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Short Communication

A remote sensing approach for assessing the invasion of *Najas marina* in Madu Ganga Estuary, Sri Lanka

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Abstract: The present study was carried out to determine the distribution *of Najas marina*, an invasive floral species in the Ramsar site of Madu Ganga Estuary in Sri Lanka using ASTER satellite data. Cloud free ASTER imageries of Madu Ganga Estuary with 15 m resolution were atmospherically corrected using the FLAASH in ENVI software. The NDVI was calculated and unsupervised classification was applied for the study site for each image and the distribution maps of *N. marina* were developed from 2007 to 2014. Methodology was validated using in situ data, which were collected in 2014 with monthly intervals parallel to ASTER overpass. The derived distribution maps indicated that *N. marina* was distributed in about 31% of the estuary in April 2014. The highest densities were mostly found in bay areas and peripheral areas. Maps developed for December 2007, December 2009 and December 2013 indicated that there is a temporal variation in the distribution of *N. marina* over the years. The overall distribution of *N. marina* has decreased from December 2007 to December 2009 and increased from December 2009 to April 2014. Low water levels and stagnation of water appears to be conducive for the variation of this species. These factors should be taken into consideration when managing the invasion of *N. marina* in this economically and ecologically important estuary.

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Introduction

Madu Ganga Estuary (915 ha) is a coastal water body located in the south western region of Sri Lanka between 06°12'-06°19'N and 080°1'-080°5'E. There are 298 vertebrate species with 20 endemics and 303 plant species with 19 endemics in this wetland which has been declared as a Ramsar site in 2003 and also as a sanctuary in 2006. It has a high economic value too due to fishing and tourism (IUCN and CEA, 2006).

Invasive alien species (IAS) are a current focus of interest of ecologists, conservationists and natural resources managers due to their rapid spread, threat to existing biodiversity and damage to the ecosystems (Polley et al., 1997). *Najas marina* is one of the nine invasive alien floral species that has been recorded in Madu Ganga Estuary (Bambaradeniya et al., 2002; IUCN and CEA, 2006). It is considered as a nuisance in this wetland because it entangles with fishing gear and the paddle wheels of outboard engines of tourist boats (Silva and Wijeyaratne, 2015).

Studies on the spread of invasive species are important for their control (McCormick, 1999). Geospatial technologies, including remote sensing (RS) and geographical information systems (GIS) are used to assess the spatial distributions and predict the spread of invasive species (Narumalani, 2008). Digital remote sensing has been widely used to determine the spatial and temporal distribution of aquatic macrophytes (Lyzenga, 1978; Armstrong, 1993; Mumby et at., 1997; Zhang, 1998; Heege and Fischer, 2004). In Sri Lanka, satellite imageries have been used to determine the eutrophication of coastal water bodies through the estimation of chlorophyll-a (Chl-a) content (Dahanayaka et al., 2011, 2012, 2013, 2015); however, no study has been yet carried out to determine the extent of submerged aquatic vegetation in Sri Lankan water bodies using satellite data. Hence, this study was aimed at investigating the possibility of

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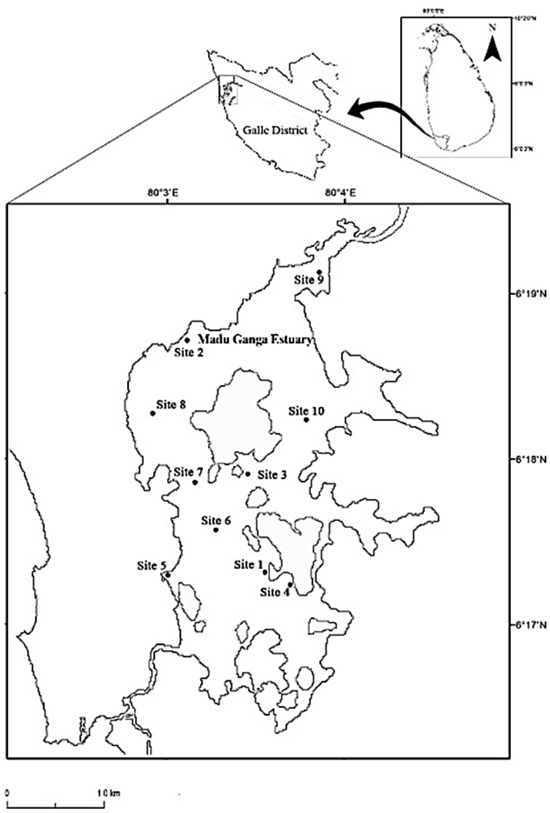

Figure 1. Map of the Madu Ganga Estuary showing the sampling sites.

using advanced spaceborne thermal emission and reflection radiometer (ASTER) data to map the distribution of *N. marina* and to assess its invasion in Madu Ganga Estuary using ASTER data obtained from the Terra satellite.

Materials and Methods

Presence or absence of *N. marina* in 10 sampling sites of Madu Ganga Estuary (Fig. 1) was recorded once a month from January to December 2014 on the days of ASTER overpasses and the GPS locations of each sampling site was recorded using a GPS receiver (Etrex/Model: Garmin summit). Cloud free ASTER imageries obtained for the period December 2007 to December 2014 were atmospherically corrected using the fast line-of-sight atmospheric analysis of spectral hypercubes (FLAASH) (Cooleya et al., 2002) available from Exelis Visual Information Solutions Inc. as part of the ENVI image processing software. The normalized difference vegetation index (NDVI) was calculated for each image using the following equation (Mahalingam and Kumar, 2014).

$$\mathrm{NDVI} = \frac{R_{\mathrm{NIR}} - R_{\mathrm{red}}}{R_{\mathrm{NIR}} + R_{\mathrm{red}}}$$

Where, R_{NIR} = reflectance of the band corresponding to near infrared (ASTER band 3) and R_{red} = reflectance of the band corresponding to red (ASTER band 2). Calculation of NDVI for a given pixel always results in a number that ranges from -1 to +1. NDVI values close to +1 indicates the high density of green leaves and value of 0 indicates soil line (USGS, 2011; Sakuno and Kunii, 2013). In this study, NDVI values greater than 0 were considered as aquatic macrophytes and since submerged aquatic vegetation was considered, NDVI = 0 condition was not applicable as there was no soil line (Sakuno and Kunii, 2013). Then an unsupervised classification was done using ENVI 5 to distinguish submerged *N. marina* from other aquatic macrophytes. Maps for the distribution of *N. marina* were developed and the results were validated using ground data. ASTER imageries for December 2007, December 2009 and December 2013 were also subjected to the same analysis and the maps showing the distribution of *N. marina* were developed. The percentage coverage of *N. marina* was calculated through a supervised classification using ArcGIS software version 10.3.

Results and Discussions

Aquatic macrophyte community was observed during the study period consisted entirely of *N. marina*. Figures 2-5 show 15 m resolution *N. marina* distribution maps estimated from atmospherically corrected ASTER imageries. Percentage coverage of *N. marina* in the Madu Ganga Estuary calculated from ASTER imageries is given in Table 1.

The highest coverage of 36% was noted in December 2007. In the month of December 2009, the % coverage was lower than that of December 2007 and in December 2013 it was higher than that of December 2009. No satellite data were available for other months during these periods due to cloud coverage. In all maps, *N. marina* coverage was

Table 1. Percentage coverage of *Najas marina* calculated from ASTER imageries.

Period	% Coverage
December 2007	36
December 2009	14
December 2013	24
April 2014	31

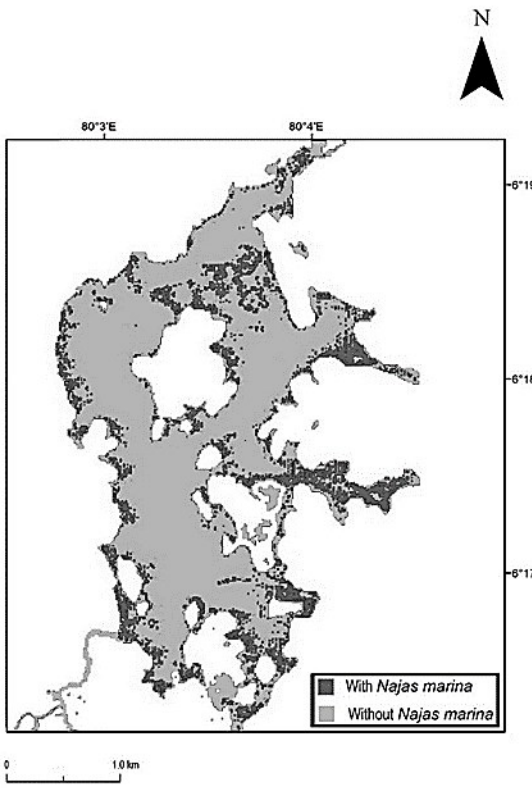

Figure 2. *Najas marina* distribution map - December 2007.

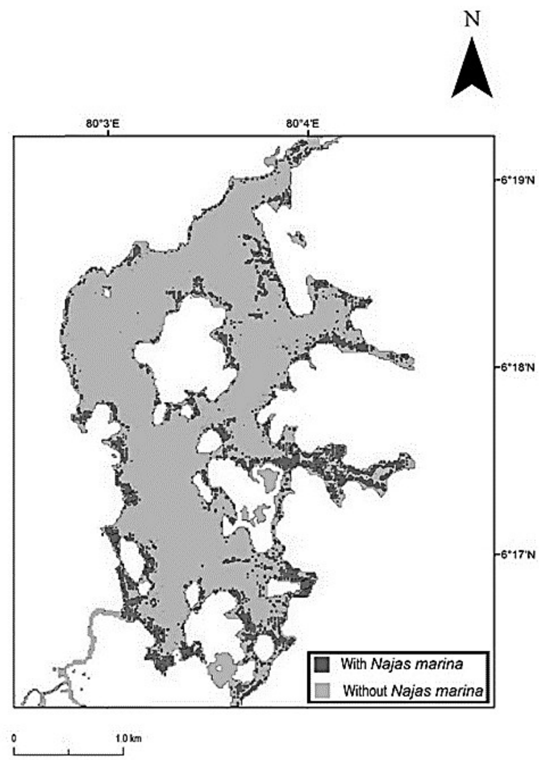

Figure 3. *Najas marina* distribution map - December 2009.

observed to be high closer to the perephery of the estuary (Figs. 2-5). In December 2007 (Fig. 2) and April 2014 (Fig. 5) coverage of *N. marina* was high in the northeastern region of the estuary also. Maps for other months of the study period could not be developed due to the unavailabiliy of satellite data.

The spread of invasive species usually stimulates the interest in the prediction of their distribution (Kumudinie and Wijeyaratne, 2005). Maps constructed through RS and GIS could be used to indicate the presence and absence of an invasive species over time through which such predictions can be made (Joshi et al., 2005). Satellite data of Landsat, MODIS and ASTER could be used to obtain information on such biological invasions where each satellite system is characterized by bands at which they measure the reflected energy (Ali, 2010). Chl-a, which is a green pigment, absorbs light most strongly in the blue portion of the electromagnetic spectrum followed by red and therefore the presence of the blue band is an advantage for the identification of Chl-a in Landsat system. However, ASTER system does not contain the blue band in its spectral channel. Although the spectral positions of ASTER/VNIR were not designed for water colour observations in aquatic systems, several such investigations of Chl-a estimation have been successfully carried out using ASTER data (Sakuno and Matsunga, 2002; Kishino et al., 2005; Nas et al., 2009; Dahanayaka et al., 2015), because ASTER has partial resolution that is sufficiently high to target small water bodies such as lakes, lagoons and estuaries. The present study was carried with the objective of investigating the possibility of using ASTER data to map the

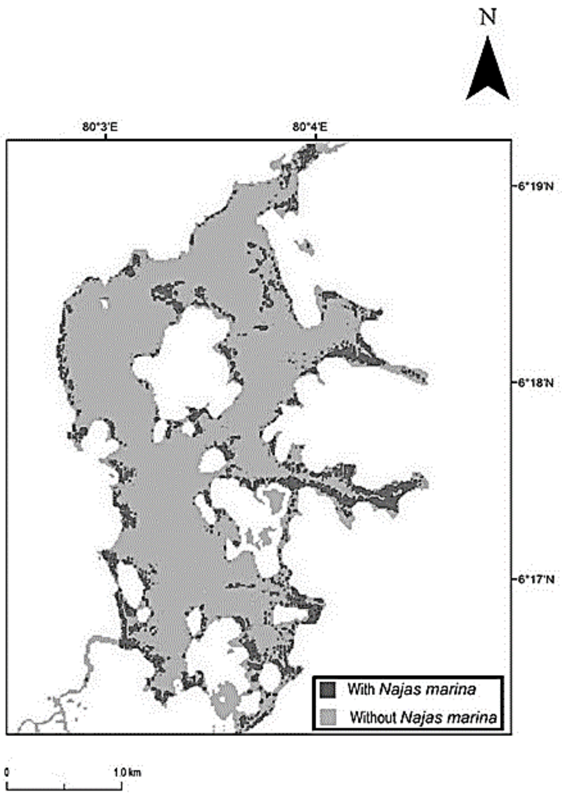

Figure 4. *Najas marina* distribution map - December 2013.

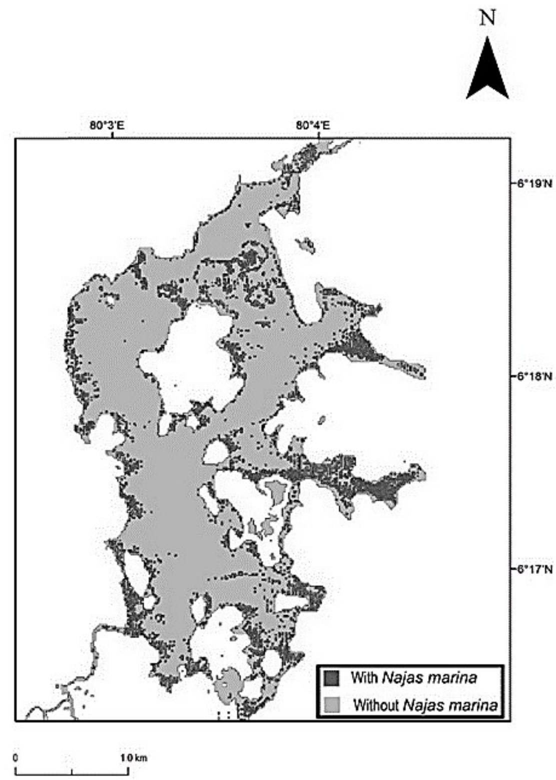

Figure 5. *Najas marina* distribution map - April 2014.

distribution of submerged macrophyte *N. marina*.

Invasive alien flora forms thickets and shades out native vegetation, and thereby displaces them gradually (Bambaradeniya, 2002). In addition, invasive alien flora may entirely modify the structure and function of an ecosystem, which could occur in many ways. For instance, the invasive floral species can produce allelopathic substances that are toxic to other native plant species making the soil unsuitable for them (Bambaradeniya 2002). This may be the reason for the absence of other aquatic macrophytes in the aquatic environment of this wetland.

Najas marina was mostly found in bay areas and peripheral areas of the estuary. In the northern region, it was found in the middle areas. Cao et al. (2012) have shown that growth of submerged and emergent aquatic macrophytes is enhanced by moderate and low water levels, primarily due to the abundance of light. This may be one of the reasons for its presence in areas close to the shoreline and also in the bay regions. In addition, absence of *N. marina* in most of the middle areas of the estuary may be due relatively high speed of water which may have prevented the establishment of the plant. The bay regions, due to slow flowing nature of water, may have facilitated its establishment. However, this may be only one reason and more studies, especially on the nutrient contents, depth and other physicochemical parameters are needed to come into a definite conclusion.

Maps generated from satellite imageries indicate that there is a temporal variation of the % coverage of *N. marina* in this wetland over the past 8 years. Nearly 36% of the estuary had been covered with the plant in December 2007 and December 2009 only 14% had been covered. In April 2014 about 31% of the estuary had been covered. Amarathunga et al. (2010), based on *in situ* observations have reported that, nearly 25% of the estuary was covered by *N. marina* from March 2006 to January 2007. They have attributed this to high loading of nutrients from the catchment. Land use of the watershed includes many agricultural activities, including paddy farming. Sri Lankan farmers are used to apply large amounts of fertilizer most of which ultimately washed away to nearby water bodies (Sangakkara and Wijeyaratne, 2015). However, more studies on the nutrient contents are needed to test the hypothesis that the distribution of *N. marina* in this wetland is associated with the nutrient content of water.

Bambaradeniya et al. (2002) have reported that the alien macrophytes such as *N. marina* could result in narrowing down of native biological diversity in a particular locality. On the other hand, in the Maduganga Estuary, it entangles with the out-board engines of tourist boats as well as with fishing gear making it a nuisance to local community. Therefore, effective management measures are needed to minimize the invasion of *N. marina* in this ecologically and economically important wetland. The widely used control measure at the moment is removal by hand (Silva and Wijeyaratne 2015). In order to carry out the control successfully, it is necessary to identify the areas where this invasive species is present. However, *in situ* observations to locate the areas where *N. marina* is present would be time consuming. In addition, it needs a large amount of travelling within the estuary causing heavy disturbances to avifauna and fishing activities. Therefore, development of the distribution maps using ASTER data, which has been proven to be feasible by this study, would be very useful in this content.

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