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Factors Related to Nesting Sites of *Oreochromis niloticus* (Linnaeus 1758; Cichlidae) in Irrigation Reservoirs, Sri Lanka

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Abstract

The nesting sites of *Oreochromis niloticus* (Linnaeus 1758) were studied in 10 irrigation reservoirs of Sri Lanka from April 2014 to April 2016 to understand the influencing factors. The optimal nesting depth and nest diameter varied across reservoirs. Nest density (ND) was negatively related to slope of the littoral area (in degrees) according to $ND = -0.070\ Slope + 0.536$ ($R^2 = 0.415$) and positively to water turbidity ($Turb$ in NTU) according to $ND = 0.033\ Turb + 0.083$ ($R^2 = 0.598$). The optimal nesting depth (NDP_{opt} in cm) was also negatively related to turbidity as $NDP_{opt} = -5.133\ Turb + 154.660$ ($R^2 = 0.509$). Mean relative reservoir water level fluctuation [$RRLF$ = (Mean reservoir level amplitude/Mean depth) x 100] had a significant negative relationship with ND according to $\ln ND = -1.185 \ln RRLF + 5.231$ ($R^2 = 0.518$). As hydrological regimes in reservoirs are mainly influenced by irrigation requirements of command areas, effective dialog between multiple users of reservoirs to achieve a win-win situation could possibly be adopted to optimise fish yield.

Keywords: exotic species, inland fisheries, irrigation impacts, littoral zone, tropical reservoirs.

Introduction

Tropical lakes and reservoirs are rich in ichthyofaunal diversity and support profitable fisheries (Craig 2015). Except in a few tropical lakes and reservoirs in Africa, where pelagic clupeids contribute to productive fisheries, the majority of fisheries in tropical lakes and reservoirs are based on littoral fish communities (Fernando and Holčik 1991). Life history patterns of littoral fish communities are likely to be constrained due to water level fluctuations in lakes and reservoirs. *Oreochromis niloticus* (Linnaeus 1758), introduced into inland waters of many countries in the Asia-Pacific region during the mid-twentieth century (De Silva et al. 2004; De Silva and Amarasinghe 2009), is essentially a littoral dweller (Philippart and Ruwet 1982).

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As this species has established self-sustaining populations in many reservoirs, providing an affordable source of animal protein for rural communities (Amarasinghe and De Silva 2015), its contribution to rural food security is very important. In Sri Lankan reservoirs, which are primarily constructed for irrigation and hydroelectricity generation, there are well-established breeding populations of *O. niloticus*.

It has been demonstrated that water level fluctuations impact fish production in lacustrine waters such as Sri Lankan reservoirs (De Silva 1985a), and in a broader sense, in a range of tropical lakes and reservoirs in Asia and Africa (Kolding and van Zwieten 2012). As hydrological regimes of irrigation reservoirs are governed by irrigation authorities, impact of water level fluctuations on the life history patterns of fish species can provide useful management implications for optimising population size and thus fisheries production. On the other hand, in spite of the ambitious proposals for more equitable allocation of freshwater resources between agriculture and fisheries, and also because of high priority setting for agricultural production, such an initiative is recognised as a difficult task in the real world due to inadequate data and complexities in the aquatic ecosystems (Brummett et al. 2010). These controversies indicate the need for specific studies to quantify the effect of water level fluctuations in lacustrine water bodies on littoral fish communities and their life history patterns.

As part of the reproductive tactic of the genus *Oreochromis*, males construct pits (spawning nests) in the soft bottoms of the littoral zones of reservoirs and females are attracted to these nesting sites to perform courtship (Bruton and Boltt 1975; Lowe-McConnell 1982; Bowen 1984) and after fertilisation of the spawned eggs, males relinquish the nesting sites. Females in turn, protect the eggs and hatchlings in their mouth (Trewavas 1983; Turner and Robinson 2000). As reservoir water levels fluctuate due to seasonal hydrological imbalance of inflow and outflow together with evaporation, it is possible that nesting performance of *O. niloticus* would be impacted. Many studies are reported on the nesting and courtship behaviour of cichlid species (e.g., Bruton and Gophen 1992; Mendonça and Gonçalves-de-Freitas 2008; Rachel 2015). Amarasinghe and Upasena (1985) and De Silva and Sirisena (1988) studied nesting habits of *Oreochromis mossambicus* (Peters 1852) in relation to morphometry and water level fluctuation in reservoirs of Sri Lanka.

Nevertheless, except for isolated studies on water level fluctuations on fisheries yields in the tropical belt such as for example, time-lag response of water level fluctuations on fish yield in a Sri Lankan reservoir (De Silva 1985a) and anthropogenic-mediated lake level changes in Lake Naivasha, Kenya that were mainly responsible for a decline in tilapiine cichlids in the fishery (Oyugi et al. 2011), there have not been comprehensive studies on the impact of water level fluctuations in reservoirs of multiple uses on the reproductive performance of cichlid species. Magnitudes of water level fluctuations in reservoirs are essentially influenced by the morphometry, being low in reservoirs with steep basins and extensive draw-down in those with gentle slopes. Hence, effect of water level fluctuations on nesting performance of *O. niloticus* in littoral zones of reservoirs might be location-specific.

Accordingly, investigation of possibilities of harmonising reservoir fish yield and irrigation demands is important for establishing effective dialogue between fisheries and irrigation authorities for their mutual benefit. In the present study, nesting sites of *O. niloticus* were investigated in relation to reservoir morphometry, sediment characteristics, turbidity and water level fluctuations in 10 irrigation reservoirs of the Kala Oya river basin, Sri Lanka. This study is important to ascertain possibilities of achieving high fish yields through optimising multiple uses of reservoir resources.

Materials and Methods

The 10 irrigation reservoirs studied are within the Kala Oya river basin and are identified in Fig. 1. This river basin drains an area of around 2,772 km^2 (N.S.F. 2000). The 10 reservoirs studied range in size from 146 ha (Siyambalangamuwa) to 1980 ha (Kalawewa) at full supply level (Table 1).

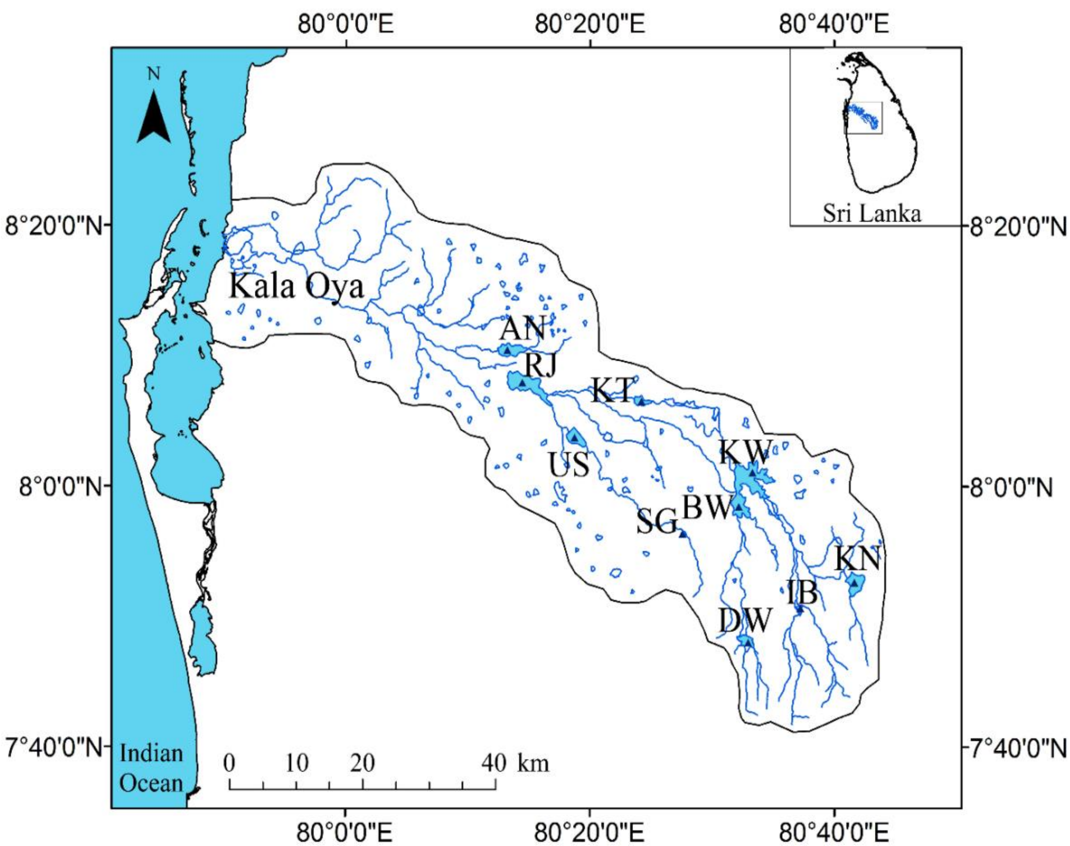


Fig.1. Map showing locations of the 10 reservoirs studied for factors related to nesting sites of *Oreochromis niloticus* in the Kala Oya river basin. The geographic location of Kala Oya river basin relative to the rest of the island is shown in the inset. Abbreviations of reservoir names: AN - Angamuwa, BW - Balaluwewa, DW - Dewahuwa, IB - Ibbankatuwa, KN - Kandalama, KT - Katiyawa, KW - Kalawewa, RJ - Rajanganaya, SG - Siyambalangamuwa, US - Usgala Siyambalangamuwa.

Table 1. Physical characteristics of the 10 reservoirs studied for factors related to nesting sites of *Oreochromis niloticus* (Sources: Irrigation Department 1975; DSWRPP 2017). MSL: Mean Sea Level; FSL: Full Supply Level.

Reservoir	Catchment (km^2)	Capacity at FSL (10^6 m^3)	FSL (m above MSL)	Mean depth (m)	Area at FSL (ha)	Shoreline length (km)
AN	129.5	15.79	64.3	1.99	792	17.7
BW	269.8	41.42	120.0	4.43	934	22.4
DW	67.3	13.56	182.1	3.13	433	15.2
IB	169.0	11.72	162.1	2.89	405	20.2
KN	98.0	33.74	162.1	4.58	736	20.2
KT	86.7	5.55	94.3	2.16	257	5.7
KW	572.0	87.81	128.1	4.43	1 980	48.9
RJ	1 611.0	100.66	68.2	6.30	1 599	59.3
SG	46.6	2.6	35.4	1.78	146	3.5
US	184.6	26.72	87.2	3.47	769	18.2

Abbreviations of reservoir names: AN - Angamuwa, BW - Balaluwewa, DW - Dewahuwa, IB - Ibbankatuwa, KN - Kandalama, KT - Katiyawa, KW - Kalawewa, RJ - Rajanganaya, SG - Siyambalangamuwa, US - Usgala Siyambalangamuwa.

This study was carried out from April 2014 to April 2016 visiting each reservoir approximately once in 2 months. Daily water level data in individual reservoirs, depending on the availability, were obtained for 3 to 6 years between 2010 and 2015 from the Irrigation Department of Sri Lanka and the Mahaweli Authority of Sri Lanka. In each reservoir, three quadrats of 5m x 5m size were established in the littoral area opposite to the dam site that is subjected to draw-down. These quadrats were not fixed, but were changed according to fluctuations in the water level. In each quadrat, nest density, nest diameter and nesting depth of *O. niloticus* were determined through underwater observations at different water depths ranging from 0.1 m to 2 m. As limitations in field studies made it difficult to visit more sampling sites in the 10 reservoirs studied, the sampling grid was restricted to 3 quadrats to represent the noticeable variability of habitats. In shallow areas (<0.5 m depth), only a diving mask was used while snorkeling with a diving mask was used for underwater observations in areas of >0.5 m depth. For determination of nest density and dimensions of nests, only freshly constructed nests, as determined by the appearance i.e., those which are not covered with debris, were chosen. As it was difficult to observe nests occupied by male *O. niloticus*, nests which were not covered with silt and those which were not invaded by aquatic plants were considered as freshly constructed. Nest density was recorded from different 10-cm depth classes ranging from 10–210 cm and optimum nesting depth (NDP_{opt}) was calculated as follows:

$$NDP_{opt} = \frac{\sum_{i=1}^{n} Ni*Zi}{\sum_{i=1}^{n} Ni}$$

where, n_i = number of depth classes in the quadrat; N_i = number of nests in i^{th} depth; and Z_i = mean water depth of the depth class. To estimate nest density in each reservoir, number of observations made during the study period ranged from 36 in Balaluwewa to 68 in Usgala Siyambalangamuwa.

Diameter of each nest in the reservoir depth classes was determined to the nearest 0.1 cm using a measuring tape. Slope of the study site in the littoral zone of each reservoir was quantified (in degrees) by measuring depth of water at 5 m intervals up to a horizontally placed rope using an aluminum spirit level (45 cm; K-TECH), which was subsequently calibrated to full supply level (*FSL*) of the reservoir. Water turbidity was determined using a portable turbidity meter (HACH/ 2100Q), which was calibrated before each measurement, at the sampling sites in each reservoir. Measurements were always taken in the morning (8.00 – 10.00 hrs).

Bottom soil samples were collected using a soil corer (500 cm^3) within study sites in each reservoir. During the study period, 15 soil samples were collected from each reservoir. Each sample was then transferred to a 1-litre measuring cylinder, filled with water, stirred well and kept for about 24 hours to settle. The total height of the soil column as well as individual heights of different soil types in the column were measured as the settling volume of various components in the measuring cylinder after stirring, based on their gravity and settling speed. These heights were assumed as proportions of different soil types and were estimated as percentage of height of each soil type from the total height of soil column.

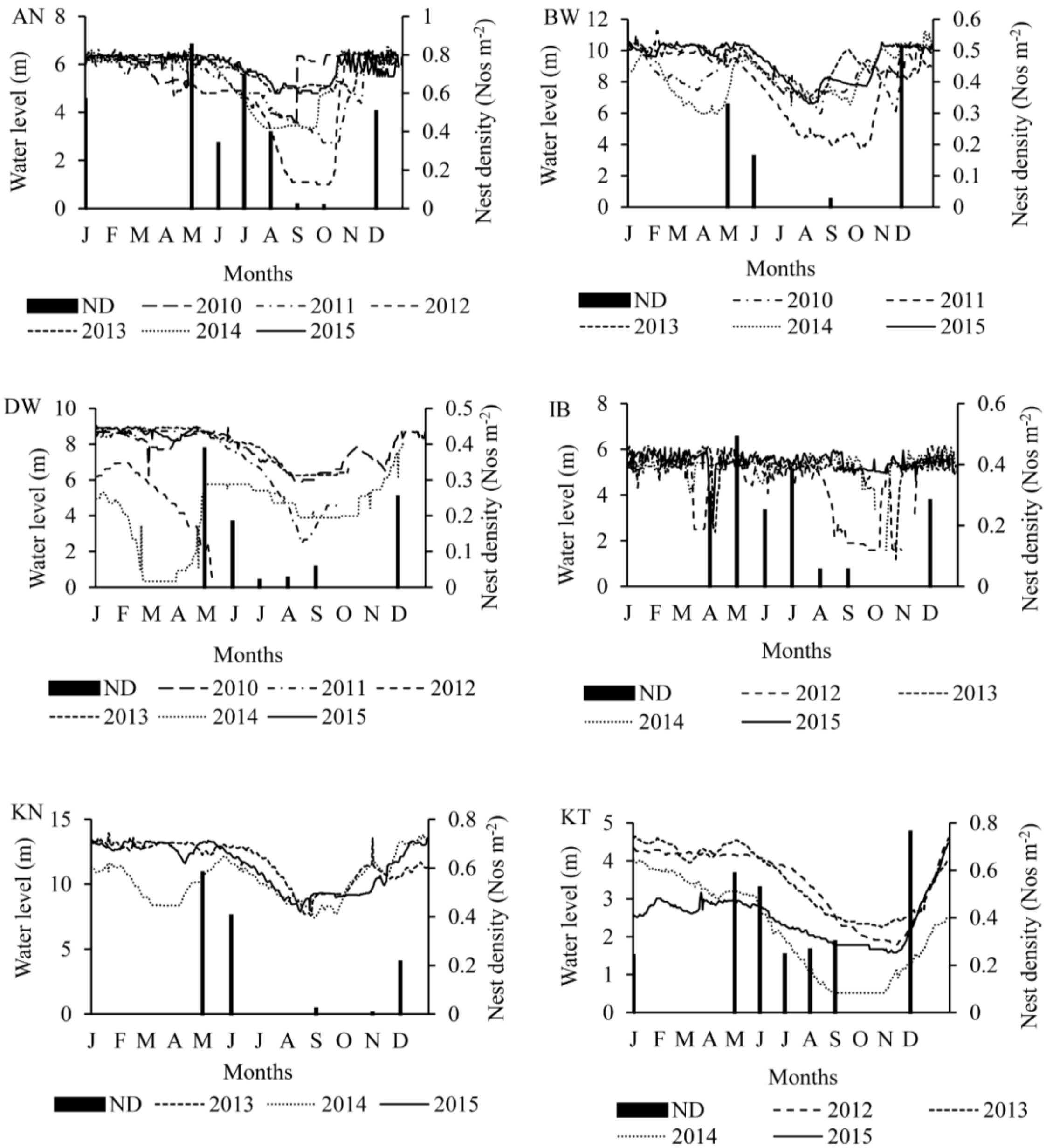
Relative reservoir level fluctuation **(***RRLF*) in each reservoir was calculated using the following equation (Kolding and van Zwieten 2006):

$$RRLF = \frac{MRLA}{Mean\ Depth} \text{x}100$$

where, *MRLA* is the mean reservoir level amplitude (i.e., Maximum water level in m – Minimum water level in m), and mean depth is in m.

Results

In all 10 reservoirs studied, water level fluctuated drastically and mean nest density of *O. niloticus* was appreciably higher in the months of low water level, rising water level and receding water level (Fig. 2), justifying the importance of investigating the effect of reservoir water level fluctuation on the nesting sites of fish. Virtually no nests were found in the months of high water level in all reservoirs (Fig. 2). From the bottom sediment characteristics in the nesting sites (Fig. 3), it was evident that most preferred substrates for nesting by *O. niloticus* were those with medium and fine sand (particle size: 0.053 – 0.47 mm).



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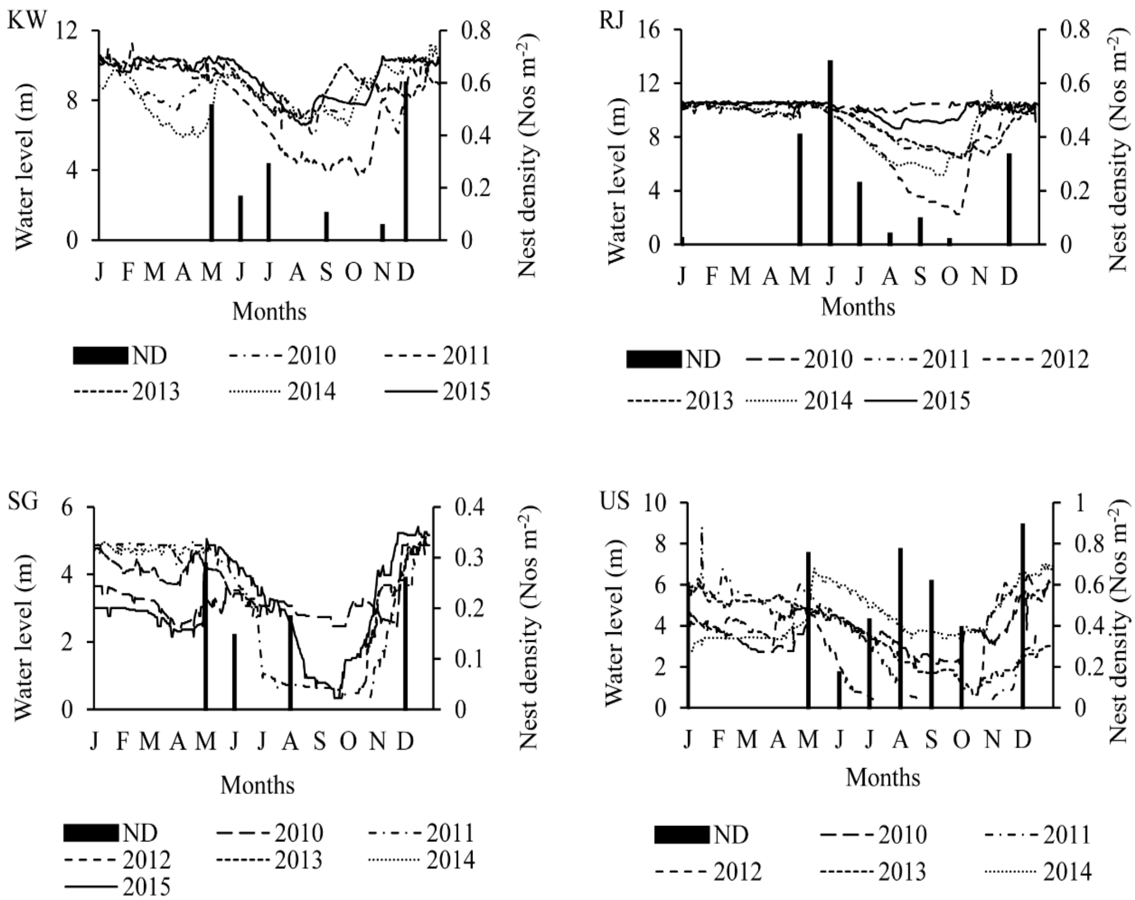

Fig. 2. Water level fluctuation (in m) during 2010-2015 in the 10 reservoirs studied for factors related to nesting sites of *Oreochromis niloticus* (Sources of data: Irrigation Department, Sri Lanka and Mahaweli Authority of Sri Lanka). Also shown here are mean monthly nest density (ND) of *O. niloticus* during the study period.

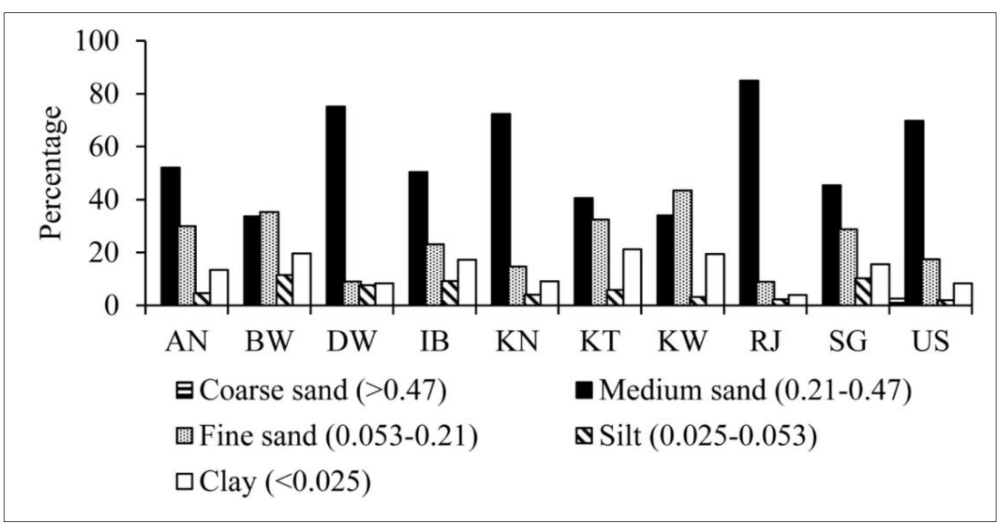

Fig. 3. Mean percentages of different soil particles in the sediments of the sampling site of the 10 reservoirs studied for factors related to nesting sites of *Oreochromis niloticus*. Size ranges (in mm) of different substrate soil particles are given in parentheses in the legend. Reservoir abbreviations are as given in Table 1. Number of soil samples analysed in each reservoir = 15.

The nests of *O. niloticus* were observed in clusters and isolated nests were very rare. Both small (< 50 cm diameter) and large (>50 cm diameter) nests were found in many clusters. However, within a given cluster, the nests were more or less of similar sizes; clusters with a mixture of nests of different sizes were virtually absent. The nest dimensions, optimal nesting depth, nest densities, and reservoir slope characteristics in the 10 reservoirs are given in Table 2.

Table 2. The mean (±SE) of nest dimensions and nest densities of *Oreochromis niloticus*, and reservoir slope characteristics in the 10 reservoirs. Reservoir abbreviations are as given in Table 1.

Reservoir	Nest diameter (cm)	Optimum nesting depth cm)	Nest density (m^{-2})	Slope of the nesting site (degrees)	Turbidity (NTU)
AN	54.0±1.3	133.4	0.46±0.18	2.12±0.29	11.30±0.94
BW	55.2±0.9	94.9	0.30±0.13	3.46±0.14	7.91±1.02
DW	45.5±1.5	78.2	0.18±0.09	4.80±1.31	5.20±0.71
IB	58.5±2.0	94.8	0.24±0.18	2.39±0.58	4.97±0.61
KN	43.6±1.8	118.8	0.28±0.23	4.36±1.08	9.58±0.68
KT	50.6±0.9	130.0	0.40±0.28	1.49±0.33	10.15±1.83
KW	56.9±0.8	136.6	0.32±0.01	3.43±0.69	7.34±1.09
RJ	57.5±2.1	122.7	0.26±0.16	2.28±0.05	3.06±0.34
SG	59.3±0.7	131.6	0.25±0.07	3.39±0.72	5.04±0.11
US	43.8±1.8	123.2	0.56±0.29	2.05±0.32	9.96± 1.51

Nests of a wide range of diameters were observed in Rajanganaya, Siyambalangamuwa and Usgala Siyambalangamuwa whilst comparatively smaller nests were found in Dewahuwa. The nest diameters of *O. niloticus* in 10 reservoirs studied ranged from 5–95 cm. The majority of the nests observed were of 40–55 cm diameter range. The optimal nesting depth ranged from 78.2 cm in Dewahuwa reservoir to 136.6 cm in Kalawewa reservoir (Table 2). The nest density of the reservoirs varied from 0.18–0.56 Nos.m^{-2}. The optimum nesting depth of *O. niloticus* in 10 reservoirs varied from 100 to 150 cm. No newly constructed nests were found in depths shallower than 50 cm. The nesting depth in Kandalama always exceeded 100 cm but in other reservoirs some nests were observed in shallower depths (50–100 cm) (Fig. 4). In Katiyawa, where dense aquatic vegetation was found in the littoral zone, some nests were observed in shallow water depths (approximately 50 cm) beneath the vegetation cover during seasons of high water level close to FSL.

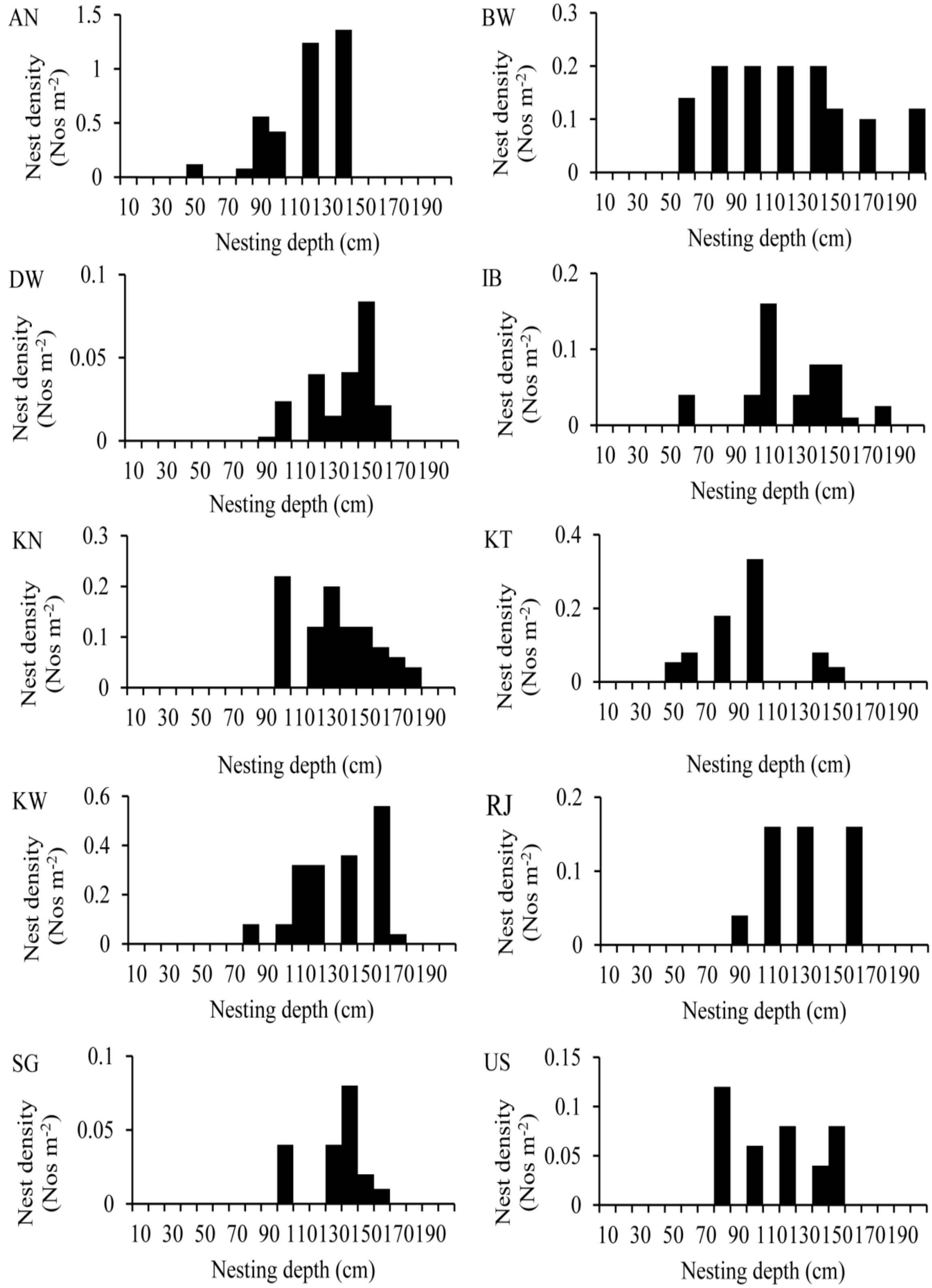

Fig. 4. Depth-wise nest densities of *Oreochromis niloticus* in 10 reservoirs of Kala Oya basin. Abbreviations of reservoir names: AN - Angamuwa, BW - Balaluwewa, DW - Dewahuwa, IB - Ibbankatuwa, KN - Kandalama, KT - Katiyawa, KW - Kalawewa, RJ - Rajanganaya, SG - Siyambalangamuwa, US - Usgala Siyambalangamuwa.

Of the various factors investigated, the nest density was, although not significant at 0.05 probability level (Table 3), negatively influenced by nest diameter (Fig. 5A), and silt percentage in the sediments (Fig. 5C). The nest density had a negative relationship with slope of the littoral area (Fig. 5B) and a positive relationship with turbidity (Fig. 5D).

Table 3. Regression relationships, coefficients of determination (R^2), correlation coefficients (r) and significance levels in the present study. p – probability level; *ND* – Nest density (no.m^{-2}); NDP_{opt} – optimal nesting depth (cm); *Slope* - slope of the littoral area (in degrees); *Silt%* - silt percentage in the sediments; *Turb* – turbidity (NTU); *RRLF* – relative reservoir level fluctuation

Regression relationship	R^2	r	p	Figure No.
$ND = -0.006N_{dia} + 0.640$	0.098	-0.314	>0.05 (ns)	5A
$ND = -0.070\ Slope + 0.536$	0.415	-0.644	<0.05	5B
$ND = -0.017\ Silt\% + 0.433$	0.256	-0.506	>0.05 (ns)	5C
$ND = 0.033\ Turb + 0.083$	0.598	0.773	<0.01	5D
$NDP_{opt} = 9.389\ Slope + 88.44$	0.257	0.507	>0.05 (ns)	6A
$NDP_{opt} = -5.133\ Turb + 154.660$	0.509	-0.713	<0.05	6B
$\ln RRLF = 0.331 \ln Slope + 5.066$	0.350	0.592	>0.05 (ns)	7A
$\ln ND = -1.185 \ln RRLF + 5.231$	0.518	-0.720	<0.02	7B

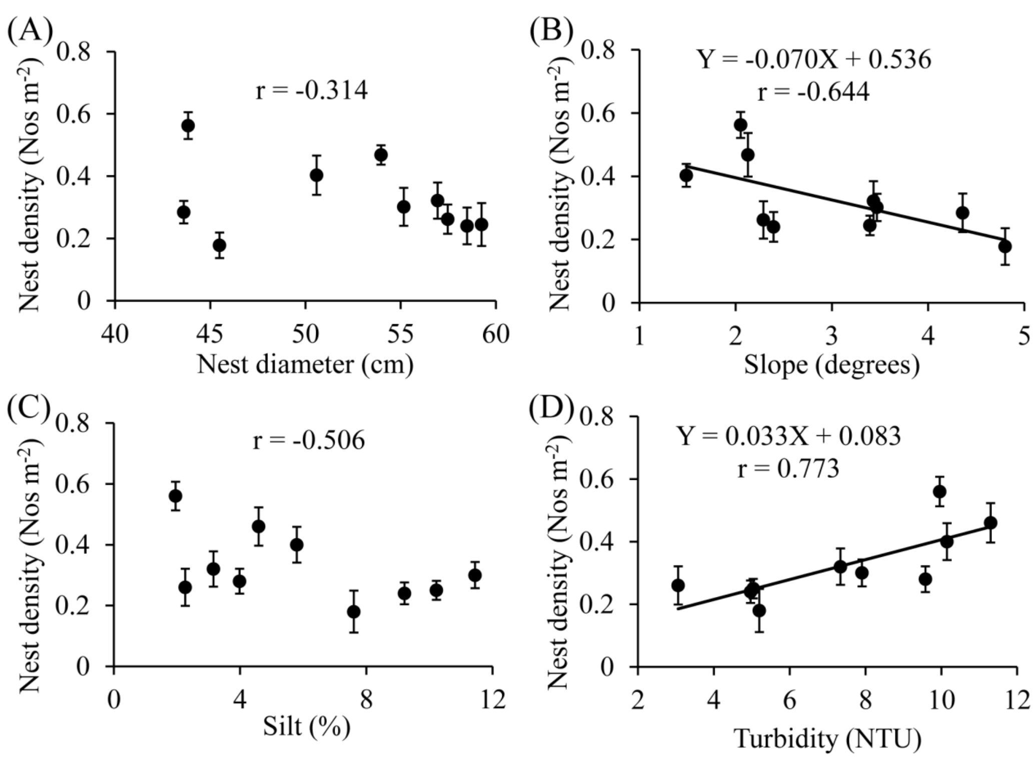

Fig. 5. Scatter plots with the lines of best fit depicting the relationships between (A) mean nest diameter and mean nest density, (B) nest density and the slope of the nesting site in the littoral zone, (C) nest density and percentage silt of substrate soil of reservoirs, and (D) nest density and turbidity.

The positive influence of the slope of the nesting site in the littoral zone on the optimum nesting depth (NDP_{opt}) was evident although statistically not significant (p>0.05; Fig. 6A). The optimal nesting depth was negatively related to the water turbidity (Fig. 6B; Table 3). The positive relationship between turbidity and nest density (Fig. 5D) perhaps indicates that in highly turbid waters *O. niloticus* tends to construct more nests in shallower areas.

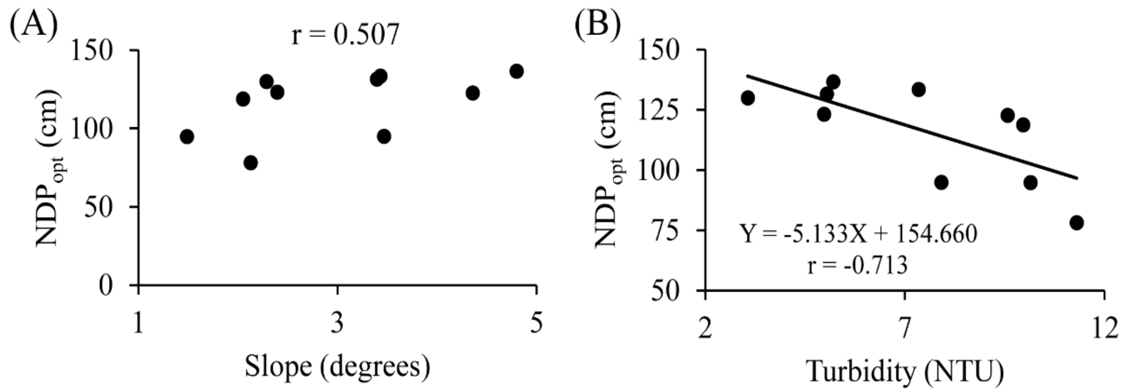

Fig. 6. Relationships between (A) optimum nesting depth (NDP_{opt}) and the slope of the nesting site in the littoral zone, and (B) optimum nesting depth and water turbidity.

From the results, it was evident that visibility in water has greater influence on the nesting performance of *O. niloticus* compared to the nature of the bottom substrate. There was an apparent positive relationship (not significant; p>0.05) between the slope of the nesting site and *RRLF* based on natural logarithms (Fig. 7A) perhaps indicating that nesting sites of *O. niloticus* may be exposed with rapidly receding water level in reservoirs with steep basins. The negative linear relationship between *RRLF* and nest density based on a natural logarithmic plot (Fig. 7B) indicates that nest density of *O. niloticus* is radically influenced negatively by *RRLF*. The regression relationships, coefficients of determination, correlation coefficients and levels of significance are given in Table 3.

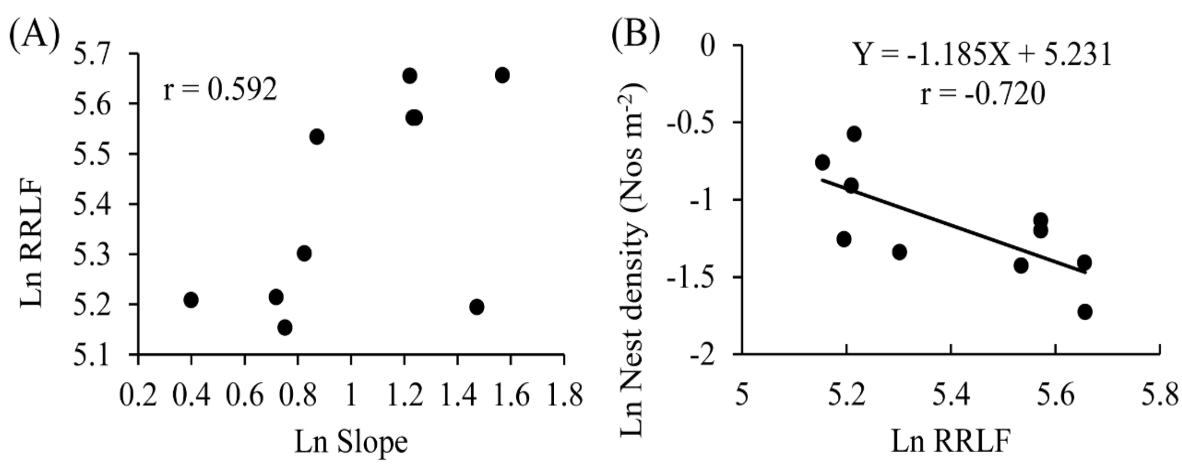

Fig. 7. Relationships of (A) *relative reservoir level fluctuation* (*RRLF*) and slope of the basin, and (B) nest density and *relative reservoir level fluctuation*.

Discussion

The positive relationship between optimal nesting depth and slope of the basin (Fig. 6A), and the negative relationship to turbidity (Fig. 6B) indicate that underwater visibility is a major factor in the choice of nest construction depth by *O. niloticus*. Interestingly, nests are aggregated in highly turbid reservoirs (Fig. 5D), which perhaps indicates that *O. niloticus* tends to construct more nests in shallower areas in turbid reservoirs. Smaller reservoirs are more turbid than deeper ones, a general limnological characteristic of lentic ecosystems (Wetzel 2001). In *O. niloticus*, sexual selection by females may be dependent on the visual cues of strong males. In polygynic animals, females are reported to invest in selecting strong males based on their successful characteristics favouring reproduction (Alcock 2001; Mendonça and Gonçalves-de-Freitas 2008; Davies et al. 2012). Visual cues during reproductive process are crucial in cichlids (Douglas and Hawryshyn 1990; Horppila et al. 2004; Venesky et al. 2005). Turbidity is linked with reduced fish vision (Berg and Northcote 1985), and in turn affects courtship, foraging (Gregory and Northcote 1993; Vogel and Beauchamp 1999) and predator avoidance behaviour (Miner and Stein 1993; Meager et al. 2005). The present analysis gives further evidence on the effect of turbidity on nesting sites of *O. niloticus* in the irrigation reservoirs studied.

Also, nest density in the nesting areas of *O. niloticus* in the 10 reservoirs studied was found to be influenced by slope of the basin, water turbidity and percentage silt content in the sediments. This evidence also substantiates the above findings that the nesting sites of *O. niloticus* are mainly influenced by reservoir morphometry. The apparent negative relationship between nest density and percentage silt content in the sediments may be due to the reason that fine particle sizes of bottom sediments may not be favourable for nesting. The negative log-log relationship between the *RRLF* and nest density unfolds the notion that the nest locations of *O. niloticus* in a reservoir are site-specific depending on its morphometry. Water level fluctuations in reservoirs are reported to influence benthic and eulittoral fish communities in various ways including loss of suitable spawning grounds (Gafny et al. 1992: Sutela and Vehanen 2008). Rachel (2015) has shown that the nests of *O. niloticus* in Lake Mutirikwi in southeastern Zimbabwe were affected by water level fluctuations. This can be expected to be extremely important in irrigation reservoirs where water level fluctuations are mainly governed by irrigation authorities and, as such, the irrigation authorities responsible for reservoir water level fluctuations have a potential role in enhancement of recruitment to the fisheries of *O. niloticus* in reservoirs.

De Silva and Chandrasoma (1980) have found that nests of *O. mossambicus* in a Sri Lankan reservoir were scarce in water depths beyond 70 cm. Based on these findings, De Silva (1985a) has shown that possible correlation of the amplitude of mean annual water level fluctuation with time-lag of about 3 years in the same irrigation reservoir to mean annual fish yield dominated by *O. mossambicus* was due to the influence of water level fluctuations during past spawning seasons of this species.

De Silva (1985a) further speculated based on this analysis that recruitment of *O. mossambicus* to the fishery would take place at the age of 2+, which was in conformity with the findings of Amarasinghe (1987). A preliminary study on nesting of *O. mossambicus* reported by Amarasinghe and Upasena (1985), and the first extensive investigation on the same aspect in several Sri Lankan reservoirs (De Silva and Sirisena 1988) provided evidence about the importance of hydrological manipulation in irrigation reservoirs for enhancement of the fisheries of nest building cichlids. The reservoir fishery of Sri Lanka, where *O. mossambicus* was the mainstay attributing to over 70 % of the landings until the late 1980s (De Silva 1985b), is as at present dominated by *O. niloticus* (Amarasinghe and Weerakoon 2009). Since the modes of construction and shape attributes of nests in cichlid species vary from species to species (Fryer and Iles 1972), the present analysis on the nest locations of *O. niloticus* in relation to water level fluctuations provides stark support to the consideration of hydrological management for reservoir fisheries enhancement in Sri Lanka.

One of the limitations in this study was that determination of nest density was based on a sampling grid of three quadrats in each reservoir. However, this has not compromised the estimates of the mean values because the standard errors of the mean registered relatively low values in all 10 reservoirs (Fig. 5).

Many tropical reservoirs in Asia and elsewhere have been constructed primarily for irrigation, hydroelectricity, water supply etc. and fisheries production is a secondary use (Sugunan 1997; Amarasinghe and De Silva 2015). Consequently, strategies for development of reservoir fisheries should be adopted within the constraints of multiple uses of reservoir resources. The present study has shown that nesting sites of *O. niloticus* are negatively related to *RRLF* of irrigation reservoirs investigated. In irrigation reservoirs of Sri Lanka, *RRLF* are predominantly governed by release of water by irrigation authorities for irrigating agricultural lands. As such, effective dialogue between irrigation authorities and fisheries authorities to achieve a win-win situation could possibly be adopted to optimise fish yield. This is of particular importance because average financial returns per reservoir fisherman were shown to be exceeding those of irrigated agriculture in Sri Lanka (Renwick 2001a, 2001b). Pushpalatha et al. (2017) have also shown that profits obtained from culture-based fisheries in reservoirs of Sri Lanka have surpassed the profits generated from the primary economic activity, downstream paddy cultivation.

Conclusion

As in many tropical countries, reservoir fisheries production in Sri Lanka is essentially a secondary use as they have been constructed in the past for irrigation of agricultural lands, apart from a handful that have been impounded in recent decades for generation of hydroelectricity. The reservoir fishery in Sri Lanka is dominated by the exotic cichlid species, *O. niloticus*. Since it is a littoral dweller which constructs spawning pits (nests) in shallow peripheral areas of reservoirs, the morphometry, sediment characteristics and turbidity of the reservoirs can be considered as influencing factors in the choice of nesting sites by *O. niloticus*.

The presently reported study has shown that nest density in the nesting areas of *O. niloticus* in the 10 reservoirs studied was influenced by slope of the basin, water turbidity and percentage silt content in the sediments. Furthermore, relative reservoir water level fluctuation had a negative significant relationship with nest density. As water level fluctuations are mainly governed by the release of reservoir water for irrigation, effective dialogue should be held between irrigation and fisheries authorities to achieve a trade-off between irrigation requirements and maintenance of reservoir water levels for a sufficient period during the peak spawning periods of *O. niloticus*.

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