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Retrospective study on changes in Dondra lagoon (2006–2017) resulting from tsunami impact and post-tsunami development

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Abstract
Spatio-temporal changes during the last twelve year period (2006–2017) and their impacts on ecological and socio-economic status of Dondra lagoon, southern coast of Sri Lanka were studied as many lagoons in southern Sri Lanka are being seriously affected due to anthropogenic pressure in the recent past. The changes of Dondra lagoon and its immediate surroundings were studied in conjunction with a GIS-coupled ecological survey and a questionnaire survey. The lagoon water surface area has decreased by about 0.92 ha (~8%) and the mangrove cover has increased by about 1.38 ha (~11%) over this period. The salinity of the lagoon has also reduced, forming a 'low saline' (3 psu) regime. About 40% of the lost water surface has scarified for a newly formed land mass (~0.4 ha) within the proximal part of the lagoon. The bridge, broken by the tsunami of 2004, has newly been constructed twice during the reporting period. The construction most likely led to impair the inflow and outflow through the lagoon mouth. Several development projects were launched in the immediate periphery of the lagoon stimulated soil erosion causing heavy siltation in the lagoon. The above changes in the morphometry of the lagoon is a cumulative effect of two factors; impaired inflow and outflow through the lagoon mouth, and the increase of the sediment input to the lagoon. If the ongoing processes are sustained, the lagoon will change into a different landscape. Therefore, early intervention to restore the lagoon hydrology is highly recommended if the lagoon ecosystem is to be protected.

Keywords Dondra lagoon · Hydrology · True mangroves · Tidal inflow · Salinity · Siltation

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Introduction

Coastal ecosystems, such as lagoons, estuaries, bays, mangrove forests, coral reefs, and sea grass beds, are among the most productive in the world (Sowell et al. 2010; Miththapala 2013). These ecosystems provide numerous ecological services, including coastal protection (Bandaranayake 1998; Cochard et al. 2008; Guannel et al. 2016; Satyanarayana et al. 2017), provision of nursery, breeding and feeding grounds for marine fauna (Dahdouh-Guebas et al. 2005b), pollution control (Tam and Wong 1995), cross ecosystem nutrient transfers (Barbier et al. 2011), carbon sequestration (Donato et al. 2011) and economic benefits such as provision of food, fuel, timber, medicine and raw materials for dye (Bandaranayake 1998; Stone 2006; Ravikumar et al. 2010). They are subjected to heavy human pressure (Eisenreich 2005; Halpern et al. 2008; Richards and Friess 2016) and are deteriorating in extent and quality (Waycott et al. 2009). According to UNEP (2006) and FAO (2007), sea grass beds, coral reefs, salt marshes and mangroves have declined by 29%, 30%, 50% and 35% respectively during the past two decades. The coastal ecosystems in Sri Lanka have not escaped this pressure (Gunaratne et al. 2010; Kennish and Paerl 2010; Samarakoon and Samarawickrama 2012). Among the aforementioned coastal features in Sri Lanka, lagoons head the list of those that have been subjected to changes driven by anthropogenic activities in the recent past (Dahdouh-Guebas et al. 2002; Jayatissa et al. 2002b; Dahdouh-Guebas et al. 2005a; Satyanarayana et al. 2011; Madarasinghe et al. 2016, 2017; Gunarathne et al. 2018).

A coastal lagoon is a shallow water body, usually located parallel to the shoreline separated from the ocean by a barrier which can be a sand bar, coral reef or barrier islands (Kjerfve 1994; Kennish and Paerl 2010). A lagoon is generally fed by freshwater run-off and riverine input from the drainage basin and with an intermittent saline water inflow from the sea via the lagoon mouth. These two influxes and lagoon morphology are the key factors which determine the hydrology of a lagoon. Local precipitation and evaporation, together with the hydrology, determine the salinity, nutrient regime and water chemistry of the lagoon (Dyer 1973; Knoppers et al. 1991; Kjerfve 1994) as well as the biota of the system. Therefore, lagoons are highly sensitive to alterations in hydrology and/or above physical processes. There are many examples in the world of lagoons being radically affected by alterations in the hydrology and/or physical processes like sediment transport, wave pattern, exchange of water, mixing processes so on (Saunders et al. 2007; Dahdouh-Guebas et al. 2011; Tulipani et al. 2014).

Many Sri Lankan lagoons have been seriously affected due to anthropogenic pressure. Kalametiya lagoon on Sri Lanka's southern coast can be considered as an extreme case and is now about to disappear due to heavy siltation. Siltation has taken place over the last six decades as a result of the diversion of excess irrigation water from the upstream paddy lands to the sea, through the lagoon (Jayatissa et al. 2002b; Dahdouh-Guebas et al. 2005a; Madarasinghe et al. 2017). Moreover, Dahdouh-Guebas et al. (2005a) reported that the mangrove cover of Kahandamodara and Rekawa lagoons, also located along the southern coast, has changed as a result of inland irrigation schemes. Another example is Garanduwa lagoon in the southern coast which is connected to the sea through a narrow canal about 1 km long. The surroundings of the lagoon underwent major land use change with the establishment of new buildings due to the booming tourism industry in the area. Gunarathne et al. (2018) reported that the species richness of the mangrove forest in Garanduwa lagoon has reduced, resulting in monospecific low saline mangrove stands (e.g., *Bruguiera sexangula*). This is considered a response to the reduction of tidal influx due to obstacles in the tidal canal (natural flow in between sea and lagoon). All these examples indicate that coastal lagoons in Sri Lanka have been neglected in many of the 'development' activities and their ecosystem services disregarded. In order to conserve the coastal lagoons of Sri Lanka, awareness of the importance of lagoons and of the negative impacts of many current and planned developments must be raised among policy-makers, and new ways found to encourage sustainable developmental activities that respect natural processes and resources.

Preliminary observations showed that changes have taken place in the morphometry of the proximal area of Dondra lagoon in the southern coast, linked with the development activities in the lagoon periphery. Therefore, the main objective of the current work is to study Dondra lagoon and associated vegetation, assess the level of risk of ecological degradation and recommend appropriate early interventions to avoid this. It is too late to restore many lagoons in the southern coastal area of Sri Lanka which have already suffered extensive damage (Madarasinghe et al. 2015, 2016; Gunarathne et al. 2018); we aim to prevent such an outcome at Dondra. This study documented the spatio-temporal changes of Dondra lagoon with particular emphasis on morphometry of the lagoon and the ecology of the associated mangrove vegetation during the past twelve years (2006–2017). The following research questions were addressed in the study: (i) what are the spatio-temporal changes that took place in Dondra lagoon during this period; (ii) what is the current ecological status of the lagoon including mangrove species richness, seedling bank and zonation of mangrove vegetation; and (iii) have such changes (if any) affected the socio-economic interactions of the dwellers with the lagoon?

Methodology

Study site

Dondra lagoon is a small, shallow coastal lagoon located at the southern tip of the island, (5° 56'N and 80° 34′ E), and between the cities of Matara and Dondra along the Colombo-Kataragama main road (Fig. 1). The maximum width and length of the lagoon body are 0.45 km and 0.8 km, respectively. However, the geometry of the lagoon is not complex. The proximal part of the lagoon narrows towards the sea and ultimately connects to the ocean through a narrow mouth which is about 15 m in width. This lagoon mouth is closed from time to time due to the formation of a sand bar, which is opened naturally or by breaching the sand bar (by the dwellers) when the lagoon water level is high. A number of small and seasonal streams flowing through agricultural lands e.g. paddy fields, are the major source of freshwater inflow into the lagoon. The lagoon depth is less than 1 m except for a few places at the center of the lagoon. Because of this shallowness (a common feature in Sri Lankan lagoon systems), Dondra lagoon is highly susceptible to changes in precipitation, evaporation and hydrology. The tidal amplitude of the sea around Sri Lanka

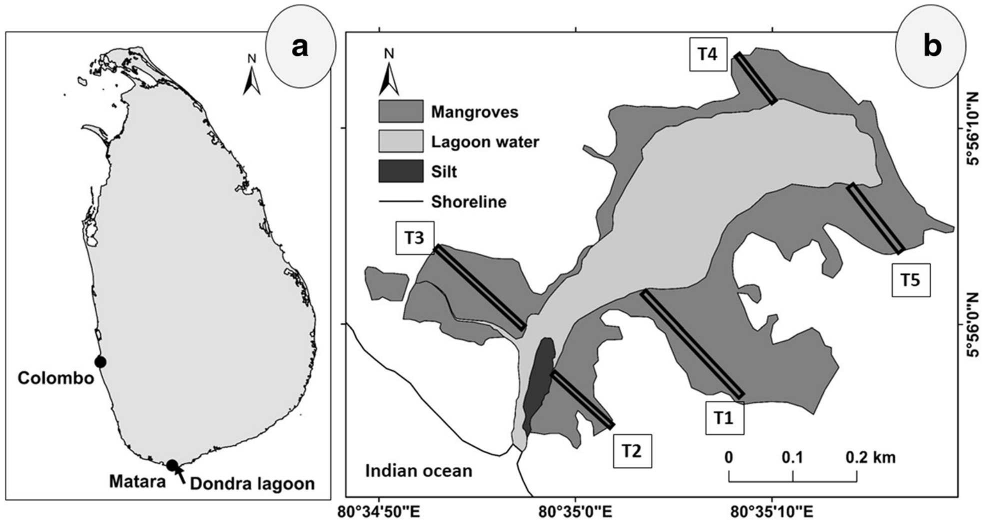

Fig. 1 The map of Sri Lanka showing the location of Dondra lagoon (black arrow head) (**a**) and the distribution of mangrove vegetation (by 2017) around Dondra lagoon (**b**). Five belt transects used for profile construction and diversity estimation (T1-T5) are shown in black colour strips

is rather low and the maximum annual range of tidal fluctuations is less than one meter and the minimum daily range of tidal fluctuation is about 20 cm (Dahdouh-Guebas et al. 2011). Under this micro-tidal regime, the salinity of the lagoon water ranges from 8 to 16 psu and the water body of the lagoon is surrounded by a mangrove forest with a high species richness (Jayatissa et al. 2002a).

Mapping and GIS work

Google Earth images of February 2006, January 2012 and February 2017, covering the Dondra lagoon area were downloaded and transferred into ArcMap v.10.1 interface. In order to avoid higher variations of the lagoon water surface area due to higher differences in the water level of the lagoon, all images were taken from the January–February period corresponding to the dry season for Matara area. These images were geo-referenced using 2–3 ground control points obtained by GPS (eTrex Gramin) and 4–6 Google Earth coordinates for each image, with root mean square error not exceeding 0.5. Mosaics were created for the images of the same year. All the images were at the same resolution (0.63 m) thus excluding the need of resolution correction. Mangrove vegetation cover and water surface area were identified using image attributes such as size, texture and tonality (cf. Dahdouh-Guebas et al. 2006) coupled with ground truthing. Identified polygons of the classes (i.e. mangrove cover, water surface area and silted area) were digitized on the above images taken in different years to produce maps of Dondra lagoon in 2006, 2012 and 2017. Next, area estimations were done for three polygon classes and the maps were superimposed to detect the area losses and gains over time. For a better understanding of land formation at the lagoon mouth and succession of the newly formed land, eight Google Earth images of 2006, 2011, 2012, 2013, 2015, 2016 and 2017 covering the lagoon mouth area were downloaded at 575 m eye altitude. The images were sequenced retrospectively to indicate the succession of the newly formed exposed land. For the error estimation, UAV (DJI mavic-pro) images with very high spatial resolution (3 cm) were obtained in December 2017 from three (20 m × 500 m) belt transects crossing the Dondra area. Error estimation was done for the 2017 map of Dondra lagoon with respect to the maps digitized using the above UAV imagery. In parallel to the GIS survey on the morphometric changes of lagoon and surroundings, the exact timing and the nature of various 'development activities' taken place in the catchment of the lagoon during the relevant period was received from relevant authorities (Table 1).

Table 1 'Development activities' which have taken place during the relevant period (2006–2017) and with a possible impact on the lagoon

Development activity	Distance to the lagoon	Year of construction
Construction of a new bridge	Across the lagoon mouth	Started in 2007 and completed in 2009
Construction of a new building for the fish market	50 m from lagoon mouth	2008
Construction of building complexes for a new school, i.e. Mahinda Rajapaksha School	500 m away from the lagoon mouth	Started in 2011 and completed in 2013
Construction of a new housing scheme	About 500 m away from the eastern bank of the lagoon	Started in 2008 and completed in 2013

Ecological and questionnaire survey

A systematic study on mangrove vegetation was carried out. The mangrove forest surrounding Dondra lagoon was visited and all the available true mangrove species and mangrove associates were recorded. Five belt transects (40 m minimal length, running from forest periphery to water edge; see Fig. 1) were selected, in the mangrove forest. Seedling bank and sapling cover of mangrove species were studied along the belt transects. The height of the trees and D_{130} (diameter at 130 cm height) were measured by using a measuring tape and PCQM (Point Centered Quarter Method) was used in case of multi-stemmed trees. Forest stratification was taken into consideration and a profile diagram was drawn according to the method by Davis and Richards (1933) using a line transect from the southern bank of the lagoon (marked as T1 in Fig. 1). The Simpson diversity Index (1-D) was calculated for five selected belt transects (40m × 5m).

$$\textit{Simpson Diversity Index} = 1 - \sum \left(\frac{n}{N} \right)^2 \quad (1)$$

where n is the total number of individual plants of a species; N, the total number of individual plants of all species.

In addition, 34 sub-surface (at a depth of 50 cm) water samples considered representative of the whole lagoon were collected randomly between October 2017–January 2018 and the salinity was measured with the help of a hand refractometer (ATAGO/Mill-E, Japan). A questionnaire survey including open-ended and structured questions (Annex 01), was conducted using face-to-face interviews with residents to gather information on human activities affecting the lagoon and temporal changes they may have experienced over the past decade. The interviewees were selected as occasional encounters and visiting them at home. In total, 41 residents were approached for the survey. They were between 40 and 60 years old and live within 1 km proximity to the lagoon's shores. All the responses were carefully reviewed for quality control of the information extracted from the questionnaire survey. The quality control was done in a way that the responses were screened to check their reliability (we included some questions to double-check the answers of the residents) and compared with the information given by the residents to extract the most reliable information of the questionnaire survey.

Results

Spatio-temporal changes in Dondra lagoon (2006–2017)

Variations of the total mangrove cover and the water surface area of the Dondra lagoon over the last twelve year period (from 2006 to 2017) are shown in Fig. 2 and Table 2. The total area of mangrove cover in Dondra lagoon reduced very slightly during the six year period from 2006 to 2012 but increased again during the last 6 year period from 2012 to 2017. The total increase is about 11% compared to the mangrove cover of 2006. The landward extensions (off-shoreline of the coast) of the mangrove cover at the eastern bank and along the freshwater inflow canal at the western bank are mostly account for this increase. The remote sensing studies and the field observations showed that the composition of the mangrove cover remains a mixture of six true mangrove species during the 12 year period, and no specific mangrove species were favoured in the increase of the mangrove cover over last six year period. However the water surface area has reduced continuously over the 12 year period and the total reduction is about 10% of the water surface in 2006.

A large part (~40% from the reduced water area) of lost water surface was occupied by newly surfacing land near to the lagoon mouth (mud-flat like land mass). In the available Google Earth satellite imagery, this land formation first appeared in 2011 (Fig. 3). This area is now vegetated with grass and small shrubs. The width of the lagoon mouth has also reduced, impeding tidal flow. At present, tidal inflow is confined to a very small canal particularly near to the lagoon mouth due to the formation of the aforementioned land.

Mangrove vegetation and lagoon ecology

The mangrove cover around the lagoon is rich in diversity of true mangrove species (Table 3). Six true mangrove species (sensu Jayatissa et al. 2002a, b) namely *Avicennia officinalis* L., *Bruguiera gymnorrhiza* (L.) Lam., *B. sexangula* (Lour.) Poir., *Rhizophora mucronata* Lam., *Sonneratia caseolaris* (L.) Engl., and *Excoecaria agallocha* L. and several mangrove associates including *Acanthus ilicifolius* L. and *Acrostichum aureum* L. were observed in this study. Mangrove tree species have well-grown to a mature tree stage and the rest are mature bushes and herbs. Average height of mangrove tree ($n = 52$) varied between species; *Rhizophora mucronata* 6.6 ± 0.4 m, *Avicennia officinalis* 6.4 ± 0.5 m, *Bruguiera gymnorrhiza* 4.5 ± 0.8 m, *Sonneratia caseolaris* 4.0 ± 0.5, *B. sexangula* 3.9 ± 0.5 m, and *Excoecaria agallocha* 2.8 ± 0.2, while the average girths of the same species were 44 ± 10 cm, 43 ± 12 cm, 36 ± 09 cm, 27 ± 05 cm, 35 ± 02 cm, and 22 ± 06 cm respectively ($n = 70$). A large seedling bank (about 15 per mature tree) and higher (about 5 per mature tree) numbers of growing saplings could be observed for almost all species.

The profile diagram of the mangrove vegetation shows a simple zonation (Fig. 4). There are three conspicuous zones as the innermost zone at the water margin, middle zone, and a peripheral zone at the landward margin. The innermost zone is dominated by a *Rhizophora mucronata*. However, in some other places, *Avicennia officinalis*, *Excoecaria agallocha* or

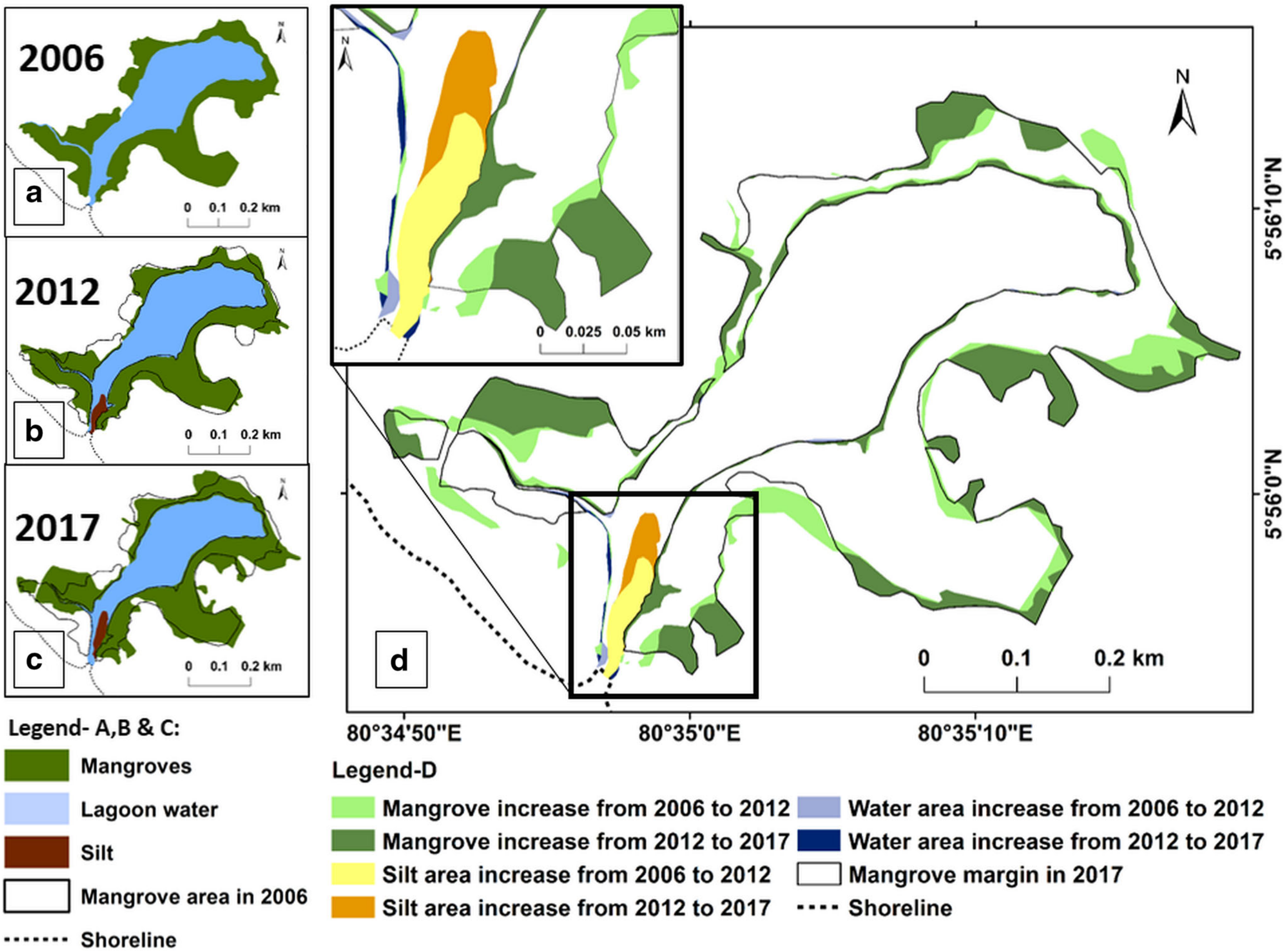

Fig. 2 Maps showing the variations of the total mangrove cover, water surface, and the silted area of Dondra lagoon over the twelve year period from 2006 (**a**), 2012 (**b**) and 2017 (**c**). The area gain map is also given for the period of 2006–2017 (**d**)

Bruguiera gymnorrhiza were dominant. The middle zone is vegetated by the mixed mangroves, for example, *Bruguiera sexangula*, *B. gymnorrhiza*, *Avicennia officinalis* and *Excoecaria agallocha.* The landward zone is dominated by mangrove associates including *Acanthus ilicifolius* and *Acrostichum aureum* as with scattered *Avicennia officinalis* trees. Clear stratification can be observed in the middle zone of the mixed mangroves, as a canopy layer, sub-canopy layer, and a shrubs layer. However, an emergent canopy layer is not clear (refer the vegetation profile of the mangrove forest of Dondra lagoon given). Salinity values showed some variations from lagoon mouth to landward side, and from lagoon mouth to freshwater inflow. Salinity was comparatively higher near to the lagoon mouth, i.e. ~6 psu ($n = 14$), as compared to the middle area of the lagoon, i.e. ~2 psu ($n = 10$). The salinity towards the freshwater inflow canals at the northern bank was less than 2 psu (n = 10). The Simpson diversity indices for the transects studied are given in the Table 3.

Table 2 Variations of the total mangrove cover, water surface, and the newly formed land area of the Dondra lagoon over the twelve year period from 2006 to 2017. Change percentages are indicated with respect to 2006, where possible to calculate

Attribute	Extent (ha)			Change (ha) From 2006 to 2017
	2006	2012	2017	
Mangrove cover	12.14	12.06	13.52	+1.38 (+11.4%)
Water surface area	9.40	8.98	8.48	−0.92 (−9.8%)
Newly formed land area	0.00	0.32	0.32	+0.37

Questionnaire survey

According to the data collected from the residents, coastal communities are largely (~73%) dependent on lagoon fisheries and fishery-related activities. A portion of the fish catch is used to sell at the market while a considerable portion is used for domestic use (~53%). From the perspective of the coastal

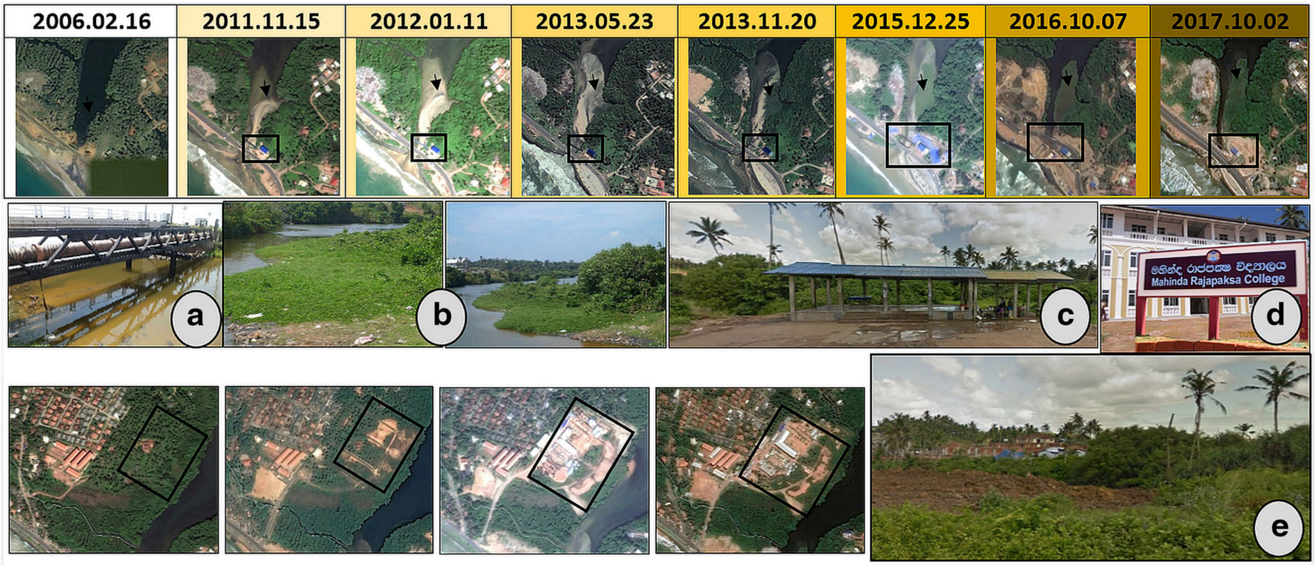

Fig. 3 The spatio-temporal sequence of newly formed land area (black arrow) during the past twelve years (2006–2017) at the top row; the intensity of the land mass formations indicates by colour gradient. Construction of the bridge and the fish market are shown by black squares (top row). Establishment of the new school (Mahinda Rajapaksha) over time is shown large black squares at the bottom row. The on-site images **a**: new bridge; **b**: newly formed land mass area; **c**: fish market; **d**: Mahinda Rajapaksha school; **e**: cleared area near to the western bank of the lagoon, are also given (Photos: Madarasinghe SK)

users, during the last decade, they have observed a large reduction in fish catch as well as changes in the composition of fish species in the lagoon towards low-saline and freshwater species e.g. eels (*Anguilla* spp.), barbs (*Pethia* spp.), garfishes (*Xenentodon* spp.), *Tilapia* sp., and *Etroplus* sp. This has led to a reduction in lagoon fishery-related activities to a certain extent. However, overfishing was not recorded. They further claimed that impedance of seawater flow could be the cause for the observed variations. In the past, the lagoon mouth was opened naturally at least twice a year when the water level was high in the lagoon. However, there were some reported instances (in early 2000) that the mouth was opened by the farmers removing the sand bar during the heavy rains to avoid flooding in their agricultural lands. Presently, the mouth is opened in neither ways. During heavy rains, low-lying areas at the landward side are regularly flooded (can happen at any time in case of heavy rain). The reduced outflow through the narrowed lagoon mouth with the new land formation near to the mouth is identified as the cause for such frequent floods. This land formation started after the tsunami of 2004, which brought a large amount of sand and debris into the lagoon. Apart from fish catch, timber/poles and fire wood collected from the mangrove forest are the major direct products taken by the dwellers from the lagoon ecosystem. Fruits of *Sonneratia caseolaris* are also used for home consumption and a few people make a commercially sold drink out of the fruits (cf. Jayatissa et al. 2006). Some of the mangrove areas, particularly on the western bank, have been cleared for infrastructure development projects like establishment of a school (Mahinda Rajapaksha School), a housing scheme and a high-electricity power line. Parallel to these projects, a new bridge and fish market were built in 2008 and people mentioned that these two constructions led to change in the structure of the lagoon mouth.

Table 3 Simpson diversity index (1-D) values for the belt transects (T1-T5). Refer to the equation given under methodology part

Transect	Simpson diversity index (1-D)
T1	0.82
T2	0.71
T3	0.74
T4	0.77
T5	0.69
Average	0.75

Discussion

Coastal lagoons are highly sensitive to ecological, physical and human disturbances; changes in flushing regime, freshwater inflow, and water chemistry are the most common consequences of such disturbances (Anthony et al. 2009). Profound changes in such aspects may affect lagoons seriously and in some cases the alterations can lead to a permanently different state. There are reports on the fact that lagoons have shifted to a different landscape as a result of such disturbances (Jayatissa et al. 2002b; Dahdouh-Guebas et al. 2005c; Madarasinghe et al. 2017; Gunarathne et al. 2018). Therefore, timely investigations and early interventions are imperative to secure the future of lagoon

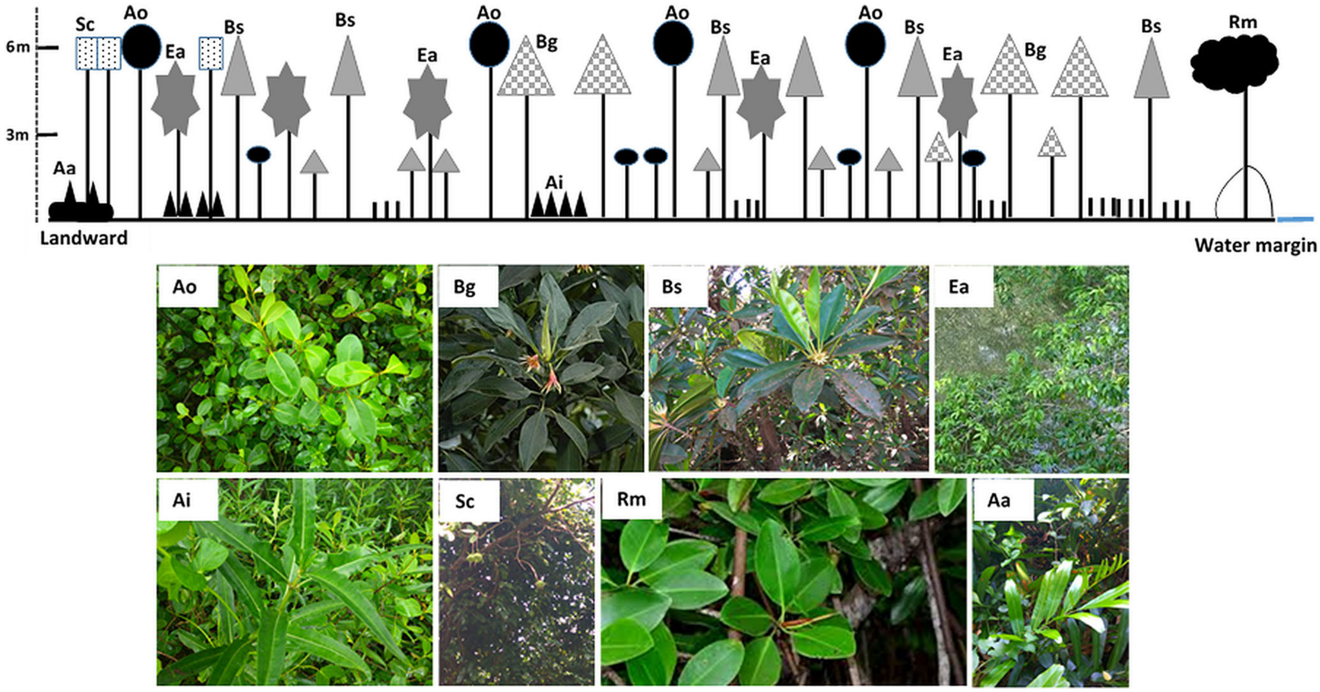

Fig. 4 Profile diagram showing the spatial distribution of mangrove species from water margin to landward side as depicted by the transect T1 of Fig. 1 which is about 200 m in length. Different shapes represents different mangrove species. Small similar form of larger illustration shows sapling stage of species while small lines are for seedlings. Ao: *Avicennia officinalis*; Bg: *Bruguiera gymnorrhiza*: Bs: *B. sexangula*; Rm: *Rhizophora mucronata*; Sc: *Sonneratia caseolaris*: Ai: *Acanthus ilicifolius*; Ea: *Excoecaria agallocha*; Aa: *Acrostichum aureum*. Below, images taken at the site are given (photos: Amarasinghe P. and group)

ecosystems, which are often subjected to severe anthropogenic pressure.

When considering the change in mangrove cover of Dondra lagoon, a considerable part of the mangrove areas has been sacrificed for development projects i.e. about 2 ha for Mahinda Rajapaksha school and housing scheme. However, the net change over the 12 year period (2006–2017) shows an increase of the mangrove cover which could be considered as a positive trend since at the time of the study the lagoon did not show any cryptic ecological degradation sensu Dahdouh-Guebas et al. (2005c) i.e. ecological degradation (a loss of functional mangrove species) that is masked by an expansion of less important (less functional) eurytopic or semi-terrestrial species. Careful observation indicates that this increase has taken place in two ways; through a "gap filling scenario" i.e., bare, non-vegetated spaces within the mangrove forest are occupied by the surrounding species and, as extensions of the mangrove belt to the periphery.

In general, true mangroves occupy the intertidal area of lagoons and estuaries in Sri Lanka (Kodikara et al. 2017a) and therefore the increase of the mangrove cover means that the intertidal area should also extend consequently. Both mechanisms outlined above, indicate that the primary cause for the increase of the mangrove cover of Dondra lagoon is the increase of the mean water level of the lagoon. Hence, it may not be wise to conclude that this is a 'positive trend', since such a mangrove increase could be a short-term response. However, the long term response could also be a cryptic ecological degradation of the mangrove vegetation (Dahdouh-Guebas et al. 2005c) or even detrimental, the entire lagoon ecosystem might shift to a different land cover which is less productive (e.g. Kalametiya lagoon, Madarasinghe et al. 2016).

The increase of the mean water level of the lagoon could be due to either increased influxes (sea water influx, or fresh water inflow or both) to the lagoon, or impaired outflow of the lagoon water. Dondra lagoon receives freshwater inflow from the catchment of 874 ha where no new irrigational intervention took place during the investigated period and the land area of paddy lands also remain unchanged. Therefore, we could not find any evidence for an increased influx of water into the lagoon. However, as evidenced by the aerial photographs, from the information received from the official sources, and from questionnaire survey, the water flow (ebb and flood) through the lagoon mouth has been disturbed during the last decade due to the several construction works. Now the lagoon mouth has been converted to a narrow (10-15 m) canal (before, it was about 100 m) with the length of about 150 m. The bridge across the lagoon mouth and along the road from Matara to Dondra collapsed at the end of 2004 due to the Indian Ocean tsunami. The debris and sand brought by the tsunami waves as well as remnants of the broken bridge obstructed the flow through the mouth. A temporary bridge was installed immediately this and a new bridge was constructed and completed within 2 years after the tsunami of 2004. Next, five years after the replacement of the tsunami-damaged bridge, another new construction was started for widening the bridge under the urban development programme and it was completed at the end of 2017. During the period of the above constructions, the ebb and flood through the lagoon mouth has partially been blocked. We find it reasonable to expect an increase of the retention time of lagoon water causing a rise of the water level of the lagoon. It may be the most plausible cause of the increase of the mean water level of the lagoon over the mentioned period. This may also be linked with the increased rainfall in the previous decade (rainfall pattern has drastically changed in the recent years). Further, during the questionnaire survey, respondents revealed that the frequency of sudden floods in low-lying areas adjacent to the lagoon during the rainy season has increased over the last few years and this can also be considered as supporting evidence for the impaired outflow of the lagoon.

A large part of the water surface area of the lagoon is replaced by the newly formed land of 0.37 ha which is responsible for much of the decrease in water surface. It is not uncommon that such land masses form close to the mouth of lagoons and estuaries (Kjerfve and Magill 1989) as a temporal land mass mainly by sand. Nevertheless, they are flushed away with floods at the next rainy season (pers. obs. land mass near Gintota, Galle, Sri Lanka). However, this land mass appeared to be a permanent formation as it has increased continuously over the last six years since 2011 as shows succession of vegetation, which can easily take place with the migration of plant seeds in case of naked land forms. It is obvious that the sediment budget of the lagoon must have changed, resulting in this new land formation. Heavy sediment accumulation in the lagoon can take place when a decrease in sediment output occurs, or an increase in sediment input, an increase in sediment throughput, or a combination of these. In this study, several activities which are responsible to increase the amount of sediment load in the lagoon were detected.

Land preparation to construct building complexes for a newly established school and a housing scheme are evident. Both of them are on small hilly areas and directly caused a higher sediment load to the lagoon by erosion. This is very intense in the rainy season. Apart from that, dumping of municipal waste in the mangrove vegetation of the western bank of the lagoon has occurred. In 2015, a part of the site where the mangroves were already destroyed due to garbage dumping, has been covered by laying soil on garbage, in order to construct a playground for the new school. The garbage and particularly the soil layer on it, also substantially contributed to increase the sediment load of the lagoon. Probably the Dondra lagoon may be too small (~ 22 ha) to bear or manage such a sediment load. In addition, fish residues and other wastes, discarded from the fish market near the lagoon mouth are directly added to the lagoon while the waste materials generated in dry-fish industry, particularly in the northeastern bank, are also dumped in the lagoon.

As a result of all these activities, it is likely that sedimentation processes in the lagoon have been boosted during the last decade. Based on all the above information and evidence, we emphasize that the visual changes that took place during the last decade in the morphometry (i.e. size, and shape of the lagoon, its water surface and associated vegetation) of the lagoon are a cumulative effect of two factors: impaired ebb and flood through the lagoon mouth, and the increase of the sediment input to the lagoon.

Our results showed that the salinity of the lagoon is also affected by these changes. According to Silva and Priyadarshana (2000), the average salinity of Dondra lagoon in late 1990's was about 12 psu while it was about 3 psu in measurement of this study. This indicates that the lagoon has shifted from moderately saline to a low saline water body during the last decade. More likely, the impedance at the lagoon mouth may have caused a salinity gradient cross the lagoon (Dias et al. 2000). Salinity of a lagoon plays a key role in determining the biota and hydraulics of the lagoon (Lamptey et al. 2008). During the questionnaire survey, fishermen of the Dondra lagoon confirmed that the fish catch has reduced in quantity and diversity and it is now dominated by low saline and freshwater fish species such as *Pethia* spp., *Tilapia* spp., and *Etroplus* spp., supporting the evidence for a salinity shift. (Seixas and Berkes 2003). In some cases, lagoons can become temporarily or permanently hypersaline due to high evaporation and reduced tidal inflow (Kjerfve 1994) though the possibility of increasing the salinity due to high evaporation is less in Dondra lagoon as it is located in the intermediate zone. The present case of Dondra Lagoon is exemplary in the sense that a tsunami-initiated natural process of siltation has been sustained by human activities, which is the exact opposite situation as the human-initiated siltation in Gazi (Kenya), that was sustained by natural siltation processes and also lead to massive loss of mangrove stands (Dahdouh-Guebas et al. 2004).

Due to the impediments to exchange of water through the lagoon mouth, the water circulation in the lagoon has reduced generating the remarkable salinity gradient from the lagoon mouth to freshwater inflows. A decade ago, the lagoon was directly opened to the sea through the lagoon mouth. However, with the formation of new land mass sacrificing a considerable part of the lagoon body, the proximal part of the lagoon body has now converted to a narrow (10-15 m) canal with the length of about 150 m. This situation has further restricted the sea water inflow to the lagoon. This could further aggravate the decrease of salinity in lagoon water (Dias et al. 2000). Salinity of a lagoon should be highly concerned in the sense of that, the salinity plays a key role in controlling the biota and hydraulics of the lagoon (Lamptey et al. 2008). This present case of Dondra Lagoon is quite exemplary in the sense that a tsunami-initiated natural process of siltation has been sustained by human activities, which is the exact opposite situation as the human-initiated siltation in Gazi (Kenya), that was sustained by natural siltation processes and also lead to massive loss of mangrove stands (Dahdouh-Guebas et al. 2004).

The mangrove forest of Dondra lagoon still holds high species richness in view of its size and against the background of the regional flora. This also holds as compared to other lagoons like Rekawa, Galle, in the southern coastal region. It has a healthy forest structure in terms of rejuvenation, probably because the aforementioned changes are still recent and not yet reflected ecosystem deterioration. High Simpson diversity index values of all the studied belt transects clearly show that no species was favoured by the changes occurred in the lagoon area. As proposed by Dahdouh-Guebas et al. (2005a), this study therefore illustrates the global need for monitoring and early warning of degradation for coastal ecosystems such as mangroves, which provide many ecosystem functions, goods and services (Lee et al. 2014). The use of very high-resolution remote sensing satellite or UAV imagery (cf. Ruwaimana et al. 2018; Otero et al. 2018) can provide much useful information on disappearance of or changes to typical, functional, valuable and vulnerable species assemblages (species shifts, introgression by mangrove associates) at an early stage (Dahdouh-Guebas et al. 2005b). Kodikara et al. (2017b) has shown that the low saline regime (nearly freshwater conditions) helps exclusive mangroves only at the seedling/sapling stage and after they need moderately saline conditions for better growth and development performance. Therefore, we are in a position to provide early warning of the risk of a long-lasting low saline regime as it might reduce the species diversity of true mangroves in the forest, favouring to low saline or euryhaline species (Dahdouh-Guebas et al. 2005a; Gunarathne et al. 2018). This may further drive cryptic ecological degradation in the mangrove forest for example, such as in the monospecific stands of *Sonneratia caseolaris* in Kalametiya and *Bruguiera sexangula* in Garanduwa (Dahdouh-Guebas et al. 2005b; Gunarathne et al. 2018). In addition, continuous reduction of the water surface of the lagoon may cause conversion into a low lying salt marsh (Madarasinghe et al. 2017).

In conclusion, if these trends of impaired inflow and outflow through the lagoon mouth, low salinity, accumulation of sediments, and gradual conversion of the water surface to a land mass continues, they will affect the proper functionality of the lagoon ecosystem in its 'mangrove state' or as a lagoon altogether. Furthermore, there is no guarantee that further development activities in the catchment of Dondra lagoon will not be launched hereafter implying that even higher siltation rates might continue in the future, unless a serious intervention is taken to protect the lagoon.

When the present situation of the lagoon as well as future possibilities are taken into consideration, it can be concluded that Dondra lagoon is in an early risk phase and there is enough time to take necessary managerial actions for rescue. This is timely, because at present the rejuvenation stage of the forest would still allow stabilizing the mangrove state. Dondra Lagoon is located between the two historic cities Matara and Dondra, and adjacent to a major national university of the country. It greatly contributes to the aesthetic value of all the above entities and provides for the livelihood of the population (Table 4) around it. Due to all those factors, it warrants further investigation and early intervention to restore and secure the lagoon ecosystem.

Table 4 Population data of the Grama Niladhari Divisions in which Dondra lagoon is located (Source: 2012 census data by Department of census and statistics, Sri Lanka)

Grama Niladhari Division	Population
Devinuwara Central	1024
Devinuwara Nugegoda	1497
Devinuwara West	574
Meddawatta South	1954
Rassandeniya	2695

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Annex 01

This is a questionnaire survey related to a research project carried out by University of Ruhuna, Sri Lanka. We expect your maximum contribution for this and we ensure to keep your information confidential.

Name:

Age:

Gender:

Address:

Approximate distance to the lagoon from home:

Since when you are living in this area?

What are the uses you and your family obtain from the lagoon:

Did Tsunami affected this area in 2004?

Have you observed any change to the lagoon area within last 10 year period?

What are they?

What do you think are the reasons for above mentioned changes?

Special comments:

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