Use of geographical information system and remote sensing techniques for planning culture-based fisheries in non-perennial reservoirs of Sri Lanka

W. M. Hiranya Kelum Wijenayake,[1] A. B. Ajith Kumara Gunaratne,[2] Sena S. De Silva[3] and Upali S. Amarasinghe[4*]

[1]Department of Aquaculture and Fisheries, Faculty of Livestock, Fisheries and Nutrition, Wayamba University of Sri Lanka, Gonawila, [2]National Aquatic Resources Research and Development Agency, Crow Island, Colombo, Sri Lanka, [3]School of Life and Environmental Sciences, Deakin University, Warrnambool, Victoria, Australia, and [4]Department of Zoology, University of Kelaniya, Kelaniya, Sri Lanka

Abstract

The presence of a wide areal extent of small-sized village reservoirs offers a considerable potential for the development of culture-based fisheries (CBFs) in Sri Lanka. To this end, this study uses geographical information systems (GISs) and remote sensing (RS) techniques to determine the morphometric and biological characteristics most useful for classifying non-perennial reservoirs for CBF development and for assessing the influence of catchment land-use patterns on potential CBF yields. The reservoir shorelines at full water supply level were mapped with a Global Positioning System to determine shoreline length and reservoir areal extent. The ratio of shoreline length to reservoir extent, which was reported to be a powerful predictor variable of CBF yields, could be reliably quantified using RS techniques. The areal extent of reservoirs, quantified with RS techniques (RS extent), was used to estimate the ratio of forest cover plus scrubland cover to RS extent and was found to be significantly related to the CBF yield ($R^2 = 0.400$; $P < 0.05$). The results of this study indicated that morphometric characteristics and catchment land-use patterns, which might be viewed as indices of biological productivity, can be quantified using RS and GIS techniques.

Key words

catchment land uses, culture-based fisheries, geographical information system, remote sensing, reservoirs.

INTRODUCTION

Although capture fisheries and aquaculture are often viewed as separate activities, there actually is a considerable overlap between these two extremes, making it difficult to differentiate between fishing and aquaculture. The release of hatchery-reared seed stock into the wild for capture fisheries enhancement is aquaculture-driven, therefore being referred to as culture-based fisheries (FAO 1997). Culture-based fisheries (CBFs) offer advantages over more conventional forms of aquaculture practices (De Silva 2003), in that:

- it is a non-consumptive water use;
- it is a secondary user of existing water resources, natural and/or quasi-natural, and rarely will compete with primary water resource users;
- its activities require minimal skill levels and capital investment, in contrast to those required for intensive and/or semi-intensive culture practices and, as such, the dissemination of the former is easier and often more attractive, even to the poorer sectors of a community;
- the types of water bodies suitable for culture-based fisheries are communal property resources often located in rural areas, being unable to naturally sustain any significant fishery activities; and
- CBF generally does not involve external feed inputs, except for grass if grass carp is stocked, thereby making it an environmental-friendly practice.

*Corresponding author. Email: zoousa@kln.ac.lk
Accepted for publication 13 July 2014.

Doi: 10.1111/lre.12071

Despite the advantages of CBF and its potential for enhancing fish production (Welcomme & Bartley 1998; Middendorp & Balarin 1999), this strategy is still considered underutilized (De Silva 2003). However, CBFs in Chinese reservoirs are the most developed in the world, with a reported estimated total production from this activity of 1 165 075 tonnes in 1997 (from a total area of 1 567 971 ha), approximating an annual yield of 743 kg ha^{-1} (Song 1999).

In Sri Lanka, reservoir construction was an integral part of its ancient civilization. With over 12 000 village reservoirs with a cumulative areal extent of about 39 000 ha (Anonymous 2000), a great potential exists for developing CBF in the country. Fisheries authorities attempted to develop CBF in village reservoirs in the 1980s (Chandrasoma & Kumarasiri 1986) but, as predicted by De Silva (1988), these attempts were unsustainable due to the absence of appropriate criteria for selecting suitable reservoirs for CBF development.

Morphometric characteristics of small-sized (often <20 ha at full supply level) village reservoirs have been found to influence biological productivity (Jayasinghe *et al.* 2006). Indices of biological productivity (based on cholorophyll-a content) also were shown to be useful for assessing the ability of non-perennial reservoirs to develop and sustain CBF (Jayasinghe *et al.* 2005a). Accurate information about reservoir area also is essential for planning CBF because stocking densities (fingerlings per ha) and fish yields (kg per ha) are estimated on the basis of reservoir area, wherein the effective area of non-perennial reservoirs is estimated to be 50% of the area at full water supply level (Amarasinghe & Nguyen 2009).

Geographical Information Systems (GISs) and remote sensing (RS) technologies can be used to effectively obtain geographically distributed information (Dahdouh-Guebas *et al.* 2002; Travaglia *et al.* 2004; Salam *et al.* 2005). Combining databases that make use of Google Earth, and analysed within a GIS platform, and yield modelling has been shown to provide useful assessment tools for inland fisheries (De Graaf *et al.* 2012). Accordingly, GIS/RS techniques also are expected to be useful for quantifying productivity-related morphometric and biological parameters in non-perennial reservoirs.

Use of GIS and RS for planning aquaculture reduces the required analysis time, is relatively economical compared to conventional methods, facilitates data/information sharing, storing and updating, and provides a greater degree of accuracy than normal surveying methods (De Graaf *et al.* 2003). As aquaculture is spatial in nature, GIS/RS exhibits a high potential for use as a collective decision-making tool (Kapetsky & Aguilar-Manjarrez 2004). De Graaf *et al.* (2004) noted the efficiency and cost-effectiveness of using RS in mapping aquaculture ponds in Bangladesh. De Silva *et al.* (2004) made a preliminary attempt to classify the suitability of some non-perennial reservoirs of Sri Lanka, using GIS for culture-based fisheries development.

Terrestrial ecosystems have impacts on the hydrological and hydrochemical properties of drainage water ultimately influencing the ecology of aquatic habitats (Cresser *et al.* 2000). Catchment area land-use changes are known to influence the chemical and physical properties (Osborne & Wiley 1988; Johnson *et al.* 1997; Nakasone & Kuroda 1999; Edwards *et al.* 2000; Filoso *et al.* 2003; Galbraith & Burns 2007) and biological properties (Ormerod *et al.* 1993; Collares-Pereira & Cowx 2004) of water bodies. Catchment land use also has been used to predict reservoir productivity (Meeuwig & Peters 1996; Amarasinghe *et al.* 2002, 2004).

Recent studies indicate that indices based on reservoir morphology and trophic status that are essentially of spatial nature (Table 1) can be used to evaluate the suitability of non-perennial reservoirs of Sri Lanka for CBF development (Jayasinghe *et al.* 2006). Due to the presence of extensive availability of small-sized village reservoirs in the island, however, methodologies are required to determine such indices in a cost-effective manner. Accordingly, this study investigates the utility of GIS and RS techniques to derive indices for quantifying productivity-related morphometric parameters and the influence of

Table 1. Summary of morphometric parameters of reservoirs needed for CBF planning and indices, based on reservoir morphology and trophic status related to CBF yield.

Parameter	Explanation
Reservoir areal extent	Stocking density and CBF yield, being essential estimates for CBF planning, are determined on the basis of areal extent of reservoir
Ratio of shoreline length to reservoir area (R_{LA} expressed in km ha^{-1})	Predictor variable of relationship: CBF Yield (kg ha^{-1}) = 6672.3 R_{LA} – 432.7 (Jayasinghe *et al.* 2006) can be determined from RS techniques
Catchment land uses	Catchment land use patterns are important properties of a reservoir drainage basin that can influence its ecology (see Introduction for references)

catchment land-use patterns on CBF yields in non-perennial reservoirs of Sri Lanka.

MATERIALS AND METHODS

Reservoir morphology

This study was focused on 45 non-perennial reservoirs in five administrative districts in Sri Lanka (Table 2). Almost all reservoirs are part of cascade systems, with preliminary data on the extents of the reservoirs provided by Anonymous (2000).

The reservoir shoreline at full water supply level of each reservoir was mapped to an accuracy of 1 m, using a Global Positioning System (GPS) (Trimbel GeoExplorer 3; Trimbel Navigation Ltd., California USA), walking along the highest water line visually judged from the nature of the surrounding vegetation cover. The data were transferred and edited using Pathfinder Office 2.51 software. The reservoir areas and shoreline lengths were calculated using the same software.

Two LANDSAT 7 ETM images were used to determine the area and aquatic plant cover of the reservoirs. LANDSAT image path 141, row 055 (Date of acquisition 28 November 2002), was used for reservoirs located in the Anuradhapura, Kurunegala and Ratnapura districts and some reservoirs in the Hambantota district. LANDSAT image path 141, row 056 (Date of acquisition 15 January 2003), was used for remaining reservoirs in Hambantota and those in the Moneragala district. These images were in Geo-TIFF format and level 1G corrected. Multispectral channels were resampled to 25 m, and panchromatic channel was resampled to 12.5 m spatial resolution. Datum and projection of the images were WGS 84 and UTM 44 N, respectively. Images were geo-referenced to the local coordinate system (i.e. 1:50 000 land-use thematic maps published by Survey Department of Sri Lanka), and the root mean square error (i.e. a measure of the difference between known locations and those that have been interpolated or digitized) was at 0.34. Colour-normalized transformation (Brovey transformation; Pohl & Van Genderen 1998) was performed to improve the spatial resolution by merging multispectral bands, 4, 3 and 2 (R, G, B), and panchromatic band as a high-resolution image, using the nearest-neighbour technique (Clark & Evans 1954). Although the HSV (Hue, Saturation and Value) transformation (Koutsias *et al.* 2000) was attempted, the Brovey transformation was found to be more suitable for the analysis. The image, using forty reference points, was used for the geo-referencing of each image, and a Sharpening filter (10 × 10) was applied for further enhancement of the images. Using geo-referenced satellite images, the reservoir areas were demarcated with ENVI 4.1 software, and the shoreline lengths also were determined with the same RS technique.

Information about small reservoirs of Sri Lanka is available in Anonymous (2000). To investigate the appropriateness of using official data on reservoir extent available in the records of the Department of Agrarian Development (Anonymous 2000), reservoir extent was related separately to those determined using GPS and RS techniques using linear regression methods. All three categories of values of reservoir extent were in ha at full water supply level. The relationship between shoreline lengths determined by GPS and PathFinder Office 2.51 software (GPS shoreline) and those determined using RS technique (RS shoreline) was computed using a linear regression technique.

Catchment land uses and reservoir productivity

Land-use maps of 1:50 000 scale, published by the Survey Department of Sri Lanka, were used to demarcate the reservoir catchment areas. As all reservoirs are located in specific river basins, the streamlets into the reservoirs were considered to demarcate catchment boundaries on the land-use maps, based on the surface run-off. Furthermore, because the village reservoirs are situated mostly in cascade systems (Panabokke 2001), the reservoir microcatchment was treated as the area between two adjacent reservoirs in a cascade. Catchment areas were demarcated on geo-referenced map sheets using the Arc GIS 9 software and subjected to on-screen digitizing. Area analysis of the land-use polygonal map was carried out using ARC GIS 9 software, and the ratio of the extent of each catchment land use to reservoir area at full water supply level was estimated.

To investigate whether or not catchment land uses influence CBF yield in reservoirs, the relationships between different catchment land uses (in total catchment and microcatchment, separately) and CBF yield were determined. The chlorophyll a (chl a) content determined by a parallel study (Jayasinghe *et al.* 2005a) was used to determine whether or not the influence of land uses in the microcatchment was biologically plausible.

RESULTS

Of the 45 reservoirs selected for this study, information about the areal extent of the reservoirs is available for only 39 reservoirs in the Department of Agrarian Development database. This parameter was measured in 40 reservoirs using GPS technique, although the shorelines of 5 reservoirs were inaccessible. The areal extent could

Table 2. Geographic locations of reservoirs, and their areal extents reported in Department of Agrarian development (DAD Extent in ha) databooks, estimated using GPS and PathFinder Office 2.51 software (GPS Extent in ha) and determined from RS technique (RS Extent in ha)

	Geographic location				
Name of reservoir	N	E	DAD Extent	GPS Extent	RS Extent
Bulankulama (A1)	08°09′56.59″	80°31′31.26″	8.1	10.4	11.3
Burutha wewa (A2)	07°58′45.96″	80°41′02.07″	NA	2.7	2.9
Gambirigasswewa(A3)	07°53′52.75″	80°31′01.46″	4.9	16.6	12.5
Hinguruwelpitiya (A4)	07°54′24.35″	80°36′22.91″	2.4	7.8	6.3
Karabegama (A5)	08°10′36.37″	80°33′20.40″	10.1	9.3	9.4
Katugampolagama (A6)	08°14′12.35″	80°23′43.64″	4.9	16.7	16.5
Lolugas wewa (A7)	08°21′54.72″	80°22′18.27″	4.5	11.9	13.9
Maha wewa (A8)	08°17′19.12″	80°21′19.60″	10.5	8.4	8.0
Meegahawewa (A9)	08°17′19.58″	80°21′20.04″	4.9	11.1	NR
Meegassegama (A10)	08°10′22.20″	80°31′45.00″	8.9	29.0	24.2
Pahalasandanankulama (A11)	08°11′03.46″	80°35′55.84″	34.0	21.3	21.7
Kumbalporuwa wewa (K1)	07°50′31.45″	80°24′38.19″	10.9	9.5	7.7
Kekunawa wewa (K2)	07°48′21.91″	80°16′59.90″	15.4	10.0	9.0
Ihalamaradankadawala (K3)	08°05′05.11″	80°10′13.86″	NA	19.2	NR
Pahalawewa (K4)	08°02′46.55″	80°18′04.72″	13.0	8.5	8.4
Divul wewa (K5)	07°36′38.88″	80°03′29.72″	10.5	NR	NR
Hindagaha wewa (K6)	07°37′59.64″	80°10′13.85″	7.3	2.9	NR
Withikuliya wewa (K7)	07°42′30.65″	80°08′25.77″	5.7	6.9	NR
Wawullewa wewa (K8)	07°49′56.44″	80°25′04.75″	8.5	20.6	20.6
Matuluwawa wewa (K9)	07°51′42.49″	80°24′36.94″	18.2	28.9	26.1
Bolhinda wewa (H1)	06°12′44.62″	81°03′00.91″	8.1	11.6	7.6
Gal wewa (H2)	06°12′38.56″	81°07′16.77″	2.4	NR	5.9
Gonnoruwa wewa (H3)	06°14′34.09″	81°06′19.84″	4.0	22.4	18.6
Kikilividda wewa (H4)	06°12′15.05″	81°07′21.03″	2.8	NR	5.2
Kudaindi wewa (H5)	06°19′35.26″	81°02′55.20″	3.2	13.4	10.8
Udana wewa (H6)	06°14′05.15″	81°07′32.76″	0.4	4.9	3.0
Lunuveraniya wewa (H7)	06°20′39.50″	81°07′05.97″	4.0	10.8	12.4
Medagamkadawarawewa (H8)	06°21′31.28″	81°09′40.52″	5.7	16.7	16.7
Muwan wewa (H9)	06°19′31.81″	81°11′25.38″	NA	6.5	5.1
Palujandura wewa (H10)	06°19′19.15″	81°07′16.76″	2.8	4.9	4.1
Weheragala wewa (H11)	06°25′05.44″	81°05′28.07″	3.2	15.1	15.1
Svodagama wewa (H12)	06°16′49.89″	81°02′54.17″	3.2	3.2	3.0
Weli wewa (H13)	06°20′15.75″	81°01′03.40″	2.4	5.7	5.7
Wewegama wewa (H14)	06°18′29.86″	81°01′47.76″	4.9	18.9	18.9
Akkarawissa wewa (M1)	06°26′10.75″	81°18′26.13″	9.7	NR	NR
Dozer wewa (M2)	06°26′37.54″	81°19′17.34″	NA	13.6	13.6
Bodhagama wewa (M3)	06°25′45.31″	81°05′42.44″	NA	13.4	13.4
Galwale wewa (M4)	06°25′58.93″	81°03′28.19″	2.8	15.7	15.7
Meegas wewa (M5)	06°27′16.08″	81°04′43.32″	17.8	21.0	21.0
Batalaara wewa (M6)	06°41′46.77″	81°06′16.08″	6.5	11.0	NR
Senasuma wewa (M7)	06°44′52.44″	81°08′23.44″	37.2	NR	21.2
Walaskema wewa (M8)	06°33′07.51″	81°07′38.29″	2.4	28.1	NR
Watagalaara wewa (M9)	06°33′30.39″	81°04′03.59″	NA	21.3	NR
Mahagalara wewa (R1)	06°22′09.13″	80°48′01.58″	8.1	8.9	8.9
Panahaduwa wewa (R2)	06°27′48.42″	80°47′27.66″	10.1	30.5	30.5

NA, not available; NR, not recorded.

be determined from the LANDSAT TM images for only 36 reservoirs because cloud cover prevented the use of this technique. The information reported in the data books of the Department of Agrarian Development (DAD extent), those estimated using the GPS (GPS extent), and those determined with the RS technique (RS extent) is given in Table 1, and their interrelationships are shown in Figure 1. The 'GPS extent' is significantly related to 'RS extent', with the gradient being about 0.94 (Fig. 1a). The 'DAD extent', however, is related neither to the 'GPS extent' nor to the 'RS extent' (Fig. 1b,c). As the 'GPS extent' is based on actual ground truth information, the 'RS extent' also gives a reasonable approximation of reservoir areal extent.

The 'GPS shoreline' and 'RS shoreline' are significantly correlated (R^2 = 0.71; $P < 0.0001$; Fig. 2). Jayasinghe *et al.* (2006) have shown that the ratio of shoreline length to reservoir area (R_{LA}) is significantly related to the CBF yield. Thus, the 'RS shoreline' and 'RS extent' are useful parameters that can be determined using RS techniques for predicting CBF yields in village reservoirs.

Ten different land-use patterns were observed in catchments, *viz.* scrublands, forest areas, 'chena' (slash-and-burn) cultivation, home gardens, paddy cultivations, coconut plantations, other plantations (i.e. planted forests such as teak), rocks, marshes and other water bodies associated with selected reservoirs. Figure 3 summarizes the land-use patterns of a reservoir catchment located in the Moneragala District, as determined with GIS. As determined with linear regression procedures, there were no significant relationships between catchment land-use patterns in the total catchment and the CBF yield. The land-use patterns in microcatchments (i.e. the area between two adjacent reservoirs in a cascade) of reservoirs, however, exhibited a positive relationship with the CBF yield, examples being:

- the ratio of forest cover (FC) plus scrubland cover (SC) to RS extent (Fig. 4a) was significantly related to the chl a content (R^2 = 0.359; $P < 0.05$);

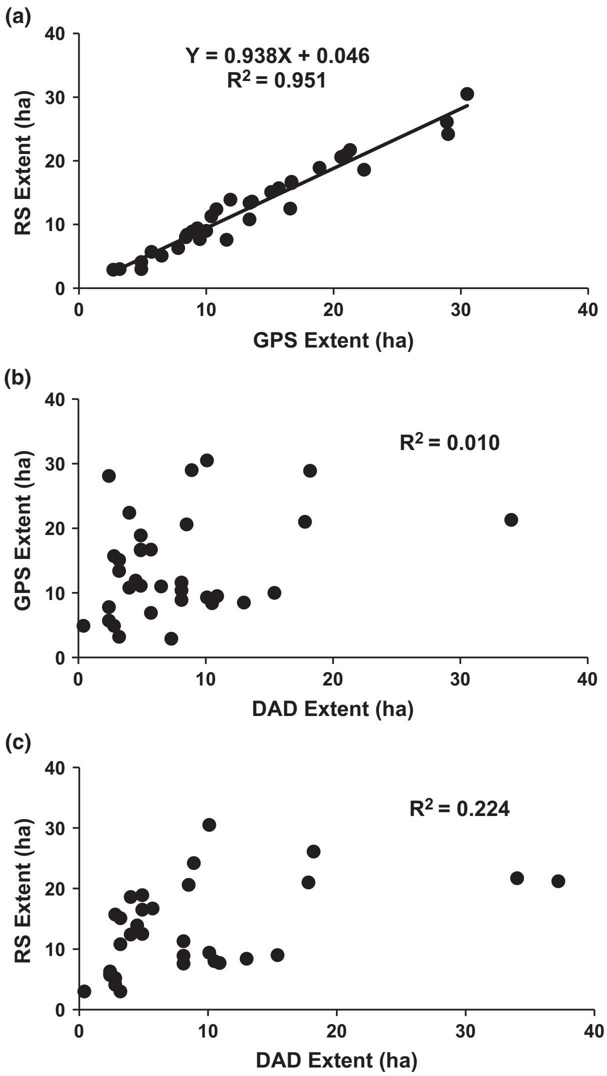

Fig. 1. Interrelationships of areal extent of reservoirs reported in Department of Agrarian development (DAD extent) databooks, those estimated using GPS and PathFinder Office 2.51 software (GPS extent), and those determined from RS technique (RS extent). (A = GPS Extent against RS Extent; B = DAD Extent against GPS Extent; C = DAD Extent against RS Extent).

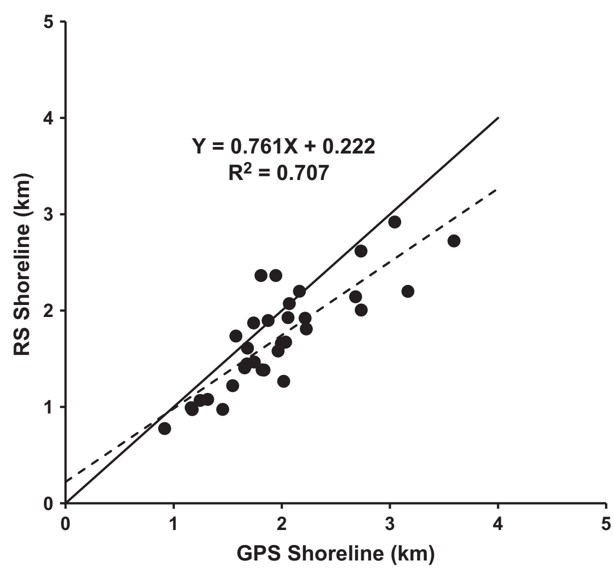

Fig. 2. Relationship between reservoir shoreline length determined by GPS and PathFinder software (GPS Shoreline), and those determined by RS technique (RS shoreline) ($P < 0.0001$; broken line indicates diagonal line of equality).

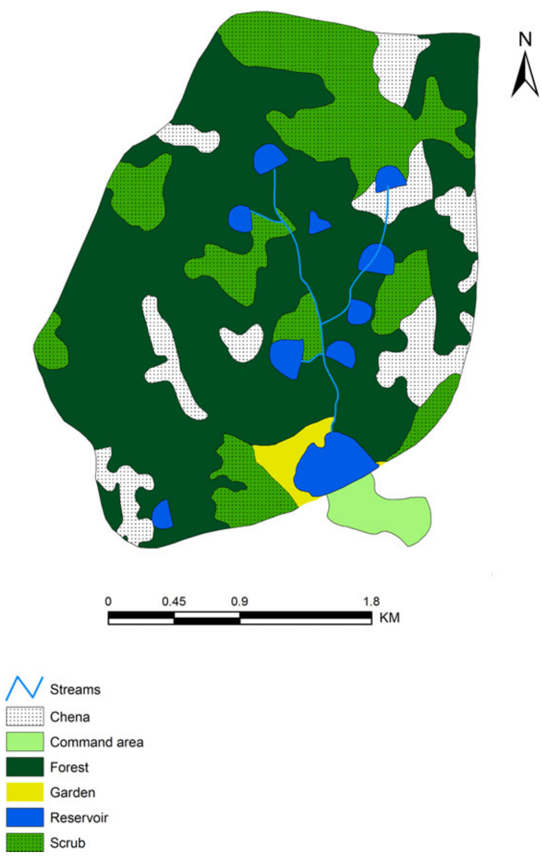

Fig. 3. Land use patterns in the Bodagama Reservoir catchment in the Moneragala District.

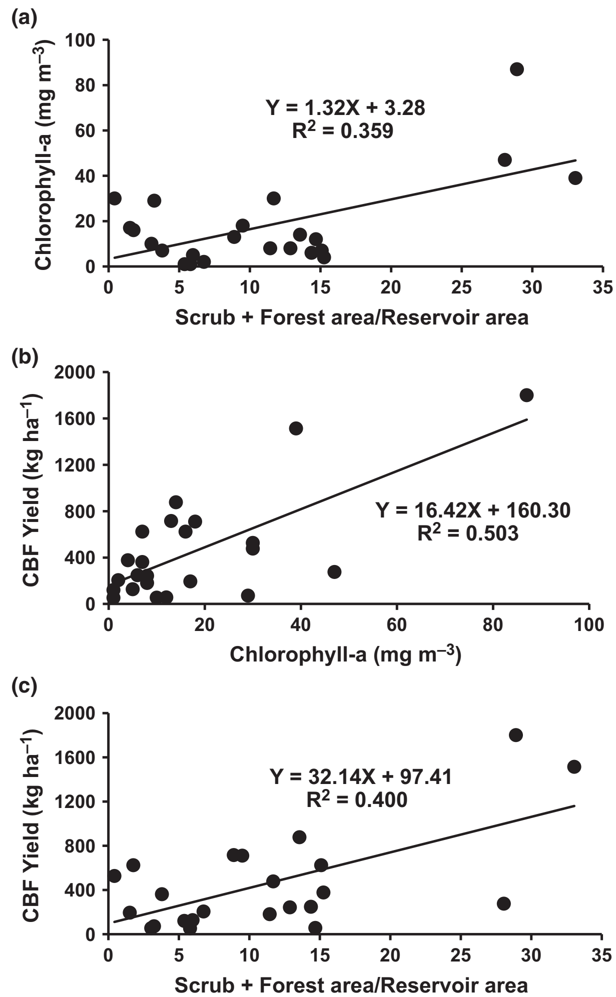

Fig. 4. Relationships between (a) Scrub + Forest area/Reservoir area ratio and Chl-a content; (b) Chl-a content and CBF yield; and (C) Scrub + Forest area/Reservoir area ratio and CBF yield (all relationships significant at 0.01 probability level).

- the relationship between the chl a content and CBF yield (Fig. 4b) also was significant ($R^2 = 0.503$; $P < 0.05$); and
- the ratio of SC + FC to RS extent was significantly related to the CBF yield ($R^2 = 0.400$; $P < 0.05$; Fig. 4c).

DISCUSSION

Culture-based fisheries are essentially fishery enhancement strategies that rely on the release of hatchery-reared fish fingerlings to quasi-natural habitats for subsequent capture (Lorenzen *et al.* 2001; De Silva 2003). The biological productivity of a water body and the associated optimal stocking density of fish fingerlings are, *inter alia,* two major factors influencing CBF yields. Several attempts were made to predict CBF yields in Sri Lankan non-perennial reservoirs, based on biological productivity. Jayasinghe *et al.* (2005a) derived trophic status indices based on chl a, Secchi disc depth and alkalinity to classify non-perennial reservoirs of Sri Lanka for planning CBF development. The Chl a content was shown to be a powerful predictor variable for CBF yield in Sri Lankan non-perennial reservoirs (Jayasinghe *et al.* 2005b). In a parallel study, Jayasinghe *et al.* (2006) have demonstrated that the ratio of shoreline length to reservoir area (R_{LA}) is significantly related to the Chl a content in non-perennial reservoirs and that R_{LA} can be used to predict the CBF yield.

This evidence suggests that the morphometric characteristics of non-perennial reservoirs (e.g. shoreline length; areal extent) are important baseline data for planning CBF activities. Stocking densities are generally determined in non-perennial reservoirs on the basis of the 'effective area' of a reservoir (i.e. 50% of the surface area at full water supply level) because the surface area of a reservoir varies from full water supply level during the rainy season to often zero during the dry season (De Silva *et al.* 2006; Amarasinghe & Nguyen 2009). Furthermore, the CBF yield must be estimated as kg ha^{-1} per culture cycle for comparative purposes. According to the present analysis, the reservoir surface areas reported in official databases (Anonymous 2000) are unrealistic, possibly attributable to these estimates having been based on aerial photographs depicting the water surface area at the time of acquisition. In the present study, the images were enhanced with spatial enhancement techniques (i.e. Brovey transformation and applying a sharpening filter). Thus, the present study indicates that enhancing the satellite images facilitates the identification of the upper water line of the drawdown area during the dry season when the water level is far below the full water supply level. Satellite images taken during the dry season generally are clearer because of a reduced cloud cover. The RS technique used in the present study to estimate 'RS extent', therefore, is an important means of accurately determining a reservoir surface area extent. The RS extent and shoreline length estimated from the RS technique also are useful to estimate R_{LA} values of non-perennial reservoirs that can be used to predict CBF yields (Jayasinghe *et al.* 2006).

For most developing countries, the non-availability of spatial data for quantifying watershed characteristics, land use, etc., using GIS and RS, generally is a major limitation (Khawlie *et al.* 2005). Land-use maps of 1:50 000 scale published by the Survey Department of Sri Lanka, however, contain sufficient resolution for quantifying land uses in the catchments of village reservoirs. Digitized maps and digital data compatible with ARC/INFO GIS software are also available from the Survey Department of Sri Lanka (http://www.survey.gov.lk/surveyweb/Home English/GeographicalInformationSystems.php). Thus, the use of RS and GIS techniques for CBF planning is facilitated.

The present study clearly demonstrates that the CBF yields in non-perennial reservoirs are positively influenced by the reservoir chl a content. Furthermore, the CBF yield was found to be positively influenced by the ratio of forest and scrubland cover in the microcatchment area to the areal extent of the reservoir ($P < 0.01$; Fig. 4a). As this ratio is also significantly related to the chl a content ($P < 0.01$; Fig. 4b), the positive influence of these land-use patterns on the CBF yield ($P < 0.01$; Fig. 4c) is biologically plausible. The allochtonous input of nutrients from the immediate catchment is known to be significant for reservoirs (Nakasone & Kuroda 1999; Wetzel 2001) and, as such, the positive influence of less-disturbed catchment land uses is understandable. Furthermore, as reservoirs are water bodies often experiencing heavy water drawdown, the immediate microcatchments of non-perennial reservoirs might serve as nutrient pools because of the inundation of the terrestrial plants that grow in the reservoir drawdown areas during the dry season. The non-significant influence of total catchment land uses on the biological productivity in the present study, however, might be attributable to the observation that the cascading reservoirs (Panabokke 2001) in the total catchment could prevent allochtonous nutrient inputs into the reservoirs. As GIS methods can be used to determine catchment land-use patterns of these water bodies, CBF planning can be facilitated using GIS methods to select reservoirs for this purpose, based on these patterns.

The present study revealed that morphometric characteristics and catchment land-use patterns, which can be treated as indices of biological productivity, can be quantified using RS and GIS techniques. Thus, these techniques are useful for planning CBF development strategies. As the non-perennial reservoirs of Sri Lanka are scattered widely over a vast geographical range, an effective and efficient approach is needed to select suitable water bodies for CBF planning. Furthermore, because RS and GIS techniques are shown to be particularly important as tools for quantifying biological productivity, the results of the present study can provide useful insight into the utility of RS and GIS technologies for the development of CBF in small water bodies, which are frequently found in most tropical Asian countries. The use of small water bodies for CBF, as a means of increasing food-fish supplies in rural communities, is becoming increasingly popular in Asian countries (Lorenzen *et al.* 2001; De Silva *et al.* 2006). Accordingly, the results of the present study should be of relevance in improving the outcomes of this strategy.

ACKNOWLEDGEMENTS

Financial support from the Australian Centre for International Agricultural Research (ACIAR Project No. FIS/2001/030) for this study is gratefully acknowledged. Mr. U.A.D. Jayasinghe helped in the field studies.

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