Cattle and water buffalo densities wading into small village reservoirs of Sri Lanka impact on yields on the culture-based fisheries thereof

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Abstract This study investigated whether allochthonous inputs generated by cattle and water buffaloes grazing in the catchment or wading in the water in small village reservoirs of Sri Lanka can make a significant effect on yields from culture-based fisheries of those reservoirs. The analysis is based on limnological data of 37 randomly selected reservoirs. As culture-based fish yield data were available over the 2002 - 2003 period only for 23 reservoirs, fish yield data from seven more reservoirs were gleaned for the present analysis. Cattle and water buffalo densities (BD) in 37 reservoirs where limnological data were available, were found to be significantly correlated to the biological productivity-related parameters such as chlorophyll-a content. Culture-based fish yield in the 30 reservoirs varied from 54.6 to 1800.8 kg ha^{-1} and BD associated with the reservoirs studied varied from 0.90 number ha^{-1} to 216.25 numbers ha^{-1}. Fish yield (FY) was significantly correlated with BD the relationship being, $FY = 4.758 BD + 242.740$ ($R^2 = 0.345$; $p<0.001$). The importance of taking into consideration factors such as grazing cattle and buffalo density in preparing management strategies for culture-based fisheries in small village reservoirs is discussed.

Keywords: allochthonous nutrient inputs; exotic carps; inland fisheries; irrigation reservoirs; stocking-and-recapture fisheries

INTRODUCTION

Animal faeces are a conventional type of fertilizer commonly used in aquaculture systems in many developing tropical countries. Addition of such organic fertilizer is done manually or through a self-nourishing systems for example as in integrated farming; fish-cum-poultry farming. Cattle manure (cow dung) can be manually added to pond water considering the nature of cultured organism, water quality and soil characteristics of that area (Bardach et al. 1972). In pond fish culture cow dung is often used in combination with or without poultry manure and/ or inorganic inputs.

For rearing Indian or Chinese carps the conventional manure dosage for pond fertilization may vary between $10 – 50$ t ha^{-1} yr^{-1} (Li and Xu 1995; Garg and Bhatnagar 2000; Das et al. 2005), and often unattainable due to scarcity of manure. In culture-based fisheries, a natural or a man-made water body often relatively far larger than a fish pond makes manual fertilization impractical. Nevertheless, if it is a non-perennial water body, which is smaller in size and if there is a higher density of cattle (*Bos taurus* L.) and water buffaloes (*Bubalus bubalis* (L.)) grazing within the catchment and wading into the water body the scenario would appear as an integrated farm setup.

For example, an experimental introduction of grazers for a 10 hr period to a small catchment in New Zealand was reported to increase particulate phosphorus in the water 100 times as opposed to the pre-grazing status (Sharpley and Syers 1979). Sharpley and Syers (1979) also observed that the disturbance of sediments by cattle movements and deposition of excreta within water enhanced the situation. Nutrient enrichment is reported to take place in a reservoir complex in Sri Lanka, which is a wetland of international importance (i.e., a Ramsar site) due to accumulation of faecal matter of migratory and resident birds, the phenomenon termed as 'guanotrophication' (Jayakody et al. 2012) and 'ornithological eutrophication' (Gunaratne et al. 2015).

Cattle and/or water buffalo are an integral part in Asian agrarian civilizations for thousands of years. The value of water buffalo is not only for milk, meat, hides and draft power for agricultural operations but sociologically as property, possession and a readily available currency converter when in need for farmer communities (Nanda and Nakao 2003). There are more than 12000 non-perennial reservoirs (not exceeding 50 ha at full supply level) scattered mainly in the dry zone of Sri Lanka (Anon. 2000) while there are estimated 3,108,620 water buffaloes and 1,068,044 cattle (2016 census) predominantly in the same agricultural areas (FAOSTAT 2017). Throughout the history, country was dominated by an agrarian society based on a "one tank – one village" ecological pattern (Siriweera 1994). Each village consists of a small irrigation reservoir, paddy fields irrigated from that reservoir and the dwellings of the owners of those paddy lands. Every cattle and water buffalo in the village graze in the reservoir catchment and at least once a day wade in the shallow water. Therefore, the reservoirs are subjected to direct or indirect inputs of allochthonous nutrients via cattle and water buffalo urine and faecal matter. As these small village reservoirs are suitable for the development of culture-based fisheries (Mendis 1965, 1977; De Silva 1988; Amarasinghe 1998) induced-productivity through cattle and buffalo depositions are likely to impact positively on fish yields. The present analysis is based on data collected for a major reservoir fisheries development project attempting to quantify the effect of grazing cattle

and water buffalo density (BD) on culture-based fish yields, and compliments the previous findings on stocking density and limnological features impacting on culture-based fisheries yield in small village reservoirs of Sri Lanka (Jayasinghe et al. 2005a, 2005b, 2006; Wijenayake et al. 2005).

MATERIALS AND METHODS

This investigation was concurrent to a major research project on the enhancement of culture-based fisheries in small village reservoirs of Sri Lanka, and the relevant methodologies have been reported earlier (Jayasinghe et al. 2005a, 2005b, 2006; Wijenayake et al. 2005). In the present analysis, data were used from 48 small village reservoirs in five administrative districts, which were randomly selected for stocking fish fingerlings. Data on the number of cattle and water buffalo associated with each reservoir were retrieved from resource profiles of village authorities and Divisional Secretariat Division offices. Cattle and water buffalo densities (BD) were calculated by dividing their number by reservoir area at full supply level. Of the selected reservoirs, only 30 could be successfully utilized for a fish culture cycle (of 8 – 10 months) during 2002 - 2003 period, and the data of fish yields in the rest of the reservoirs were not reliable due to false reporting and poaching (Jayasinghe et al. 2005a, 2005b, 2006), and therefore were discarded. The reservoirs were stocked with fingerlings of exotic species rohu (*Labeo rohita* Hamilton), catla (*Catla catla* Hamilton), common carp (*Cyprinus carpio* L.), bighead carp (*Aristichthys nobilis* Richardson), mrigal (*Cirrhinus mrigala* Hamilton), the GIFT strain of Nile tilapia (*Oreochromis niloticus* L.) and the indigenous species, giant freshwater prawn (*Macrobrachium rosenbergii* De Man). Stocking densities ranged from 218 to 4372 fingerlings ha^{-1}. When the water level of reservoirs was 0.5 – 1.0 m along with the dry season, all fishes surviving were caught using a 5 cm mesh 62 m x 8.5 m seine net and the total fish yield was estimated for each reservoir (Table 3).

Previous investigations on limnological parameters of small village reservoirs have revealed that parameters such as Secchi disc depth, total phosphorous, chlorophyll-a, inorganic and organic turbidity determine the trophic

heterogeneity of those reservoirs (Jayasinghe et al. 2005b). In this analysis, we attempted to find out possible relationships of these limnological parameters with cattle and water buffalo densities. However, in seven reservoirs in the Hambantota district, water quality parameters could not be determined due to various practical difficulties encountered such as non-availability of transport facilities.

In the present analysis, the potential impacts of cattle and water buffalo separately on the nutrient enrichment in reservoirs were not differentiated, due to logistical difficulties. As such the combined density of cattle and water buffalo was taken as the index of nutrient enrichment even though nitrogen, phosphorous, potassium and calcium contents of cattle and water buffalo excreta (dung and urine) are known to be different (Kolay 2007), and this is a potential area for further investigation on relative contribution to productivity from cattle as opposed to water buffaloes.

Inter-relationships between biological productivity-related limnological parameters were determined. The relationships of cattle and water buffalo densities (BD) with these biological productivity-related limnological parameters were also determined. Finally, for the 30 reservoirs with a successful culture-based fisheries harvest, BD was related to the culture-based fish yield.

RESULTS

Extents of reservoirs used in the present analysis varied from 2.7 ha of Burutha wewa in Anuradhapura district to 46.0 ha of Nimalawa wewa in Hambantota district. Cattle and water buffalo densities associated with the reservoirs studied varied from 0.90 numbers ha^{-1} in Meegahawewa in Anuradhapura district to 216.25 numbers ha^{-1} in Swodagama wewa in the Hambantota district (Table 1). As mentioned above limnological data were available only from 37 reservoirs and culture-based fisheries yields were from 30 reservoirs (Table 1). Culture-based fish yield in the fish culture cycle during 2002 - 2003 period in the 30 reservoirs ranged from 54.6 kg ha^{-1} to 188.8 kg ha^{-1}.

Secchi disc depth (SDD), which is an important parameter indicating underwater light attenuation, was found to be influenced negative log-linearly by both organic turbidity (Figure 1A) and inorganic turbidity (Figure 1B). The negative logarithmic relationship between SDD and chlorophyll-a content (Figure 1C) is also evident indicating that phytoplankton biomass was drastically low in reservoirs with high light penetration. Secchi disc depth had a negative log-linear relationship with the cattle and water buffalo density (Figure 2A). The positive log-linear relationships of cattle and water buffalo density with organic turbidity (Figure 2B) and inorganic turbidity (Figure 2C) indicate that high densities of grazing cattle and buffaloes could be a reason for declined water transparency. A positive linear relationship between cattle and water buffalo density and chlorophyll-a content is evident from the present analysis (Figure 2D) showing that grazing cattle and water buffaloes had noticeable positive effect on the biological productivity of the reservoirs. All the regression relationships presented in Figures 1 and 2 were significant at least at 0.05 probability level (Table 2). Culture-based fisheries yield (FY in kg ha^{-1} yr^{-1}) in the 30 reservoirs showed a significant correlation to cattle and buffalo density (BD in numbers ha^{-1}), the relationship being, FY = 4.758 BD + 242.740 (R^2 = 0.345; p<0.001; Figure 3).

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Table 1. Major biological productivity-related limnological data, cattle and water buffalo densities (BD) and culture-based fish yield in small village reservoirs studied. FSL – full supply level; SDD – Secchi disc depth; OT – organic turbidity; IT – inorganic turbidity; TP – total phosphorous; Chl-a – chlorophyll-a content; nd – no data. (Source of limnological data: Jayasinghe et al. 2005b; Fisheries data: Jayasinghe et al. 2005b and present study)

District/Reservoir	Extent at FSL (ha)	SDD (cm)	OT (mg L^{-1})	IT (mg L^{-1})	TP (mg L^{-1})	Chl-a (mg m^{-3})	BD (Nos ha^{-1})	Fish yield (kg ha^{-1})
Anuradhapura								
Bulankulama	10.4	69.6	9.26	17.63	0.20	6.95	0.96	352.5
Burutha wewa	2.7	31.3	15.04	38.69	0.33	40.27	182.22	nd
Gambirigas wewa	16.6	69.9	9.59	15.86	0.48	5.34	10.54	127.1
Hinguruvelpitiya	7.8	101.1	7.57	8.29	0.49	1.88	12.85	nd
Karambegama	9.3	77.9	14.81	15.33	0.20	1.37	1.07	nd
Katugampalagama	16.7	41.9	17.42	41.77	0.27	7.92	29.98	242.9
Lolugas wewa	11.9	62.4	15.87	35.86	0.21	12.32	8.40	nd
Maha wewa	8.4	38.6	40.76	112.00	0.25	19.16	23.93	nd
Meegaha wewa	11.1	49.3	13.73	104.59	0.44	4.57	0.90	nd
Meegassegama	29.0	66.9	16.33	22.81	0.16	6.51	5.18	nd
Pahalasandalamkulama	21.3	33.8	27.63	91.18	0.28	16.63	23.51	194.5
Kurunegala								
Kumbalporuwa	9.5	136.4	3.05	2.32	0.13	1.92	8.41	nd
Kekunawa	10.0	74.4	6.78	9.48	0.23	16.05	5.02	nd
Ihalamaradankadawala	19.2	132.2	4.08	10.40	0.16	1.57	16.19	nd
Pahala wewa	8.5	42.7	22.65	57.70	0.39	30.23	23.49	nd
Hindagaha wewa	2.9	55.4	11.29	34.33	0.19	3.10	43.66	nd
Withikuliya wewa	6.9	85.2	5.30	10.97	0.17	2.80	3.60	nd
Wavullewa wewa	20.6	108.6	1.50	7.58	0.21	1.03	24.23	120.4
Matulu wawa	28.9	72.0	1.39	11.61	0.14	12.48	3.47	56.7
Hambantota								
Bolhinda	11.6	18.4	28.95	88.14	0.44	13.46	129.65	nd
Gonnoruwa	22.4	16.4	70.91	446.05	0.58	9.89	22.33	54.6
Kudaindi wewa	13.4	13.6	26.12	93.22	0.22	4.21	37.30	377.1
Udana wewa	4.9	36.2	6.93	28.62	0.52	3.45	91.65	nd
Lunuveraniya	10.8	15.8	28.79	140.46	0.25	18.10	92.98	710.4
Medagankadavara	16.7	21.4	16.07	68.33	0.47	29.14	89.61	72.4
Palujadura	4.9	45.5	9.60	46.45	0.21	7.45	51.49	275.9
Svodagama	3.2	10.6	35.52	122.81	0.49	86.60	216.25	1800.8
Weli wewa	5.7	27.0	28.11	48.60	0.37	29.71	10.57	372.7
Wawegama	18.9	7.5	165.46	258.90	0.47	7.96	61.00	181.9
Andalla wewa	25.1	nd	nd	nd	Nd	nd	20.93	280.2
Katupila wewa	14.6	nd	nd	nd	Nd	nd	64.98	522.4
Nimalawa wewa	46.0	nd	nd	nd	Nd	nd	16.38	96.9
Palugas wewa	18.8	nd	nd	nd	Nd	nd	23.94	321.5
Orukengala wewa	6.3	nd	nd	nd	Nd	nd	143.77	853.9

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Angunukola wewa	8.4	nd	nd	nd	Nd	nd	149.52	878.0
Neralugas wewa	16.7	nd	nd	nd	Nd	nd	10.47	333.9
Hambuwe wewa	10.5	nd	nd	nd	Nd	nd	86.21	731.1
Unathu wewa	12.5	nd	nd	nd	Nd	nd	79.74	508.1
Pelessa wewa	29.3	nd	nd	nd	Nd	nd	5.13	141.7
Mahapelessa wewa	18.8	nd	nd	nd	Nd	nd	5.32	235.0
Moneragala								
Dozerwewa	13.6	21.1	25.43	107.74	0.40	38.56	14.72	1513.9
Bodhagama wewa	13.4	22.1	17.29	128.86	0.36	7.08	7.44	623.4
Galwale wewa	15.7	38.5	18.07	85.83	0.20	5.82	44.48	247.9
Meegas wewa	21.0	19.3	15.35	106.40	0.32	13.48	9.53	715.6
Batalaara wewa	11.0	66.0	9.72	12.77	0.11	13.17	2.72	nd
Walaskema wewa	28.1	15.2	20.90	97.03	0.26	10.78	71.09	nd
Ratnapura								
Mahagalara	8.9	81.5	3.50	12.00	0.16	13.89	17.51	877.1
Panahaduwa	30.5	27.8	30.67	128.34	0.29	30.21	39.37	nd
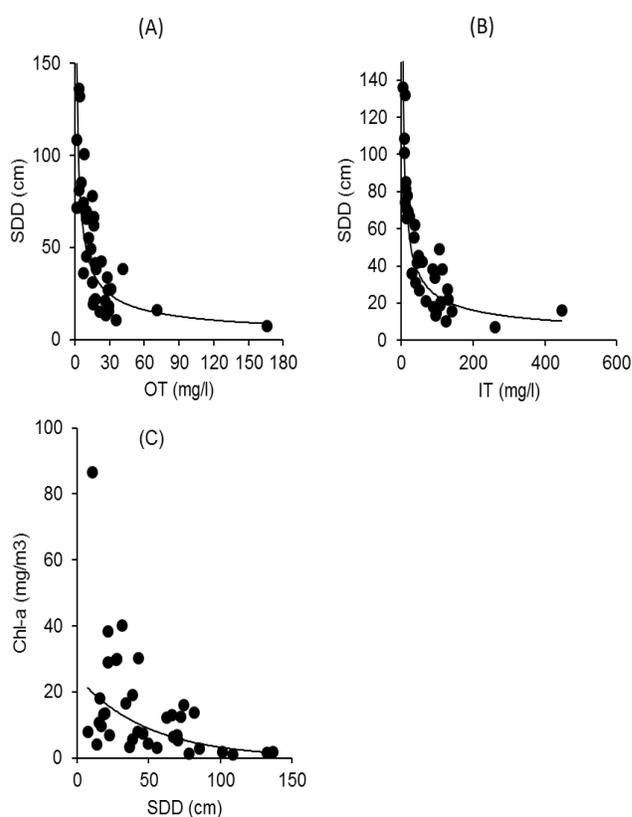
Figure 1. Interrelationships of biological productivity-related limnological parameters in 37 small village reservoirs studied (Data from Jayasinghe et al. 2005). SDD – Secchi disc depth; OT – organic turbidity; IT – inorganic turbidity; Chl-a – chlorophyll-a content.
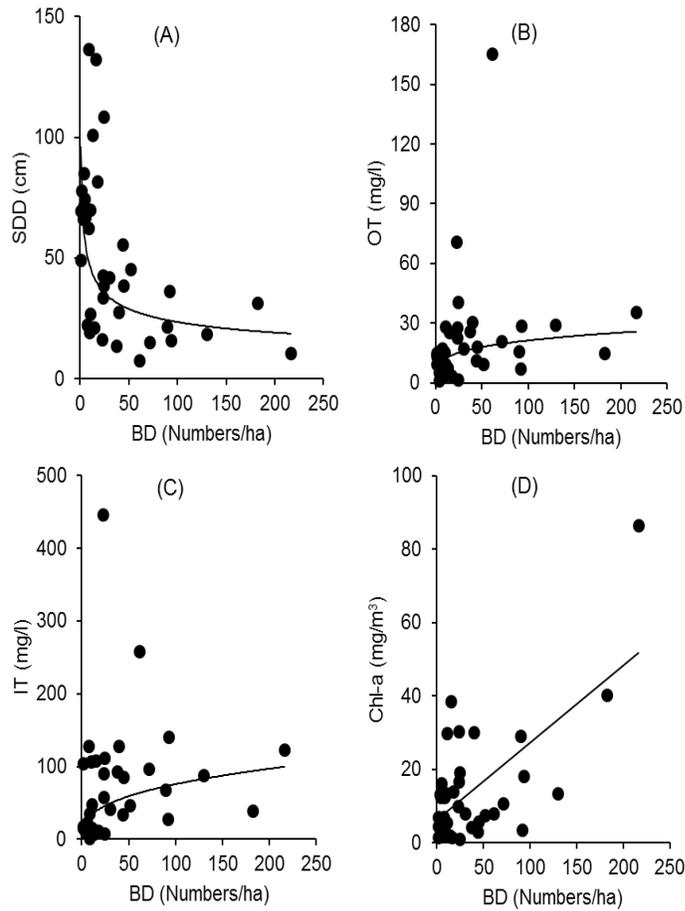
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Figure 2. Relationships of cattle and water buffalo density (BD) with biological productivity-related limnological parameters in 37 small village reservoirs studied. SDD – Secchi disk depth; OT – organic turbidity; IT – inorganic turbidity; Chl-a – chlorophyll-a content.

Table 2. Regression relationships shown in Figures 1 and 2. df – degrees of freedom; r = correlation coefficient; p – probability level.

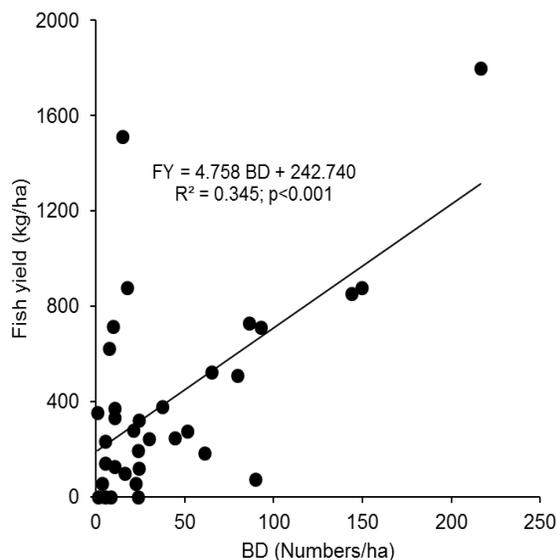| Relationship	Df	R	p	Figure No.
SDD = 196.680 OT$^{-0.611}$	35	0.804	<0.001	1A
SDD = 315.450 IT$^{-0.561}$	35	0.886	<0.001	1B
Chl-a = 24.707 e$^{-0.020 \, SDD}$	35	0.659	<0.001	1C
SDD = 92.988 BD$^{-0.299}$	35	0.573	<0.001	2A
OT = 6.846 BD$^{0.246}$	35	0.359	<0.05	2B
IT = 14.657 BD$^{0.357}$	35	0.433	<0.01	2C
Chl-a = 0.210 BD + 6.299	35	0.649	<0.001	2D

Figure 3. Relationship between cattle and water buffalo density (BD) and culture-based fish yield in 30 village reservoirs.

DISCUSSION

Cattle and water buffalo rearing is a common activity in most rural areas in Asia. These livestock with individual identification marks, are often permitted to graze and water in common pool resources such as small village reservoirs and the corresponding catchments, freely, and is herded in the evenings by their owners. This is a common life style in rural Sri Lanka, particularly in the dry zone areas where each village is bestowed with a small irrigation reservoir. The current study has demonstrated that the grazing cattle and water buffalo density impacts the fish yield in the corresponding reservoir, as expected, but quantitatively for the first time.

Livestock grazing within the catchments contribute a considerable amount of nitrogen and phosphorus through their urine and faecal matter (DEFRA 2002; English Nature 2003; Jennings et al. 2003). Though the amount of phosphorus is low in cattle urine (Braithwaite 1976), a considerable amount is heaped on the soil via faeces (Nash and Halliwell 1999, 2000; Bravo et al. 2003). Furthermore, nutrient release rate from dung is normally higher than that released from submerged vegetation although there are slight differences due to animal species that produce it (McLachlan 1971).

Nutrients are transported via surface runoff, subsurface flow and leaching to ground water, which are spatially and temporally dynamic pathways (Jennings et al. 2003). Draw down areas of small village reservoirs are open to the growth of grass or shrubs and remain dry for most of the time in the year. Also, these areas are mottled with piles of dung. During the dry periods, residues of faecal wastes may accumulate in the soil (Jennings et al. 2003). With low frequency/high intensity rainfall, great losses of nutrients from soil to nearby water bodies can occur. Subsequently the nutrient load in water is expressed by the high level of chlorophyll content. Present study shows strong relationships between key limnological parameters responsible for trophic differences of small village reservoirs and cattle/ buffalo density associated with those reservoirs.

Amount of allochthonous inputs into a water body is largely determined by the extent of the land-water interface. Regardless of the cattle and buffalo density, dendritic margin of a reservoir increases the allochthonous nutrients, and thus productivity. The significance of shoreline: area ratio as a good predictor of culture-based fish yield in small village reservoirs of Sri Lanka was shown by Jayasinghe et al. (2006). Higher values of this morphometric parameter are effective in resulting an increased culture-based fish yield. Also, from the present analysis it is evident that fish yield can be optimized if, simultaneously, there is a higher cattle and water buffalo density associated with the reservoir and the fishery is well managed by keeping the stocking density at an optimum level, as shown by Wijenayake et al. (2005).

Due to easy access to databases on cattle and water buffalo density in villages, as given in resource profiles of divisional secretariats, for fisheries management purposes, it is practicable to use data on cattle and water buffalo density rather than measuring chlorophyll-a content of the water for which technical skills and lab facilities are necessary. For years to come, the link between cattle and water buffaloes and agrarian communities will be persistent in spite of the technological innovations. Among numerous helps of these animals to mankind, indirect fertilizing of the culture facility in culture-based fisheries would be another important one with its wise use not only in Sri Lanka but also in most agrarian communities in Asia.

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Acknowledgements

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