dosages) to prevent or treat diseases during the last production season. Interviews were conducted using semi-structured questionnaires, with discussions supported by picture cards of diseased shrimp and prawn in order to get a better understanding of clinical signs, types and frequency of diseases/syndromes from the respondents. Moreover, rationales for decision-making on chemical use were discussed with the respondents. Respondents were also asked about perceived health hazards during work in their farms, the use of protective equipment at handling chemicals, understanding toxic effects and risks due to improper use of chemicals. The questionnaire was 'pre-tested', and then modified to prepare the final version. Furthermore, 20 focus group discussions (FGD) were organized in study area to triangulate information with emphasis on clinical signs and management practices. A set of disease picture cards were displayed during FGDs and respondents were asked for observed major disease/clinical signs during the last production year. Respondents were also asked for shrimp/prawn health management practices related to disease treatment or prevention and personnel health hazards due to chemicals application. Key informant interviews included chemical shop operators and veterinary chemical companies marketing representatives in the study area to generate a database of product information including brand names and active ingredients and recommended dosages (i.e., product label prescriptions).

2.2. Compound classification

The chemical and biological products were classified into the following categories: antibiotics, disinfectants, pesticides, feed additives, and probiotics. The active ingredient(s) of each product was recorded based on information in the product labels. In case of non-availability of such information in the product labels, the database generated through consultation with key informant and published literature was used.

2.3. Data analyses

The data obtained from the questionnaires (including chemical product ingredient names) and from the key informant interviews were coded and entered into a customized electronic database developed using computer software MS Access (Microsoft Corporation, Redmond, WA, USA), then exported to MS Excel (Microsoft Corporation) and analyzed using the Statistical Package for Social Science, SPSS 16.0 (SPSS, Chicago, IL, USA). The data were checked for normality, and used to assess significant differences between farm categories to each parameter using a one way analysis of variance (ANOVA) followed by the Bonferroni multiple range test.

The correlation between each individual parameters describing the farming characteristics and the dataset containing the reported disease/symptom occurrence was studied by using Monte Carlo permutation tests under the Redundancy Analysis (RDA) option. Similarly, the relationship between each parameter describing the farming characteristics, including the disease/symptom reported, frequencies, and the dataset containing all substances aggregated into chemical categories was analyzed by Monte Carlo permutation tests using RDA. In both cases the Monte Carlo permutation tests ($n = 499$) were performed with the CANOCO 5 software package (Ter Braak & Šmilauer, 2012). The results of the Monte Carlo permutation test were considered to be significant when $p \leq 0.05$, and marginally significant when $0.05 < p < 0.1$. Subsequently, individual bi-plots were constructed for each farming category, including the explanatory variables that were considered significant or marginally significant as part of the individual parameter Monte Carlo permutation test. Such bi-plots allowed a visual interpretation of the sign and the strength of the correlations among the included respondent and farm characteristic parameters, and the number of chemicals within each category or the diseases/syndromes reported by the interviewed farmers.

3. Results

3.1. Farmer background and farm water management

Shrimp and prawn polyculture (SPP) farmers had received more formal education ($p \leq 0.05$) than shrimp polyculture (SP) or prawn polyculture (PP) farmers (Table 2). None of the farmers had a bachelor degree in aquaculture or related subjects. The mean 'gher' size and water surface area were significantly higher ($p \leq 0.05$) in SP (1.2 ± 1.1 and 1.1 ± 1.0 ha, respectively) than SPP (0.55 ± 0.35 and 0.46 ± 0.25 ha, respectively) and PP (0.45 ± 0.32 and 0.39 ± 0.28 ha,

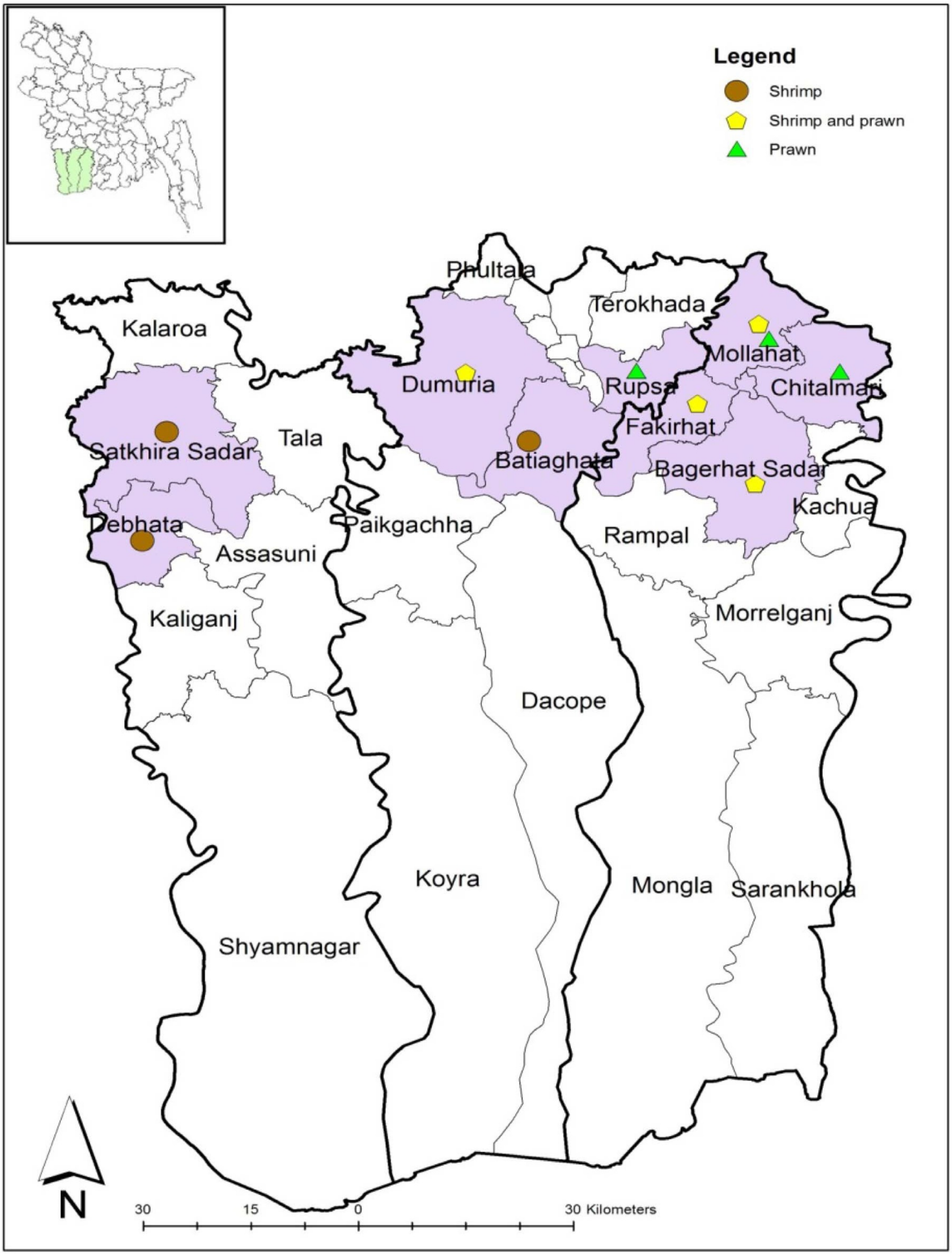


Fig. 1. Map showing geographical distribution of studied farm groups.

respectively) farms. Water depth (m) was reported to be significantly lower ($p \leq 0.05$) in SP (0.81 ± 0.15) compared to SPP (0.92 ± 0.19) and PP (0.97 ± 0.26) farms (Table 2). The stocking densities of post-larvae (PL) per square meter (PL m^{-2}) were 11 ± 6.1, 7.9 ± 4.0 and 1.8 ± 1.0 in SP, SPP and PP farms, respectively and differed significantly ($p \leq 0.05$) by farm groups. In addition to shrimp/prawn PL, all farmers stocked carp and other fishes at the rate of 0.01–9.3 per m^2 for SP, 0.01–1.2 per m^2 for SPP and 0.01–0.53 per m^2 for PP farms. The mean stocking densities were observed to be significantly higher ($p \leq 0.05$) in SP than SPP and PP farms (Table 2). The shrimp/prawn production per hectare (kg/ha) was highest ($p \leq 0.05$) in SPP (627 ± 326) followed by PP (416 ± 278) and SP (376 ± 185) farms (Table 2). Surface water (canal and river) was the primary source 100% in SP, 72% in SPP and only 2.6% in PP farms. Conversely, rainfall was the major water source for PP (97%) followed by SPP (28%) farms and insignificant compared to other water input sources for SP farms

Table 1
Characteristics of the surveyed farm groups in the present study.

Farm group abbreviation	Main species	Main production system	Location	Number of farms surveyed
SP	Shrimp (*Penaeus monodon*)	Improved extensive (brackish water gher[a])	Khulna/Satkhira	127
SPP	Shrimp (*P. monodon*) and prawn (*Macrobrachium rosenbergii*)	Improved extensive concurrent with rice (brackish /fresh water gher[a])	Khulna/Bagerhat	139
PP	Prawn (*M. rosenbergii*)	Improved extensive concurrent with rice (freshwater gher)	Khulna/Bagerhat	114

SP, Shrimp polyculture; SPP, Shrimp and prawn polyculture; PP, Prawn polyculture.
[a] The term gher refers to a paddy field which has been modified for shrimp or prawn production. Typically, paddy is cultivated in the middle of the field, which is surrounded by canals with high wide dikes into which the shrimp and prawn are stocked.

(Table 2). Furthermore, rainfall was described as the secondary source for SP (87%) and SPP farms (65%). Twenty eight percent of the surveyed SP farmers, 43% of SPP and 11% of PP farmers exchanged water at a rate of 5–80% of the total water volume per crop (Table 2). All SP, SPP and PP farmers dried the farms at the end of the season whereas 65% of farms discharged water to a canal, 23% to neighbor farms, 9% to rivers, and 3.5% to crop lands without treatment.

3.2. Disease diagnostic capacity

None of the studied farms had a health management plan or disease diagnostic facilities in their farm. More than half of the surveyed farmers had attended one or more short term aquaculture training courses (Table 2); however, the training did not included disease diagnostics. Overall, 88% of interviewed farmers were affected due to disease in cultured shrimp/prawn. Most of the SP (88%), SPP (90%) and PP (83%) farmers' use own experience, consult with neighbors or friends for disease treatment (Fig. 2). This study documented that chemical supply shops were important sources of information for farmers, and on average 46% of the surveyed farmers (21% SP, 64% SPP and 62% PP farmers) used the knowledge of chemical supply shops for presumptive disease diagnosis and treatment (Fig. 2). Small scale farmers were found to depend more on chemical supply shops for this information than medium and large holders.

3.3. Diseases/syndromes reported by studied farm groups

Eight diseases/syndromes were reported by shrimp/prawn farmers (Table 3) with the higher frequency of outbreaks observed between April and October (Table 4). The results showed that white spot disease (WSD) was a major problem in shrimp production, whereas broken antenna and rostrum were more common in prawn.

3.3.1. Diseases/syndromes reported for shrimp species

Farmers described four different diseases/syndromes for shrimp species. The higher percentage of famers reported WSD (64%) followed by Vibriosis (6%), unidentified disease (6%) and cotton shrimp disease (2.6%). WSD was reported by 90% SP and 40% SPP farmers (Table 3). A positive correlation was observed between WSD and canal as primary water source ($p = 0.03$) in SP and volume of water exchange ($p = 0.09$) in SPP farms (Fig. S1). The occurrence of WSD was negatively correlated with farm production in SP ($p = 0.03$) and SPP ($p = 0.03$) farms (Fig S1). A trend towards higher incidence of WSD was found in large farms (66%) compared to medium (64%) and small (60%) farms. One to four WSD incidents per season (mean: 2) in SP and one to three incidents per season (mean: 1.5) in SPP farms were reported. WSD occurred mainly between March - August accompanied with temperature fluctuation and salinity drops in the monsoon due to heavy rain (Table 4). A higher number of SP farmers (9.2%) reported Vibriosis compared to SPP farmers (2.9%). The outbreak of Vibriosis was positively correlated with the source of water in SP farms and crop duration in SPP farms (Fig. S1). Asing relatively small portion of SP (3.9%) and SPP (1.4%) farmers reported cotton shrimp disease and it was observed positive correlation between disease outbreak and farm size in SP farms (Fig. S1).

3.3.2. Diseases/syndromes reported for prawn species

Overall, 87% farmers reported five different diseases/syndromes for

Table 2
Respondent and production characteristics of studied farm groups (values expressed as mean ± SD excluding percentages which are expressed as mean values).

Characteristics	Studied farm group			
	SP	SPP	PP	Overall
Respondent age (years)	42 ± 11[ab]	40 ± 11[b]	44 ± 11[a]	42 ± 11
Schooling years (years)	6.2 ± 3.9[a]	7.6 ± 3.1[b]	5.9 ± 3.9[a]	6.6 ± 3.7
Aquaculture experience (years)	16 ± 8.0[a]	14 ± 6.8[a]	15 ± 6.5[a]	15 ± 7.1
Attended aquaculture education program (%)	66	47	48	54
Total farm area (ha)	1.2 ± 1.1[a]	0.55 ± 0.35[b]	0.45 ± 0.32[b]	0.75 ± 1.1
Farm surface water area (ha)	1.1 ± 1.0[a]	0.46 ± 0.25[b]	0.39 ± 0.28[b]	0.66 ± 1.0
Gher water depth (m)	0.81 ± 0.15[a]	0.92 ± 0.19[b]	0.97 ± 0.26[b]	0.90 ± 0.21
Crop duration (days per year)	299 ± 17[a]	283 ± 31[b]	264 ± 33[c]	283 ± 31
Stocking density of shrimp/prawn (no./m^2)	11 ± 6.1[a]	7.9 ± 4.0[b]	1.8 ± 1.0[c]	7.0 ± 5.6
Stocking density of fish (no./m^2)	1.0 ± 1.5[a]	0.15 ± 0.20[b]	0.10 ± 0.10[b]	0.42 ± 0.95
Shrimp and prawn production (kg/ha)	376 ± 185[a]	627 ± 326[b]	416 ± 278[a]	480 ± 293
Fish production (kg/ha)	753 ± 856[a]	862 ± 528[a]	800 ± 552[a]	807 ± 662
Main water source (%)				
Surface water	100	72	2.6	61
Rainfall	0.00	28	97	39
Water exchange (% farm exchanging water)	28	43	11	29
Water exchange frequency (times/ production cycle)	5.6 ± 4.9[a]	4.9 ± 3.4[a]	1.6 ± 0.9[b]	4.6 ± 3.9
Volume of water exchange (% of total water in gher)	43 ± 20[a]	26 ± 14[b]	12 ± 10[c]	29 ± 19

Mean values followed by different superscript letters indicate significant differences as result of the Bonferroni test ($P \leq 0.05$).

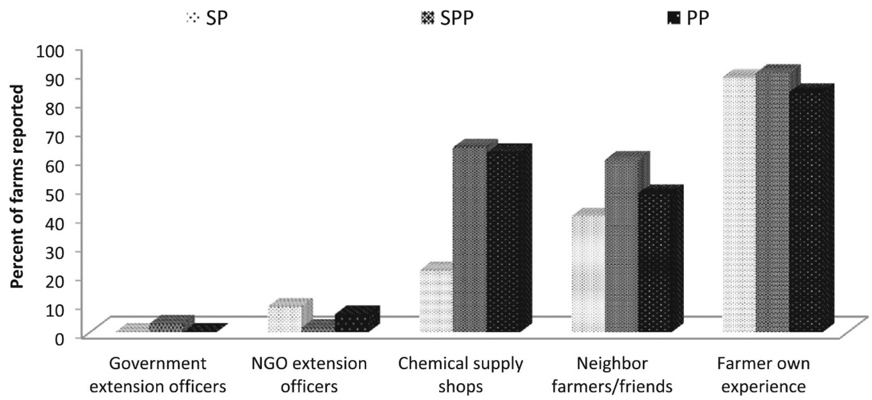


Fig. 2. Sources of information in studied farm groups for application of health products.

prawn species. Broken antenna and rostrum was a common symptom (78% of farms reported) compared to black gill (18% of farms reported), soft shell (11% of farms reported), hepatopancreatic necrosis (10% of farms reported) and unidentified disease (2.4% of farms reported). The broken antenna and rostrum symptom was reported by PP (82%) and SPP (74%) farmers (Table 3). The reported occurrence of this symptom trends to be higher in large farms (83%) followed by medium (78%) and small (75%) farms. PP farmers experienced one to three incidents per season (average: 1.4) whereas SPP farms reported one to four incidents per season (average: 1.4). Nineteen percent of SPP and 17% of PP farmers reported black gill, whereas hepatopancreatic necrosis was reported by 14% PP and 7.2% SPP farmers. Soft shell in prawn was found to be higher in PP (12%) farms followed by SPP (10%) farms. The results showed a positive correlation between reported diseases and volume of water exchange ($p = 0.02$) in PP farms and crop duration ($p = 0.07$) in SPP farms (Fig. S1).

3.4. Chemical and biological products to prevent/treatment of disease

Thirty five different chemicals and biological substances were used by surveyed farmers to prevent or control disease (Table 5). None of the farmers reported using any chemicals banned under the 2011 national code of conduct for the regulation of aquaculture in Bangladesh (DoF, 2011).

3.4.1. Antimicrobial products for the treatment of disease

Antibiotics, including chlortetracycline, oxytetracycline, doxycycline and neomycin sulfate were reported by SPP (30%) and PP (5.3%) farmers for disease treatment (Table 5). However, none of the SP farmers applied antimicrobials to treat disease even in case of epidemic WSD caused by white spot syndrome virus. This is an interesting observation, which points to the fact that experienced farmers know very well that antimicrobials can't be used to treat viral diseases. Farmers reported the application of antimicrobials together with vitamins to treat broken antenna and rostrum and black gill. The use of antimicrobial products was found to be higher in large scale farms (19%) followed by medium (14%) and small (7.1%) scale farms (Fig. 3). Antimicrobial products and vitamins were mixed in a container and dissolved in water by stirring with bare hands or with a stick. Then the solution was mixed with pelleted feed or flattened rice by using bare hands to prepare medicated feed and sundried for 20–30 min. Among the farmers who applied antibiotics, 80% farmers applied single antibiotic products, while the rest used a mixture of two different active ingredients (for example, oxytetracycline and doxycycline; neomycin sulfate and doxycycline).

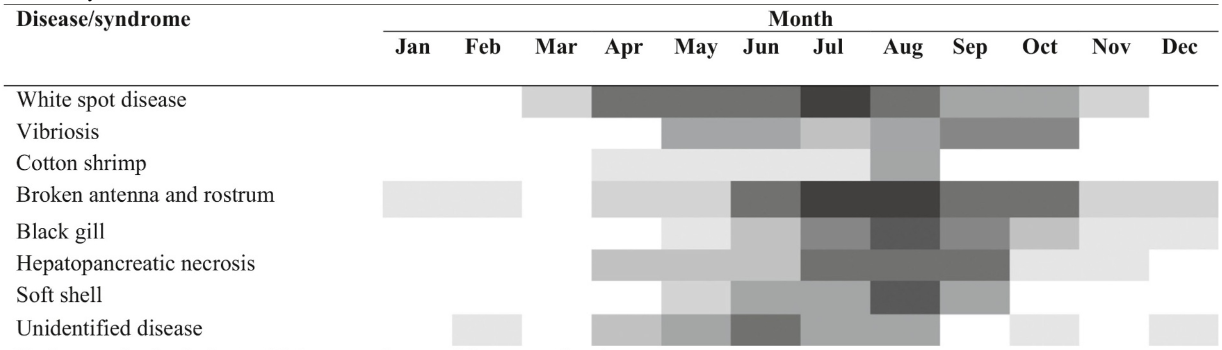
3.4.2. Disinfectants

Fifteen different disinfectants were applied to treat pond water and sediment irregularly throughout the production cycles and to reduce pathogen and disease treatment (Table 5). In general, disinfectants were diluted in pond water, and spread over the pond surface, except in a few cases where substances such as zeolite were sprayed directly to the water surface. Disinfectants were commonly used in SP (66%), PP (65%) and SPP (54%) farms. Farmers purchased disinfectants following advice of the chemical supply shops during disease outbreaks without any diagnosis of the disease. Lime was the most commonly applied

Table 3
Clinical signs of shrimp and prawn diseases/syndromes observed by farmers.

Diseases/syndrome	Farm reported (%)			Species	Clinical signs observed by farmers
	SP	SPP	PP		
White spot disease	90	40	0.00	Shrimp	White spot mainly on carapace and/or sometimes a little bit on whole body surface, aggregation at gher edge, lethargic, less appetite, reduced preening activities, erratic or spinning swimming near to gher dikes, reddish discoloration
Vibriosis	9.4	2.9	0.00	Shrimp	Lethargic, black spot on different parts of the shell, abnormal swimming behavior at the edge or surface of gher
Cotton shrimp	3.9	1.4	0.00	Shrimp	Spongy body, sluggish movement, opaque and whitish muscle (looked like cooked shrimp)
Broken antenna and rostrum	0.00	74	82	Prawn	Antenna and rostrum broken, erosion of antenna and rostrum, lethargic, less appetite, aggregation at the gher edge
Black gill	0.00	19	17	Prawn	Black spot on gill under carapace, erosion on carapace and gill, sluggish movement, less appetite, damage gill
Hepatopancreatic necrosis	0.00	7.2	14	Prawn	Swelling of gills or water accumulation under carapace, sluggish movement, erratic swimming at gher edge, less appetite, discoloration of hepatopancreas
Soft shell	0.00	10	12	Prawn	Shell is thin and persistently soft, shell is rough and wrinkled, lethargic, slow growth rate
Unidentified disease	10	0.00	5.3	Shrimp/prawn	Blue or greenish scum on body surface, lethargic, less appetite, aggregation near the gher bottom

Table 4
Seasonality of the different disease outbreaks on the studied farms.



Darkness of color indicates higher prevalence of disease outbreak

Table 5
List of chemicals applied by SP, SPP and PP farmers (% of farmers those reported the use of each chemical).

Substance	Studied farm group			
	SP	SPP	PP	Overall mean
Antibiotics (n = 4)				
Chlortetracycline	0.00	4.3	1.8	2.1
Oxytetracycline	0.00	24	2.6	9.5
Doxycycline	0.00	1.4	0.88	0.79
Neomycin sulfate	0.00	1.4	0.00	0.53
Disinfectants (n = 15)				
Calcium carbonate	99	96	100	98
Calcium oxide	7.1	5.0	1.8	4.7
Calcium magnesium carbonate	4.7	3.6	0.88	3.2
Zeolite	43	42	32	39
Sodium thiosulfate	1.6	7.2	7.9	5.5
Aluminum potassium sulfate	7.1	1.4	3.5	3.9
Sodium percarbonate	1.6	3.6	7.9	4.2
Hydrogen peroxide	0.79	6.5	8.8	5.3
Calcium peroxide	0.00	0.00	2.6	0.79
Tetra acetyl ethylene diamine	0.79	0.00	0.88	0.53
Potassium permanganate	22	7.2	9.6	13
Benzalkonium chloride	4.0	9.4	11	8.1
Chlorine	30	25	9.6	22
Potassium peroxymono sulfate	0.79	1.4	0.00	0.79
Unidentified	3.1	17	7.9	9.5
Pesticides (n = 13)				
Rotenone	16	17	21	18
Saponin (teaseed cake)	0.00	8.6	1.8	3.7
Malathion	1.6	0.72	0.00	0.79
Methylene blue	0.79	11	0.88	4.5
Copper sulfate	14	0.00	0.00	4.7
Tobacco dust	8.7	0.00	0.00	2.9
Carbofuran	4.7	0.00	0.00	1.6
Diazinone	2.4	0.00	0.00	0.79
Cartap	6.3	0.00	0.00	2.1
Cypermethrin	0.79	0.00	0.00	0.26
Thiamethoxam	0.00	0.72	0.00	0.26
Endrin	2.4	0.00	0.00	0.79
Thydrine	3.1	0.00	0.00	1.1
Feed additives (n = 2)				
Vitamin and mineral premix	2.4	10	7.0	6.6
Vitamin C	0.79	12	5.3	6.1
Probiotics	13	11	4.4	9.5

compound to disinfect water and sediment during pond preparation, and for disease treatment (Table 5). Zeolite was used by 43% SP, 42% SPP and 32% PP farmers. Potassium permanganate was applied similarly in three farm categories (7.2–22%) to disinfect water and to treat disease (Table 5). The highest frequency of chlorine and chlorine releasing compounds application was found in SPP (35%) farms compared to SP (34%) and PP (21%) farms.

3.4.3. Pesticides

Farmers reported 13 different pesticides used to kill unwanted organisms (pathogen carriers, predators) in the farms and to treat diseases (Table 5). There was a marked difference in application of pesticide compounds used among the farm groups. More SP (48%) farmers applied a wide range of pesticides than SPP (33%) and PP (24%) farmers (Table 5). SP farmers (13%) used several highly toxic insecticides between the production cycles to eradicate unwanted organisms, even to rapidly kill shrimp affected during the WSD outbreak. The highest proportions of farmers using pesticides were within the large scale farms (49%) followed by medium (34%) and small (26%) scale farms (Fig. 3).

3.4.4. Feed additives and probiotics

The use of feed additives (e.g. vitamins and mineral premix) was found to be highest in SPP farms (22%) followed by PP (12%) and SP (3.2%) farms (Table 5). Farmers reported to usefeed additives for better growth of culture species (58% of reported applications), and to treat disease outbreaks (42%). Feed additives were typically administered after mixing with feed one time per day to improve shrimp health and to treat broken antenna and rostrum syndrome and soft shell disease.

The percentages of farmers that applied probiotics were 13%, 11% and 4.4% in SP, SPP and PP farmers, respectively (Table 5). Higher number of large scale farms (20%) applied probiotics as compared to medium (6.0%) and small (5.0%) farms (Fig. 3). Probiotics were applied directly to water or sediment. In general, probiotics were dissolved in farm water and spread over the water surface; although a few farmers mixed probiotics with sandy soil and spread this over the water surface. The probiotics species were *Bacillus* spp., *Nitrosomonas* spp., *Nitrobacter* spp., and yeast. According to key informant interviews and FGD, the majority of the farmers were not aware of the beneficial effect of probiotics. Probiotics was considered as being safe in application.

3.5. Variables related to use of chemical and biological products

The results of multivariate analyses showed that the use of chemical and biological products differed significantly by different farm groups (Fig. S2), indicating the relatively high use of antibiotics and feed additives in the SPP farms in comparison to the other farm groups. This also showed a relatively high frequency of pesticides and probiotics in the SP farms followed by SPP and PP farms.

The characteristics of the surveyed farm groups and the parameters tested in the multivariate analysis are shown in Table 2. The results from the Monte Carlo permutation test for each of the surveyed farm groups are provided in the Supplementary materials (Fig. S3). The number of chemical and biological products used was found to be positively correlated with stocking density of PL in SP ($p = 0.03$) and SPP ($p = 0.004$) farms. The higher production of shrimp/prawn was positively correlated with the use of antibiotics, pesticides, feed additives

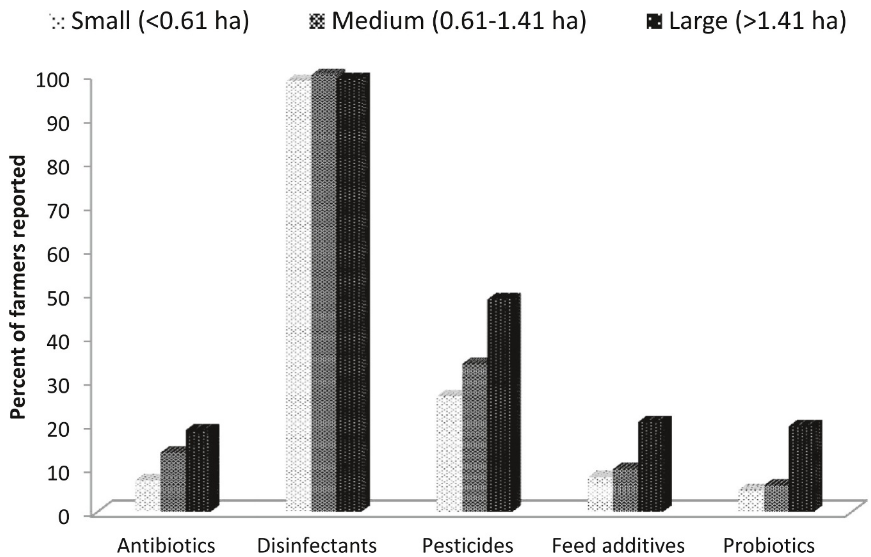


Fig. 3. Chemical and biological products used in different farm size.

and probiotics in SPP ($p = 0.01$) farms and disinfectants and probiotics in SP ($p = 0.03$) farms. The larger scale farms, compared to medium and small scale farms, tended to use disinfectant, pesticides, probiotics and feed additives more frequently during gher preparation and between production cycles as a preventive measure than SPP ($p = 0.002$) and PP ($p = 0.002$) farm groups. A similar trend was also observed for the number of gher on a farm in SPP ($p = 0.04$) and PP ($p = 0.01$) farm groups. In the SP farm group, a positive correlation was found between the number of feed additives used and the frequency ($p = 0.02$) and volume of water exchange ($p = 0.07$). Similarly, disinfectants use in SPP farms was positively correlated by the volume of water exchange ($p = 0.04$).

A significantly positive correlation was found between the number of pesticides, probiotics, feed additives and antibiotics used and keeping record on chemical use ($p = 0.01$) in SPP farms. Farmers who received training on aquaculture production trended to use a greater range of disinfectants and probiotics in SP ($p = 0.01$) farms and a similar trend was also observed in PP ($p = 0.04$) farms. The higher use of chemical inputs in PP farms was positively correlated to the number of formal schooling year of the respondents ($p = 0.02$). In the SPP farm group, a significant positive correlation was observed between the use of disinfectants and the higher number ($p = 0.002$) and frequency of diseases/syndromes reported ($p = 0.03$). Accordingly, a higher number of disinfectants was applied in PP farms with reported higher frequency of broken antenna and rostrum ($p = 0.04$) and a similar result was also found in SPP farms with reported black gill ($p = 0.002$). On the other hand, the application of feed additives in SP farms was marginally positively correlated with the frequency of Vibrosis reported ($p = 0.08$).

3.6. Occupational health hazards

More than 86% farmers reported direct skin contact of chemicals or dissolved chemicals in water during handling using bare hands (Table 6). Overall, 58% farmers reported primary protective measures such as cloth masks and hands covered with polythene during chemicals handling. The information sources of protective measures were aquaculture extension training, neighboring farmers and press media. Higher numbers of farmers/workers used protective measures during their work in large farms (64%) than medium (60%) and small farms (52%) (Table S1). More SPP farmers (42%) received suggestions on safe chemical handling compare to PP (33%) and SP (18%) farmers (Table 6). Higher number of SP farmers (43%) and large farm holders/workers were aware of banned chemicals in aquaculture than SPP (20%), PP (25%) farmers and medium and small farm holders/workers. Farmers' stored chemicals at the living place (41%) or temporary shelter in ghers (24%) constructed mainly for guards. Overall, 13% of farmers had records of chemicals application. About 50% farmers reported health hazards such as skin lesion, skin allergy, rough skin, coughing and complications of the eyes due to chemicals handling, although about 50% farmers reported awareness about the health and environmental risks associated with chemicals usage (Table 6).

4. Discussion

4.1. Disease diagnostic capacity

Our study showed that none of the farmers had prepared a specific farm level health management plan. Health management plans are required for sustainable aquaculture management, often in the form of "better management practices" (Belton, Haque, Little, & Sinh, 2011). However, farmers adopted some strategies to minimize the impacts of disease outbreaks; such as multiple stocking and harvesting, immediate harvesting followed by the appearance of symptoms, dead fish collection, and burial underground. In the present study, farmers were in general experienced in aquaculture but they had no formal education in aquaculture and aquatic animal health management. This lack of knowledge seems to be a limiting factor in disease diagnosis and consequent decisions on treatment. Farmers reportedly observed clinical signs in the cultured species (Table 3) and made decisions for treatment based on these signs. Disease diagnostics on the basis of clinical signs are not confirmatory as clinical signs are largely non-specific. Definitive detections often require laboratory testing facilities. Most farmers reported that testing would be too expensive, this would include both the potential 'direct' high cost, as well as the considerable time needed for sampling and follow up. Therefore, establishing linkages between diagnostics laboratory facilities (e.g. Bangladesh Fisheries Research Institute, Khulna University) and farmers would be essential to increase the likelihood that farmers would test and scientifically diagnose a disease before applying a treatment. Local governmental extension offices could play a significant role in establishing linkages to the nearest disease diagnosis laboratory. This would include assistance with proper sampling, transport of samples to the lab and dissemination of testing results to the affected farmer and other farmers in the region. A close cooperation between government extension officers and input shop operators might establish a sustainable private sector supported diagnostic service for the farmers. Input shops would benefit where effective

Table 6
Farmer perceptions on occupational health hazards associated with chemical use.

Variables	Percent of studied farms reported			
	SP	SPP	PP	Overall
Chemicals administrated according to				
Safety instructions on product label	2.4	2.2	6.1	3.4
Instructions by chemical supplier	19	53	48	40
Instructions by govt. extension staff	0.79	2.9	0.00	1.3
Instructions by NGO extension staff	22	3.6	7.0	11
Information from neighbor farmers/friends	28	37	17	28
Farmers own experience	69	53	49	57
Use protection during handling chemicals	46	71	56	58
Direct contact between skin and chemicals	74	59	75	69
Direct contact between skin and water containing chemicals	81	85	88	84
Farmers were informed about the health and environmental risks associated with chemical use	64	57	46	56
Farmers were instructed on safely handling of chemicals	18	42	33	32
Farmers were informed about banned chemicals	43	20	25	29
Health problem faced followed by using chemicals (skin lesion, skin allergy, coughing)	46	41	53	46
Stored chemicals				
Farmers home	31	55	34	41
Guard shed at farm site	23	26	22	24
Record keeping of chemical use	14	17	8.8	13

disease/health management leads to increased production and increased purchase capacity of farmers, for inputs such as feed and feed additives.

With an increasing trend towards intensification of farming systems, many chemical supply shops have become established in the study areas, and farmers purchased chemicals and biological products from these shops. Farmers also depend on chemical supply shops for the suggestion on presumptive disease diagnosis and treatment. The advisory services of chemical shops are free of cost, easily accessible for the famers, and related / linked with sales and promotion of products. The shop operators provide advisory services based on product label information, and sales representatives guidelines, and do so without formal or informal training on health management. Further assessment on the quality of the advisory service of chemical shops and a training needs assessment are required. Specialized veterinarians and aquatic animal disease scientists should be involved in preparation of the training module. Innovative approaches need to be considered to improve advisory services to the farmers. For example, some farmers already use smart phones, suggesting market opportunities for internet based veterinary services to prevent and control disease (such as atlas based guides for initial disease diagnosis). The sale of harmful drugs should be restricted to licensed shops which receive regular support from the authorities.

4.2. Chemical and biological products to prevent/treatment of disease

Broken antenna and rostrum and black gill were the most common symptoms seen in prawn, treated with antibiotics; mainly chlortetracycline and oxytetracycline. This finding did not reveal that specific antibiotics were used for disease treatment due to presumptive diagnosis of disease by farmers and chemical shop operators. The studied farmers reported some antibiotic treatments to be less effective, which might be due to insufficient dosages as advised by chemical shops or inferior quality of antimicrobial products. A recent reported by Phu, Phuong, Scippo, and Dalsgaard (2015) found that common antibiotic products used in Vietnamese aquaculture contained lower antimicrobial concentrations than declared, with some products even not containing the declared substances. During the survey, it was found that antibiotics were applied mixed with feed once a day for a period of one to five days. In many cases, the application period was shorter than the recommendation (5–10 days) on the product label which might lead to inefficacy of the treatment. The regular application of antibiotics and the exposure of bacteria to sub-therapeutic dosages might result in the development of antibiotic resistant pathogens which may compromise both human and animals' health (Holmström et al., 2003) with a consequent loss of the efficacy of these antibiotics (Bartie et al., 2012; Dung et al., 2009). The use of antimicrobial products in shrimp and prawn aquaculture has previously led to widespread consumer health concerns and export bans by importing countries (Rahman, 2013).

A large number and quantity of disinfectants were used by farmers for multiple purposes. This was also documented in a recent study conducted in shrimp/prawn farming area of Bangladesh, which estimated that a total of 456 g, 75.8 g and 1203 g of disinfectants were used throughout the production cycle to produce 1 MT of shrimp, prawn and both shrimp and prawn, respectively (Rico et al., 2013). The disinfectant list contained some widely used mineral products used to treat water and sediments (e.g. calcium carbonate, potassium permanganate, and zeolite) which are considered to have a low environmental impact, and synthetic products (benzalkonium chloride) or effective oxidizing molecules (hydrogen peroxide, calcium peroxide), which may affect the growth of some primary producer species and affect the structure of microbial communities in the pond environment (Rico & Van den Brink, 2014; Seier-Petersen et al., 2014).

A wide range of pesticides were used by SP farmers compared to SPP and PP to kill unwanted organisms, even to kill disease affected shrimp. Normally these pesticides are used to kill pests affecting rice crops, and are highly toxic to non-target aquatic insects and crustaceans (Sumon et al., 2016). Pesticides in aquaculture ponds may accumulate in sediments, as well as in the cultured organism's body, possibly resulting in risks for consumers and for the export of aquaculture products to countries with well-defined food safety regulations such as USA, Europe, and Japan (Ahmed & Garnett, 2010). SP farmers also used copper sulfate to control disease outbreaks which has a potential risk for human health due to bioaccumulation of copper in the cultured species (Li, Zhao, & Yang, 2005). Furthermore, copper is highly toxic to aquatic organisms, e.g. it has a negative effect on fish haematological parameters (Carvalho & Fernandes, 2006).

Probiotics enrich the intestinal microbial population, improve water and soil quality, enhance growth and improve immunological status of cultured species (Decamp, Moriarty, & Lavens, 2008; Qi, Zhang, Boon, & Bossier, 2009; Wang, Li, & Lin, 2008). Similarly, feed additives ensure optimal diet quality and improve immunological status of cultured organisms (Ali, Rico, Jahan & Belton, 2016). Recently, these products have been introduced in Bangladesh aquaculture, and could be the alternative to the prophylactic use of antibiotics (Ali, Rico, Jahan & Belton, 2016). However, a further investigation is necessary to analyze and up-grading the value chain and to provide quality support service to the farmers. Our studied farmers used *Bacillus* spp., *Nitrosomonas* spp., *Nitrobacter* spp., and yeast. Normally, bacterial genera were listed on the product labels but species name and their concentration in the products were often not declared. This is consistent with a recent study conducted in Vietnam by Uddin et al. (2015) where common probiotic products used in shrimp culture did not contain any information on specific bacterial strains included and often products did not contain the declared bacterial species. Hence, manufacturers should provide documentation of the efficiency and composition of microorganisms in their probiotic products in addition with formal government approval. A further independent study is needed on the composition and concentration of microorganisms in probiotic brands, efficacy and cost-effectiveness of probiotic used by farmers in Bangladesh.

4.3. Variables related to use of chemical and biological products

The results from the multivariate analyses on usage patterns of chemical and biological products showed that the observed variability within the studied farm groups was correlated with a number of factors. The application of these products was positively correlated to stocking density of PL in the SP and SPP farm groups. This result suggests that the application of disinfectants and probiotics in extensive and improved extensive farming system mainly could increase opportunities for stocking PL at higher densities. A similar finding was presented by Rico et al. (2013) and Ali, Rico, Jahan and Belton (2016), which reported the use of these products was correlated with increasing stocking densities and survival rates of PL in shrimp and prawn farming in Bangladesh. Similarly, a correlation between probiotic use and shrimp/prawn productivity was found in these farm groups suggesting that preventive use against disease outbreaks is related to increasing profits in shrimp aquaculture. Chemical use patterns in SPP and PP farms showed a significant correlation between the chemical groups used and the size of the farms, indicating that large farms with better investment possibilities trended to use greater amounts of chemical and biological products during gher preparation and between production cycles as a preventive measure. Keeping records on farm production performance and use of chemical and biological products are usually suggested for the adoption of farm certifications.

In the present study, several diseases/syndromes were identified. Those were recognized as the main obstacles to the development of shrimp and prawn farming in Bangladesh (Karim et al., 2012; Paul & Vogl, 2011). A number of factors, including higher stocking densities and high level use of feeds, which often result in deteriorating water quality, have been associated with a higher incidence of disease (Rahman, 2013). Farmers applied chemical and biological products based on their own understanding or on the instructions provided by chemical supply shops to treat/prevent disease outbreaks. A trend towards higher numbers and frequency of disease and higher use of disinfectants was found in SPP farms. Furthermore, the application of disinfectants in PP and SPP farms was positively correlated to outbreaks of the broken antenna and rostrum and black gill syndromes, respectively. This could be related with increasing stocking densities and high level of feed application, which deteriorated water quality (MacRae, Chapman, Nabi, & Dhar, 2002), and the lower efficacy of disinfection methods under large volume of organic matter and the possible development of antibiotic resistance. However, further studies are required to confirm this hypothesis.

4.4. Occupational health hazards

This study showed that farmers had frequent skin contact during handling chemicals. Hands were particularly at high risk of exposure to dangerous chemicals during preparation, mixing with feed and application of disinfectants and pesticides. Only half of the studied farmers reported to use protective measures while using chemicals. Protective measures consisted of masks made of cloth, which are likely to be insufficient for the protection from gaseous toxicants inhalation such as chlorine-based disinfectants. This indicates a high risk of inhalation of antimicrobials, pesticides and disinfectants during handling these compounds in the absence of proper protection for respiration. Moreover, antimicrobials might cause skin allergy, organ-specific reactions and systemic reactions or a combinations of these (Moreau & Neis, 2009; Phu et al., 2016; Sapkota et al., 2008) and pesticides can produce dizziness, vomiting and neurotoxic disorders when applied improperly (Sumon et al., 2016). The reason for insufficient use of protective measures was found to be related with a lack of knowledge on health hazards associated with chemicals, a lack of precautionary and warning messages on the product label, the misunderstanding of some of these messages in the case they were available, and the unavailability or unaffordability of safety equipment for chemical application.

Farmers reported that they were instructed how to handle chemicals safely, and were informed about the associated health risks when handling chemicals; however, they were not able to describe appropriate measures for the safe handling of chemicals and associated health risks, suggesting a need for better education and training. DoF (2015) has developed guidelines for using chemicals in aquaculture, and with specification and requirement for farmers to keep detailed written records of any chemical used; they must store chemicals safely; they must wear protective measures when handling them, and they must be instructed how to handle chemicals safely. These guidelines are intended to lead to reduced exposure to toxic chemicals and improved health of farmers and their families. Almost half of the studied farmers reported different skin related problems which requires further investigation, e.g. studies involving specialized health experts and social scientists. A focus on education and training about safe chemical handling procedures is urgently needed.

5. Conclusions and recommendations

This study identified eight different types of diseases/syndromes in shrimp/prawn farms; white spot disease and broken antenna and rostrum were the most common in shrimp and prawn, respectively. A wide range of chemicals and biological products were used to prevent and/or treat these diseases, including some which can potentially pose a risk to aquatic animal health, the surrounding environment, and to human health. Farmers reported that they apply probiotics as an alternative to antimicrobial compounds similarly to the trends observed in other Asian countries. This suggests that further intensive research to test the efficacy and cost-benefit analysis of these products is required. An urgent need for further education and training for farmers, chemical supply shop operators, and government extension staff about disease management and responsible use of chemicals has become apparent from this study.

This study shows the urgent need to improve knowledge on prudent use of chemicals, including the disease diagnostic services available to the farmers through training on aquatic animal health and improved access to testing facilities and extension services. Chemical supply shop operators were important sources of information for chemical use, and the role of chemical supply shops in the promotion of chemical treatments are most likely inappropriate without proper diagnosis. Therefore, the chemical supply shop operators and other local service providers role could be more effective through contact to diagnostic laboratory facilities. This may play a role in improving existing government and private sector extension services including chemical suppliers in providing information to farmers. The development and adherence to a comprehensive set of “better management practices” for Bangladesh shrimp and prawn farmers is needed. Moreover, an improved and coordinated approach is required to establish a registration and authorization process for chemicals used in aquaculture in Bangladesh. Such processes should receive support from existing regulatory authorities and researchers, and should consider the possible risks of currently use and new chemicals products on human and environmental health.

Conflict of interest statement

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.vas.2018.01.002.

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