2.3 Production trends and yield predictive models for culture-based fisheries in irrigation reservoirs of Sri Lanka

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Abstract

This study aims to develop empirical yield predictive models for CBF in perennial irrigation reservoirs of Sri Lanka, focusing on the GFP (*M. rosenbergii*), alongside carp and tilapia species. Conducted across 39 reservoirs, the research involved the collection of extensive data on species stocking densities, fish yields and various limnological parameters. Results indicate that stocking densities of carp and GFP significantly influenced yields, with optimal stocking densities identified as over 900 fingerlings ha^{-1} yr^{-1} for carp and approximately 1,000 post larvae ha^{-1} yr^{-1} for GFP in major reservoirs. Notably, the study found a significant relationship between fishing intensity and carp yield, although no such correlation was observed for GFP. Limnological assessments revealed that chlorophyll-a concentrations positively correlated with carp yields, while other parameters exhibited limited variability. TSI indicated that most reservoirs were classified as eutrophic. PCA highlighted key variables influencing productivity, with significant relationships established for carp yield. The study underscores the critical role of stocking strategies and limnological factors in optimising fish production, providing valuable insights for sustainable aquaculture development in Sri Lanka's inland water bodies. The predictive models developed offer a framework for enhancing CBF, thereby contributing to improved livelihoods in rural communities reliant on freshwater fish as a vital protein source.

***Keywords**: culture-based fisheries, perennial irrigation reservoirs, yield predictive models*

Introduction

Sri Lanka is reputed to have a large number of irrigation reservoirs, some major reservoirs of which are over 2,000 years old. The cumulative extent of reservoirs is about 206,000 ha (Jayasinghe et al. 2005a). Based on their hydrological regimes, they are classified as perennial and seasonal reservoirs. These reservoirs, with a few exceptions, are irrigation reservoirs and are very diverse in size, age, hydrology and catchment features (Amarasinghe et al. 2005). Perennial reservoirs (around 200,000 ha) are divided into 3 broad categories; large (>800 ha), medium (200–800 ha) and small (<200 ha) based on the water spread at the full supply level. Reservoirs are primarily used for irrigation, hydroelectricity generation and drinking water supply, and inland fisheries are essentially a secondary use of them (Welcomme 2010; Amarasinghe and De Silva 2015).

The expansion of inland fisheries and aquaculture has been given a high priority in Sri Lanka because freshwater fish is a cheap source of animal protein for rural low-income communities. In the early 1980s, Sri Lanka initiated CBF (Pushapalatha and Chandrasoma 2010). This system was first introduced to seasonal reservoirs and later it was expanded to the perennial reservoirs (Thayaparan 1982; Chakrabarty and Samaranayake 1983; Chandrasoma and Kumarasiri 1986; De Silva et al. 2006b). The introduction of CBF into minor perennial reservoirs commenced in 2004 and gradually expanded to cover the other 2 size categories of perennial reservoirs: medium and large reservoirs (Chandrasoma and Pushpalatha 2018). CBF in Sri Lanka is well developed in reservoirs, and over the last 2 decades the fishery has enhanced inland fish production through a co-management strategy (De Silva 2003; Amarasinghe and Nguyen 2010; Amarasinghe and Wijenayake 2015; Chandrasoma et al. 2015). Pushapalatha and Chandrasoma (2010) and Chandrasoma et al. (2015) mentioned that several strategies were implemented in recent years to encourage further development of existing CBF in Sri Lanka.

GFP, *Macrobrachium rosenbergii* (De Man 1879), is one of the most demanded and widely cultured crustacean species in the world (Smith et al. 2005; Hammed et al. 2012). The stocking program of GFP was initiated under the CBF approach in Sri Lanka and currently it is beginning to become one of the most important sectors of the national economy of Sri Lanka. GFP contributed around 0.6% to the total annual freshwater fish production of the country during 2010–2014 (Chandrasoma et al. 2015). Because of the high export potential of the GFP, the fisheries sector has given significant attention to developing the CBF of GFP. The preliminary research indicated that historical stocking and fishery production data for GFP was very limited and yields were highly variable. It was further evidence that this variation could neither adequately be explained by the stocking procedures nor by the physical attributes of the reservoirs. GFP dynamics cannot be evaluated in isolation and the dynamics of stocked finfish species have to be considered to obtain a complete understanding (Amarasinghe et al. 2021).

Simple empirical models have been used to predict fish yield in lakes and reservoirs for over 70 years (Ryder 1965; Henderson et al. 1973; Moreau and De Silva 1991). Rawson (1952) demonstrated the possibility of estimating fish yields of lakes based on mean depth. Some others also tried to assess fish yield potential from biotic and morphometric parameters (Hayes 1957; Northcote and Larkin 1956). Ryder (1965) developed morphoedaphic index

(MEI) by using the ratio of total dissolved solids to mean depth using 23 temperate lakes. Later many researchers used other dependent variables such as lake surface area, temperature and other parameters along with MEI for the prediction of fish yields in lakes and reservoirs in many countries (for example, Henderson and Welcomme 1974; Toews and Griffith 1979; Jenkins 1982; Schlesinger and Reglier 1982; Machena and Fair 1986). MEI along with fisheries variables such as numbers of fishers, boast and effort are used to predict the yield of African lakes (Henderson and Welcomme 1974). Maximum sustainable fish yield of Sri Lankan reservoirs was calculated (Wijeyaratne and Amarasinghe 1987; Nissanka et al. 2000). Nadarajah et al. (2018) used morphological, edaphic, and hydrological parameters together with fishing intensity to predict the fish yield in irrigation reservoirs of Sri Lanka. Rawson (1952) grouped lake productivity parameters into 3 groups (that is, climatic, morphometric and edaphic). Potential fish yield from morphological parameters such as reservoir area, volume, depth and shoreline development or gradient are some of the key morphological parameters to assess productivity. Wijeyaratne and Amarasinghe (1987) showed that maximum sustainable yield (MSY) in several reservoirs of Sri Lanka was correlated with the MEI. Amarasinghe et al. (2002) have shown that catchment features like the ratio of catchment land use patterns to reservoir capacity are important predictor variables of fish yields in Sri Lankan reservoirs. All these fish yield predictive models in Sri Lankan reservoirs have been developed for capture fisheries, except for the attempts made by Jayasinghe et al. (2005b) for predicting CBF yields in non-perennial reservoirs. Hitherto, no such predictive models have been developed for CBF yield prediction in perennial irrigation reservoirs of Sri Lanka.

Thus, the present study proposes to develop empirical yield predictive models for the fisheries of perennial irrigation reservoirs of Sri Lanka, incorporating morphological, edaphic and hydrological parameters together with fishing intensity. In this study, a special emphasis will be paid to identifying potential for optimising GFP, *M. rosenbergii* fish yield.

Methodology

The study was carried out in 39 irrigation reservoirs (located in Anuradhapura, Batticaloa, Hambanthota, Kilinochchi, Kurunegala, Monaragala, Mulathive, Puttalam, Trincomalee and Vavuniya districts of Sri Lanka). Post larvae stocking of finfish species and GFP (*M. rosenbergii*) and harvest data of these species was collected from the database of NAQDA. Fingerlings and post larvae packing practices and harvesting data was obtained from the logbook records of the fisheries societies in reservoirs. Reservoir landing sites were visited from time to time for cross-checking the accuracy of data. Reservoir hydrological data such as surface area, minimum and maximum depth, reservoir volume, extent at full supply level (FSL), capacity at FSL, daily water level data, and inflow and outflow data catchment area was collected from the Department of Irrigation and Mahaweli Authority of Sri Lanka. All reservoirs were mapped using GPS (Trimbel GeoExolorer 3; Trimpel Navigation Ltd, California, USA) and reservoir area and shoreline length at full supply level was estimated. Each reservoir was visited at least once in 3 months covering wet, dry and intermediate seasons. In each reservoir, water samples were collected at least from 3 sampling sites, packed in ice in an insulated Styrofoam box and were taken to the laboratory to determine chlorophyll-a , nitrate, ammonia, orthophosphate and total phosphorous contents. Air and water temperature, SDD, electrical conductivity (using a conductivity meter), and total alkalinity (using the titrimetric method) were determined in situ. The number of fishers involved and the number of boats used for fishing activity of each reservoir on each fishing day were collected from the logbook data of fisheries societies of the reservoirs. During field visits, the accuracy of logbook data was cross-checked. Shoreline development (D_L) and shoreline area ratio (R_{LA}) index, mean annual reservoir water level fluctuation (RRLF) index, hydraulic retention time (HRT) or water residence time, catchment area (CA) and reservoir capacity (RC) ratio, MEI and TSI were calculated using appropriate equations.

Results

The stocking density of fish fingerlings and post larvae of FWP of the 2022–2024 culture periods is illustrated in Table 2.3.1. Stocking density of carp, tilapia and FWP varied 90–1994 fingerlings ha^{-1} yr^{1}, 115–1715 fingerlings ha^{-1} yr^{1} and 0–1937 post larvae ha^{-1} yr^{1}, respectively. The carp, tilapia and FWP CBF activities in 37 perennial reservoirs during the 2022–2024 period varied considerably among the reservoirs, ranging from 15 kg ha^{-1} yr^{1} to 315 kg ha^{-1} yr^{1}, 1 kg ha^{-1} yr^{1} to 358 kg ha^{-1} yr^{1} and 0 kg ha^{-1} yr^{1}, respectively (Table 2.3.2).

A significant relationship was observed between carp and FWP stocking and yield during the 2022–2024 culture period ($p<0.05$). However, carp production in these reservoirs was managed at a suboptimal level. In contrast, tilapia stocking did not exhibit a significant relationship with yield (Figure 2.3.1). The relationship between carp species and major perennial reservoirs demonstrates a significant correlation, indicating that their management is currently under suboptimal conditions. The optimum stocking density for carp species in major reservoirs is estimated to be over 900 fingerlings ha^{-1} yr^{-1}. In contrast, the stocking of tilapia species did not exhibit a significant relationship with yield, suggesting that regular stocking of tilapia in major perennial reservoirs is not advisable. Additionally, the optimum stocking density for FWP in major reservoirs is approximately 1,000 post larvae ha^{-1} yr^{-1} .

However, both carp and FWP demonstrate optimal production in medium-sized reservoirs. The optimum stocking density for carp in these reservoirs is approximately 1,250–1,500 fingerlings ha^{-1} yr^{-1}, while the optimum stocking density for FWP is around 1,500 post larvae ha^{-1} yr^{-1}. In minor perennial reservoirs, carp stocking exhibits a strong significant relationship with yield, with an optimum stocking density exceeding 1,800 fingerlings ha^{-1} yr^{-1}. However, similar to major and medium reservoirs, tilapia stocking does not show any significant relationship with production. In contrast, FWP stocking demonstrates a significant relationship with yield, with an optimum stocking density exceeding 2,000 post larvae ha^{-1} yr^{-1} (Figure 2.3.3).

Fishing intensity (number of boat days ha^{-1}) exhibits a significant relationship with the yield of carp and tilapia species ($p<0.05$). However, no significant relationship is observed between fishing intensity and the yield of FWP (Figure 2.3.2).

Table 2.3.1: Fish and FWP stocking density of selected reservoirs

Reservoir name	Code	Mean SD fingerlings/PL/ha/yr		
		Carp	Tilapia	FWP
Aluthdiulwewa	A5	733.97	1,612.99	809.52
Mahakanadarawa	A3	138.65	205.39	736.79
Nachchaduwa	A4	434.28	384.64	388.21
Manakkatiya	A6	285.33	321.56	2,270.70
Ranawa	A8	1,579.42	1,584.39	0.00
Mahawilachchiya	A2	209.23	255.65	750.00
Unnichchai	B1	261.19	206.22	1,436.60
Wadamunai	B3	609.91	306.82	1,021.17
Redeeyagama	H1	259.15	772.90	1,800.51
Iranamadu	KL2	90.62	195.29	494.00
Puthuurippu	KL3	281.46	841.06	2,963.01
Muthukandiya	MO4	836.87	455.24	1,519.53
Hambegamuwa	MO1	1,391.19	300.52	2,012.53
Hadhapanagala	MO2	1,424.81	807.99	2,060.13
Getupana	MO7	343.13	488.75	1,500.00
Kiriibbanwewa	MO3	1,640.61	1,715.17	1,086.92
Mullativu	MU1	164.73	543.05	776.22
Karavitagaraya	P2	321.66	319.15	812.32
Kottukachchiya	P6	891.79	1,652.94	1,933.06
Mahauswewa	P3	388.42	385.39	980.92
Mahadiulwewa	T1	135.89	180.48	1,950.15
Kalmadu	V2	122.55	550.75	1,510.15
Urusitawewa	MO5	1,994.63	1,497.09	1,555.71
Weerawila	H2	351.32	523.27	968.78
Usgala siyabalangamuwa	KU2	366.61	165.39	827.93
Hakwatunaoya	KU1	343.41	1,196.31	2,046.20
Tabbowa	P4	396.90	115.32	898.96
Phariya	P8	1,166.67	333.33	1,666.67
Morawewa	T2	139.53	188.88	750.00
Vijayakotupotha	P5	1,317.90	1,321.13	3,191.37
Dewalahandiya	P1	769.77	1,249.16	4,937.28

Table 2.3.2: Fish and FWP yield of selected reservoirs

Reservoir name	Code	Mean production kg/ha/y		
		Carp	Tilapia	FWP
Aluthdiulwewa	A5	76.77	44.83	2.45
Mahakanadarawa	A3	44.39	113.95	2.25
Nachchaduwa	A4	58.00	107.35	0.46
Manakkatiya	A6	25.00	21.33	3.77
Ranawa	A8	269.22	357.98	0.00
Mahawilachchiya	A2	60.95	223.18	1.22
Unnichchai	B1	85.00	84.27	0.67
Wadamunai	B3	23.50	160.52	1.74
Redeeyagama	H1	78.00	13.43	4.65
Iranamadu	KL2	69.00	42.79	1.56
Puthuurippu	KL3	15.00	35.00	33.23
Muthukandiya	MO4	75.00	1.38	2.89
Hambegamuwa	MO1	210.00	40.84	2.65
Hadhapanagala	MO2	167.00	64.72	6.85
Getupana	MO7	72.82	34.61	0.45
Kiriibbanwewa	MO3	110.00	43.12	3.46
Mullativu	MU1	75.00	81.91	3.28
Karavitagaraya	P2	40.04	9.94	0.47
Kottukachchiya	P6	114.23	49.33	5.37
Mahauswewa	P3	115.97	98.30	7.05
Mahadiulwewa	T1	77.56	33.26	2.09
Kalmadu	V2	55.00	62.26	3.04
Urusitawewa	MO5	315.00	5.79	0.49
Weerawila	H2	40.00	1.16	0.12
Usgala siyabalangamuwa	KU2	150.00	14.04	0.57
Hakwatunaoya	KU1	87.00	9.27	0.15
Tabbowa	P4	55.00	4.61	1.57
Phariya	P8	150.00	23.91	0.82
Morawewa	T2	70.00	8.85	0.20
Vijayakotupotha	P5	168.00	8.01	2.69
Dewalahandiya	P1	35.00	5.53	1.66

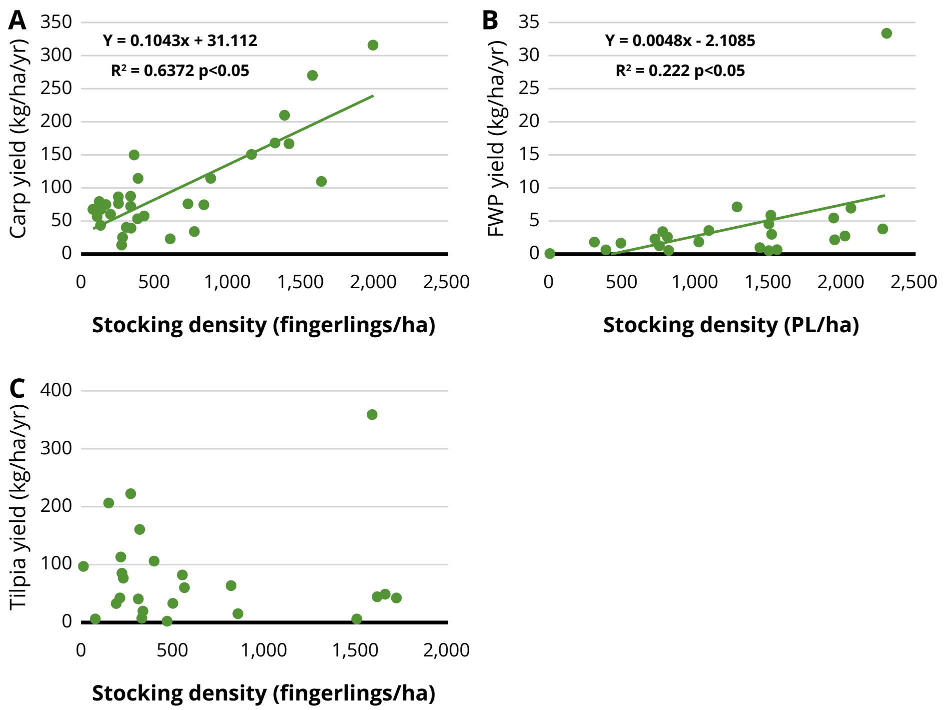

Figure 2.3.1: Relationships of stocking and yield

Note: (a) carp species (b) freshwater prawn (c) tilapia species

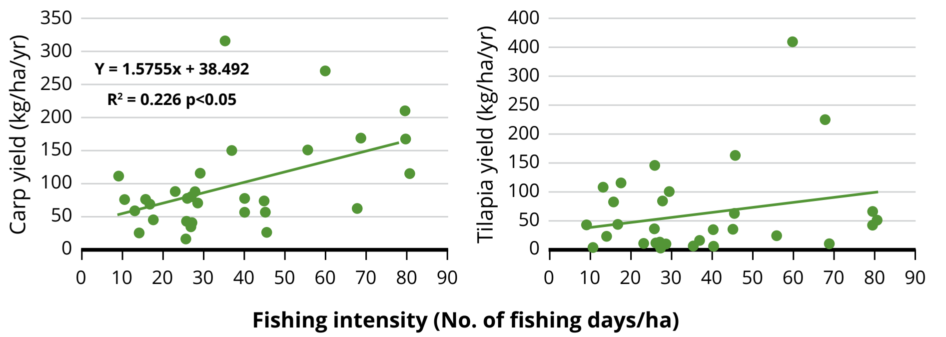

Figure 2.3.2: Relationship of fishing intensity (number of boat days ha^{-1}) with yield (kg ha^{-1} yr^{-1})

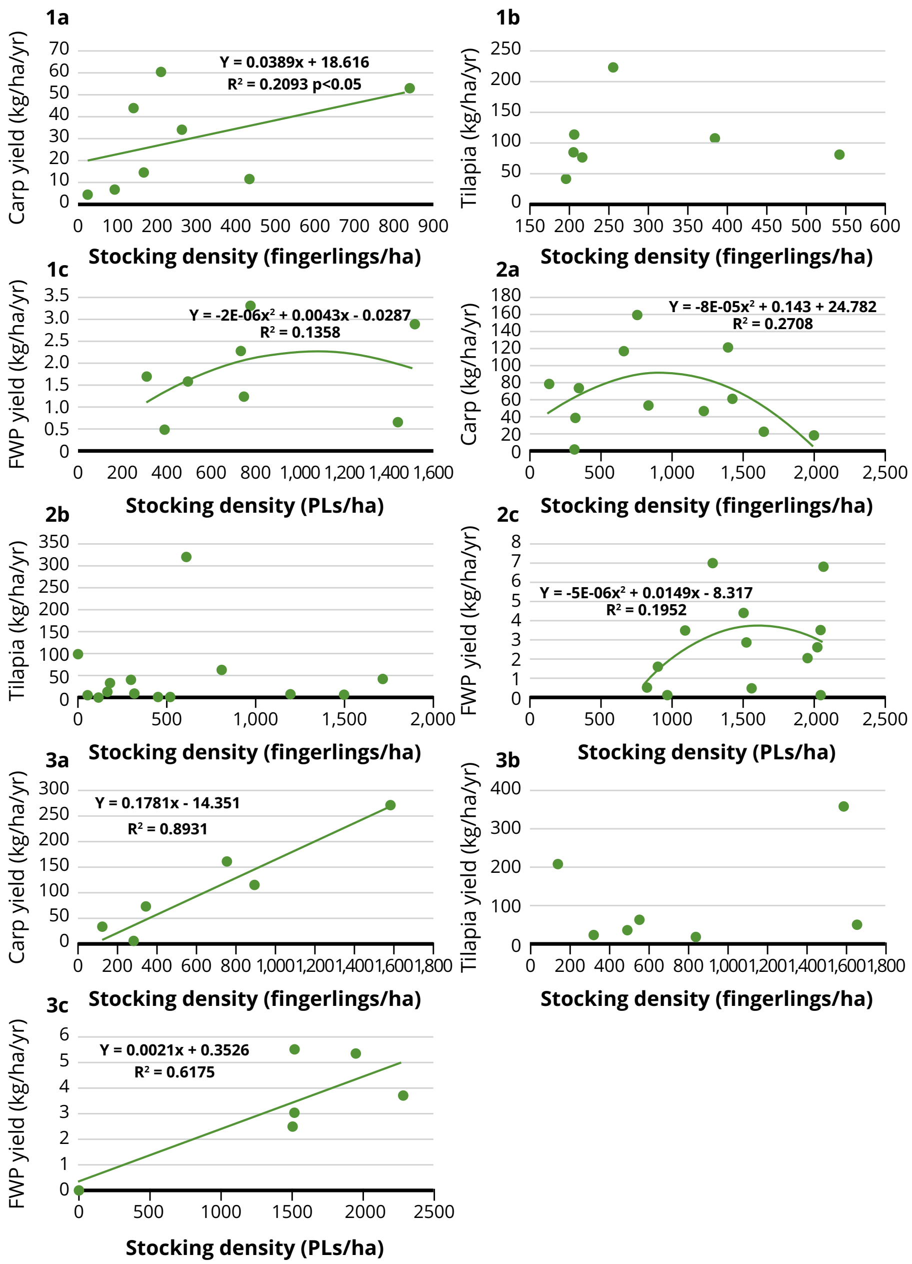

Figure 2.3.3: Relationship between stocking and yield

Note: 1a, 2a, 3a – carp species in major, medium and minor perennial reservoirs, 2a,2b,3a – tilapia species in major, medium and minor perennial reservoirs, 3a, 3b, 3c – FWP in major, medium and minor perennial reservoirs.

In the 39 perennial reservoirs studied, the limnological parameters measured did not show much variation with the time. Therefore, mean values of the limnological parameters measured during all sampling visits from December 2022 to December 2024 period (Figure 2.3.4) in each reservoir were considered for further calculations. Surface water temperature in 39 reservoirs ranged from 28.1±1.5 ˚C to 31.7±0.7 ˚C, pH 7.64±0.1 to 8.87±0.3. The range of conductivity was from 53.93±9 to 1108.25±90 (µS cm^{-1}) and alkalinity 43.42±10.1 to 518.33±125.5. Chlorophyll-a of the selected reservoirs were varied 3.20±0.2 to 27.83±5.1 and total phosphorus of the surface water ranged from 0.21±0.05 to 1.2±0.5. Chlorophyll-a shows positive correlation with the carp yield whereas other species did not show significant correlation with chlorophyll-a (Figure 2.3.5).

The TSI for SDD (TSI-SDD), total phosphorus (TSI-TP), and chlorophyll-a (TSI-Chl-a) were estimated using the equations described in the methodology. Analysis of 39 reservoirs revealed the pattern TSI (TP) = TSI (SDD) > TSI (Chl-a), indicating that underwater light attenuation is primarily influenced by non-algal particulate matter or water colour (Figure 2.3.6). The exceptionally high values of TSI (SDD) and TSI (TP) observed in these reservoirs are attributed to non-algal turbidity. Consequently, the classification of Sri Lanka's perennial reservoirs based on these 2 indices is not appropriate. Therefore, TSI (Chl-a) was used to classify the trophic status of the reservoirs to support the development of CBF. Also, in 37 reservoirs carp yield is significantly related to TSI (Chl-a) (Figure 2.3.7). Nevertheless, TSI (SDD) and TSI (TP) were not significantly related to the fish yield ($p>0.05$).

Carlson and Simpson (1996) has been used to classify reservoirs based on the Carlson trophic states index (CTSI) (Table 2.3.3).

Table 2.3.3: Category of Carlson Trophic State Index (CTSI)

Category	Range
Oligotrophic	0–30
Mesotrophic	30–50
Eutrophic	50–70
Hyper-eutrophic	70–100

Based on the calculated CTSI values, the selected reservoirs are classified as eutrophic, as they fall within the CTSI range of 50–70 (Figure 2.3.8).

Carp yield of the 37 reservoirs exhibited significant linear relationship with the TSI Chl-a (Figure 2.3.9).

Eleven limnological parameters (temperature, pH, DO, conductivity, alkalinity, NO_3, total phosphorus, orthophosphate, ammonia, SDD and chlorophyll-a) were used in the first PCA. Of these parameters, conductivity, alkalinity, chlorophyll-a, total phosphorous and SDD showed high variability across the dataset. For the final PCA, conductivity, alkalinity, chlorophyll-a, total phosphorous and SDD were used as input parameters, with the results presented in Table 2.3.4.

The PCA score plot of the 3 principal component axes (PC1, PC2 and PC3) explains the cumulative variances of 40.17%, 64.85% and 81.5%, respectively. The negative loading along the PC1 axis was related to high level of alkalinity and SDD, whereas positive loading on the same axis was related to high conductivity, total phosphorus and chlorophyll-a. On the PC2 axis, negative loading was related to a high level of chlorophyll-a, total phosphorous and SDD. While the positive loading was

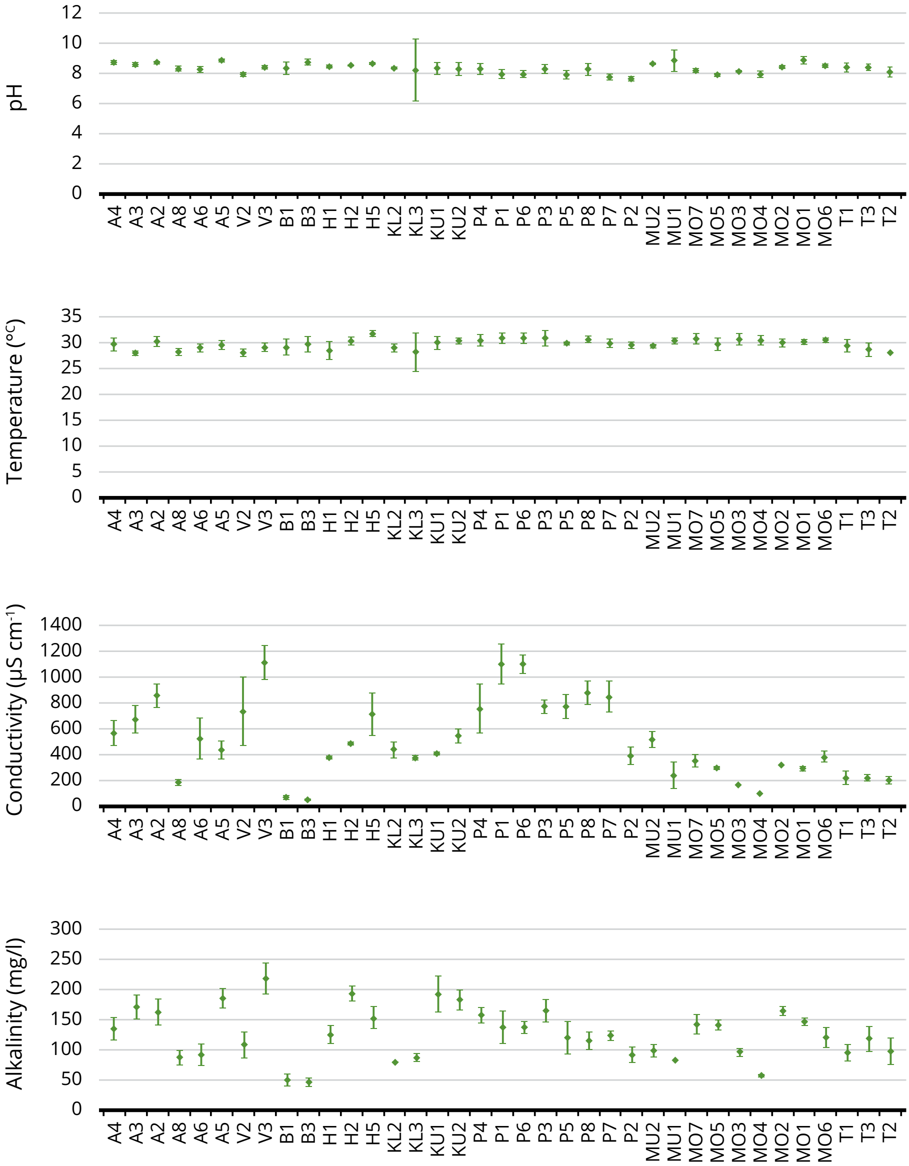

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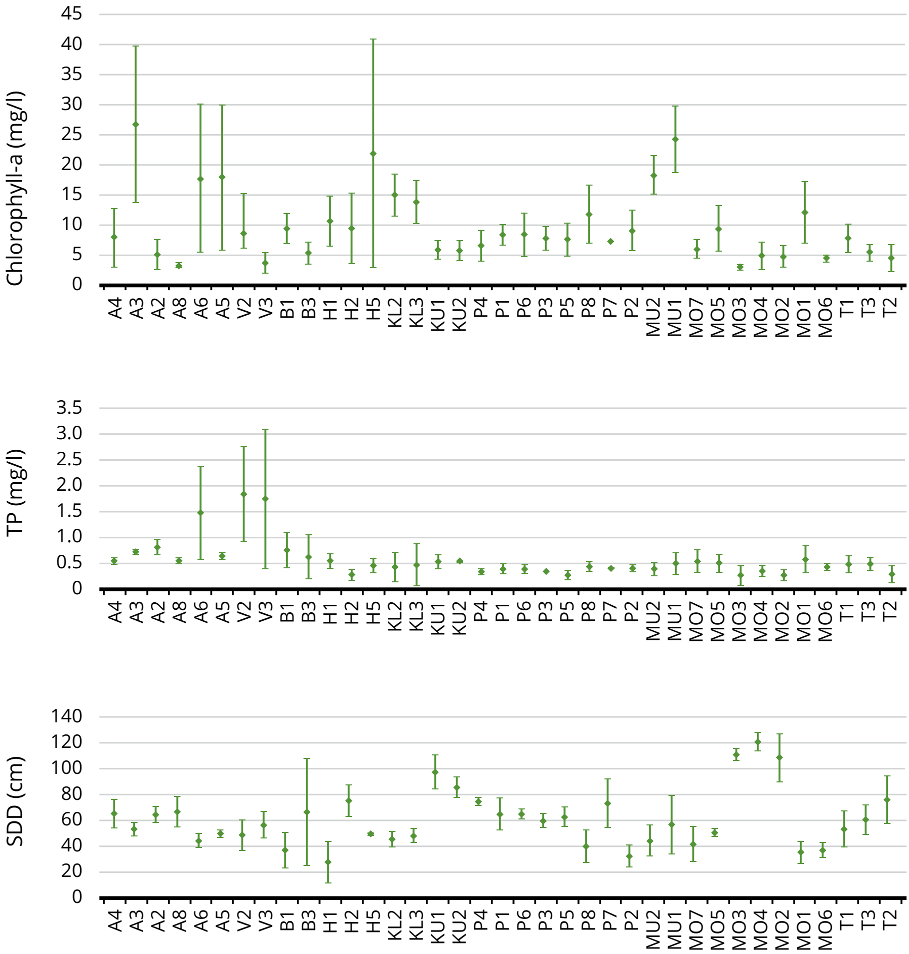
Figure 2.3.4: Variation of water pH, temperature (T in °C), conductivity (Con. in µS cm^{-1}), alkalinity (Alk. in mg l^{-1}), chlorophyll-a (Chl-a in µg l^{-1}), total phosphorous (TP in mg l^{-1}) and Secchi Disk Depth (SDD in cm) in 39 reservoirs

Note: Error bars denote the standard errors of mean.



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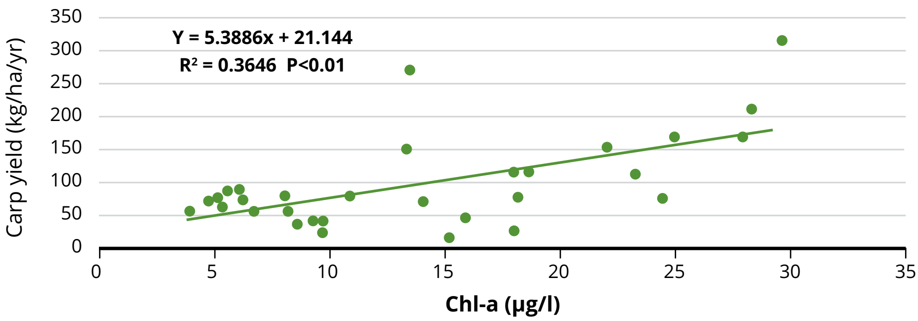

Figure 2.3.5: Relationship of chlorophyll-a and carp yield of 39 reservoirs

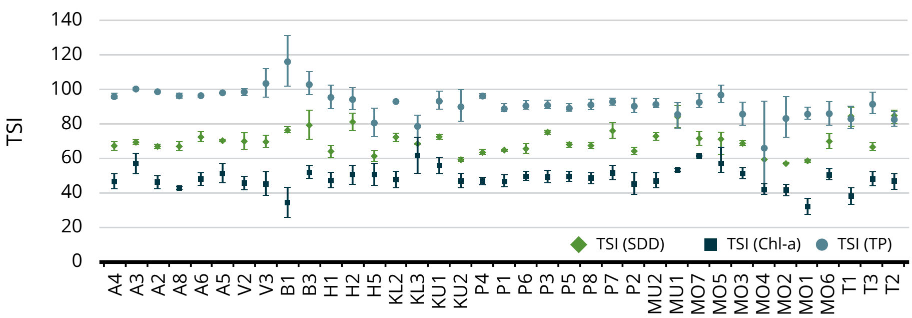

Figure 2.3.6: TSI of 3 definitions in 39 reservoirs

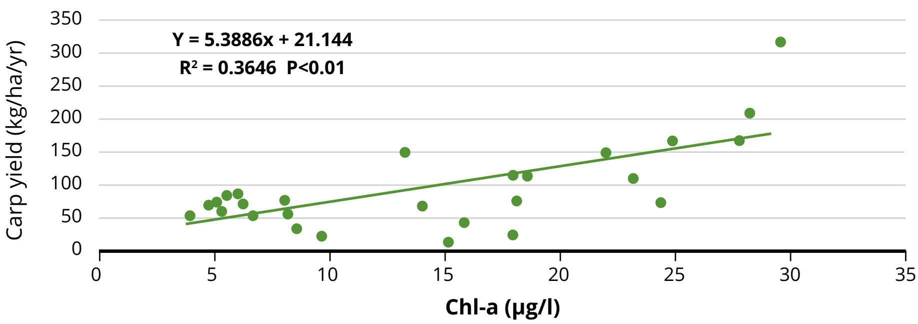

Figure 2.3.7: Relationship between TSI based on chlorophyll-a and carp yield in 39 reservoirs

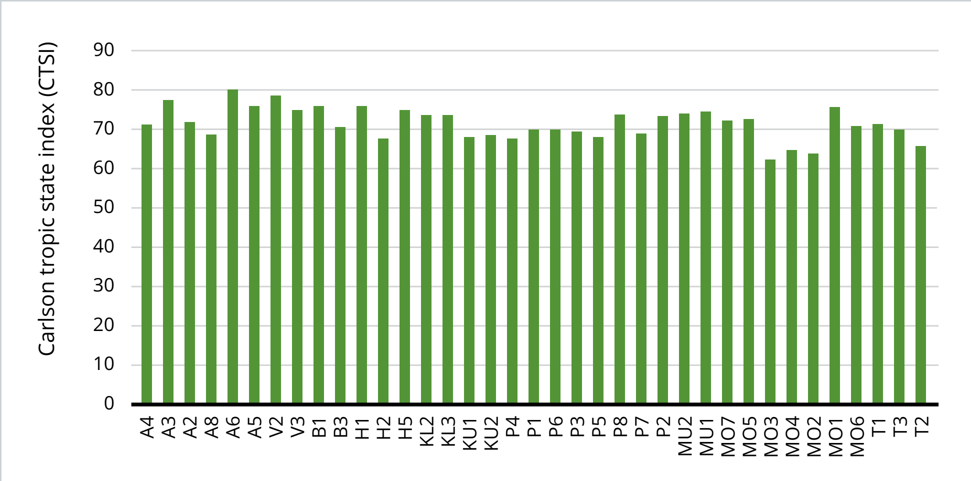

Figure 2.3.8: Variation of CTSI of selected reservoirs

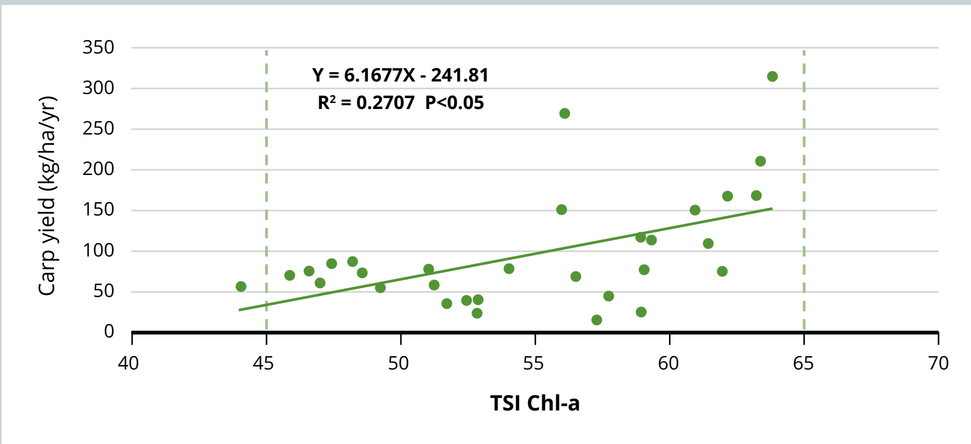

Figure 2.3.9: Relationship between carp yield and TSI Chl-a

related to a high level of conductivity and alkalinity. When PC1 scores are considered, reservoirs with positive scores represent more productive perennial than those with negative PC1 scores. The fish yield of 37 reservoirs was positively correlated ($p<0.1$) to the PC1 scores. However, other 2 species of tilapia and FWP yield was non-significant with the PC1 scores (Figure 2.3.10).

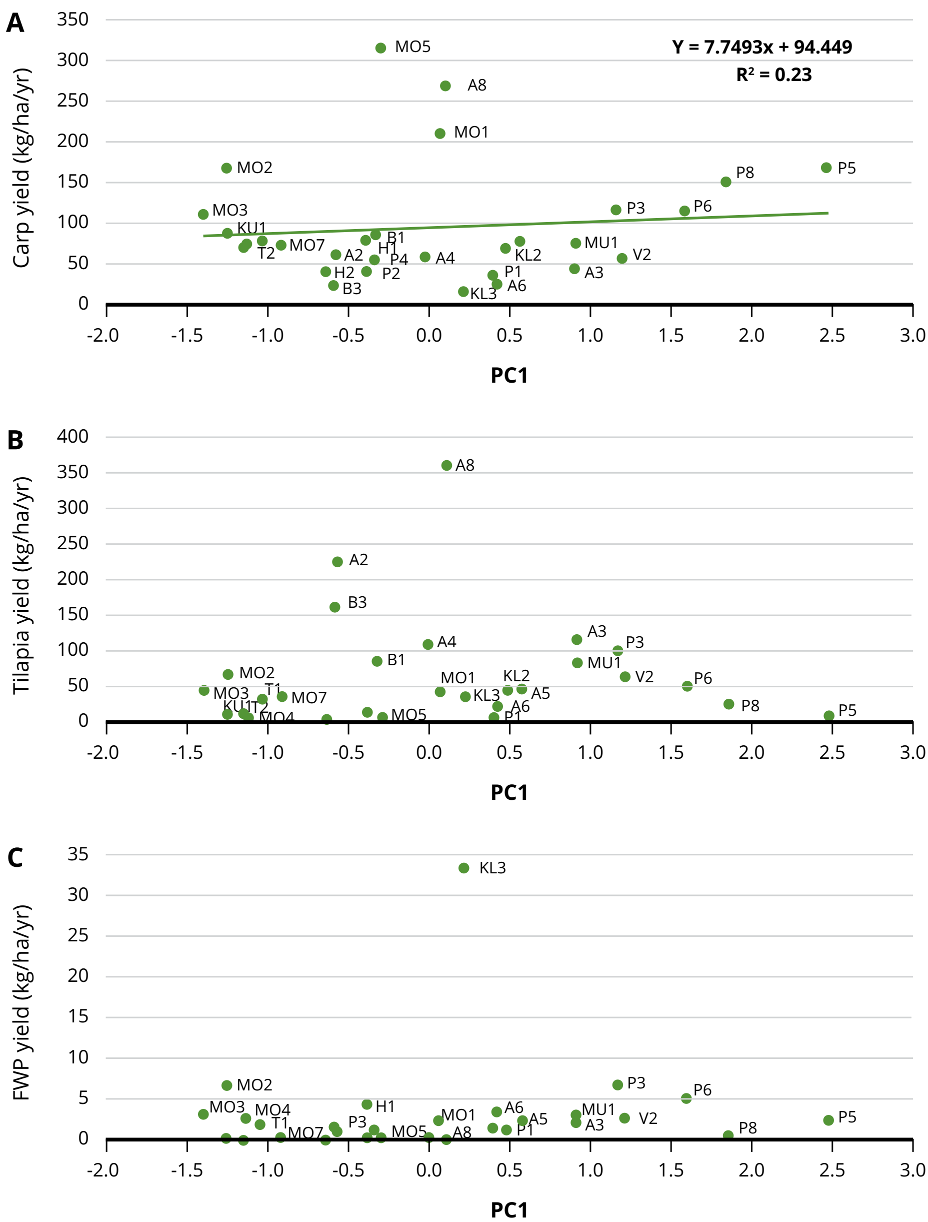

Figure 2.3.10: The relationship between PC1 scores and yield (a) carp (b) tilapia (c) FWP in 39 perennial reservoirs

The cluster analysis distinguished between 2 major clusters at a similarity level of 94% and 3 clusters at a level of 95.5%. There were just 3 reservoirs in the first cluster, which were spread across the districts of Anuradhapura, Killinochchi and Hambanthota. There were 12 and 21 reservoirs in the other 2 clusters, respectively. Stocking and the yield of clusters 3 and 5 were significantly ($p<0.05$) correlated. Carp yield (kg/ha/yr) and stocking (number of fingerlings) of cluster 3 and cluster 5 were found to have a significant linear relationship. Similarly, the chlorophyll-a concentration of 2 clusters also exhibited a significant linear relationship with the carp yield. All relationships for tilapia and FWP were non-significant ($p>0.05$). In addition, the natural logarithmic value of MEI based on the alkalinity and conductivity also shows a significant relationship with carp yield. Accordingly, yield predictive models were developed for each clusters separately (Table 2.3.5 and Table 2.3.6).

Table 2.3.4: The final results of the PCA of the limnological parameters in 39 perennial reservoirs

Parameter	PC1	PC2	PC3
Eigen value	2.008	1.234	0.834
% variance explained	40.169	24.678	16.673
Cumulative %	40.169	64.849	81.520
Variables			
Conductivity	0.142	0.197	0.918
Alkalinity	-1.03	0.900	0.207
Chlorophyll-a	0.746	-0.283	0.327
Total Phosphorus	0.802	-0.166	0.183
Secchi disc depth	-0.793	-0.404	-0.121

Table 2.3.5: Yield predictive models for cluster 03 reservoirs

Relationship	r	R_2
Y= 12.928+0.825 SD	0.825	0.681
Y=-50.650+0.842 Chl-a	0.808	0.653
Y= 10.424+ 0.783 FI	0.783	0.613
Y= -7.541+0.689 SD+0.200 Chl-a	0.838	0.702
Y= 4.472+ 0.554 SD+0.923 FI	0.849	0.720
Y= -91.715- 5.18 SD + 0.775 Chl-a+1.012 FI	0.940	0.883
Y= -632.944+0.057 SD+ 0.920 FI + 0.734 TSI Chl-a	0.952	0.907
LnY=-1.582+ 0.938 Ln MEIa	0.938	0.880

r=Correlation coefficient R^2= Coefficient of determination

Table 2.3.6: Yield predictive models for cluster 05 reservoirs

Relationship	r	R2
Y = 34.838+0.888 SD	0.880	0.774
Y = 24.017+0.794 Chl-a	0.794	0.630
Y = -502.840 + 0.803 TSI Chl-a	0.783	0.613
Y = -85.303+0.730 SD + 0.597 TSI Chl-a	0.884	0.782
Y = 25.364+ 0.863 SD+0.55 FI	0.884	0.782
Y = 25.335 +0.748SD + 0.138 Chl-a+0.043 FI	0.940	0.883
Y = -85.728+0.725 SD+ 0.044 FI + 0.163 TSI Chl-a	0.881	0.777

r=Correlation coefficient R^2= Coefficient of determination

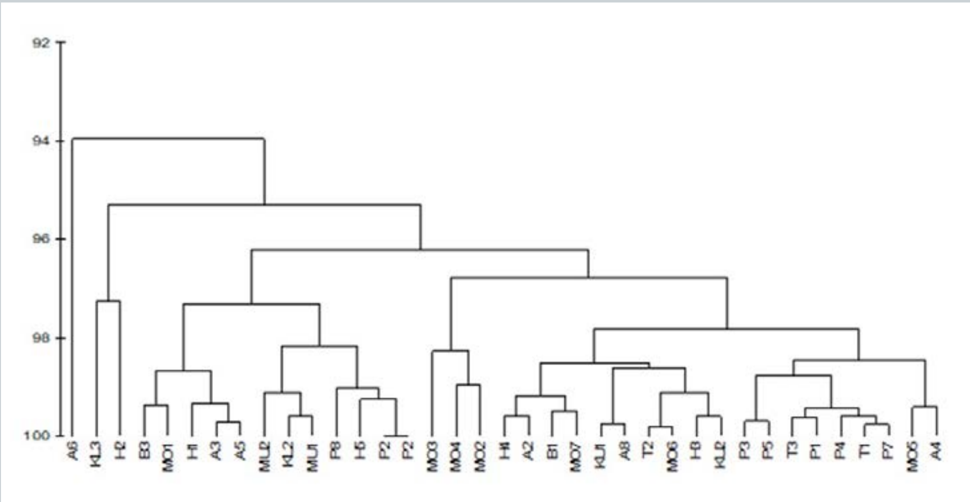

Figure 2.3.11: Dendrogram of the Bray-Curtis similarity analysis of 39 reservoirs

Several studies have examined the relationships between stocking densities, fish yields and limnological parameters in Sri Lankan reservoirs. The present study's findings align with previous research, particularly in terms of the positive correlation between stocking density and fish yield. Jayasinghe et al. (2005a) reported that increased stocking densities led to higher fish production in CBF, consistent with our findings. Similarly, Jayasinghe et al. (2005b) demonstrated that stocking density and primary productivity significantly influence fish yield, a relationship also observed in the present study. Further, the study confirms the findings of De Silva (1988), who emphasised the importance of nutrient availability, particularly phosphorus and nitrogen, in determining fish yield. Furthermore, Jayasinghe et al. (2005a) highlighted the role of TSI in predicting fish production, which our research also supports. In contrast, some studies, such as those by Wijenayake et al. (2005), suggest that beyond a threshold, excessive stocking can negatively impact fish growth and survival due to competition for resources. Overall, the findings of this study reinforce the established understanding of the factors influencing fish yield in Sri Lankan reservoirs while providing new insights into optimising stocking strategies. The results of this study align with previous research on the relationship between limnological parameters and fish yield in tropical reservoirs. Similarly, De Silva et al. (2006) highlighted the influence of SDD and nutrient availability on fisheries productivity in tropical lacustrine ecosystems. In comparison, Nguyen et al. (2005) found a positive correlation between conductivity and fish yield in managed aquaculture systems, emphasising the role of water chemistry in determining fish production potential. However, unlike some previous studies, where tilapia yield was significantly correlated with productivity indicators (for example, FAO 2010), this study did not find a strong relationship between PC1 scores and tilapia or FWP yields. This discrepancy may be due to species-specific ecological adaptations and stocking variations in the studied reservoirs. Further research incorporating stocking density and trophic interactions may be necessary to refine these predictive models. The findings of this study align with previous research on limnological parameters and fish yield relationships in freshwater reservoirs. Several studies have demonstrated significant correlations between chlorophyll-a concentration, SDD, and total phosphorus with fish yield (Henderson and Welcomme 1974; Melack 1976). Our results further corroborate these observations, as chlorophyll-a and SDD showed significant relationships with carp yield.

Moreover, past studies have indicated that MEI-based models provide reliable yield predictions, particularly for stocked reservoirs (Ryder et al. 1974; Schlesinger and Regier 1982). The present study supports this claim, with significant relationships observed between the natural logarithmic values of MEI and carp yield in both clusters. Additionally, the importance of stocking density in determining carp yield has been emphasised in previous works (De Silva et al. 1991; Wijenayake et al. 2005), and our findings reinforce the role of stocking in yield optimisation.

However, unlike some previous studies that reported significant relationships between tilapia yield and limnological factors (Moreau and De Silva 1991), our results did not find significant associations between tilapia and FWP yield. This discrepancy might be due to variations in ecological conditions, species composition, or management strategies across different reservoirs.

Overall, the results of this study highlight the importance of limnological parameters and stocking in predicting fish yield in perennial reservoirs. The derived models offer valuable insights for fisheries management and sustainable aquaculture development in Sri Lanka's inland water bodies.

References

Amarasinghe US and De Silva SS (2015) 'Fishes and fisheries of Asian inland lacustrine waters' in Craig JF (ed) *Freshwater Fisheries Ecology*, Wiley-Blackwell, Chichester, UK, doi:10.1002/9781118394380.ch31.

Amarasinghe US, De Silva SS, De Croos MDST, Digamadulla S, Jayasinghe A, Yomal GATK and Deepananda KHMA (2021) *Final report: Assessing production of giant freshwater prawn in reservoirs in Sri Lanka*, ACIAR, Canberra.

Amarasinghe US, De Silva SS and Nissanka C (2002a) 'Evaluation of the robustness of predictive yield models developed for Sri Lankan reservoir fisheries', *Fisheries Management and Ecology*, 9(4-5):293–302.

Amarasinghe US, De Silva SS and Nissanka C (2005) 'Fish yield prediction based on catchment features, quantified using Geographical information system, in lowland reservoir of Sri Lanka' in *GIS- Spatial analyses in the fishery and aquatic science (volume 2): Proceedings of the second international symposium on GIS-Spatial analyses in the fishery and aquatic science* (University of Sussex, Brighton, UK 3–6 September 2002), Fishery aquatic GIS Research group, Kawagoe-city, Saitama, Japan.

Amarasinghe US and Nguyen TT (2010) 'Enhancing rural farmer income through fish production: secondary use of water resources in Sri Lanka and elsewhere', *Success stories in Asian aquaculture,* Springer, Dordrecht, Netherlands.

Amarasinghe US and Wijenayake WMHK (2015) 'Results of a decade of R&D efforts on culture-based fisheries in Sri Lanka', *Perspectives on culture-based fisheries developments in Asia*: 59–71.

Carlson RE and Simpson J (1996) *A Coordinator's Guide to Volunteer Lake Monitoring Methods,* North American Lake Management Society.

Chakrabarty RD and Samaranayake RADB (1983) 'Fish culture in seasonal tank in Sri Lanka', *Journal of Inland Fisheries, Sri Lanka*, 2:107–111.

Chandrasoma J and Kumarairi WSAAL (1986) 'Observation of polyculture of fish in seasonal tank in Sri Lanka', *Journal of Inland fisheries, Sri Lanka*, 3:49–55.

Chandrasoma J and Pushpalatha KBC (2018) 'Fisheries enhancements in inland water in Sri Lanka with special reference to culture based fisheries: current status and impacts', *Sri Lankan Journal of Aquatic Science*, 23(1):49–65.

Chandrasoma J, Pushpalatha KBC and Fernando WAJR (2015) 'Impact of introduction of culture based fisheries on fish production in perennial reservoirs of Sri Lanka' in De Silva SS, Ingram BA and Wilkinon S (eds) *Perspectives on culture based fisheries development in Asia. Proceedings of the Regional Consultation on culture base fisheries developments in Asia, 21 to 23 October 2014*, Siem Reap, Cambodia, NACA, Bangkok and ACIAR.

De Man JG (1879) 'On some species of the genus Palaemon Fabr. with descriptions of two new forms', *Notes from the Leyden Museum*, 1(3):165–184.

De Silva SS (1988) *Reservoirs of Sri Lanka and Their Fisheries,* FAO Fisheries Technical Paper No. 298, Food and Agriculture Organization of the United Nations, Rome.

De Silva SS (2003) 'Culture based fisheries: an under-utilized opportunity in aquaculture development', *Aquaculture,* 221:221–243.

De Silva SS, Amarasinghe US and Nguyen TTT (eds) (2006) *Better practice approaches to culture-based fisheries development in Asia*, ACIAR Monograph, ACIAR.

De Silva SS, Yu Z and Xiang LH (1991) 'A brief review of the status and practices of the reservoir fishery in mainland China', *Aquaculture and Fisheries Management***,** 22(1-2):73–84.

FAO (2010) *The State of World Fisheries and Aquaculture 2010,* Food and Agriculture Organization of the United Nations, SOFIA.

Godoy, AC, LUR Chiavelli, JH Oxford, RB Rodrigues, I de O. Ferreira, AS Marcondes, CAH da Silva, D Neu 2021. Evaluation of limnological dynamics in Nile tilapia farming tank. Aquaculture and Fisheries, 6(5): 485-494. https://doi.org/10.1016/j.aaf.2020.08.005.

Hameed A, Sahul S, Yoganandhan K, Widada J Sri and Bonami J-R (2012) 'White Tail Disease of freshwater prawn, Macrobrachium rosenbergii: a disease of viral origin', *Aquaculture Research*, 43(1):1–12.

Hayes FR (1957) 'On the variation in bottom fauna and fish yield in relation to trophic level and lake dimensions', *Journal of the Fisheries Board of Canada*, 14(1):1–32.

Henderson HF, Ryder RA and Kudhongania AW (1973) 'Assessing fishery potentials of lakes and reservoirs', *Journal of the Fisheries Research Board of Canada*, 30:2000–2009.

Henderson HF and Welcomme RL (1974) 'The relationship of yield to morphoedaphic index and number of fishermen in African inland waters', *CIFA Occasional Paper 1*:19, FAO, Rome.

Jayasinghe UAD, Amarasinghe US and De Silva SS (2005a) 'Trophic classification of non-perennial reservoirs utilized for culture-based fisheries: implications for yield optimization', *Fisheries Management and Ecology*, 12(1):19–29, doi:10.1111/j.1365-2400.2004.00420.x.

Jayasinghe UAD, Amarasinghe US and De Silva SS (2005b) 'Limnology and culture-based fisheries in non-perennial reservoirs in Sri Lanka', *Lakes & Reservoirs: Research & Management*, 10(3):157–166.

Jenkins RM and Oglesby RT (1982) 'The morphoedaphic index – concepts and practices: The morphoedaphic index and reservoir fish production', *Transactions of the American Fisheries Society*, 111(2):133–140.

Machena C and Fair P (1986) 'Comparison of fish yields from prediction models between Lakes Tanganyika and Kariba', *Hydrobiologia*, 137(1):29–32.

Melack JM (1976) 'Primary productivity and fish yields in tropical lakes', *Transactions of the American Fisheries Society,* 105(5):575–580.

Moreau J and De Silva SS (1991) 'Predictive fish yield models for lakes and reservoirs of the Philippines, Sri Lanka and Thailand', *FAO Fisheries Technical Paper,* 319:42.

Nadarajah S, Wijenayake WHMK and Amarasinghe US (2018), 'Empirical yield predictive models for the fisheries of irrigation reservoirs', *Sri Lanka Journal of Aquatic Science,* 23(2):201–208.

Nguyen HS, Bui AT, Nguyen DQ, Truong DQ, Le LT, Abery NW and De Silva SS (2005) 'Culture-based fisheries in small reservoirs in northern Vietnam: effect of stocking density and species combinations', *Aquaculture Research*, 36:1037–1048.

Nissanka C, Amarasinghe US and De Silva SS (2000) 'Yield predictive models for Sri Lankan reservoir fisheries', *Fisheries Management and Ecology*, 7:425–436.

Northcote TG and Larkin PA (1956) 'Indices of productivity in British Columbia lakes', *Journal of the Fisheries Board of Canada*, 13(4):515–540.

Pushpalatha KBC and Chandrasoma J (2010) 'Culture-based fisheries in minor perennial reservoirs in Sri Lanka: variability in production, stocked species and yield implications', *Journal of Applied Ichthyology*, 26(1):98–103.

Rawson DS (1952) 'Mean depth and the fish production of large lakes', *Ecology*, 33(4):513–521.

Ryder RA (1965) 'A method for estimating the potential fish production of north-temperate lakes', *Transactions of the American Fisheries Society*, 94(3):214–218.

Ryder RA, Kerr SR, Loftus KH and Regier HA (1974) 'The morphoedaphic index, a fish yield estimator—review and evaluation', *Journal of the Fisheries Research Board of Canada*, 31(5):663–688.

Schlesinger DA and Regier HA (1982) 'Climatic and morpho-edaphic indices of fish yields from natural lakes', *Transactions of the American Fisheries Society,* 111*(*2):141–150.

Smith LED, Nguyen-khoa S and Lorenzen K (2005) 'Livelihood functions of inland fisheries: policy implications in developing countries', *Water Policy*, 7:359–383.

Thayaparan K (1982) 'The role of seasonal tanks in the development of freshwater fisheries in Sri Lanka', *Journal of Inland Fisheries (Sri Lanka)*, 1:133–167.

Toews DR and Griffith JS (1979) 'Empirical estimates of potential fish yield for the Lake Bangweulu system, Zambia, Central Africa', *Transactions of the American Fisheries Society*, 108(3):241–252.

Welcomme RL, Cowx IG, Coates D, Béné C, Funge-Smith S, Halls A and Lorenzen K (2010) 'Inland capture fisheries', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554):2881–2896, doi:10.1098/rstb.2010.0168.

Wijeyaratne MJS and Amarasinghe US (1987) 'Estimation of maximum sustainable fish yield and stocking densities of fingerlings in freshwater lake and reservoirs', *Archiv fur Hydrobiologie, Beiheft Ergebnisse der Limnologie,* 28:305–308.

Wijenayake, W.M.H.K., U.A.D. Jayasinghe, U.S. Amarasinghe, J.A. Athula, K.B.C. Pushpalatha and S.S. De Silva (2005). Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. Fisheries Management and Ecology 12: 249-258. DOI: 10.1111/j.1365-2400.2005.00447.x