The farmers' perceptions of ANPS pollution and its influencing factors in Poyang Lake Region, China

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ABSTRACT

Individual farmers represent the main management entities of agricultural production under the family-contract responsibility system in China, and thus play crucial roles in the prevention and control of agricultural nonpoint source (ANPS) pollution. The analysis of the farmers' perceptions of ANPS pollution as well as the factors affecting their perceptions can provide valuable information for relevant policy-making to preserve high quality water in Poyang Lake and regional quality of arable land. Through a survey titled 'Farmers' perceptions of ANPS pollution and farming behaviors in the Poyang Lake Region', the data related to the perceptions of farmers on ANPS pollution were collected. The factors that affect their awareness of ANPS pollution were identified with the method of boosted regression trees (BRT). The results indicated that the farmers had awareness of the risk of ANPS pollution to some extent, but they lacked adequate scientific knowledge. Generally, they had no consciousness about how to prevent and control ANPS pollution and did not understand techniques needed for proper scientifically sound application of fertilizers and pesticides. The main factors that influenced their perceptions of ANPS pollution are (from high to low): the ratio of total income which comes from farming, per capita farmland, age, education level, and household income. Some measures targeted to improve the prevention and control of ANPS pollution were proposed: developing modern agricultural techniques and promoting large-scale farming, increasing public campaigns related to ANPS pollution prevention and control with the goal of raising the level of awareness of farmers, and reforming the methods used to promote science and technology in agriculture and encourage the proper use of chemical fertilizers and pesticides.

Key words | agricultural nonpoint source pollution, boosted regression trees, farmers' perceptions, influencing factors, Poyang Lake Region

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INTRODUCTION

Agricultural nonpoint source (ANPS) pollution has become one of the most significant contributors to the impairment of water quality and arable land (Duchemin & Hogue 2009; Lee *et al.* 2010; Shen *et al.* 2012; Liu *et al.* 2013a, 2013b; Gao *et al.* 2014; Zhang *et al.* 2014). Under the family-contract responsibility system in China, individual farmers have served as the main managers of agricultural production; thus, they played crucial roles in the preservation of water quality as well as arable land quality (Chen *et al.* 2007, 2008; Liu & Lu 2014; Marc *et al.* 2014; Rabotyagov *et al.* 2014; Shan *et al.* 2014). The long-term excessive use of chemical fertilizers and pesticides by farmers has resulted in nutrient imbalances in arable land and deterioration of soil structure, leading to water quality decline in the river and lake (Guo *et al.* 2010; Shen *et al.* 2012; Liu *et al.* 2013a, 2013b). Located in the north part of Jiangxi Province in China and on the south bank of the middle-lower reaches of Yangtze River, Poyang Lake is China's largest freshwater lake and plays an important role in maintaining drinking water supply and controlling flooding for the middle-lower reaches of the Yangtze River. The Poyang Lake Region serves as one of China's major commodity production regions for grain, cotton, and vegetable oil (Zhou 2009). The use of chemical fertilizers and pesticides by farmers in this region has a direct impact on water quality in Poyang Lake and regional quality of arable land. An in-depth research of the farmers' perceptions on ANPS pollution in the Poyang Lake Region and the factors influencing their

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perceptions will lead to the development of appropriate policies and measures to improve effective ANPS pollution prevention and control. Using data from a survey titled 'Farmers' perceptions of ANPS pollution and farming behavior of the Poyang Lake Region' and the boosted regression tree (BRT) method, the farmers' perceptions on ANPS pollution in the Poyang Lake Region and the various factors affecting their perceptions were analyzed. Some measures on the prevention and control of ANPS pollution were proposed for the development of best management practices related to controlling ANPS pollution with the goal of preserving high quality arable land in the Poyang Lake Region (Logan 1993; Dowd *et al.* 2008).

MATERIALS AND METHODS

Survey sites and data collection

The Poyang Lake Region is the area around lake and covers 12 counties (districts): Nanchang, Xinjian, Jinxian, Lushan, Yongxiu, Xingzi, Dean, Hukou, Duchang, Yugan, and Poyang Counties, and Gongqing City (Gan 2002). The survey was mainly conducted through questionnaires, supplemented with small forum discussions. The topography and degree of agricultural development in areas around the mainstream and tributaries of Poyang Lake were considered when determining the sample distribution in the questionnaire survey. Ten villages from six counties were selected in which to conduct the survey: Poban village in Yongxiu, Guangzhou and Xinxing villages in Poyang, Leifang village in Nanchang, Lujiagang and Xinye villages in Duchang, Liufang and Wangsi villages in Hukou, and Lianchi and Shizhu villages in Yugan.

The household was selected as the unit of survey. We typically approached the eldest person of the household and interviewed them, because in rural China they make the decisions on major issues, including land management and farming behaviors (Wei *et al.* 2009).

The first part of the three-part questionnaire consisted of questions related to the basic characteristics of the farmers and their households, including household size, contracted farmland area, household income, income from farming, and gender, age and education level of the head of household. The second part investigated farmers' knowledge and awareness of ANPS pollution by asking them about their knowledge and use of pesticides, chemical fertilizers, and agricultural films. The third part surveyed the farmers' intention in the prevention and control of ANPS pollution by asking them what measures should be taken to reduce pesticide and agricultural film use. Agricultural film is comprised of a thermoplastic resin film and contains an ethylene copolymer with a hindered amine used for improving agricultural production. In the summer of 2013, our research group conducted 'face to face' interviews in each sample to make sure they understood the questionnaire and to ensure the validity and authenticity of the data we collected. 339 of 350 questionnaires were valid responses.

Research method

The BRT method was selected to examine driving factors influencing the awareness of farmers of ANPS pollution. BRT is one of several techniques that aim to improve the performance of a single model by fitting many models and combining them for prediction.

BRT is a multivariate technique based on binary decisions (Deconinck *et al.* 2007; Salonen *et al.* 2012), which combines the regression tree and boosting methods (Elith *et al.* 2008).

The regression tree method continuously (or recursively) split samples into branches, and each branching point (representing a response variable) was selected to show the greatest difference between the two branches, which are from the classification and regression tree ('decision tree') group of models. Therefore, the homogeneity of samples within each node increases with further branching, until the samples become homogenous within a node or the sample size becomes too small to split (Mo *et al.* 2002; Deconinck *et al.* 2005). The boosting model assigns a weight to each point in a data set based on the importance of that point, which builds and combines a collection of models (Elith *et al.* 2008). The weight of each point is adjusted using a model training process. If the classification is correct or incorrect, the weight decreases or increases, respectively. Therefore, the initial weights are equal. As the program progresses, the trained models will become more focused on those points with higher weights. This method has powerful capacities for handling predictor variables of different types (categorical, nominal, and continuous) and distributions (Gaussian, Poisson, binomial, and others), for accommodating missing data and outliers and for automatically handling interaction effects between predictor variables (Elith *et al.* 2008). Furthermore, the method has no prior assumptions about the independence of predictor variables, can fit complex nonlinear relationships, and is highly resistant to inclusion of large numbers of irrelevant predictor variables. More detailed description of the BRT method is found in Hastie *et al.* (2009), and working guides in Ridgeway (2007) and Elith *et al.* (2008).

Parameter setting is a preliminary step in BRT modeling. Five parameters should be determined: loss function (for minimizing squared error), learning rate, tree complexity, bagging fraction and k-fold cross-validation (Ridgeway 2007; Elith *et al.* 2008; Zhang *et al.* 2012). The learning rate is a constant value applied to each individual regression tree for determining its contribution to the final model. Tree complexity gives the size of simple regression trees and maximum depth of variable interactions. The bag fraction introduces randomness into a model to reduce overfitting by random selection of a data portion for model training and validation. The cross-validation specifies the number of times to randomly divide the data for model fitting and validation. All BRT analyses were conducted in R software version 2.15.1, using the 'gbm' package (Ridgeway 2012).

Variable selection

The answer to the question 'Is the current widespread deterioration of water quality in rivers and lakes associated with increasing usage of pesticides and chemical fertilizers by farmers?' was selected to be the dependent variable providing an indicator of each farmer's awareness of ANPS pollution. For independent variables, based on the literature (Luo 2011), we considered both internal factors and external conditions, and decided to analyze the following eight factors: household size, number of labors, household income, gender, age, level of education, per capita cultivated land area and the ratio of income from farming. Table 1 provides descriptions of these variables.

Table 1 | Factors influencing farmers' perceptions of agricultural non-point source pollution

Independent variable	Abbreviation of variable	Mean value	Standard deviation
Household size (person)	HS	5.42	2.115
Number of persons able to work (person)	NPW	3.22	1.264
Household income (10,000 Yuan)	HI	4.21	3.896
Per capita farmland area (mu)	PFA	1.13	0.826
Ratio of income from farming (%)	RIF	27.44	21.274
Gender	G	0.67	0.47
Age	A	50.44	9.653
Education level	LE	1.78	0.756

Note: Per capita farmland area = planted land area/household size; ratio of income from farming = income from farming/household income.
Gender: male = 1, female = 0; does this person work on the farm year round: yes = 1, no = 0; Education level: primary school education and below = 1, middle school = 2, high school = 3, polytechnic and above = 4.

Table 2 | The perceptions of farmers related to agricultural nonpoint source pollution

Question	Choices	Sample size	Percentage (%)
Is it better to use more chemical fertilizers?	No Yes	316 23	93.2 6.8
Is it better to use more pesticides?	No Yes	314 25	92.6 7.4
Is the current widespread deterioration of water quality in rivers and lakes associated with increased use of pesticides and chemical fertilizers by farmers?	No Yes	87 251	25.7 74.3
Manures from large-scale pig farms may contain residual heavy metal additives. Is it safe to use?	No Yes	270 69	79.6 20.4

RESULTS AND DISCUSSION

Farmers' perceptions of ANPS pollution in the Poyang Lake Region

We conducted a survey using a questionnaire to analyze farmers' knowledge and behavior related to the use of pesticides, chemical fertilizers, and agricultural films. In addition, using soil-testing and formulated fertilization techniques as a marker, we investigated the farmers' awareness of proper scientific usage of fertilizers.

Insufficiency of farmers' awareness of the risks of ANPS pollution and lack of adequate scientific knowledge

Table 2 shows the level of farmers' awareness related to ANPS pollution. The majority of the farmers recognized that chemical fertilizers and pesticides could affect the environment. When asked 'Is it better to use more chemical fertilizers?' or 'Is it better to use more pesticides?', most of them (93.2% and 92.6% of all subjects, respectively) chose 'No' as their answer. This indicated that the vast majority of farmers knew pesticides and chemical fertilizers should be used moderately. But when asked 'Is the current widespread deterioration of water quality in rivers and lakes associated with the increasing usage of pesticides and chemical fertilizers by farmers?' and 'Manures from large-scale pig farms may contain heavy metal residues. Is this manure safe to use?', 25.7% of farmers answered 'not associated' and 20.4% of farmers answered 'safe to use'. This showed that some farmers lacked basic knowledge related to the specific dangers and the intrinsic mechanisms of ANPS pollution.

Farmers generally lacked knowledge related to the prevention and control of ANPS pollution and the techniques were needed for the proper application of chemical fertilizers and pesticides

Farmers' use of pesticides, chemical fertilizers, and agricultural films directly reflects their knowledge of ANPS pollution prevention and control, or lack thereof. There were few technical specialists who came to affluent farmers or subsidized advisory service by government authority. In the survey, we conducted the questions 'How to determine the amount of chemical fertilizers to use?', 'How to choose the type of pesticide to use?', and 'How to choose an agricultural film?' to investigate their knowledge of ANPS pollution prevention and control. The results showed that the farmers generally have inadequate knowledge related to the prevention and control of ANPS pollution (Table 3). To determine the amount of chemical fertilizers to use, most people relied on their own experience (63.1%) or followed other farmers' methods (12.4%). Both of these methods were highly subjective. Only 59 farmers (17.4%), most of whom had large areas of cultivated lands, answered that they referred to the instruction manual and sought help from technical specialists. 53.1% of farmers chose highly toxic pesticides that are effective in pest control. This suggests that most farmers selected pesticides based on the standard of 'fast and effective', focusing on short-term pest control without considering the effects of pesticide residues. When choosing agricultural films, 51.6 and 23.6% of farmers chose agricultural films depending on their durability and price, respectively. Durable and inexpensive films usually degrade slowly, and the films remaining in the soil can release toxic substances during the process of degradation, aggravating soil and groundwater pollution. Proper fertilizer application requires soil-testing and formulated fertilization at its core (Zhang 2010). The Ministry of Agriculture has started a nation wide campaign to encourage soil-testing and formulated fertilization since 2005; thus, the use of this technique is a good indicator of proper fertilizer use. However, the results from our survey indicated that the public campaign to promote soil-testing and formulated fertilization had been inadequate, because only 73 farmers (21.5%) had learned about this technique and only 54 farmers (15.9%) had actually used it in agricultural production. This further implied that farmers still tended to use traditional methods of fertilization, and their skills related to scientifically sound application of fertilizers and pesticides needed to be improved.

Analysis of factors influencing the awareness of farmers to ANPS pollution

We used the BRT program package written by Elith *et al.* (2008) for data analysis. The BRT parameters were set as

Table 3 | Farmers' knowledge of prevention and control methods related to agricultural non-point source pollution

Question	Choices	Sample size	Percentage (%)
How do you determine the amount of chemical fertilizers to use?	Personal experience	214	63.1
	What other people use	42	12.4
	Price of the fertilizer	24	7.1
	Seek help from technical specialists	24	7.1
	Follow the instruction manual	35	10.3
How do you choose the type of pesticide to use?	High toxicity and effective at killing pests	180	53.1
	Cheap	44	13
	Low toxicity and low residue	115	33.9
How do you choose an agricultural film?	Durable	175	51.6
	Cheap	80	23.6
	Degradable and low residue	84	24.8
Do you know of the soil-testing and formulated fertilization technique?	No	266	78.5
	Yes	73	21.5
Do you use the soil-testing and formulated fertilization technique?	No	285	84.1
	Yes	54	15.9

follows: the tree complexity (tc) = 5, the learning rate (lr) = 0.001, and the bag fraction = 0.5. The bag fraction is the fraction of the training set observation randomly selected to propose the next tree in the expansion. We always used 50% of the data for model fitting and the remainder for independent evaluation because the bag fraction is 0.5, and used 10-fold cross-validation to determine the number of trees. Ultimately, we obtained a model composed of 2,800 trees (Figure 1). The default number of trees is between 100 and 20,000 (Elith *et al.* 2008), so this is a normal result.

The contributions of the above eight selected factors related to a farmer's awareness of ANPS pollution were (in descending order): the ratio of household income from farming (21.3%), per capita farmland area (19.7%), age of head of household (18.7%), head of household farmer's level of education (15.3%), total household income (11.6%), household size (6.8%), head of household farmer's gender (4%), and the number of persons able to work in the household (2.6%). Based on the data related to the main factors contributing to farmer's awareness of ANPS, the first five factors were considered to be the main factors influencing farmer's awareness of ANPS pollution, because their cumulative contribution totaled 86.6%. The total contribution of household size, head of household farmer's gender, and the number of labor in the household was only 13.4%; thus, these factors were considered negligible.

The two most important factors, the ratio of income from farming and per capita cultivated land area, were both closely related to the amount of cultivated land a family manages and contributed a combined 41% to a farmer's awareness of ANPS pollution. When the ratio of income from farming was greater than 35% or the per capita cultivated land area was greater than 1.3 mu (a Chinese unit of area equal to 666.7 m^2), they were positively correlated with the farmer's awareness of ANPS pollution. This indicated that with a higher ratio of income from farming and a greater amount of cultivated land per capita, farmers had a higher awareness of ANPS pollution. This meant that when the ratio of income from farming and per capita cultivated land area reaches a certain threshold, farmers would likely be more aware of the hazards of ANPS pollution and would genuinely care about controlling such pollution. A possible explanation was that farmers with higher ratios of income from farming and higher per capita cultivated land mainly relied on farming for their income. They also preferred to spend more time learning as they were not distracted by other work. These farmers usually had the largest farms in the local area and had acquired more knowledge related to modern agriculture; thus, they had better perceptions of the hazards and need to manage ANPS pollution. However, the statistical analysis also revealed an exception to this rule. Only considering the ratio of income, when it was less than 8%, this factor also

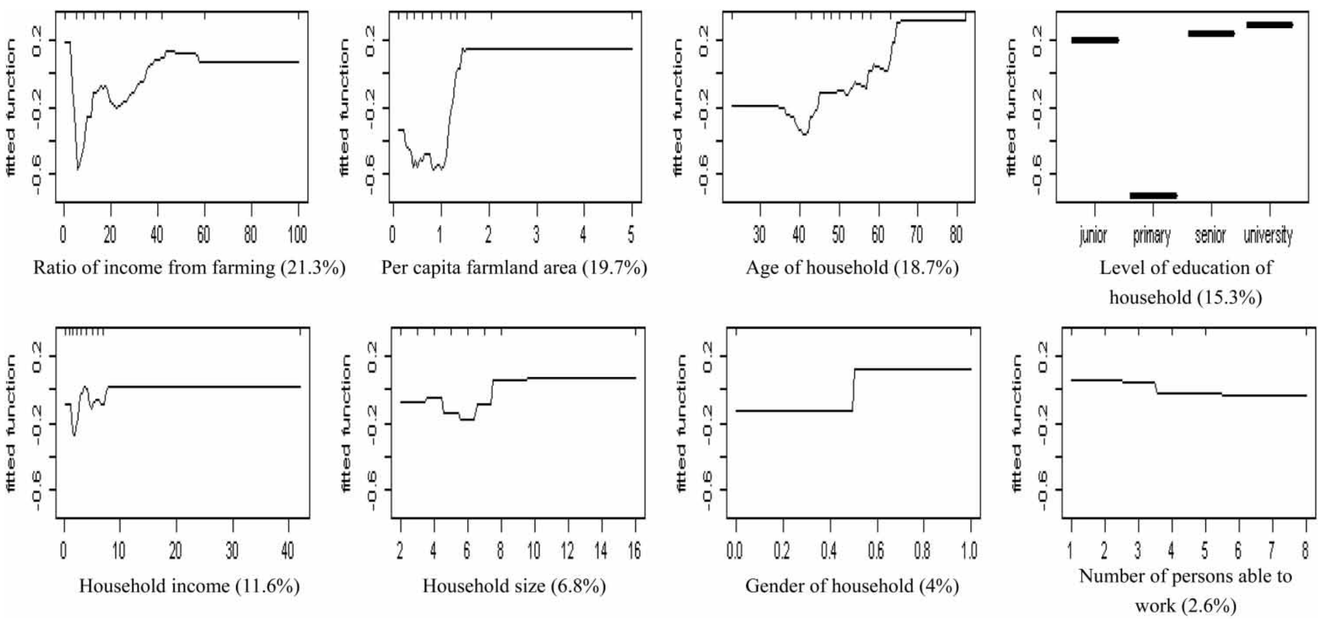

Figure 1 | Partial dependence plots for the seven most influential variables in the model for the farmer's perceptions of ANPS pollution. For the explanation of variables and their units see Table 1. Y axes are on the logit scale and are centered to have zero mean over the data distribution. Rug plots on inside top of plots show distribution of sites across that variable, in deciles.

positively correlated with farmers' awareness of ANPS pollution. This probably occurs because the crops produced by these farmers were mainly used for their own consumption; therefore, they had a vested interest in food safety. Farmers with moderate ratios of income from farming and per capita cultivated land area were usually the ones who were considering alternative employment opportunities other than farming. Their education levels were usually low, making it difficult for them to obtain new information and farming techniques; therefore, they lacked knowledge related to ANPS pollution.

The level of farmers' awareness of ANPS pollution was influenced by age, with the age of 55 years as a dividing point. For farmers under or over 55 years old, age was negatively or positively correlated with the awareness, respectively. That is, farmers in the younger age group had a lower awareness of problems related to ANPS pollution. Age had no correlation to income in any way. This seems to contradict the assumption that 'younger people have more scientific knowledge'; however, in the current situation, people who remain in the villages are mostly women, children, and the elderly (Chen *et al.* 2007). Therefore, the vast majority of agricultural production is not performed by young male farmers but by the elderly and women who could not seek employment far from home (Chen *et al.* 2011a, 2011b). Young males mostly work away from their villages year-round for high salaries; thus, they have left farming and do not help with agricultural production. This situation limits the remaining farmers' awareness of ANPS pollution to some extent.

The level of education contributed 15.3% to the farmers' awareness of ANPS pollution. Those with a low education level, such as primary school education or no formal education at all, had a severely limited awareness of ANPS pollution; the influence coefficient for level of education was −0.8. Farmers who had completed middle school, high school, or university had positive correlation with their awareness of ANPS pollution. This may be explained by the fact that the education level directly affected a person's perceptions and acceptance of new techniques and technologies. Farmers with a higher level of education thus had more knowledge related to ANPS pollution.

Household income was negatively correlated with farmers' awareness of ANPS pollution when the per capita income was less than 90,000 Yuan, but the correlation coefficient was low and fluctuated between −0.3 and 0. Households with income of more than 90,000 Yuan had a correlation coefficient close to 0, suggesting no correlation. Household income was associated with level of education to some extent, because most families with very low income couldn't afford the cost of education, training, or specialist advice and services. The population with a low education level had limited the implementation of ANPS pollution prevention and control policies.

CONCLUSIONS AND POLICY IMPLICATIONS

The above analysis shows that even though most farmers recognized that chemical products such as pesticides, chemical fertilizers, and agricultural films had adverse effects to the environment, such as river water quality, they generally lacked basic knowledge related to preventing and controlling ANPS pollution. The major factors that affected farmers' awareness of ANPS pollution were (in descending order according to their contributions): the ratio of household income from farming, per capita cultivated land area, age of the head of household, education level of the head of household, and household annual income. Therefore, from the perspective of farmers, the following measures could be taken to improve the prevention and control of ANPS pollution.

First, modern agriculture techniques should be developed to promote large-scale farming and increase the economic benefits of agricultural production. The ratio of income from farming and the per capita cultivated land area were the two factors with the greatest effects on farmers' awareness of ANPS pollution. Therefore, developing modern agriculture techniques, promoting large-scale farming, and enhancing the economic benefits of agricultural production could effectively raise farmers' awareness of ANPS pollution and, therefore, improve efforts to prevent and control ANPS pollution. According to the policy of the family-contract responsibility system in China, arable lands are assigned proportionally to the population of the family. Large-scale farming can only be achieved by renting others' contracted-farmland with a certain amount of rent. Farmers should be encouraged to conduct large-scale farming. The government can implement policies that benefit farmers with large areas of cultivated land, such as taxation-related incentives. Modern and scientifically sound agricultural production techniques should be introduced to farmers.

Secondly, public awareness campaigns related to the prevention and control of ANPS pollution should be conducted to raise farmers' awareness of the related problems.

Although most farmers recognized the dangers of ANPS pollution, they generally lacked knowledge related to its prevention and control, and they also lacked knowledge of scientifically sound farming techniques. Therefore, local governments need to put more effort into conducting public campaigns designed to educate farmers about ANPS pollution. Local governments can use multiple methods, such as providing lectures or brochures, or by paying for television, radio, and billboard advertising to help farmers gain a more comprehensive perception of pollution associated with commonly used pesticides, fertilizers, and agricultural films. This will improve farmers' awareness of the need for environment protection and their knowledge of scientifically sound farming. In addition, local governments can invite experts to teach farmers the proper usage of pesticides, chemical fertilizers, and agricultural films, and to further implement the soil-testing and formulated fertilization technology.

Thirdly, the methods of promoting the application of science and technology in agricultural production should be reformed to help farmers implement scientifically sound use of chemical fertilizers and pesticides. ANPS pollution prevention and control requires complex and long-term efforts; therefore, it is essential that many farmers master the techniques of proper usage of chemical fertilizers and pesticides. As mentioned above, age was considered to be a key affecting factor. Age influenced the level of farmers' awareness of ANPS pollution with 55 years of age as a dividing point. For farmers under or over 55 years old, age was negatively or positively correlated with the awareness. Currently, most people who remain in the villages and work in the farmlands are between 55 to 65 years old. Most of them have a low education level, which makes it difficult for them to understand and accept new knowledge and techniques. Furthermore, problems exist in the methods currently used to promote the application of sound science and technology in agricultural production.

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