Human–Wildlife Interactions 14(2):273–286, Fall 2020 • digitalcommons.usu.edu/hwi

Role of farmer knowledge in agro-ecosystem science: rice farming and amphibians in the Philippines

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Abstract: Rice (*Oryza sativa*) agriculture provides food and economic security for nearly half of the world's population. Rice agriculture is intensive in both land and agrochemical use. However, rice fields also provide aquatic resources for wildlife, including amphibians. In turn, some species may provide ecosystem services back to the farmers working in the rice agroecosystem. The foundation for understanding the complexity of agroecosystem–human relationships requires garnering information regarding human perceptions and knowledge of the role of biodiversity in these rice agroecosystems. Understanding farmer knowledge and perceptions of the ecosystem services provided by wildlife in their fields, along with their understanding of the risks to wildlife associated with agrochemical exposure, can inform biodiversity preservation efforts. In June and July 2014, we used focus groups and structured and semi-structured interviews that engaged 22 individuals involved in rice agriculture operations in Laguna, Philippines, a village close to the International Rice Research Institute in Los Baños, Philippines, to learn more about farmer perceptions and knowledge of amphibians in their rice fields. We found that many, though not all farm workers (managers, tenants, and laborers) noted declines in amphibian populations over time, expressed how they incorporated frogs and toads (Anura) into their daily lives, and recognized the value of amphibians as ecosystem service providers. Specifically, farmers noted that amphibians provide pest-management through consumption of rice pests, act as biomonitors for pesticide-related health outcomes, and provide a local food and economic resource. Some farmers and farm workers noted the general cultural value of listening to the "frogs sing when it rains." Overall, our findings demonstrate that farmers have an understanding of the value of amphibians in their fields. Future efforts can support how engagement with farmers and farm workers to evaluate the value of wildlife in their fields can lead to directed education efforts to support biodiversity conservation in agroecosystems.

Key words: agriculture, amphibians, Anura, ecosystem services, ethnography, frog, human dimensions, integrated pest management, *Oryza sativa*, pesticides, Philippines, rice

Rice (*Oryza sativa*) agriculture supplies a fundamental food to nearly half of the world's population (Global Rice Science Partnership, [GRiSP] 2013, Muthayya et al. 2014). Asia produces 88% of the global harvest of rice (Redfern et al. 2012). Rice is the food staple of the Philippines. The Philippines is the eighth highest producer of rice globally, with annual production approximately 16 million tons (GRiSP 2013). However, because of the intensive land use necessary for rice agriculture, which in highly productive lowland or wetland environments is mainly grown in a monoculture, environmental degradation impacting biodiversity is a high risk (Bhullar 2015). Rice crops grown in mesic or wetland environments may provide aquatic habitats that support wildlife biodiversity, which can contribute to sustainable rice production (Lawler 2001, Luo et al. 2014).

Different amphibian species serve different

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roles in acting as supports or possible inhibitors of successful rice yield (Shuman-Goodier et al. 2019), and farmer practices can potentially provide a negative impact on amphibian populations. In tropical systems, rice is the dominant crop during the monsoon season, and human-modified wetlands are an important habitat for biodiversity given that 35% of wetlands have been lost since 1970 (Ramsar Convention on Wetlands 2018).

Amphibians are one of the most endangered vertebrate clades on the planet, and scientists are only just beginning to understand the ecosystem services amphibians provide in both natural and agricultural settings by acting as biomonitoring, economic and/or cultural resources (reviewed in Stuart et al. 2004, Valencia-Aguilar et al. 2013, Hocking and Babbitt 2014, Alroy 2015). Amphibians provide health and economic services by reducing zoonotic insect vector populations and consuming agricultural crop pests or providing provisioning as a food or market resource (Hocking and Babbitt 2014, Shuman-Goodier et al. 2019). Amphibians act as important sentinels for pesticide toxicity to ecosystem and human health (Park et al. 2001, Park and Propper 2002, Attademo et al. 2016, Shuman-Goodier and Propper 2016). Humans also value amphibians in many parts of the world as a cultural resource, where these animals have a long history in art, culture, and mythology (Hocking and Babbitt 2014, Crump 2015).

Research into the interactions between humans and wildlife in agricultural systems has focused primarily on conflicts between the needs for human food resources and wildlife that act as pests or other sources of socio-economic impact (Ezealor and Giles 1997, Sudarmaji et al. 2010). For example, Tancoigne et al. (2014) reviewed the literature for socio-agroecosystem studies and found few that clearly integrated these service linkages with wildlife, although several studies identified the need for such human–wildlife integration, especially in agricultural systems outside the developed world (Elphick et al. 2010, Stafford et al. 2010, Luo et al. 2014, Tekken et al. 2017). However, there is growing literature regarding the ecosystem services some wildlife provide within the context of agroecology. Feintrenie et al. (2010) found the main drivers of farmer land use practices in Indonesia were economic, suggesting that efforts to support biodiversity need to be clearly linked to economic gains for them to be successful. A study within South Korea's Civilian Control Zone found that farmers had concerns about the impact wildlife conservation had on farming resources and rice value (Kim et al. 2011). In Japan, the effectiveness of wildlife-friendly practices regarding the crested crane are most readily implemented when the economic burden on the farmers is minimized (Tsuge et al. 2014). Finding solutions combining rural stakeholders and wildlife needs is essential for positive biodiversity outcomes.

Rice is a staple crop in the Philippines and accounts for 25% of household food expenditure (Philippine Rice Research Institute 2016). There are 2.5 million households who obtain income from rice in the Philippines (Gonzales 2013). Thus, rice is crucial not only for the national economy, but also for Filipino economic and social systems. Rice agriculture in the Philippines consists of small operations, where farmers manage 1.42 ha on average producing wetland rice (Philippine Rice Research Institute 2016). Many amphibian species use rice fields as habitat in the absence of natural wetlands (Naito et al. 2012), but little is known about whether farmers value the amphibians as a resource.

Understanding the complex interactions between rice agriculture and wildlife requires an integrated biological and social science approach. Research incorporating an understanding of how humans interact with animals and ecosystems is crucial for tracking the impact of agricultural practices on ecosystems, reducing pathogens and epidemics, and protecting and supporting global food production (Destoumieux-Garzón et al. 2018).

In this study, our goal was to understand farmer perceptions and experiences with amphibians in rice fields in Laguna Province, Philippines. We used a mixed methods approach, incorporating focus groups, surveys, and individual interviews to accomplish this goal. Results from this approach and these methods may help inform broader efforts supporting sustainable practices for rice agriculture and provide a broader model for understanding not only the conflicts between wildlife and farm stakeholders, but also for evaluating the ecosystem services some wildlife may provide that can contribute to the global One Health initiative (Lebov et al. 2017).

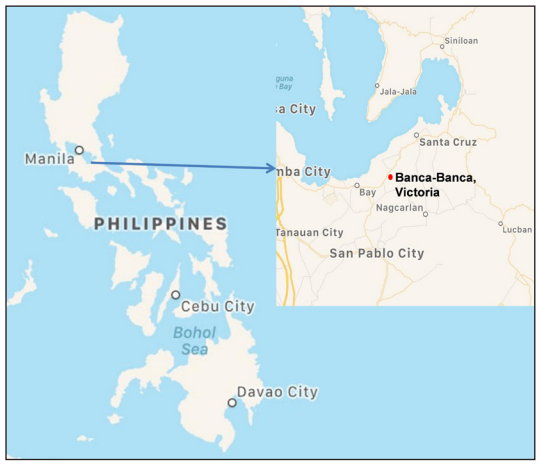

Figure 1. Map of the Philippines indicating the study site in 2014: Banca-Banca, Victoria, Province of Laguna.

Study area

We conducted our study in the barangay (administrative division) Banca-Banca, a village in Victoria, Laguna, Philippines (Figure 1) with a population of approximately 3,837 people within a larger population of >39,000 people in the province (Philippine Statistics Authority 2015). The primary language spoken is Tagalog, and most people also speak at least some English. The climate is tropical monsoon with the main rainfall from June to December. The study site is dominated by lowland irrigated rice land with 2 cropping seasons per year: January to May, and June to October. Irrigation water is supplied to the fields by manmade canals. Small plantations of bananas, coconuts, and vegetables, primarily for personal use, are planted near the houses. The area is close to the Laguna de Bay lake, and residents are also involved in fish and duck farming.

Methods

Recruitment and sampling

In June and July 2014, we selected 22 participating farmers (6 women, 16 men) for our study based on information provided by the extension office of the Local Government Unit of Victoria, Laguna, the village leader from Banca-Banca, and the local farmer cooperative. Individual farmers included rice farm owners, managers, tenants, and laborers. Selection for the study was based on involvement in rice cultivation and willingness to be interviewed. All participating farmers were involved in rice production for at least 1 of the 2 growing seasons (wet/dry) per year. Rice production responsibilities ranged from overseeing the rice fields, managing the pesticide spraying schedule, cultivating and planting seeds, transplanting young rice plants, cutting weeds, and harvesting, drying, and selling the rice. We used purposive sampling to explore cultural knowledge and expertise regarding amphibians as rice pest predators. Gender-specific roles in rice farming usually means that women are mostly involved in crop establishment, weeding, and harvesting (Food and Agriculture Organization of the United Nations [FAO] 2000, Lu 2007). Men are involved in the other tasks, particularly pest management. Hence, there were more men than women who were willing to be interviewed regarding amphibians in the rice fields. General demographics of the participants in the study are provided (Table 1).

Participants in our study managed rice plots ranging from 0.25–3.0 ha. To supplement incomes, farmers had vegetable gardens, jobs in local government, and external financial resources from family members working in Manila, Philippines, as well as internationally. All participating farmers either owned or worked on rice farms and had farmed for at least 5 years.

Focus groups, surveys, and interviews

We used a mixed-methods research design including 22 structured interviews with surveys, 5 semi-structured in-depth interviews, and 2 focus groups (N = 12 total farmers) to understand farmer perceptions and knowledge of amphibians in the region. A researcher and an accompanying interpreter conducted interviews and focus groups in English and Tagalog. Tagalog is the primary language at this site.

We used structured interviews to identify which amphibian species farmers observed in their fields and assess their perceptions of the general value of frogs and toads (anurans). We developed a structured interview instrument that included 8 Likert scale questions about different species. We asked participating farmers to review a set of photographs selected based on recognition of the species they are likely to see in their fields (A. Diesmos, National Museum of the Philippines, personal communication; see list of species in Table 2). We followed

Table 1. Demographic and socio-economic characteristics of farmer participants (n = 22) interviewed in Laguna, Philippines, 2014.

Variable	Women	Men	Total
n	6	16	22
Mean age	51	57.6	55.8
Mean education	10.8	9.2	9.6
Married/widowed	6	14	20/22 (91%)
Farm owner	2	5	7/22 (32%)
Farm manager	2	0	2/22 (9%)
Farm tenant	2	9	11/22 (50%)
Farm laborer	0	2	2/22 (9%)
Years reported farming			
>5	1	3	4/22 (18%)
6–10	0	2	2/22 (9%)
11–20	3	2	5/22 (23%)
<21	2	9	11/22 (50%)

Table 2. List of frogs and toads used in photos provided to farmer participants in Laguna, Philippines, 2014. N = Native species, I = Invasive species, and LC = Least concern.

Species	Common name	Family	N/I	IUCN Red List status	Amphibiaweb URL
Rhinella marina	Cane toad	Bufonidae	I	LC	https://amphibiaweb.org/species/229
Fejervarya moodiei	Crab-eating frog	Discroglossidae	N	LC	https://amphibiaweb.org/species/7818
Fejervarya vittigera	Luzon wart frog	Discroglossidae	N	LC	https://amphibiaweb.org/species/4805
Hoplobatrachus rugulosus	AsiFan Peters frog	Discroglossidae	I	LC	https://amphibiaweb.org/species/4714
Occidozyga laevis	Puddle frog	Discroglossidae	N	LC	https://amphibiaweb.org/species/4849
Kaloula picta	Narrowmouth painted toad	Microhylidae	N	LC	https://amphibiaweb.org/species/2156
Kaloula pulchra	Asian painted frog	Microhylidae	I	LC	https://amphibiaweb.org/species/2157
Polypedates leucomystax	Asian brown treefrog	Rhacophoridae	N	LC	https://amphibiaweb.org/species/4479

structured interviews with an activity asking farmers to list the species of frogs and toads they observed in their fields (Bernard 2018).

We used semi-structured interviews to supplement our understanding of farmer perceptions of human–amphibian interactions. Semi-structured interviews allow researchers to ask open-ended and exploratory questions leading to additional depth and context in a conversation style between researcher and participant (Bernard 2018). The lead researcher and interpreter conducted these conversational, guided interviews with selected farmers for 1–2 hours in their homes or near their rice fields. Inter-

views allowed researchers to ask farmers about their multi-sensory perceptions of frogs and toads and to delve more deeply into farmer perceptions of the function of amphibians in their fields. Interview questions were designed to explore farmer interactions with amphibians, observations about amphibians in fields, and perceptions related to pesticide application and amphibian populations. We also audio-recorded, transcribed, and translated each interview. Although we only collected 5 semi-structured interviews, the depth of the information obtained during those activities and in analysis informed our other methods.

Our mixed-methods research design also included focus groups. The focus groups allowed us to understand consensus and disagreement between a set of selected participants that further informs a stronger understanding of data collected through other methods (Bernard 2018). We developed a guide for focus group interviews that asked questions about perceptions of different amphibian species in their rice fields, self-reported amphibian practices including amphibian consumption, and perceived benefits of amphibians to compare against data collected through semi-structured interviews. We also audio-recorded, transcribed, and translated each focus group, as well as observed and documented interactions that took place in the group indicating agreement and disagreement between farmers.

Data analysis

We used a mixed-methods analysis design to identify qualitatively emergent and quantitatively measurable results (Creswell 2014). We identified overlapping themes in a field journal on initial patterns to develop a coherent logic for the categories and themes and developed a code list based on external research questions and themes that emerged during semi-structured interviews (Creswell 2014). We then applied these themes in the coding software Atlas.ti to all quantitative and qualitative data, a field notebook, interview summaries, transcripts, and survey results to understand results of each method and to triangulate themes between methods. Triangulation of multiple methods obtained through different datasets allowed us to compare and corroborate data to enhance and elaborate on overall findings and understand patterns comprehensively (Patton 2002). Triangulation also allowed for validation of consensus and identification of inconsistencies in the full dataset (Trotter et al. 2001). We selected themes to report here that were salient in analysis of mixed-methods design. All participants received and signed a Human Subject Consent Form translated into Tagalog, which outlined the project purpose, explained the procedures, confidentiality, and benefits and risks of participation in accordance with ethical guidelines of research and approval by Northern Arizona University's Institutional Review Board under Human Subjects Protocol #598482-4.

Results

We organized our results according to 2 investigated and emergent themes from analysis of mixed-methods data collection with quantitative and qualitative findings. Themes included farmer perceptions of amphibians with regard to: (1) population changes over time, and (2) providers of ecosystem services. We also included findings on amphibians as food sources and connections between political economic context and the environment. We selected quotes from interview transcripts as illustrative of the larger dataset.

Perceptions of amphibian population trends

Farmer responses to both surveys and structured interviews provided variable perceptions regarding whether populations were changing and whether pesticide use affected amphibian health.

Structured interviews with surveys results. Nine of 22 participating farmers (Table 1) reported decreased amphibian populations in the past 5–10 years, 3 farmers thought they had increased, and the remaining 10 farmers were evenly split between reporting that populations were stable or that they did not know. Fifteen participants stated that chemical pesticides affect frog populations, and 12 participants indicated that toads were affected. The rest disagreed and thought that neither group was affected.

Focus group and semi-structured interview outcomes. Results from these data collection methods were layered. Survey results showed changes in anuran populations over time, and this was reflected in exploratory interviews as well. Examples of these observations included

farmer memories of catching sacks full of native frogs as young people and additional observations that they can no longer catch as many frogs to eat. Although limited, there is a market for selling edible frogs in the area.

The farmers reported observing life, death, and movement of frogs and toads in relationship to chemical spraying and timed their sales and consumption of amphibians according to the introduction of chemicals into rice fields. The farmers reported observations that amphibians were affected by chemical pest management, stating in interviews that frogs appear dazed after spraying, and that eggs and tadpoles die. One participant stated that when they spray the pesticides, the frogs "breathe it in and cough." Other participants said that native frogs eat the insects that are affected by pesticides so they are also affected by the poisoned insects.

While in the field, researchers spoke with a farmer who pointed to dead frogs and the oily-looking residues left behind from spraying chemical pesticides. He explained that when he sprays pesticides, some frogs and toads leave, and chemicals penetrate the eyes of remaining frogs and kill them. Farmers who said toad populations are not affected by chemical pesticides remarked, "they have thicker skin," "they are poisonous, so they are not affected," and "toads leave when they spray [chemical pesticides]." Some farmers disagreed that "pesticides impact amphibians," because they believe that amphibians leave the rice fields when they spray.

Whether because of overt toxicity or because the frogs leave the fields, some farmers related that there was a pesticide-related frog population decline, which reduced the number of frogs that they once caught and consumed. One farmer lamented the reduction in frog population and his ability to consume or sell frogs for income following the introduction of pesticides. Another said: "During those days, we were very happy because aside from the fact that we could eat the frogs, we could also sell it, getting more income. Before, whenever we harvest and catch frogs, I will let my wife prepare the frogs...I was wondering why the frogs are few, even though I caught a lot."

The same farmer said that vendors in a neighboring village may sell frogs from the plots with pesticide contamination, indicating the possibility that people consume frogs after pesticide use.

Perceptions of amphibians as ecosystem services

Farmers generally perceived amphibians as beneficial to their farms by acting as bioindicators of overall environmental health and providing pest management services.

Structured interviews with surveys results. Twenty-one of 22 farmers answered the question "frogs are beneficial for the farming environment" positively, and 17 of 22 farmers conveyed that toads (the introduced cane toad [*Rhinella marina*]) help the farming environment (Figure 2A). Farmers indicated that amphibians in their fields act as bioindicators of environmental health (Figure 2B) and noted that amphibians are negatively impacted by pesticide use (Figure 3A). With regard to non-chemical crop management, 19 participants agreed or strongly agreed that frogs and toads are useful for insect management (Figure 3B).

Focus group and semi-structured interview outcomes. Farmers noted that amphibians in their fields provide several ecosystem services. As biomonitors for environmental health, as stated above, farmers recognized that the frogs' responses to pesticide application was of concern. In response to the question, "do you notice if there are any changes in the population of the frogs whenever you spray pesticides?" 1 participant discussed stopping the use of a specific pesticide because of observations of dead frogs and said that in general, he saw dead frogs in his rice field after using insecticides. The farmers also believed that the frogs provided a direct service to the quality of the farming fields through their effects on the soil, nutrient cycling, and pest management services. Farmers discussed the role of frogs in soil cultivation, documenting their perceptions of the interactions of amphibians in keeping fields healthy. Some farmers described how frogs and toads helped circulate nutrients in the soil by swimming, burrowing, and moving throughout the rice paddies. One farmer described this outcome by stating: "Frogs in the field, they help crush/mash the soil to neutralize it easily (loosen the soil for easier cultivation) because they live under the soil, right? During the dry season they live under the soil, then they come out during the rainy season so they help the soil to neutralize."

Most of our respondents viewed frogs and

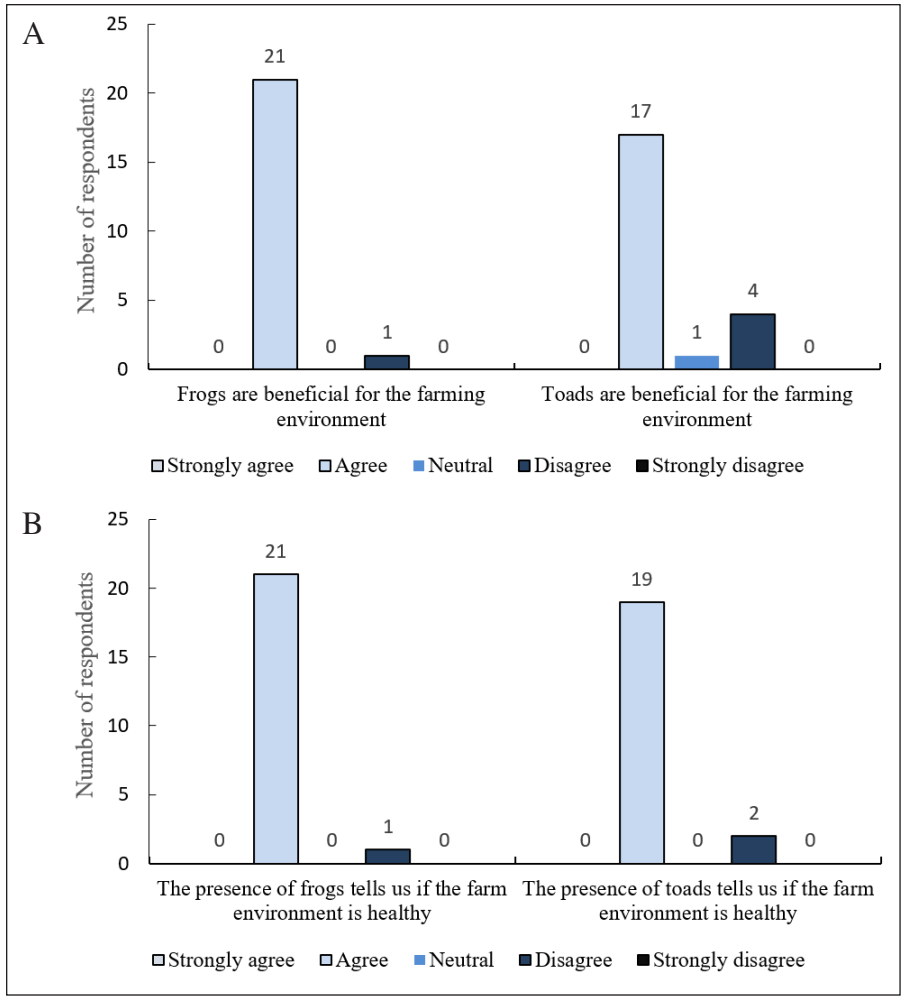

Figure 2. Responses of farmers in Laguna, Philippines to the questions regarding their belief about whether frogs and toads are beneficial to the environment (A) and whether their presence is an indication of a healthy farm environment (B). Surveys were conducted in June and July 2014. *N* = 22 respondents.

toads as effective managers of pests because they ate insects in the rice paddies. One interview participant noted that amphibians eat "black bugs," a common rice pest. Farmers also discussed how frogs and toads support pest management not only in the fields, but also around their homes. One participant recalled how cane toads helped them to manage insects around the house and in their rice fields, recalling: "toads eat moths, those that flock the light," while pointing to the street lamp across the dirt path in front of their house. This same farmer explained that the moths die and frogs eat them much to the entertainment of family members who watch this wildlife activity from home and observe the same species in the rice fields during the day. The surveys also demonstrated that farmers utilize amphibians as a food and market resource as mentioned by the farmer who noted the decline in populations indicated above.

Amphibians may also have an aesthetic significance. Farmers provided in-depth reflections on how and where frogs and toads are associated with a pleasant sound in the environment linked to their everyday lives. Farmers said the sound of frogs harmonizing signals oncoming rain. The embodiment of farming includes listening to environmental sounds in ways that shape farmer understandings of their rice crops reflected in this farmer's comment: "…we know if it's going to rain, they sing."

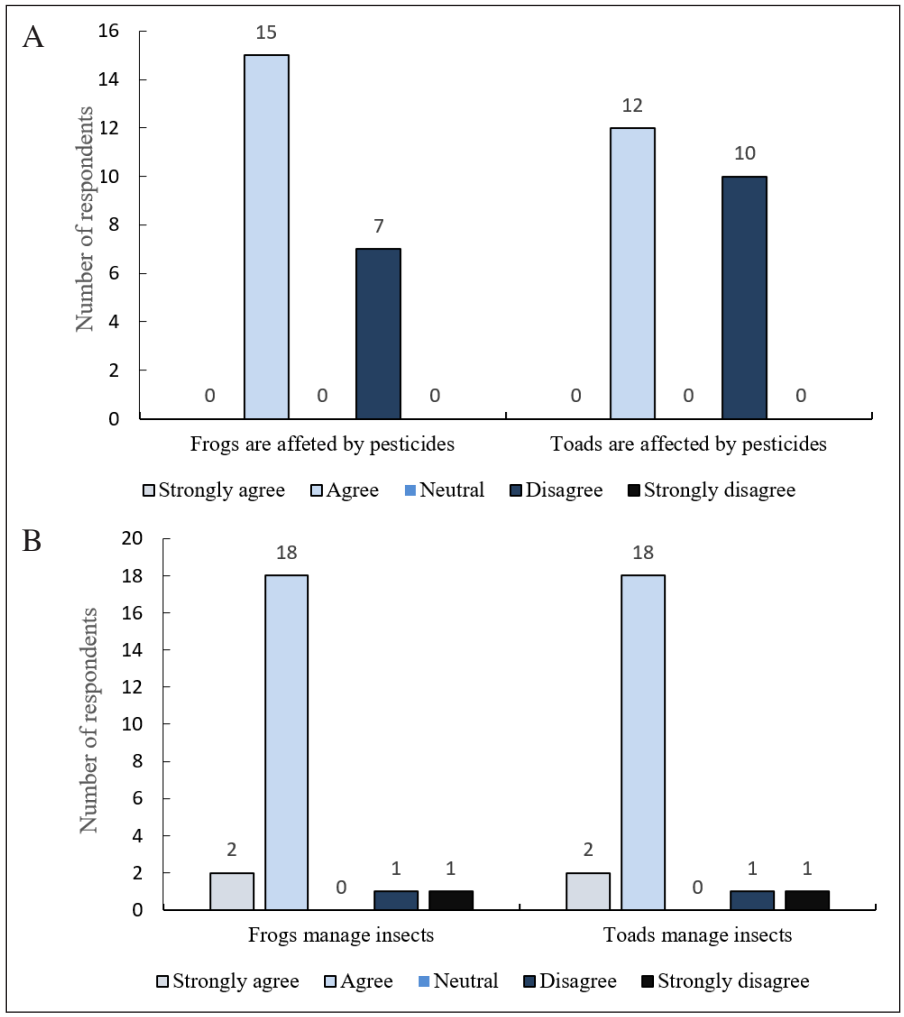

Figure 3. Perceived beliefs of farmers in Laguna, Philippines regarding the impact of pesticides on amphibians and toads (A) and perceived knowledge regarding whether amphibians help manage insect pests of rice (B). Surveys were conducted in June and July 2014. *N* = 22 respondents.

Other observations

Negative associations with amphibians for the farmers included those who disagreed with the statement that "toads help the farming environment." These farmers qualified their responses by stating that toads are poisonous, overpopulated, or inedible. Negative perceptions, specifically of the cane toads, included the idea that the species may have been introduced by Japan during World War II to kill pests at a plant nursery near Manila. It is these farmers' understanding that Japan played a significant role in changing contexts in the Philippines, from the introduction of the cane toad to political conflicts and memories of extreme violence during wartime. One participating farmer said, "cane toads are poisonous, there are too many of them, they cannot be eaten, and they take over the native frog populations that the farmers used to eat." Another farmer said that *palakang baka* (the cow frog [*Kaloula pulchra*]) was introduced by a government institute. The cow frog was also disliked by farmers who called it a "loud frog" and said it was not edible. These results suggest that farmers' perceptions of wildlife on their farms include complex associations between competing geopolitical, food resource, and agricultural needs.

Discussion

Filipino farmers in this study demonstrated knowledge of anuran amphibian species present

in their fields. The farmers indicated mixed responses about how amphibian populations have changed through time but generally believed that the species inhabiting their fields provide valuable ecosystem services, including pest management, acting as bioindicators for environmental health, provisioning, and aesthetics.

Hocking and Babbitt (2014) and Valencia-Aguilar et al. (2013) described the ecosystem services amphibians provide, and many apply to wetland rice agriculture. Farmers in our survey stated that amphibians provide pest management and additional food and economic security, and the declines in population levels were considered a loss to these services. Previous studies have also identified the ecosystem services that amphibians provide in the context of rice agriculture. Teng et al. (2016) demonstrated that adding frogs to rice plots significantly reduced the number of rice pests and pathogens, improved soil chemistry, induced shifts in the soil microbiome, and importantly, increased rice yield over fields that contained no frogs. Khatiwada et al. (2016) verified that frogs in rice fields consumed both rice pests and vectors of human disease. Shuman-Goodier et al. (2019) found that a native species of frogs in rice fields in the Philippines ate a predominance of rice pests, although this same study showed that the introduced and invasive cane toad consumed a large number of predators of rice pests, and therefore may have a negative impact on pest management. Farmers in this study believed all species eat rice pests and are potentially beneficial. This result suggests that farmer knowledge does not always align with the actual impacts of wildlife in their agricultural systems as demonstrated in Shuman-Goodier et al. (2019). These studies suggest that some, though not all species of amphibians play an important role in containing pests in rice fields, and their presence provides ecosystem services in the fields that can lead to increased rice yields even beyond their ability to manage insect pests.

Farmers in this study also reported concerns about the reduction of consumable frogs in their fields and suspected that the decline was a result of pesticide use. Frogs as a food resource were identified as important for the farmers and their families as a source of nutrition and economics, and the relationship between frog consumption and pesticides in surrounding areas was a concern. Frog species as important economic and food resources has been reported in other countries. For example, in Laos, amphibians as well as other wildlife make up a significant portion of the protein consumed by rural rice farmers (Nurhasan et al. 2010). In Madagascar, frogs provide significant income to people who harvested them from local forests and then sell them in towns to local restaurants (Jenkins et al. 2009). In Burkina Faso, Africa, local ethnic groups have described both the food and medicinal value of frogs in their environment (Mohneke et al. 2011). Conservation education efforts in the future may focus on the economic, cultural, medicinal, and culinary value of frogs to farmers and may provide a motivating factor for reducing pesticide use.

Amphibians also support ecoservice systems that range outside of their ability to provide food and pest management services. For example, we found that Filipinos use cane toads as tourist consumer products that they sold as small purses locally and in larger outlets (C. Propper and B. Howard, personal observation), demonstrating economic uses for these animals unrelated to being a food resource.

Amphibians also act as biomonitors for wildlife and human health. Some farmers in Laguna reported displeasure related to population declines in numbers of amphibians. This local-level observation mirrors the declines amphibians encounter across the globe (Stuart et al. 2004, Alroy 2015). The causes of these declines are complex and probably integrated, but include exposure to pesticides, pathogens, and habitat destruction along with issues associated with climate change. In rice fields, cropping practices such as transplanting and pesticide application can affect population numbers of amphibian species.

In the Philippines, exposure to the herbicide butachlor at levels found in environmental water samples influences development of the cane toad but has little effect on the native species, Luzon wart frog (*Fejervarya vittigera*; Shuman-Goodier et al. 2017). Two pesticides used in France, the insecticide alphacypermetrine and the herbicide oxadiazon, dramatically influence the number of Iberian green frogs (*Pelophylax perezi*) commonly found in rice fields (Mesleard et al. 2016). Recent meta-analyses have demonstrated that exposure to chemical pollutants

clearly affects amphibian health, development and survivorship (Egea-Serrano et al. 2012, Shuman-Goodier and Propper 2016). These studies demonstrate the value of amphibians as biomonitors for both wildlife and human health in some agricultural settings.

Lastly, there are cultural and aesthetic aspects amphibians provide to local farmers. With regard to positive associations, farmers in this study reported specific benefits these vertebrates presented to them in their fields and discussed ways in which the sounds and sensory experiences associated with these amphibians related to their own sense of place. Memories of frog and toad vocalizations over time and associations between certain species and wartime show how farmer relationships with their environment are important for in-depth understanding of human–amphibian relationships. Amphibians have played an important part of culture throughout history (Crump 2015), and our findings support the importance of acknowledging these sometimes less tangible, but nevertheless important ecosystem services derived from wildlife populations in the agroecosystem.

There were also a few factors that farmers reported as negative aspects of amphibians, including the annoying sounds that 1 invasive species (*Kaloula pulchra*) made in particular. Perceptions of the cane toad as an invasive species are connected to the geopolitical history and some expressed skepticism over the reason for their introduction. In general, none of the farmers viewed amphibians as negatively as they view wildlife that more directly affects their crops, such as mice, rats (Stenseth et al. 2003, Flor and Singleton 2011), and some bird species (Lorenzon et al. 2019) as examples. These results demonstrate that farmers can have nuanced relationships with the wildlife in their fields.

Not surprisingly, an overarching theme for wildlife conservation in agricultural settings is that farmers' economic needs will be considered as paramount if they are to practice "wildlife friendly" farming practices (Yokomizo 2014). Therefore, central to supporting these conservation strategies is understanding how current farm practices influence wildlife and how wildlife influence the farmer's economic outcomes. This strategy has been applied to other vertebrate species that are commonly found in rice fields. Singleton and Flor (2015) reviewed sociological and communication aspects of rodent management in agricultural settings (mainly rice) in developing countries, where some rodent species provide ecosystem benefits in such landscapes. Bird et al. (2000) found that supporting aquatic bird habitat when crops are fallow leads to an increase in rice straw decomposition and decreases the need to burn and tillage, both of which reduces costs and pollution. In the Philippines, ecological engineering that includes high diversity vegetable patches increases bird diversity, provides extra food and economic resources, and does no damage to rice yield (Horgan et al. 2017). In the Sahelian region of Africa, indigenous peoples' attitudes toward vertebrates found that although 36% of the species were perceived as pests, >50% of the species also serve as food, cultural, medicinal, or aesthetic purposes (Ezealor and Giles 1997) that have a positive impact on the quality of life of these people. Notably, more than half of the communities in that study stated they would tolerate at least a 15% crop loss to preserve these wildlife-provided beneficial ecosystem services. These studies suggest that conservation efforts aimed to protect amphibian species may benefit both farmers and biodiversity, especially in tropical agricultural landscapes (Ramsar Convention on Wetlands 2018). These studies demonstrate that working with local farmers to change farming practices may lead to improved economic and cultural outcomes.

Given that amphibians are a critically threatened clade (Stuart et al. 2004, Alroy 2015), in part as a result of heavy pesticide use (Shuman-Goodier and Propper 2016), studies that evaluate the value of this group to local populations may lead to culturally appropriate education and conservation efforts. Farmers across the globe use pesticides to manage weeds, diseases, and pests in their fields. While many farmers know which non-crop species are in their fields, they do not always know the role natural enemies may play in managing these pests, nor do they always have the knowledge base to implement the best ecologically based management strategies to balance pesticide use to maximize the ecosystem services provided by beneficial species (Rahaman et al. 2018). Extension offices and education organizations can partner with local stakeholders to develop community-based participatory research plans to identify

the overall value, both economic and cultural, of threatened and endangered wildlife and follow up with collaborative educational outreach that supports both wildlife and community partners.

Although the sample size for this study is small, the value of the findings lay a foundation for ongoing mixed-methods research at the confluence of scientific and farmer knowledge of human–wildlife interactions. Understanding the relationships, both positive and negative, between farmers and the wildlife inhabiting their fields can help to enhance studies of the linkages between biodiversity and global food production by documenting perceptions and behaviors of farmers and other stakeholders.

Management implications

This study demonstrates how mixed-methods data collection adds depth to the understanding of how farmers perceive different anuran species and their potential concerns regarding how farming practices may be linked to the health of amphibian populations. This study can serve as a model for a broader understanding of how farmers and other stakeholders regard wildlife in their fields. Similar research that incorporates methods for understanding farmer perceptions of their lands may lead to the development of effective community-based participatory programs designed to support farmer productivity and wildlife conservation in locally appropriate ways.

Acknowledgments

This work was supported by the National Institute on Minority Health and Health Disparities of the National Institutes of Health under Award Number T37MD008626 to CRP and the Swiss Agency for Development and Cooperation, through the Closing Rice Yield Gaps (CORIGAP) Project # 7F08412 to GRS. We also thank J. Matienzo for providing translation support. We thank A. Diesmos for kindly providing information regarding which amphibians were likely to be found in the rice fields near our study site. None of the authors have any financial interest to declare related to the work and research presented here. Comments provided by D. Whisson, HWI associate editor, and an anonymous reviewer greatly improved an earlier version of this paper.

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