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Empirical yield predictive models for the fisheries of irrigation reservoirs in Sri Lanka

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Abstract As fisheries production in reservoirs of most countries is a secondary use, challenges for improved management of fisheries should be addressed by building partnership between fisheries and other interested groups such as agriculture concerned with water management. Attempts were therefore made to develop empirical fish yield predictive models in ten irrigation reservoirs of Sri Lanka incorporating morphological, edaphic and hydrological parameters together with fishing intensity, with a view to investigating their influence on fish yields.

Reservoir fish yield was found to be significantly correlated with two formulations of morpho-edaphic index (i.e., conductivity in μS cm^{-1}/mean depth in m [MEI_c] and alkalinity in m. equiv. l^{-1})/mean depth in m [MEI_a]), and a relative reservoir level fluctuation index (RRLF), defined as the mean amplitude of the annual reservoir level fluctuations divided by the mean depth of the reservoir. Both MEI_c and MEI_a also had significant positive ln-ln relationships with RRWL, indicating that RRWL can be used as an independent variable in reservoir fish yield prediction. Reservoir fish yield was also related to fishing intensity (FI in boat-days ha^{-1}, yr^{-1}) conforming to a ln-linear regression model ($p<0.05$). When MEI_a, MEI_c and RRWL were used as predctor variables together with FI, reservoir fish yield (FY) was multiply correlated as follows:

$$\text{Ln FY} = 3.245 + 0.327 \text{ Ln } MEI_a + 0.023 \text{ FI } (R^2 = 0.355; p< 0.01)$$
$$\text{Ln FY} = 3.403 + 0.249 \text{ Ln } MEI_c + 0.019 \text{ FI } (R^2 = 0.369; p< 0.01)$$
$$\text{Ln FY} = 1.330 + 0.650 \text{ Ln RRWL} + 0.016 \text{ FI } (R^2 = 0.593; p< 0.001)$$

The empirical yield predictive model based on RRWL and FI as independent variables was more robust than those based on MEI_a and MEI_c, and the former has significant management implications because RRWL can be manipulated by irrigation authorities whereas control of FI is under the jurisdiction of fisheries authorities. Hence, through an effective dialogue between irrigation and fisheries authorities, there is a considerable potential to optimize fish yields in irrigation reservoirs of Sri Lanka.

Keywords: inland fisheries; quick-and-dirty methods; reservoir fisheries; tropical reservoirs; yield predictive models

INTRODUCTION

Reservoirs in the tropical world significantly contribute to inland fish production, despite their primary uses are irrigation, hydroelectricity generation and drinking water supply (Fernando and Holičik 1991; Welcomme 2001; Amarasinghe and De Silva 2015). The challenges for sustaining and ensuring improved management of inland fish production in reservoirs are therefore needed to be addressed by building partnerships between fisheries and other interested groups concerned with water management (Dugan, Sugunan, Welcomme, Bene, Boummett, Beveridge et al. 2007). This is particularly important in irrigation reservoirs because those who are engaged in water management for agriculture are also keen to increase overall benefits of water productivity to food security and poverty reduction (Dugan et al. 2007).

There has been an increasing trend in the recent past to develop empirical models for prediction of fish yields in lakes and reservoirs, which in general relied on the assumption that lakes and reservoirs are characterized by static morphological characteristics and chemical paramters (Rawson 1952; Ryder 1965, 1982; Henderson and Welcomme 1974; Dowing, Plante, and Lalonde 1990). Kolding and van Zwieten (2012) have shown however, as lakes and reservoirs are rarely closed entities and as their chemical composition is therefore a function of the hydrological regime, the dynamic impact of shifting of water supplies on their biological productivity is important to be considered for meaningful fish yield predictive model development. Most reservoirs in Sri Lanka, except for a few upland reservoirs constructed recently for hydroelectricity generation, are irrigation reservoirs and are subjected to drastic water level fluctuations due to irrigation control of hydrological regimes (De Silva 1988; Amarasinghe and Weerakoon 2009). Several studies have shown that it would also be important to incorporate fishing effort together with the morphometric and edaphic variables to predict fish yields in lakes and reservoirs (Ranta and Lindström 1989; Bayley 1988; Moreau and De Silva 1991).

In the present paper, an attempt is made to develop empirical yield predictive models for the fisheries of irrigation reservoirs of Sri Lanka, incorporating morphological, edaphic and hydrological parameters together with fishing intensity, with a view to identifying the potential for optimizing fish yields through building partnerships between fisheries authorities and irrigation authorities concerned with water management.

MATERIALS AND METHODS

In the present analysis, there were two sources of data, i.e., the data collected from ten selected irrigation reservoirs in the Kala oya river basin of Sri Lanka (Fig. 1) from June 2013 to February 2016, and those reported by Nissanka, Amarasinghe and De Silva (2000) and Amarasinghe, De Silva and Nissanka (2002) for several irrigation reservoirs of Sri Lanka. Reservoirs selected from the Kala oya river basin in the present study were Angamuwa, Balaluwewa, Dewahuwa, Ibbankatuwa, Kalawewa, Kandalama, Katiyawa, Rajanganaya, Siyambalangamuwa and Usgala Siyambalangamuwa. Some morphometric characteristics of these 10 reservoirs and those which were gleaned from Nissanka et al. (2000) and Amarasinghe et al. (2002) are given in Table 1.

Each of the 10 reservoirs of Kala oya river basin was visited approximately once in two months. In each reservoir, at three predetermined sampling stations, conductivity was measured using a conductivity meter (Make: Hanna; Model: HI86303). Total alkalinity was determined by a standard titrimetric method (APHA 2012), using 0.1 N standard HCl and mixed bromocresol green-methyl red indicator, and expressed as $CaCO_3$ m. equiv. l^{-1}.

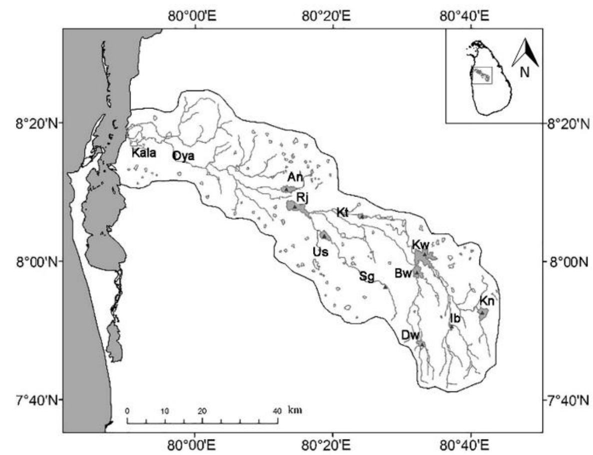

Fig. 1 Map of the study area showing the sampling sites of Kala oya river Basin. An - Angamuwa, Bw - Balaluwewa, Dw - Dewahuwa, Ib - Ibbankatuwa, Kn - Kandalama, Kt - Katiyawa, Kw - Kalawewa, Rj - Rajanganaya, Sg - Siyambalangamuwa, Us - Usgala siyambalangamuwa.

Daily water level data in each reservoir were obtained from the Mahaweli authority of Sri Lanka and Irrigation department. For gathering data of fisheries production and fishing intensity, data sheets were distributed among fishers. Landing sites were visited from time-to-time for cross-checking the accuracy of data-logs recorded by fishers.

Two expressions of morpho-edaphic index (MEI) were defined as follows:

$$MEI_c = \frac{\text{Conductivity } (\mu\text{S cm}^{-1})}{\text{Mean depth (m)}}$$

(Henderson and Welcomme 1974) (1)

$$MEI_a = \frac{\text{Total alkalinity (m.equiv. } l^{-1})}{\text{Mean depth (m)}}$$

(Miller et al. 2005; Cardoso et al. 2007) (2)

Mean annual relative reservoir level fluctuation **(**RRLF) in each reservoir was calculated using the following equation (Kolding & van Zwieten, 2006).

$$RRWL = \frac{Z_{Max} - Z_{Min}}{\text{Mean depth}} x100 \quad (3)$$

where, Z_{Max} = Maximum water level in m, Z_{Min} = Minimum water level in m, and mean depth is in m. In Ibbankatuwa reservoir however, the water level during October 2013 was at the minimum level corresponding to dead storage due to the reason that Irrigation Department has drained the reservoir to carry out rehabilitation works in the reservoir bund. As such, in Ibbankatuwa reservoir RRWL was determined disregarding the water level in October 2013.

Mean annual reservoir fish yields were estimated from the data logs of fishers and were expressed as kg ha^{-1}, yr^{-1}. Mean annual fishing intensity (FI) was also estimated and expressed as boat-days ha^{-1}, yr^{-1}. The relationships of fish yield (FY) to MEI_a, MEI_c and RRWL were determined by linear regression techniques with appropriate data transformations. The relationship between FY and FI was also determined. The yield predictive models were then derived using FI and other three predictor variables (MEI_a, MEI_c and RRWL) separately and FY as the dependent variable using multiple regression techniques.

Table 1 Some morphometric characteristics of ten irrigation reservoirs of the Kala Oya River Basin. Abb – Abbreviations of reservoir names; CA – Catchment area; RA - Reservoir area; RC - Reservoir capacity; * data from Nissanka et al. (2000); Amarasinghe et al. (2002); ** data from the Irrigation Department of Sri Lanka and Mahaweli Authority of Sri Lanka.

Reservoir	Abb	RA (km^2)	CA (km^2)	RC (km^3)	Mean depth (m)
Badagiriya*	Bd	4.86	340.3	0.011	2.35
Chandrikawewa*	Ch	4.39	213.8	0.029	6.56
Kaudulla*	Ku	27.13	362.1	0.128	4.72
Mahawilachchciya*	Mw	9.72	367.0	0.040	4.11
Minneriya*	Mn	25.50	217.1	0.135	5.30
Muthukandiya*	Mu	3.89	25.4	0.030	7.76
Nachchaduwa*	Na	17.85	591.7	0.057	3.20
Nuwarawewa*	Nu	11.99	67.0	0.044	3.70
Parakrama Samudra*	Ps	26.62	57.7	0.142	5.34
Udawalawe*	Ud	34.2	1108.0	0.296	7.84
Angamuwa**	An	7.92	129.5	0.020	1.99
Balaluwewa**	Bw	9.34	269.8	0.041	4.43
Dewahuwa**	Dw	4.33	67.3	0.014	3.13
Ibbankatuwa**	Ib	4.05	169.0	0.012	2.89
Kandalama**	Kn	7.36	98.0	0.034	4.58
Katiyawa**	Kt	2.57	86.7	0.056	2.16
Kalawewa**	Kw	19.80	571.9	0.088	4.43
Rajanganaya**	Rj	15.99	1610.9	0.101	6.30
Siyambalangamuwa**	Sg	1.46	46.8	0.003	1.78
Usgala Siyambalangamuwa**	Us	7.69	184.6	0.027	3.47

RESULTS

Alkalinity, electrical conductivity, biological productivity related indices (MEI_a, MEI_c and RRWL) and fishery-related data of 20 reservoirs are presented in Table 2. Also give in Table 2 are RRLF, FI and fish yield data of five more reservoirs that were used for validation of the empirical model developed in the present study.

Both forms of morpho-edaphic index (MEI_a and MEI_c) had significant positive ln-ln relationships with reservoir fish yield ($p<0.05$; Fig. 2). Further, both MEI_a and MEI_c also had significant positive ln-ln relationships with RRWL ($p<0.02$; Fig. 3) indicating that RRWL can also be used as an independent variable in reservoir fish yield prediction. Fish yield was significantly correlated with RRWL according to a positive ln-ln relationship ($p<0.001$; Fig. 4a) indicating high predictive power of RRWL in reservoir fish yield prediction. Reservoir fish yield was also related to FI conforming to a ln-linear regression model ($p<0.05$; Fig. 4b).

Table 2 Edaphic and fisheries characteristics of ten irrigation reservoirs of the Kala Oya River Basin. * data from Nissanka et al. (2000); Amarasinghe et al. (2002); ** data from the present study; Alk- Alkalinity; Cond - Conductivity; MEI_a=Alkalinity/mean depth; MEI_c=Conductivity/mean depth; RRLF - Relative reservoir level fluctuation; FI - Fishing intensity.

Reservoir	Alk (m. equiv. l^{-1})	Cond (µS cm^{-1})	MEI_a	MEI_c	RRLF	FI (boat-days ha^{-1}, yr^{-1})	Fish yield (kg ha^{-1}, yr^{-1})
Badagiriya*	152.0	417.1	67.2	184.6	188.9	6.9	181.3
Chandrikawewa*	118.4	144.1	17.9	21.8	27.5	4.4	28.6
Kaudulla*	117.3	176.7	24.9	37.5	136.6	9.2	182.2
Mahawilachchciya*	246.0	521.3	59.8	126.7	122.6	9.5	108.5
Minneriya*	131.5	156.1	22.8	29.5	158.6	9.0	111.7
Muthukandiya*	76.0	92.28	9.8	11.9	90.3	5.4	68.4
Nachchaduwa*	144.8	376.3	45.4	118	149.5	14.4	193.2
Nuwarawewa*	163.1	364.0	44.4	99.2	104.9	15.2	138.2
Parakrama Samudra*	149.3	201.8	25.4	40.1	97.0	7.6	86.2
Udawalawe*	103.5	121.4	13.1	15.4	91.4	2.6	95.2
Angamuwa**	170.7	407.2	85.6	204.2	164.4	26.8	175.4
Balaluwewa**	115.5	244.8	26.0	55.2	166.9	25.1	160.5
Dewahuwa**	130.7	275.6	41.7	88.0	209.2	18.0	102.9
Ibbankatuwa**	100.0	169.0	34.6	58.4	208.2	7.0	94.5
Kandalama**	111.9	200.8	24.4	43.8	88.8	10.3	43.9
Katiyawa**	153.8	377.9	71.2	175.0	134.4	9.0	76.5
Kalawewa**	98.2	207.2	22.2	46.7	166.9	26.9	120.4
Rajanganaya**	153.2	380.1	24.3	60.4	69.04	21.6	114.6
Siyambalangamuwa**	138.4	384.2	77.7	215.7	255.1	13.2	175.6
Usgala Siyambalangamuwa**	148.4	448.1	42.2	128.9	173.0	15.3	134.1

When MEI_a, MEI_c and RRWL were used as predictor variables together with FI, reservoir fish yield (FY) was multiply correlated according to the following relationships.

$$Ln\ FY = 3.245 + 0.327\ Ln\ MEI_a + 0.023\ FI \quad (R^2 = 0.355;\ r = 0.596;\ p< 0.01) \qquad (4)$$

$$Ln\ FY = 3.403 + 0.249\ Ln\ MEI_c + 0.019\ FI \quad (R^2 = 0.369;\ r = 0.607;\ p< 0.01) \qquad (5)$$

$$Ln\ FY = 1.330 + 0.650\ Ln\ RRWL + 0.016\ FI \quad (R^2 = 0.593;\ r = 0.770;\ p< 0.001) \qquad (6)$$

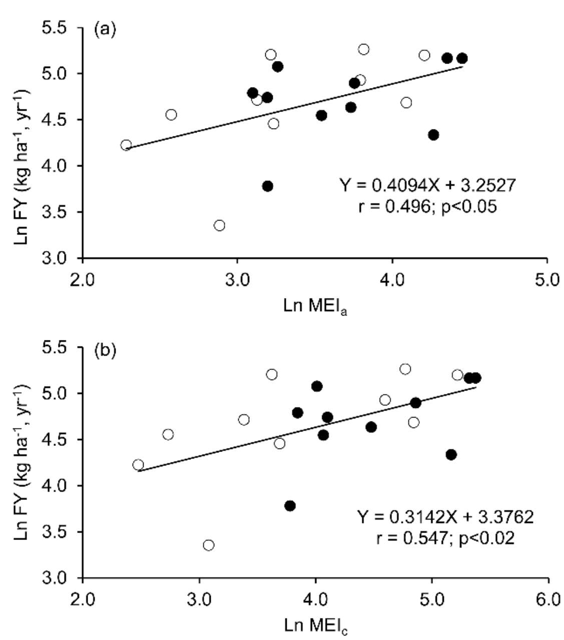

Fig. 2 Relationship of fish yield (FY) in the 20 reservoirs of Sri Lanka with morpho-edaphic indices (MEI_a and MEI_c). The open circles represent the reservoirs from Nissanka et al. (2000) and Amarasinghe et al. (2002) and the black circles represents the reservoirs of the Kala oya river basin in the present study.

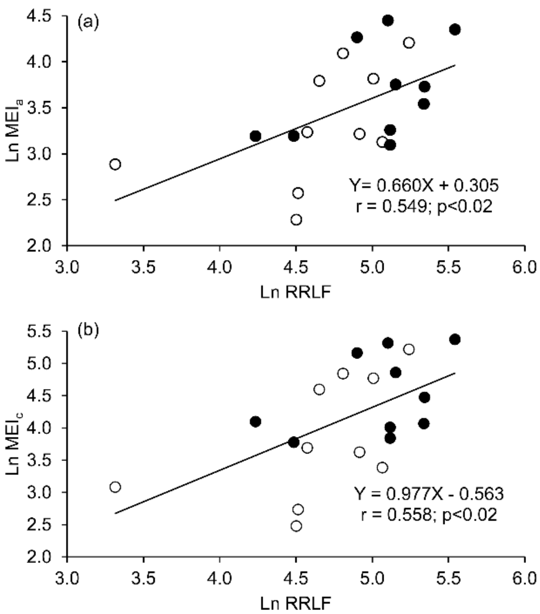

Fig. 3 Relationship of Morpho-edaphic indices (MEI_a and MEI_c) in the 20 reservoirs of Sri Lanka with Relative reservoir level fluctuation (RRLF). The open circles represent the reservoirs from Nissanka et al. (2000) and Amarasinghe et al. (2002) and the black circles represents the reservoirs of the Kala oya river basin in the present study.

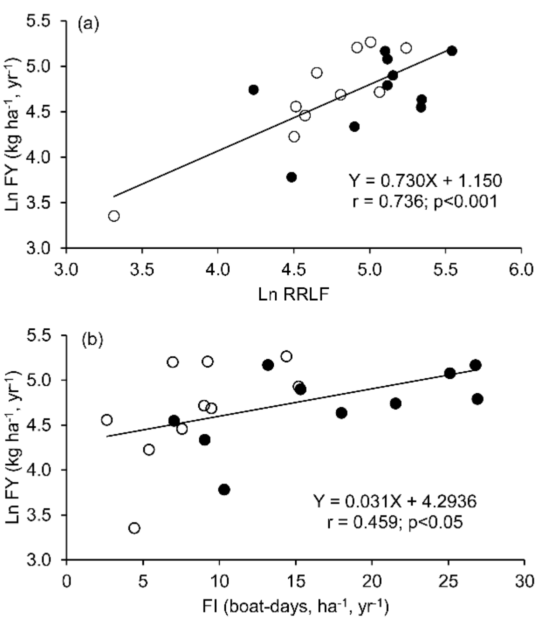

Fig. 4 Relationships of Fish yield (FY) in 20 reservoirs of Sri Lanka with (a) relative reservoir level fluctuation (RRLF) and (b) fishing intensity (FI). The open circles represent the reservoirs from Nissanka et al. (2000) and Amarasinghe et al. (2002) and the black circles represents the reservoirs of the Kala oya river basin in the present study.

DISCUSSION

In a comprehensive assessment of inland fisheries in the world, it has been recognized that competition for water and aquatic habitat is the most critical challenge facing inland fisheries in many countries (Dugan et al. 2007). Also, according to Dugan et al. (2007), the need for water to support fish and fisheries can conflict with the needs of other sectors, in particular agriculture. In Sri Lanka, development of reservoir fisheries has essentially been a secondary use because they were constructed in the past for irrigating rice paddy cultivation lands, and more recently in uplands for generation of hydroelectricity (De Silva 1988; Amarasinghe and Weerakoon 2009). Consequently, decisions on water management frequently do not take into account the impact on fish and fisheries. Due to the diverse nature of biological productivity of reservoirs across the country (Silva et al. 2002), empirical yield predictive models are useful for yield prediction in the reservoir fisheries. Regier, Ita and Kudhongania (1988) mentioned the value of empirical approaches which treat complexities in reservoirs more holistically instead of data reduction approaches which might lead to over-simplification.

Mean depth of lakes and reservoirs is a morphometric attribute, which determines the process of vertical mixing, facilitating nutrient enrichment in the euphotic zone and as such, directly inlfuences biological productivity (Rawson 1952). The empirical fish yield predictive models based on the combination of morphometric and chemical parameters such as MEI therefore provide reasonable estimates of potential fish yield in lakes and reservoirs (Ryder 1965, 1982; Henderson and Welcomme 1974; Wijeyaratne and Costa 1981; Rempel and Colby 1991). Due to the simplicity in concept and strong predictive power, subsequent to original derivation of MEI in North American lakes (Ryder 1965), its worldwide application for fish yield prediction in lakes and reservoirs has been evident with regional modifications (e.g., Henderson and Welcomme 1974; Marshall 1984; Wijeyaratne and Amarasinghe 1987). From the present analysis, it was evident that both MEI_a and MEI_c can be used for reservoir fish yield prediction in Sri Lankan reservoirs.

It was also found in the present analysis that relative reservoir level amplitude, measured as

RRLF, had a strong predictive power of reservoir fish yield. Kolding and van Zwieten (2006, 2012) have also shown that in tropical lakes and reservoirs, fish yield could be predicted from relative lake level fluctuation. Water level fluctuation in lakes and reservoirs facilitates nutrient enrichment stimulating fish production. During high water level, terrestrial shrub vegetation in the peripheral areas of reservoirs are inundated and nutrients leaching from decomposing organic matter result in increased plankton and fish production (McLachlan 1970; Kolding and van Zwieten 2012). The positive influence of RRLF on MEI_a and MEI_c as evident from the present study, indicates that RRLF can be treated as an index of biological productivity. Kolding and van Zwieten (2012) also have shown that relative water level fluctuations in tropical lakes and reservoirs affect biological productivity. According to Keitel et al. (2015), water level fluctuations in a tropical reservoir in NE Brazil influenced release of bioavailable phosphorous affecting productivity. In irrigation reservoirs of Sri Lanka, as in many parts of the world, reservoir water level fluctuations are essentially controlled by irrigation authorities for their primary use of irrigation of agricultural lands.

Fishing effort is an important factor influencing fish production in any fishery. In Finnish lakes, fishing effort was shown to be far more relevant in affecting fish yield than water quality (Ranta and Lindström 1989). Bayley (1988) has shown the importance of incorporating fishing effort together with the variables that relate to the fisheries and to biological productivity. In the present analysis, when the fishing intensity (FI) was used as an independent variable together with MEI_a, MEI_c and RRLF, predictive power has considerably increased. However, in some reservoirs of Sri Lanka, regular stocking of fish fingerlings (i.e., Chinease and Indian major carps and Nile tilapia) is performed for the development of culture-based fisheries (Pushpalatha and Chandrasoma 2009). This approach is not applicable for such reservoirs, and therefore, search for appropriate empirical yield predictive models for the culture-based fisheries in reservoirs is an innovative opportunity for future research on reservoir fisheries development and management.

The empirical yield predictive model based on RRWL and FI as independent variables was more robust than those based on MEI_a and MEI_c. As MEI-based models are essentially related to biological productivity, they are useful as diagnostic models. These kinds of models are generally based on the derivation of relationships between observed fish yields and observed and static independent variables such as MEI. However, the empirical model based on RRWL and FI can be treated as a model of management implications because RRWL can be manipulated by irrigation authorities whereas control of FI would be under the jurisdiction of fisheries authorities. Hence, through an effective dialogue between irrigation and fisheries authorities, there is a considerable potential to optimize fish yields in irrigation reservoirs.

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