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Finfish marine aquaculture in northern Vietnam: Factors related to pathogen introduction and spread

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ABSTRACT

Marine finfish aquaculture is a rapidly growing subsector in the Asia-Pacific region, including Vietnam. However, in-depth information about health management practices is often inadequate. Our objective was to describe multi-species marine finfish aquaculture in northern Vietnam at the farm and species level, and identify practices that may influence fish health. Two surveys were conducted in April 2014 and April 2015 on respectively 120 and 119 farms of which 57% were the same farms, located in floating villages near Cat Ba Island in Hai Phong Province, Vietnam. Most management practices were not different between the multiple species per farm. Duration of grow-out season was part of both surveys and differed for most species between surveys, and also with findings from other studies. Most farmers did not have aquaculture related education. Few farmers recorded stocking, harvesting or mortality parameters, and there was little involvement of health professionals. Most stock originated from China, which could pose a risk on emerging diseases. Median proximity of farms was 3 m, which is a large potential for spread of pathogens between farms. There were few biosecurity practices in place to prevent pathogens from entering the farm, e.g. few farmers treated fish before stocking, and none indicated disinfection of harvesters. Overall mortality was different between species, but overall 50–75% was expected for many production cycles. This study provides a basic understanding that could inform future outbreak investigations or development of risk-based surveillance programs.

Statement of relevance: This is the first study that provides a basic understanding of health related factors in marine finfish aquaculture management in northern Vietnam. As the sector is growing, early interventions to adapt farmers to better practices may lead to a cascade of improvements, and may optimize and stabilize the sector as more families become dependent upon the industry for their livelihoods.

1. Introduction

In the Asia-Pacific region where finfish production is generally dominated by inland aquaculture, marine finfish aquaculture is a rapidly growing subsector (FAO, 2014; Nguyen and Truong, 2005). The sector consists mainly of small-scale farms, due to limited fingerling supply, irregular demand, and unreliable export markets (Kongkeo et al., 2010). The advantages of small-scale operations, such as proximity to domestic consumers, low capital investment, low operating cost, flexible management, and options for periodic discontinuation, make the sector ideal for local farmers. To enhance growth of the sector, fields of improvement include hatchery establishments, nursery technologies, feeding methods, disease control, health management, and market expansion (Kongkeo et al., 2010).

Vietnam has a coastline of >3000 km, which offers great potential for marine aquaculture. Currently, marine finfish production comprises only about 2.4% (51,000 t) of the total finfish production (FAO, 2014) in Vietnam. In the northern part of the country, most marine finfish production takes place in Hai Phong and Quang Ninh provinces; in 2007 the 9000 and 7250 farms in Quang Ninh and Hai Phong produced 4200 and 1900 t respectively (Kongkeo et al., 2010). A typical farm consists of traditional wooden cages of about 3 m × 3–5 m and 2–3 m deep, connected to each other and anchored to the bottom to form a large floating raft. Each raft usually has accommodation for the owners who live on site, a high pressure pump, a freshwater pipe, and electricity (Fig. 1). Generally, these small-scale farms are located in floating villages (Nguyen and Truong, 2005). Most farmers rely on low cost captured fish from commercial fisheries as food for their stock (De Silva and Phillips, 2007). In these type of farms in Northern Vietnam, the main marine finfish species cultured are grouper (*Epinephelus spp.*), cobia (*Rachycentron canadum*), Asian sea bass (*Lates calcarifer*), snapper (*Lutjanus spp*), and red drum (*Sciaenops ocellatus*). Each farm cultures multiple species,

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Fig. 1. Location of finfish marine aquaculture in northern Vietnam.

usually a single species per cage. The type of species cultured may change yearly due to market demands.

In 2011, the Vietnamese government made development of mariculture a priority with the total production goal for this sector being 200,000 to 260,000 tons by 2020, with a value of approximately 1.8 billion USD (Ministry-of-Agriculture-and-Rural-development, 2011). Growth requires the sector to be innovative so that development can be responsible and sustainable (Troell, 2009).

Strategies and policies in support of marine aquaculture development in Vietnam, including health management, are considered important. Practices that may affect fish health are trade of live fish, introduction of fry and fingerlings, live fish harvests, biosecurity measures, and awareness of emerging diseases (Bondad-Reantaso et al., 2005). One way to improve health management is through an understanding of these practices and their interactions within the sector (Subasinghe, 2005), but in-depth information about health management practices for multi-species marine finfish aquaculture in Vietnam is inadequate.

Objective of this study was to describe multi-species marine finfish aquaculture in northern Vietnam at the farm and species level, and identify characteristics and management practices that may influence fish health. The rationale for generating such descriptions was to do so in a manner that informs and facilitates future risk-based disease surveillance and mitigation strategies.

2. Materials and methods

2.1. Surveys

This study was based on two surveys conducted in April 2014 and April 2015. The study population consisted of approximately 290 farms, located in floating villages near Cat Ba Island in Hai Phong Province, Vietnam (Fig. 1). The first survey was developed, pre-tested, and conducted in April 2014 on 120 farms randomly selected from a database provided by local authorities. >90% of the farms participated. If a farm could not participate in the survey, another randomly-selected farm was approached. This survey consisted of 56 questions focused on describing at-risk populations (e.g. location, distance to neighboring farm, number of cages of each species, number of fish present) and farming practices that might influence study protocols. The second survey was developed, pre-tested, and conducted in April 2015, and consisted of 110 questions focused on management practices and health of fish, and included more species-specific questions. Fifty-seven percent of the farmers from the first survey participated in the second survey. For farmers from the first survey who were not able to participate again, a nearby farm of approximately the same size was selected. During both surveys, farmers were interviewed by staff of Research Institute for Aquaculture No. 1.

2.2. Data management and analysis

Records from the paper-based survey results were entered in the computer program EpiData 3.1 (Lauritsen, 2000-2008). Data verification and analysis were carried out using STATA14.0 (StataCorp, 2015) and SAS 9.2 (SAS, 2008). For verification, answers to questions were individually evaluated, standardized, split, and categorized, depending on their structure.

At site level, there were 120 (survey 1) and 119 (survey 2) observations. For categorical variables, we described the percentage of farmers choosing a category and, for continuous variables, the median (min-max), unless described differently.

At species level, there were 460 observations, with a median of four (min-max: 1–7) species per farm for 119 farms in the first survey, and 338 observations with a median of 3 (1–7) species per farm for 113 farms in the second survey. Records from one farm in survey 1 and six farms in survey 2 were dropped because only site-level results had been reported. We excluded pompano and sea bream because they were produced in ≤6% of the occupied cages. The final data sets that we used for species-level analysis consisted of 118 farms and 431 species-level observations for survey 1, and 112 farms and 331 species-level observations for survey 2.

To assess differences between species, we re-categorized ordinal and nominal categorical variables so that each category consisted of ≥7.5% of the data. For variables for which this was not possible, we could not assess differences between species. The remaining variables were continuous, binary, ordinal categorical, or nominal. For continuous variables, we first Box—Cox transformed the variables to meet the normality assumptions, and then developed linear mixed-effect models with the variable of interest as the outcome (e.g. average length of fingerlings at stocking), species as predictor, and farm as random effect. For binary variables (e.g. sex of the farmer), we performed GEE estimation (Hardin and Hilbe, 2013) with the variable of interest as the outcome, species as predictor, the Bernoulli distribution, an exchangeable within-farm correlation structure, and robust standard errors. For ordinal categorical variables (e.g. mixing of fish stocked at different times; always vs usually vs sometimes vs never), we developed ordered logistic regression models to use the ordering information to assess differences. The variable of interest was used as the outcome, species as predictor, and we accounted for the effect of farm on the standard error by using robust standard errors clustered on farms. For nominal categorical variables (e.g. origin of fingerlings; China vs Mekong Delta vs elsewhere), we developed multinomial (polytomous) logistic regression models using the variable of interest as the outcome, species as predictor, and we accounted for the effect of farm on the standard error by using robust standard errors clustered on farms. For all models, differences between species were further analyzed using the Wald test in pairwise comparisons with Bonferroni adjustments.

In both surveys, we asked farmers to indicate the duration of the grow-out period by species. Differences between surveys were analyzed using a linear mixed-effect model. The "Duration of grow-out period (months)," square-root transformed, as indicated by Box—Cox analysis, was used as the outcome variable. Predictor variables were "species," "survey" (1 or 2), and an interaction between survey and species. "Farm" and "survey within farm" were included as random effects to account for farm effect on duration and the repeated measure that existed for farmers that participated in both surveys. Normality and homoscedasticity assumptions were deemed acceptable.

3. Results

Results from the questionnaires are presented in Supplement 1. Values of continuous variables represent medians (min-max) unless otherwise specified. A summary of key findings is presented here.

3.1. Farmer

Seventy percent of interviewees were males, with a median birth year of 1970 (1952–1989) and 30% were females, with a median birth year of1976 (1954–1993), and almost all interviewees owned their sites. Eleven percent of the owners owned sites elsewhere, and only 6% of the multiple site owners shared nets and cages between sites. Almost all interviewees slept on their sites. The education level of 5% of the farmers was college, two-thirds of the farmers had secondary education, and the others primary education. None of the farmers had formal or academic aquaculture-related training. Family tradition was an important source of skills training for most farmers, as was working on other farms; of lesser importance were school or training courses in aquaculture.

Fish from their own site were consumed by 83% of the respondents at least occasionally, and 4% did so daily. The species they consumed were, from most to least, red drum (61% of farmers consumed this fish), snapper (48%), cobia (31%), grouper (25%), sea bass (22%), and pompano (8%). Sixty-three percent of farmers also consumed fish caught within 500 m of their site.

3.2. Site

A median (min-max) of 2 (1–8) full-time year round employees work on each farm, accompanied by a range of 0–6 part-time employees. Farms had been in operation for an average of 10 (1 — 20) years in their current locations. The closest distance between farms was a median of 3 (0 — 200) meters. Almost 10% of farmers had changed the number of cages in the last year, 5% moved cages, and 7% moved the entire site. Median (min max) number of cages per farm was 20 (4–194), with 27% (0–81%) of cages being empty at the time of the survey. Cage sizes were 3.5 (2.5–8) by 3 (2.5–5.5) meters, with a depth of 3 (1.6–5) meters. Only 7% of farmers did not have a dog on their site, while >50% had 2 dogs or more. Forty percent of sites also had resident cats.

3.3. Fallow

After harvest, almost two-thirds of farmers indicated having no established plan for the type of species that would be stocked after a cage was harvested. Almost a third of farmers always stocked the same species as they harvested. Almost all farmers always cleaned nets before stocking with the same species (98%) or another species (92%). About half of the farmers did not have an established plan for the duration of the fallow period of a cage. Some farmers were more consistent in the duration of their fallow periods; <10% of farmers fallowed for a week or less and about 20% fallowed for 2–10 weeks.

3.4. Stocking of fish

About one-fifth of farmers recorded the numbers of fish stocked. Of those farmers, 46% merged records by species, 42% by cage, and 8% by site. Most recording of stocking numbers (82%) was done during stocking, while others updated records later. Records were kept in a book (95%) or on loose paper (5%) (Supplement 2D).

The main species of fish stocked on the farms were grouper, cobia, sea bass, pompano, snapper, and red drum. On average, farms cultured more cages with red drum (4.5) than any other species (≤ 3). The numbers of fish per cage were higher for snapper and red drum (on average, 500 and 300 fish per cage, respectively), than for grouper, cobia, and sea bass (Table 1). (Note: this was a snapshot at the time of the survey, so it included different sizes of fish and cages at different stages in the production cycle.)

For most species, the main source of fingerlings was China. The exception was grouper, which were mainly (42%) obtained from the wild, and sea bass, of which a third of the stock was obtained within Vietnam. Most farmers stocked half or more of their fish in the summer months, except for grouper, which was stocked year round. In deciding which species to stock, farmers indicated that rapid growth based on previous experience, and low mortality rates, based on previous experience, and high expected sale prices for harvested fish were the most important decision factors. Least important were whether fingerlings originated from the wild or from a hatchery, recommendations by other farmers, and the availability of fingerlings (Supplement 3C).

The stocking length of fish differed between species, with grouper and cobia at a median of 10 cm at stocking, and the other species at 3–5 cm (Table 1).

Mortality within the first 2 weeks post-stocking did not differ between species; about one-quarter of farmers reported no mortality issues, another quarter experienced 0–5%, and another quarter >10%. The most common anticipated reasons for this mortality were stress (30%), multi factorial (16%), and temperature fluctuations (15%). Across species, 15% of fish received a bath treatment before stocking, usually with fresh water (80%), or formaldehyde (7%), or occasionally with antibiotics, other chemicals, or combinations of chemicals with fresh water. Only 2 farmers differentiated their treatment approaches between species.

Table 1
Stocking and harvest information.

Variable	Grouper	Cobia	Sea bass	Snapper	Red drum	Emperor
Number of cages stocked at the farm ($n = 417$)	2[a]	2[a]	3[ab]	2[a]	5[b]	3[a]
Density at stocking (fish/m^2) ($n = 327$)	88[cd]	60[d]	100[bc]	100[ab]	154[a]	150[ab]
Stocking fish length (cm) ($n = 370$)	10[c]	10[c]	5[b]	3[a]	4[b]	3[ab]
Density at snapshot (fish/pen) ($n = 377$)	167[a]	138[a]	333[b]	500[b]	300[b]	.
Anticipated harvest weight (kg) (n = 417)	3	4	2[b]	1[a]	2[b]	1[a]
Density at time of harvest (fish/m^2) ($n = 324$)	20[a]	12[a]	30[bc]	30[bc]	30[b]	38[c]

[abc]: different superscripts within rows indicate significant differences (Bonferroni adjusted) between species.

3.5. Grow-out

Farmers' anticipated durations of the grow-out period for each fish species were shorter and more consistent across farmers in the second survey (Fig. 2). In the first year, the average expected duration of the grow-out cycle ranged from 19 months for red drum to 31 months for grouper. In the second survey, the average expected durations for red drum was 13 months and for grouper it was 16 months. All fish were fed low value captured fish bought from fisherman, except for one farmer who used pelleted food for pompano. Regardless of the size of fish, feeding was estimated to take about 1 h per cage per day.

Few farmers (16%) mixed fish stocked at different times during the production cycle. Almost all farmers (97%) moved fish within the site, most farmers (64%) did so 2–10 times per cage for each production cycle. Almost all farmers (97%) never moved fish between sites after stocking for the grow-out period.

An overview of clinical signs observed, by species, in the last production cycle can be found in Fig. 3. Overall, cobia had the most abnormal clinical signs and emperor the least. Clinical signs occurred to some degree in all species, but there were notable differences between species. There were more emperor and red drum observed with parasites but fewer with external abnormalities than other species, and more red drum with internal abnormalities than other species. Emperors were least likely to be observed with reduced appetite (Supplement 1D). We asked farmers about their impression of associations between these clinical signs and dead fish (Fig. 4). Farmers associated lower percentages of clinical signs with dead emperor and red drum than for other species. Reduced appetite occurred most in grouper and sea bass (both 30% of mortalities). For sea bass, 30% of the mortalities had external abnormalities, such as skin problems. External parasites attributed by the farmer, were the most common clinical sign reported.

Almost half of all farmers indicated an overall mortality between stocking and harvesting of 50 to 75%. Overall mortality for emperor was perceived to be lower than most other species (most farmers indicate <50%), and despite being one of the most commonly stocked species, red drum was perceived as having higher cumulative mortality then other species (about a third of the farmers indicate >75%; Fig. 5).

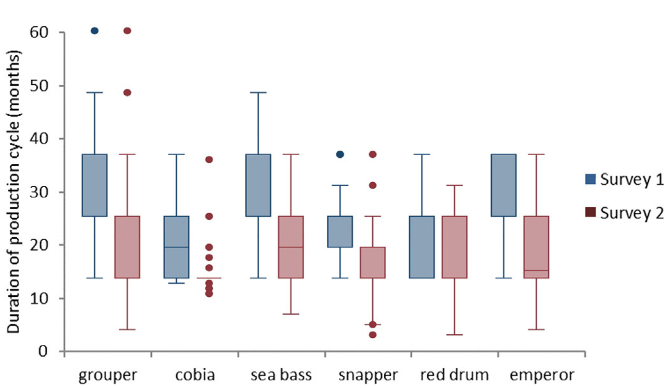

Fig. 2. Box-plot of distributions of farmers' anticipated duration of grow-out period in the 2 surveys, for each species. Error bars indicate 95% confidence interval.

There were no differences between species for perceived reason for mortality. The main reasons attributed to mortality were, from most to least important, pollution, multifactorial, disease, temperature fluctuations, and unknown. Three percent of farmers recorded mortalities per cage in a record book, usually accompanied by a record of the suspected reason for death. Three percent of farmers sent dead fish to a laboratory for testing, and 1 farmer kept these results in a record book.

A few farmers (3%) recorded environmental parameters at the site level. The farmers who recorded information on mortality, environmental parameters, and laboratory testing were not the same individuals.

For three-quarters of the farmers, the most recent treatment was less than a week before the survey, with grouper and snapper less likely to be treated than other fish species (Supplement 3E). Most farmers (81%) treated the entire farm, and about 25% of farmers indicated that treatments occurred simultaneously for multiple species. Treatments were, in 83% of the cases, done with fresh water only. Although overall lower occurrence, the most common other treatment compounds were antibiotics and $KMnO_4$ (<12% as single compound or in combination with fresh water and other compounds).

3.6. Harvesting of fish

Harvests were conducted year round. Harvest weights of cobia and grouper were highest at, 3 and 4 kg, respectively, with 2 kg for sea bass and red drum, and 1 kg for snapper and emperor. Since the cage sizes did not usually differ, weight differences were reflected in densities near harvest, with the highest for emperor, at 38 fish per m^2, and lowest for cobia and grouper, 12 and 20 fish per m^2, respectively (Table 1). About half of the farmers considered "price of fish" the most important reason to harvest. Other reasons were market demand and a combination of price and demand. Most farmers indicated that fish were harvested by an intermediate buyer; in only 1% of the cases did the restaurant owners directly harvest the fish. If harvested by an intermediate buyer, most farmers were unaware of the final destination of the product. More than half of the farmers indicated that harvesters usually harvested >1 cage per day and all fish at once. Fish almost always leave the site alive at harvest time. Nearly half of the farmers indicated that harvesters always visit other farms on the same day; only 11% indicated that harvesters never visit other farms at the same day. Nets used for harvesting are, in 65% of the cases, owned by harvesters and used, and thus shared, on multiple sites. Farmers reported that harvesters never used disinfectants.

Twenty percent of farmers recorded the number of fish harvested. Of those, 50% recorded the number of fish harvested per cage, 33% merged records by species, and 8% merged all records for the entire site. Eighty percent kept records in a log book, and 20% used loose paper.

4. Discussion

This study describing multi-species marine finfish aquaculture in northern Vietnam provides fundamental knowledge of the production system as context to inform fish health in general and, in particular, the potential for pathogen introduction to a farm or entire region, or spread between or within farms for pathogens already introduced. Data were collected by personal interviews, which had the disadvantage

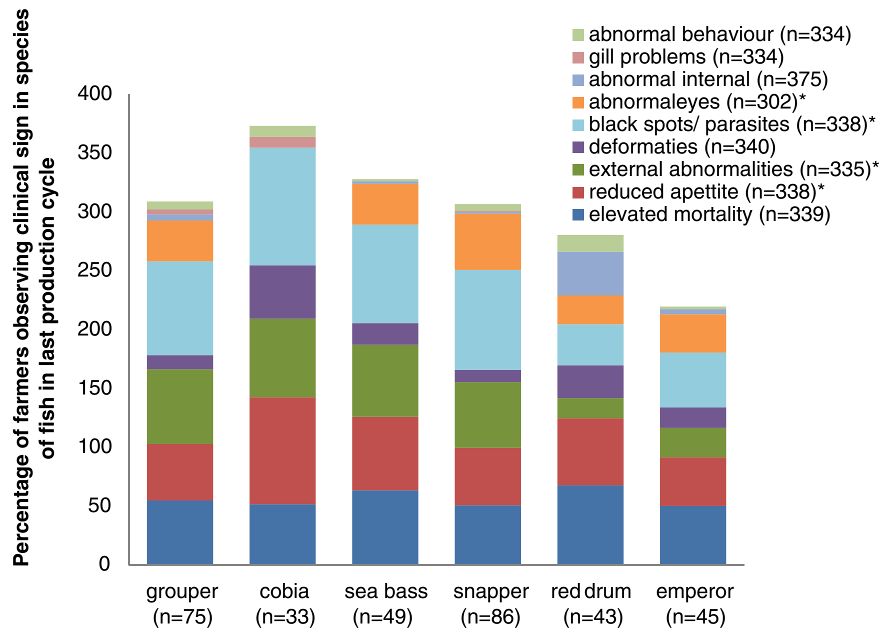

Fig. 3. Farmers' observed prevalence of clinical signs during the last production cycle, by percentages (e.g. of all farmers culturing grouper, 55% observed elevated mortality, 48% reduced appetite, 64% external abnormalities, etc.). For exact results, see Supplement 1D. *: percentages of clinical signs were significantly different between species ($p < 0.03$). Significance was not assessed for abnormal behaviour, gill problems, and abnormal internal, due to low prevalence of clinical signs. $N_{clinical\ signs}$: number of farmers answering this question. $N_{species}$: median number of farmers who provided information on clinical signs for this species.

of potentially introducing interviewer bias, but was the only method considered feasible to generate a high response rate on extensive questionnaires involving farmers located remotely.

4.1. Management practices

Most farmers did not have an aquaculture-related education, but obtained their knowledge mainly from family traditions and working on other farms. It is not uncommon that small-scale farmers have little formal training in fish health management principles (Subasinghe and Phillips, 2002). Although the experiences of farmers are an important source of innovation (Stuiver et al., 2004), evidence-based adaptations derived from shared observations across many similar farms and time, may lead to improvements that farmers would otherwise not acquire. An example from the salmon industry is the system of synchronized fallowing, in which farms located in epidemiologically-isolated

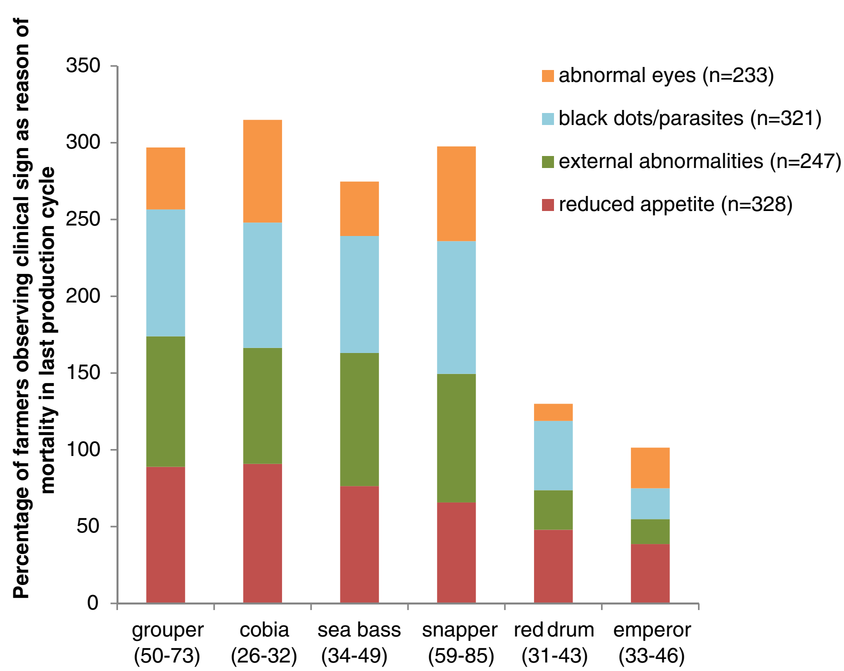

Fig. 4. Farmers' expected prevalence of clinical signs as reason for mortality during the last production cycle, by percentages (e.g. of all farmers culturing grouper, 88% considered reduced appetite a reason for mortality, 85% external abnormalities, 83% black dots/parasites, and 45% abnormal eyes). For percentages of fish that died from/with these clinical signs, see Supplement 1B. For most clinical signs, percentages for red drum and emperor were smaller than for other fish ($p < 0.01$), see Supplement 1B. $N_{clinical\ signs}$: number of farmers answering this question. $N_{species}$: number of farmers who provided information on clinical signs for this species.

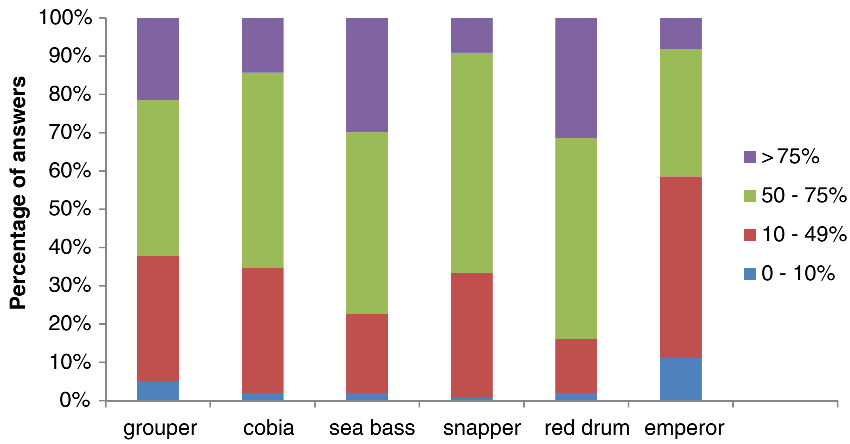

Fig. 5. Observed percentages of farmers anticipating a mortality-percentage between stocking and harvesting.

management areas apply synchronized fallowing. Advantage is that in the absence of hosts, free roaming pathogens (e.g. parasites or bacteria in bottom debris) will die off, reducing background disease pressures (Werkman et al., 2011). Such a system could benefit health status in the marine finfish aquaculture sector, but it requires delineation of distinctive areas and a high level of cooperation usually requiring other financial incentives or government regulation. This would pose virtually insurmountable obstacles for the current production system, in which farmers rely on continuous harvests for their income. With different durations of production cycles between the species, farm-level fallowing may not be feasible without economic losses, due to suboptimal harvesting strategies. And, there is no method to predict if fallowing one species at a time would experience the same benefit as all species simultaneously. Furthermore, farms within close proximity (e.g. the median of 3 m) could be considered as one unit, which would then require unit-level synchronization (within and between farms). Such a recommendation would be too great a financial burden for the unproved risk reduction based solely on best practice principles.

Most farm management practices that could be species specific (e.g. treatment, most common harvest season, and mixing of fish stocked at different times) were not different between species, implying that management is mainly a farm-level practice with a general health management approach. This could allow the farmer to culture multiple species with a constant management regime. However, species-specific management may improve production. For example, currently, all marine fish are fed low value captured fish, which practice impairs the long-term sustainability of the sector and may contribute to disease transmission. However, feeding low value captured fish is usually perceived as the better performance food and thus there is often little incentive to change to pellet feed (De Silva and Phillips, 2007; Hasan, 2012; Sim et al., 2005). Advantage of pellets could be the development of species-specific pellets, as different species have different nutritional needs. Currently, farmers' access to species-specific pellet feed is poor, and feed manufacturers are hesitant to produce species-specific food due to relatively low volumes of food needed (Hasan, 2012). The expected growth of the industry could lead to higher volumes of feed demand, but each species is still likely to remain only a proportion of overall production and thus demand for species-specific feed might remain low. The incentive to change to pelleted feed may be greater if all species could receive appropriate nutritional components through the same type of feed.

There were differences between our observations on stocking and harvesting practices compared to findings by Kongkeo et al. (2010) and Petersen et al. (2015). For example, stocking densities in our study area were >8 times higher for cobia than those observed by Kongkeo et al. (2010), which may reflect improvement of culture methods, or may compensate for high mortality. The duration of the grow-out period for sea bass was twice of the duration indicated in these other studies, and harvest weights of grouper were 4 times higher than reported by Petersen et al. (2015). Also, survival rates obtained by Kongkeo et al. (2010) were much higher than ours, i.e. 70–80%, whereas ours were < 50%, which could be year effects. Estimates from Petersen et al. (2015) on survival in the northern region of Vietnam were closer to our estimates, and their estimates for the southern regions were similar to estimates by Kongkeo et al. (2010) who did not present area-specific estimates. The difference in survival between northern and central–southern regions of Vietnam may be due to geographical factors, like water temperature, and rainfall, or traditional practices of farmers. For duration of grow-out period, there were large differences between northern and southern regions in Petersen et al. (2015), and also within regions as shown for the northern region by our 2 surveys and Petersen et al. (2015). These may reflect the resilience of the industry and its ability to adjust to circumstances such as shifts in harvest prices (Petersen et al., 2015). However, differences between our surveys may also indicate that relying on farmer perceptions for such summaries could be affected by their most recent perceptions that likely fluctuate by time of year even for the same farmer. In addition, farmers may have affected estimates, e.g. consuming their own fish may have altered overall survival perception. More reliable information would need to rely on a prospective data collection program in which daily or weekly records are maintained.

4.2. Disease and spread

The marine finfish aquaculture sector in many parts of Asia relies on multi-species production within the same farm. With regard to infectious disease agents, high host diversity usually leads to a decreased disease risk, especially when transmission is frequency dependent (i.e. dependent on absolute number of hosts; reviewed by Keesing et al. (2006)). Even though marine aquaculture systems differ from ecology models where hosts interact freely, the restricted movement patterns in aquaculture do not prevent transmission through fomites (e.g. harvesting boats and nets) or directly through water. Different pathogens may have different potential for impact on fish farms. Multi-species pathogens may be affected by increased species abundance, whereas transmission of species-specific pathogens may be reduced if the most susceptible host species are separated by other species. Our results showed variation in the prevalence of clinical signs of hosts between species, which may indicate a difference in susceptibility between species for certain pathogens, and could indicate that culturing different species in neighboring cages may lead to a reduction in disease incidence. However, this may reflect a stable host-pathogen balance being influenced by environmental factors and this could change with a novel pathogen if introduced to a naïve population.

Few farmers recorded stocking, harvesting, mortality, or other parameters and if they did record, the practice was not systematic. In addition, there was little involvement of health professionals or diagnostic laboratories for disease testing, nor recording of such results. This could result in a lack of early detection of emerging diseases or identifying deviations from expected patterns that may or may not fluctuate by season (Soares et al., 2012). Parasites were a common problem in all fish species, but there were no parasite prevalence or abundance monitoring activities reported. In other industries, such as the salmon industry, parasite-counting events are a standard practice that provide information on abundance and treatment effects (Gautam et al., 2016), and patterns changing over time (Jones et al., 2012). The absence of standardized records may compromise the ability to investigate or mitigate disease outbreaks in a timely manner, leading to greater economic impacts on food production for a community that has little economic buffering capacity.

The risk for pathogen introduction to farms via live fish movements (Oidtmann et al., 2011) is most obvious when considering fish stocking practices. Many fingerlings originated from China, where fish pathogens may differ from local pathogens found in Vietnam, and may lead to emerging diseases (Bondad-Reantaso et al., 2005). There could also be different risks between fingerlings from hatcheries and wild stock, but most farmers did not consider the differences between those origins to be important when they obtained their stock. As the health status of imported juveniles from China is unknown, the risk of pathogen introduction via live fish movement to the area remains unknown. Most farmers never move fish between sites once stocked, which reduces its importance as a potential source of pathogen introduction or spread. Fish are mainly harvested alive, and there is a risk of pathogen spread from farm to farm with the harvesters. Most farmers were unaware of the final destination of harvested fish, but if fish are sold directly to restaurants or markets, the risk of transmitting pathogens to other farms during fish harvest may be low.

Low value captured fish used as feed for farmed fish may carry pathogens that could be transmitted to cultured fish. In addition, pathogen introduction to the farm via dead fish movement may occur through human consumption of fish that were caught or purchased off-farm. >65% of farmers consume fish caught within 500 m of the farm, and such fish, if unconsumed remains are fed to fish, could provide the entry point and the source of potential pathogen introduction.

The proximity of farms to other farms was close, with a median of only 3 m. Proximity is an important risk factor for pathogen exposure in aquaculture (McClure et al., 2005; Stene et al., 2014), providing potential for pathogens to spread, either through water, fomites, or wild fish that feed on low value captured fish remains. Many small farms in close proximity, as is the case in marine fish industry in northern Vietnam, generates greater risk for sharing pathogens throughout the nearby farms than would be expected if there were fewer larger farms (Salama and Murray, 2011). The social factors creating the current farm composition would not make this feasible or even desirable. However, understanding these potential introduction and spread pathways provide the impetus for other mitigation strategies to be developed.

Several practices indicated that pathogen transmission by mechanical transmission and biosecurity practices were weaknesses that could be addressed. First, most farmers did not bathe fish before stocking, ignoring an opportunity to reduce transmission of ecto-parasites. Second, there was no use of disinfectants on nets or equipment by harvesters, even though they regularly visited multiple farms on the same day. Harvesters could be a risk factor for disease, as are other kinds of boat traffic (Murray et al., 2002). The use of harvesters' nets, without disinfecting between farms, could be a means of transferring pathogens. Spread of pathogens within the farm could be affected by not cleaning nets before stocking, short duration fallow periods, and mixing of fish from different cages.

4.3. Conclusion

This is the first study that provides a basic understanding of health related factors in marine finfish aquaculture management in northern Vietnam.

Should an outbreak investigation be necessary or a risk-based surveillance program be considered, factors representing higher risk of pathogen introduction or spread between farms would inform the most efficient approaches to design. Although basic health management principles of biosecurity would most likely reduce the probability of new introductions or spread, there are some important factors that cannot be altered. The proximity of sites to each other is not likely to change due to the community structure of this production, but shows the need to consider the system as a unit. The use of low value captured fish for feed is driven by economic constraints that provide little incentive to feed suppliers to address the many species needs of the area. Similarly, juvenile sources are driven by outside factors. The marine finfish sector is growing, and early interventions to adapt farmers to better practices may lead to a cascade of improvements, and may optimize and stabilize the sector as more families become dependent upon the industry for their livelihoods.

Improvements in biosecurity practices can be considered to meet the objective of reducing the probability and severity of infectious diseases at the community level. Disinfectant use by harvesters is achievable by influencing very few individuals but may reduce an obvious risk. Likewise, freshwater baths of juveniles before stocking may be possible using containers as fish are transported to the site for stocking. Lastly, net cleaning (e.g. using sunlight and drying) should be encouraged.

All of these practices make sense biologically. However, they may be resisted due to the added cost perceived, particularly if there is little empirical evidence to support that practical benefit will impact the economic success of farmers. For this reason, it would be advisable that applied trials be employed to assess the benefit. For example, a portion of harvesters could be asked to initiate disinfection protocols for their harvest nets. A formal comparison of health and productivity outcomes, including external lesions reflecting skin parasite burdens and survival, would be necessary to demonstrate the utility of any proposed intervention compared to those harvesters not altering their practices. Similarly, a freshwater bath trial could be randomized to cage groups to compare health outcomes.

A final consideration that provides the foundation on which any of these changes can be assessed, or for providing evidence of an emerging disease, is the use of detailed survival and productivity records. The benefit to an individual farmer is limited since they can obviously produce at their current level, barring any new pathogen creating catastrophic economic consequences. However, the collective nature of the community success requires an early warning system and the ability to make improvements that can be quantified and convince producers which practices are worth investing effort and cost to achieve sustainable productivity.

Contributors

ASB and KLH conceived the study; ASB, KVN, JD, VTP TNB, LTD and KLH designed the study protocol; KVN conducted the surveys; ASB, HS and KLH analyzed and interpreted the data; ASB and KLH wrote the manuscript; all authors critically revised the manuscript, read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interests.

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Appendix A. Supplementary data

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