The impact of shrimp farming on water quality in Anlung Pring, a protected landscape in Cambodia

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Paper submitted 27 December 2016, revised manuscript accepted 21 March 2017.

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តំបន់ដីសើមទឹកភ្លាវផ្តល់ជាទីជម្រកយ៉ាងសំខាន់សម្រាប់សត្វស្លាបទឹក និងប្រភេទជលជាតិផ្សេងៗទៀត ប៉ុន្តែនៅភាគខាងត្បូង នៃប្រទេសកម្ពុជា តំបន់នេះកំពុងទទួលរងនូវការគំរាមកំហែងកាន់តែខ្លាំងឡើងៗ ដោយសារការអភិវឌ្ឍន៍វារីវប្បកម្ម។ តំបន់ទឹកភ្លាវភាគច្រើននៅជុំវិញតំបន់ការពារទេសភាពអន្លង់ព្រីង ដែលមានទីតាំងភូមិសាស្ត្រស្ថិតនៅខេត្តកំពតត្រូវបានកែប្រែទៅជាកសិដ្ឋានចិញ្ចឹមបង្គាដែលផ្តល់នូវក្តីកង្វល់យ៉ាងខ្លាំងថា វានឹងអាចផ្តល់ផលប៉ះពាល់ដល់គុណភាពទឹកនៅក្នុងតំបន់អភិរក្ស។ ដើម្បីធ្វើការស៊ើបអង្កេតតាមដានពីបញ្ហានេះ យើងបានប្រមូលសំណាកទឹកចំនួន ៣ខែ (ខែមករា មីនា និងខែឧសភា ឆ្នាំ២០១៦) ពីប្រាំកន្លែងផ្សេងៗគ្នាទាំងក្នុង និងក្រៅតំបន់ការពារ ហើយធ្វើការវិភាគដើម្បីវាយតម្លៃគុណភាពទឹក និងផលប៉ះពាល់នៃទឹកសំណល់ ដែលត្រូវបានបញ្ចេញពីកសិដ្ឋានចិញ្ចឹមបង្គានៅក្បែរនោះ។ កម្រិតនៃចរន្ត (conductivity) កម្រិតល្អក់ (turbidity) សំណល់រឹងរលាយសរុប (TDS) ស៊ុលផាត (SO_4) អាម៉ូញ៉ូម (NH_4-N) គីមីសាស្ត្រមានតម្រូវការអុកស៊ីសែន (COD) និងជីវសាស្ត្រមានតម្រូវការអុកស៊ីសែន (BOD) មានកម្រិតខ្ពស់ជាងកម្រិតស្តង់ដារនៅតាមកន្លែងប្រមូលសំណាកជាច្រើន ជាពិសេសកន្លែងទាំងនោះស្ថិតនៅក្នុង និងក្បែរកសិដ្ឋានចិញ្ចឹមបង្គា។ ប៉ារ៉ាម៉ែត្របី (សំណល់រឹងរលាយសរុប គីមីសាស្ត្រ និងជីវសាស្ត្រដែលមានតម្រូវការអុកស៊ីសែន) គឺមានកម្រិតខ្ពស់ខ្លាំងនៅក្នុងកសិដ្ឋានចិញ្ចឹមបង្គាដែលត្រូវបានគិតថាជាមូលហេតុនៃការបំពុល។ កន្លែងសំណាកដែលប្រមូលនៅក្នុងតំបន់អភិរក្ស ប៉ុន្តែមានទឹកដាច់ដោយឡែកពីកសិដ្ឋានចិញ្ចឹមបង្គាបង្ហាញថា កម្រិតនៃប៉ារ៉ាម៉ែត្រនីមួយៗភាគច្រើនក្បែរ និងក្នុងកម្រិតស្តង់ដារចំពោះប៉ារ៉ាម៉ែត្រដូចគ្នា។ យើងសំណូមពររកដំណោះស្រាយ ដើម្បីកាត់បន្ថយផលប៉ះពាល់នៃកសិដ្ឋានចិញ្ចឹមបង្គាទៅលើគុណភាពទឹក និងទាមទារឱ្យធ្វើការសិក្សាស្រាវជ្រាវបន្ថែមទៀតអំពីកម្រិតនៃផលប៉ះពាល់លើប្រព័ន្ធអេកូឡូស៊ី។

Abstract

Estuaries provide a critically important habitat for waterbirds and other aquatic species, but in southern Cambodia they are increasingly threatened by aquaculture development. Much of the area around Anlung Pring Protected Landscape in Kampot Province has been converted to shrimp farming and there are concerns that these farms may negatively impact water quality inside the protected area. To investigate this, we collected water samples (in January, March and

CITATION: Yav N., Seng K., Nhim S., Chea V., Bou V. & Avent, T. (2017) The impact of shrimp farming on water quality in Anlung Pring, a protected landscape in Cambodia. *Cambodian Journal of Natural History*, 2017, 49–54.

May, 2016) from five discrete locations inside and outside of the reserve and analyzed these to determine the effects of waste water from nearby shrimp farms on local water quality. Levels of conductivity, turbidity, total dissolved solids, sulphate, ammonium, chemical and biological oxygen demand were higher than recommended levels at many sampling points, especially those within and adjacent to the shrimp farms. Three parameters (coliforms, chemical and biological oxygen demand) were substantially higher within the shrimp farms, suggesting that they were the cause of this pollution. Sampling points that were in the reserve, but hydrologically isolated from shrimp farms, showed levels much closer to, and often within, recommended guidelines for the same parameters. We suggest that solutions to minimize the impact of shrimp farms on water quality, and further research on their ecological impact, are required.

Keywords

Water quality, shrimp farming, environmental impact.

Introduction

Estuaries are important ecosystems and provide critical habitat for waterbirds and other aquatic species. They are also excellent areas for aquaculture development (Hossain, 2001; Wouter & Patrick, 2003; Primavera, 2006) and land conversion for shrimp farming is a cause for environmental concern, especially in relation to water quality (Flaherty & Karnjanakesorn, 1995; Graslund & Bengtsson, 2001; Hossain, 2001; Jones *et al.*, 2001; Paezosuna *et al.*, 2003; Islam & Tanaka, 2004; Primavera, 2006; Crab *et al.*, 2007) and the subsequent potential for long-term damage to aquatic food webs (Kennish, 1997).

Many studies have reported significant environment degradation due to shrimp farming (Paezosuna *et al.*, 2003), including increased organic pollution (Bui *et al.*, 2012; Wilbers *et al.*, 2014), creation of favorable habitat for pathogenic microorganisms (Anh *et al.*, 2010), high nutrient waste (Bui *et al.*, 2012), increased phytoplankton productivity (Islam & Tanaka, 2004), removal of nutrients from culture water (Crab *et al.*, 2007), and decline of aquatic ecosystem health (Naylor *et al.*, 2000; Bui *et al.*, 2012). As a consequence, the Thai government has identified areas where shrimp farming is permitted and areas where it is banned (Flaherty *et al.*, 2000). Many shrimp farms have recently been developed along canals in coastal and inland areas in Cambodia and Vietnam (Anh *et al.*, 2010) and it is likely that these have caused dramatic declines in numbers of sarus cranes (*Grus antigone*) visiting Hon Chong in southern Vietnam (van Zalinge *et al.*, 2011). Water quality in Cambodia is protected by a sub-degree on pollution which was issued in 1999 (Royal Government of Cambodia, Sub-decree 27, 1999).

Anlung Pring Protected Landscape (APPL) is one of three protected non-breeding areas of the globally Endangered eastern sarus crane *G. a. sharpii* in Cambodia (Yav *et al.*, 2015). Most wetlands to the south of APPL have been converted to shrimp farming and the landscape has directly abutted one shrimp farm since 2013 (Yav, 2014). Concerns regarding the farms include the impact of water pollution on the wetland ecosystem of the area, especially as changes to water quality may affect growth of *Eleocharis* spp., which are the main food for the cranes (Yav, 2014; Yav *et al.*, 2015). Rigorous understanding of the influence of water waste discharged from shrimp farming is consequently required, especially regarding chemical substances that may affect the ecology of the wetland. This study consequently assessed water quality inside and outside of APPL and investigated the effects of shrimp farms on levels of pollutants entering the site.

Methods

Study site

APPL covers 217 ha in Kampong Trach District of Kampot Province (10°28′40′′N, 104°31′32′′E) in southern Cambodia, approximately one kilometre from the border with Vietnam within the lower Mekong floodplain (Fig. 1). The site is divided into two parts by a road embankment, and the northern part covers 33 ha and southern section 184 ha. As many as 342 sarus cranes foraged in the site in 2013 (Yav, 2014). The cranes mainly feed upon *Eleocharis* tubers and preferentially select areas where these occur (Yav *et al.*, 2015). The area also supports the livelihoods of surrounding communities through the provision of fire wood, wild food, tourism and livestock fodder (van Zalinge *et al.*, 2013)

The area of APPL is low-lying with an elevation range of 0.0–3.5 m above sea level and is next to a small river that experiences tidal influences, even though the site is approximately 20 km from the Gulf of Thailand (Yav *et al.*, 2015). The area around the southern section of APPL is dominated by shrimp farms, some of which are contiguous with the conservation area (Fig. 1). Waste water is regularly discharged from these shrimp farms into a canal which is influenced by tidal movements, allowing waste water to flow into the conservation area (Yav *et al.*, 2015). The eastern, northern and western sections of APPL are mainly surrounded by rice fields and settlements.

Sample collection

Water samples were collected from five discrete areas within APPL during the sarus crane feeding season on 11 January, 11 March and 16 May 2016 (Fig. 1). With the exception of one sampling area in the northern section of the reserve, all other sampling areas were hydrologically linked to the shrimp farms. The five areas comprised: 1) the northern part of the reserve (NPR), which is hydrologically separated from the rest of the reserve by an embankment and receives fresh water from northern uplands during the wet season; 2) canals inside the central section of the reserve (CIR); 3) the southern part of the reserve, which is adjacent to but separated by an embankment from the shrimp farms (SPR); 4) inside the shrimp farms (SF); and finally, 5) canals outside the reserve and adjacent to shrimp farms, which receive water from the farms and tidal flows (COR). Two points at least 200 m apart were sampled in each of the five areas every month, resulting in a total of 30 samples.

Samples were collected by filling containers with water taken from a depth of 30–50 cm (approximately the middle of the water column). Different containers were used to collect water for different analyses. Water for coliform analysis was collected in a 250 ml glass bottle, sterilized at 120°C. Water for biochemical oxygen demand tests was collected in a 1,000 ml glass bottle, filled with no air bubbles remaining. Water for total phosphorus, iron and chemical oxygen demand tests were collected in 500 ml polyethylene bottles and preserved with H_2SO_4. Water for other tests including pH, EC, turbidity, sulphate, ammonium, nitrate as nitrogen and nitrite-nitrogen were collected in 1,000 ml polyethylene bottles with no preservation. All samples were kept in ice boxes at temperatures of 4–6 °C.

Sample tests and data analysis

Samples were tested by the Department of Hydrology and River Works of the Ministry of Water Resources and Meteorology for pH, conductivity, turbidity, salinity, total dissolved solids (TDS), sulphate (SO_4), ammonium (NH_4-N), nitrate as nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (TP), iron (Fe), coliforms, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and aluminum (Al).

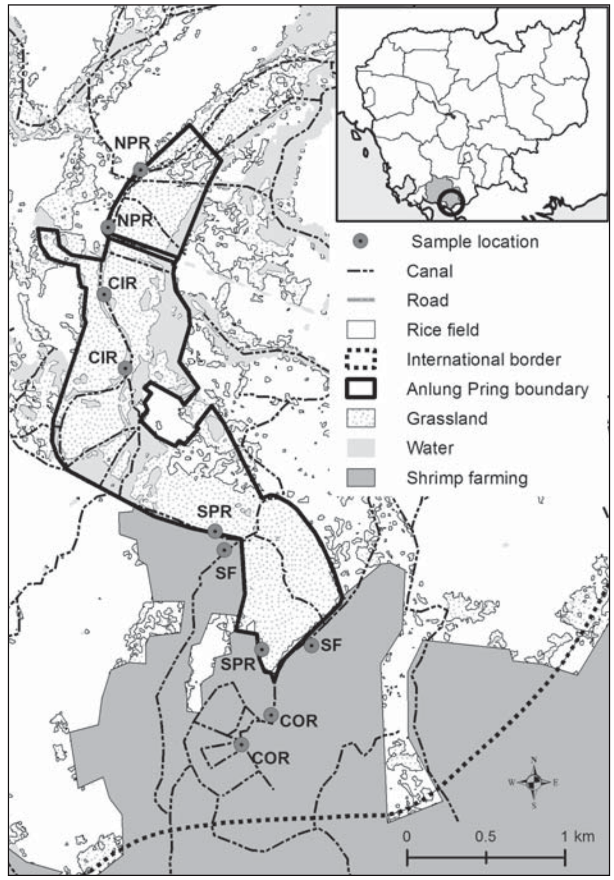

Fig. 1 Locations of water sampling at Anlung Pring Protected Landscape, Kampot Province. SF = shrimp farm, COR = canal outside reserve, SPR = southern part of reserve, CIR = canals inside reserve, NPR = northern part of reserve.

The mean values from the three sampling events at each sample location were calculated. Data normality was tested using one-sample Kolmogorov-Smirnov tests and Shapiro-Wilk tests (Dytham, 2011; Stowell, 2014). A one-way analysis of variance (ANOVA) was used for group comparisons and Tukey HSD tests for pairwise comparisons (Stowell, 2014) if data were normally distributed (p>0.05), whereas Kruskal-Wallis tests and Mann-Whitney U tests were used if data were not normally distributed (p<0.05). The statistical packages SPSS vers. 20 and R vers. 3.3.2 were employed for this purpose.

Results

Significant variation was found among the five areas sampled in terms of pH, conductivity, salinity, TDS, NO_3-N, coliforms, COD and BOD (all values of p<0.01) (Table 1). No significant differences were found between

Table 1 Water quality parameters (Mean ±SE) sampled in and around Anlung Pring Protected Landscape in 2016. Bold font indicates significantly different values, and dashes indicate a parameter was not recorded. SF = shrimp farm, COR = canals outside reserve, SPR = southern part of reserve, CIR = canals inside reserve, NPR = northern part of reserve.

Parameter	Mean ±SE					Advised levels	Associated references
	SF	COR	SPR	CIR	NPR		
pH	8.00 ±0.14	7.02 ±0.09	7.10 ±0.14	6.62 ±0.03	**2.30 ±0.77**	6–9	Anh *et al.* (2010); Bui *et al.* (2012)
Conductivity (mS/cm)	49.85 ±6.78	40.38 ±6.61	40.75 ±3.07	42.97 ±5.08	**10.15 ±6.64**	<0.01	Bartram & Ballance (1996)
Turbidity (NTU)	29.63 ±11.15	133.00 ±40.20	60.97 ±21.10	26.40 ±2.86	19.33 ±7.03	<5	Chapman (1996); WHO (2011)
Salinity (g/l)	32.98 ±4.95	25.48 ±1.93	26.65 ±2.71	27.80 ±3.72	**6.28 ±4.21**	No limit	Boyd & Green (2002)
TDS (g/l)	23.23 ±5.24	21.16 ±1.56	21.18 ±1.89	22.47 ±2.63	**5.18 ±3.38**	<0.6	WHO (1996, 2011)
SO_4 (mg/l)	1,869.28 ±451.45	1,674.00 ±392.69	1,846.20 ±482.44	1,948.87 ±622.77	757.65 ±456.83	100	Chapman (1996)
NH_4-N (mg/l)	0.19 ±0.07	0.16 ±0.02	0.27 ±0.07	0.46 ±0.12	1.95 ±0.68	<0.1	Bui *et al.* (2012)
NO_3-N (mg/l)	0.05 ±0.01	0.07 ±0.02	0.08 ±0.02	0.04 ±0.01	**0.01 ±0.00**	<0.06	Pulatsu *et al.* (2004); Bui *et al.* (2012)
NO_2-N (mg/l)	0.05 ±0.01	0.06 ±0.01	0.06 ±0.01	0.04 ±0.01	0.02 ±0.01	0.1–0.75	Boyd & Green (2002)
TP (mg/l)	0.09 ±0.04	0.15 ±0.04	0.09 ±0.02	0.05 ±0.01	0.05 ±0.02	<0.3	Boyd (2003); Bui *et al.* (2012)
Fe (mg/l)	0.63 ±0.21	0.72 ±0.05	0.88 ±0.13	1.04 ±0.12	1.87 ±0.96	0.03	Ramakrishnaiah *et al.* (2009)
Coliforms (MPN/litre)	**280.00 ±149.55**	**146.67 ±23.90**	78.33 ±26.26	76.67 ±28.60	31.67 ±15.79	<500	Anh *et al.* (2010)
COD (mg/l)	**25.48 ±2.11**	14.65 ±1.37	15.27 ±1.28	17.03 ±1.41	**7.07 ±4.16**	<3	Bui *et al.* (2012); Ly & Larsen (2012)
BOD (mg/l)	**20.72 ±4.88**	7.18 ±1.16	6.27 ±0.66	7.38 ±0.55	**2.33 ±0.86**	<6	Boyd & Green (2002); Bui *et al.* (2012)
Aluminum (mg/l)	0.03 ±0.01	0.03 ±0.00	0.06 ±0.03	0.04 ±0.01	-	0.2	Chapman (1996)

sampling areas in the remaining parameters (turbidity, SO_4, NH_4-N, NO_2-N, TP, Fe, and Al) (all values of $p>0.05$).

Compared to the northern section of the reserve, levels of conductivity, salinity, TDS, and NO_3-N were significantly higher within the shrimp farm and all hydrologically connected areas (all values of $p<0.01$). Levels of coliforms were also significantly higher within shrimp farms and adjacent canals outside the reserve compared to other hydrologically linked areas (southern section of the reserve and central canals) and the northern section of the reserve ($p<0.01$). Compared to all other areas, pH levels were significantly higher within the shrimp farms ($p<0.05$) and significantly lower within the northern section of the reserve ($p<0.01$) (Table 1). The same was true of BOD and COD (all values of $p<0.05$).

Discussion

Our results show significant variation in water quality between the shrimp farms, hydrologically linked areas and a hydrologically unconnected area in APPL. Because the northern section of Anlung Pring is hydrologically isolated from all other areas of the site by a road embankment, water quality in this section is unaffected by discharge from shrimp farms adjacent to the southern section of the reserve. Values for pH were very low in the northern section and fall outside recommended ranges for protecting farming and aquatic ecosystems (Anh *et al.*, 2010; Bui *et al.*, 2012). This may be due to the embankment separating the reserve and allowing chemical fertilizers from rice fields in northerly catchment areas to accumulate in the northern section, creating increased acidification. This is supported by the fact that levels of ammonia nitrogen (NH_4-N) were also much higher in the northern section of the site. Ammonia can acidify the environment through the release of H^+ ions during the biochemical conversion to nitrate (Schuurkes & Mosello, 1988).

Conductivity, TDS, SO_4, NH_4-N, NO_3-N, Fe, COD and BOD were higher than recommended levels for a variety of water uses at most sampling points outside of the hydrologically isolated northern section of Anlung Pring (Lloyd, 1987; Bartram & Ballance, 1996; Chapman, 1996; World Health Organization, 1996, 2011; Boyd & Green, 2002; Ramakrishnaiah *et al.*, 2009; Bui *et al.*, 2012; Ly & Larsen, 2012). In addition, the highest levels of conductivity, TDS, BOD and COD were found in shrimp farms, suggesting that effluent from these may be affecting water quality within the protected landscape. TDS is normally positively correlated with conductivity (Ansari *et al.*, 2015) and indicates the degree of dissolved substances such as metal ions in water (Efe *et al.*, 2005; Ubwa *et al.*, 2013). BOD measures of the amount of oxygen required by bacteria and other microorganisms that stabilize decomposable organic matter (Ubwa *et al.*, 2013). High levels of COD and BOD indicate reductions in water quality (Ubwa *et al.*, 2013; Ansari *et al.*, 2015) by organic compounds (Bui *et al.*, 2012; Ubwa *et al.*, 2013) and reflect high organic and inorganic matter (Boyd & Green, 2002; Bui *et al.*, 2012; Ansari *et al.*, 2015). This has negative impacts on ecosystem health (Anh *et al.*, 2010; Bui *et al.*, 2012) and reduces habitat quality for fish (Nguyen *et al.*, 2006). High levels of both COD and BOD can result from organic waste from abattoirs (Bartram & Ballance, 1996), pellet feed use and discharge from shrimp farming (Anh *et al.*, 2010).

Our analyses indicates that many water quality parameters fall outside of a variety of recommended guidelines at APPL and may therefore be negatively affecting the quality of wetland habitats at the site. In Cambodia, Yang & Guo (2003) suggest that water pollution mostly occurs in transnational waters in the Lower Mekong Basin. Poor water quality affects habitat integrity (Simeonov *et al.*, 2003), fish and aquatic production (Lloyd, 1987), causes acid sulphate soils and algae blooms (Boyd & Green, 2002; Bui *et al.*, 2012), and creates favourable conditions for pathogenic microorganisms (Anh *et al.*, 2010). Though some aspects of Cambodia's environment have remained cleaner compared to some neighbouring countries (Monirith *et al.*, 2000), wetland pollution along the coastline threatens habitat integrity and could have a highly adverse impact on biodiversity (Naylor, 1998). We consequently suggest monitoring of water quality and engagement with shrimp farmers to minimize the impact of their practices on protected areas. The development of structures to prevent polluted waters from entering APPL may also prove necessary, and further research on the ecological impacts of water pollution is required to assess the effectiveness of related conservation interventions.

Acknowledgements

The authors thank the AAGE. V. Jensen charity foundation, Critical Ecosystem Partnership Fund and UK Darwin Initiative for supporting this study. We also thank Dr Neil Furey for his comments on the text and Mr Hor Pok and other members of the field survey team including local communities, conservation groups and authorities.

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