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Spatial data analysis for the marine fisheries and habitat management of Sri Lanka

D.D.G.L. Dahanayaka

Department of Zoology, Faculty of Natural Sciences, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka

Correspondence (dddah@ou.ac.lk)
https://orcid.org/0000-0001-9052-3873

Abstract Satellite Remote Sensing (RS) can be effectively used for the fisheries applications, including stock assessment, management of marine resources and fish harvesting. Further, there is an extensive range of fisheries related applications of RS data, including identifying marine managed areas, detection of harmful algal blooms, bycatch reduction, long term monitoring of fisheries related habitat changes and control of illegal fishing. Applications on RS related to marine fisheries sector in Sri Lanka, seem to be meager. Limited studies have been conducted on the fisheries related ecosystem damage assessment using RS after December 2004 Tsunami disaster. To fulfill the gaps of research on coastal fisheries identified, the author conducted some research on habitat changes such as monitoring of land use changes and water quality at economically important estuarine environments around Sri Lanka using multi temporal satellite imageries. In these studies, several environmental issues have been addressed such as localized eutrophication, disturbance of water circulations and sudden fish kills etc. Furthermore, since satellite RS is a useful tool that could be applied for planning marine fisheries development in Sri Lanka, the National Aquatic Resources Research and Development Agency (NARA) is currently conducting forecasting of fishing ground using satellite data for off-shore/ high seas fishery, providing accurate information on large pelagic fishing grounds considering sea surface temperature and chlorophyll distribution. As illegal, Unreported and Unregulated (IUU) fishing is a serious threat to the long-term economic and environmental sustainability of Sri Lankan oceans, RS techniques exhibit great potential for supporting to develop fisheries monitoring system around Sri Lankan waters which is timely important for control IUU fishing. VIIRS Boat Detection system of NOAA and *Global Fishing Watch* were discussed as the possible systems that can support the future monitoring and management of Sri Lankan marine fisheries sector. This paper summarizes the present RS related applications to the marine fishery sector of Sri Lanka. Further, it also provides guidelines for sustainable management of the sector that can result from RS, and identify existing applications which can effectively support the marine fishery management of the country.

Keywords: Fisheries, *Global Fishing Watch*, Remote Sensing, Sri Lanka, VIIRS Boat Detection

INTRODUCTION

Marine fisheries in Sri Lanka can be categorized into coastal and offshore fisheries. Coastal fisheries contribute about 67% for marine fishery products and has limited capacity for further expansion due to the limited resource (Wijayaratne 2001). Sri Lanka has comparatively narrow continental shelf (5-25 km), which sustains limited habitats for the coastal fishery. Many fish stocks in the costal fisheries sector are in optimal level of exploitation and some stocks have already manifested signs of overexploitation (Wijayaratne 2001). To meet the demands in the local as well as the export market, fishery production is needed to be increased by promoting deep sea fishery sector. Several efforts were made to develop the fishing more towards the offshore areas (Maldeniya 1998). Promotion of deep sea fishery is hampered due to unbearable investments and uncertainty of finding fish resources. Unpredictable catches of highly migratory species such as Yellowfin Tuna for Sri Lankan fishermen, who spend longer time at sea (2-4 weeks) in a fishing trip cause uncertainties in offshore fishing (Rajapaksha et al. 2013). In order to exploit these resources more effectively, fishermen must use state -of-the-art technology such as satellite based fish forecasting system. Therefore, habitats of fish stock in relation to ocean environment condition in the East Indian Ocean are helpful to develop a satellite based fishery forecasting system which is a timely important challenge.

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REMOTE SENSING AND FISHERIES SECTOR OF SRI LANKA

The distribution, abundance and availability of marine fish populations depend on the variations of the conditions in marine environment. Thus, information is required on the "changing ocean," in near real time (NRT) observations rather than the "average ocean" to predict the potential areas of fish aggregation. Remote Sensing (RS) can be successfully applied in fishery research and fishery management by providing synoptic views of ocean environmental variations on abundance and distribution of fish populations. Satellite sensors provide information on water colour, sea surface temperature, chlorophyll, sea surface heights and winds in NRT. NRT information is essential to monitor the parameters since the ocean is dynamic or semi-dynamic in nature. Differences in ocean conditions play a key role in natural variations of fish stocks and in their susceptibility to harvesting (Hela and Laevastu 1962). Fishery forecasting technology has been developed and used by some countries successfully in temperate waters (Kuno et al. 2001). However, those methods are not viable to adopt in the tropics due to different environmental conditions and unavailability of adequate fisheries information on targeted groups in the region. Therefore, there is an essential need to understand the environment and the targeted fish occurrences and their migratory movements for developing a fish forecasting system. During last two decades, commercial fishing in deep oceans becomes an increasingly competitive and economically risky industry. To ensure the profit, it has become necessary to use available technology and scientific knowledge. Therefore, modern fishing operations require timely reliable and accurate meteorological, oceanographic and fisheries information. Since satellite RS is a useful tool that could be employed for planning fisheries and aquaculture development in Sri Lanka, the National Aquatic Resources Research and Development Agency (NARA) is successfully conducting a satellite based fishery forecasting system, providing accurate information on large pelagic fishing grounds, considering chlorophyll distribution and sea surface temperature using satellite imageries. An example of a forecast map showing potential fishing grounds and suitable fishing depths is issued by the NARA on the 25th November 2017 (Fig. 1).

FISHERIES RELATED ECOSYSTEM MANAGEMENT WITH REMOTE SENSING

Hydrological Analysis

RS can provide a comprehensive spatial and/or temporal overview of many water quality parameters that can complement site-specific in situ monitoring, which will ultimately important for the sustainable fisheries. Suspended sediments, dissolved organic matter, algae, and thermal releases all affect the spectral signature of electromagnetic energy leaving a water environment, and as such, these properties can be measured and monitored using RS systems. Time series changes on chlorophyll-a (Chl-a) in economically important estuarine environments around Sri Lanka such as Negombo estuary (Dahanayaka et al. 2012; Dahanayaka et al. 2013), Chilaw lagoon (Dahanayaka et al. 2011), Puttalam lagoon (Dahanayaka et al. 2010) and Bolgoda lake (Dahanayaka et al. 2016) were studied extensively using multi temporal satellite imageries. Fig. 2 shows Chl-a distribution estimated from Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) band 1/2 ratio on respective coastal water environments. Based on these studies, several environmental issues related to coastal waters have been addressed such as localized eutrophication, disturbance of water circulations and sudden fish kills etc. Those studies also highlight the guidelines for sustainable management that can result from RS, and identify existent gaps and research priorities. Findings of the study can be implemented to identify the areas with high risk and corrective actions could be taken at early stage to mitigate the water quality issues to enhance the fisheries activities.

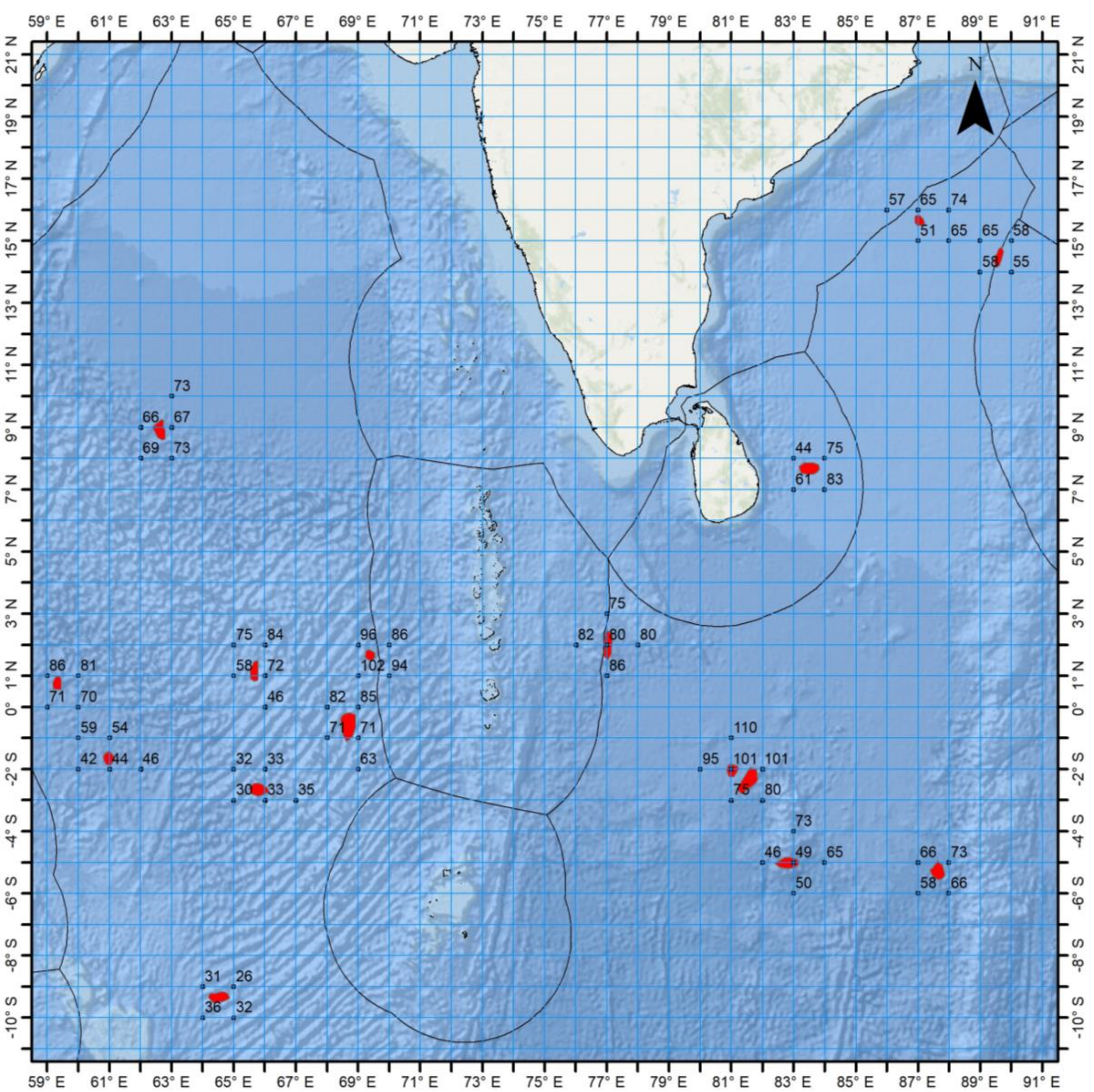

Fig. 1 Forecast map showing potential fishing grounds (red) and suitable fishing depth in meters. The map is issued by the NARA on 25th Nov 2017 (Credit to J.K. Rajapaksha).

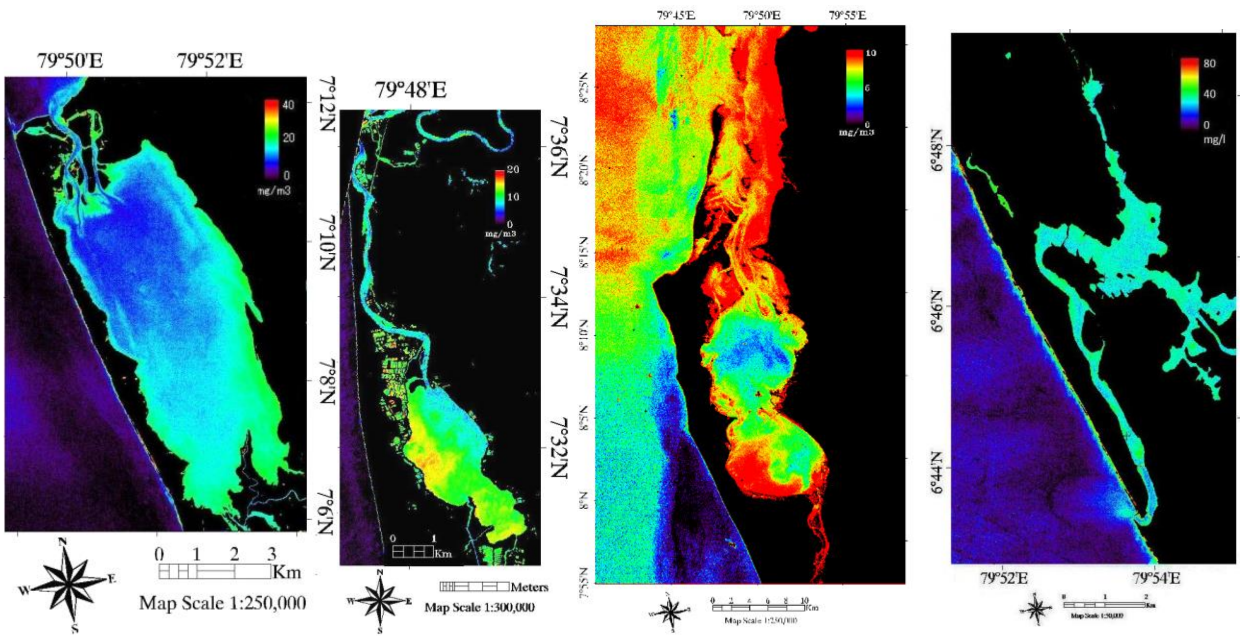

Fig. 2 Maps of selected coastal water environments showing Chl-a distribution resulting from satellite data. From left to right: Negombo Estuary on 16th February 2009; Chilaw Lagoon on 03rd December 2007; Puttalam Lagoon on 31st January 2009; Bolgoda Lake on 10th June 2013 from ASTER VNIR band 1/2 data.

Land use, land cover analysis and mapping

The understanding of regional land use, land cover status and how changes at the local scale within a fishery related ecosystem is important in fisheries monitring programs. This section reviews how RS technologies were used to monitor land use, land cover over time and mapping of the fishery related ecosystems in Sri Lanka.

The Negombo Estuary and the adjoining Muthurajawela marsh were studied using RS, to discover trends in land uses by Rebelo and Nagabhatla (2009). Multi-spectral Landsat satellite imagery was used to monitor changes in the land cover and land use of the wetlands and adjacent land area during 1992 to 2002. The multi temporal images were analyzed and supervised classifier (Maximum Likelihood Algorithm) used as a classification technique. Land use changes in the Pambala–Chilaw lagoon complex was studied using RS and GIS aiming on conservation of mangroves with the expansion of the shrimp farms of the area (Dahdouh-Guebas et al. 2002). Travaglia et al. (1999) also studied, using RS approach, rapid development of the aquaculture industry, especially areas of shrimp farms in the Northwestern Sri Lanka and revealed their adverse impact on surrounding wetland habitats.

Dahanayaka et al. (2012) described three decadal changes of land use and their impacts on the nutrient dynamics of Negombo Estuary using multi temporal satellite data. Results of long term monitoring of the land use changes in the channel segment of the Negombo Estuary carried out using multitemporal, multi satellite data are given in Fig. 3.

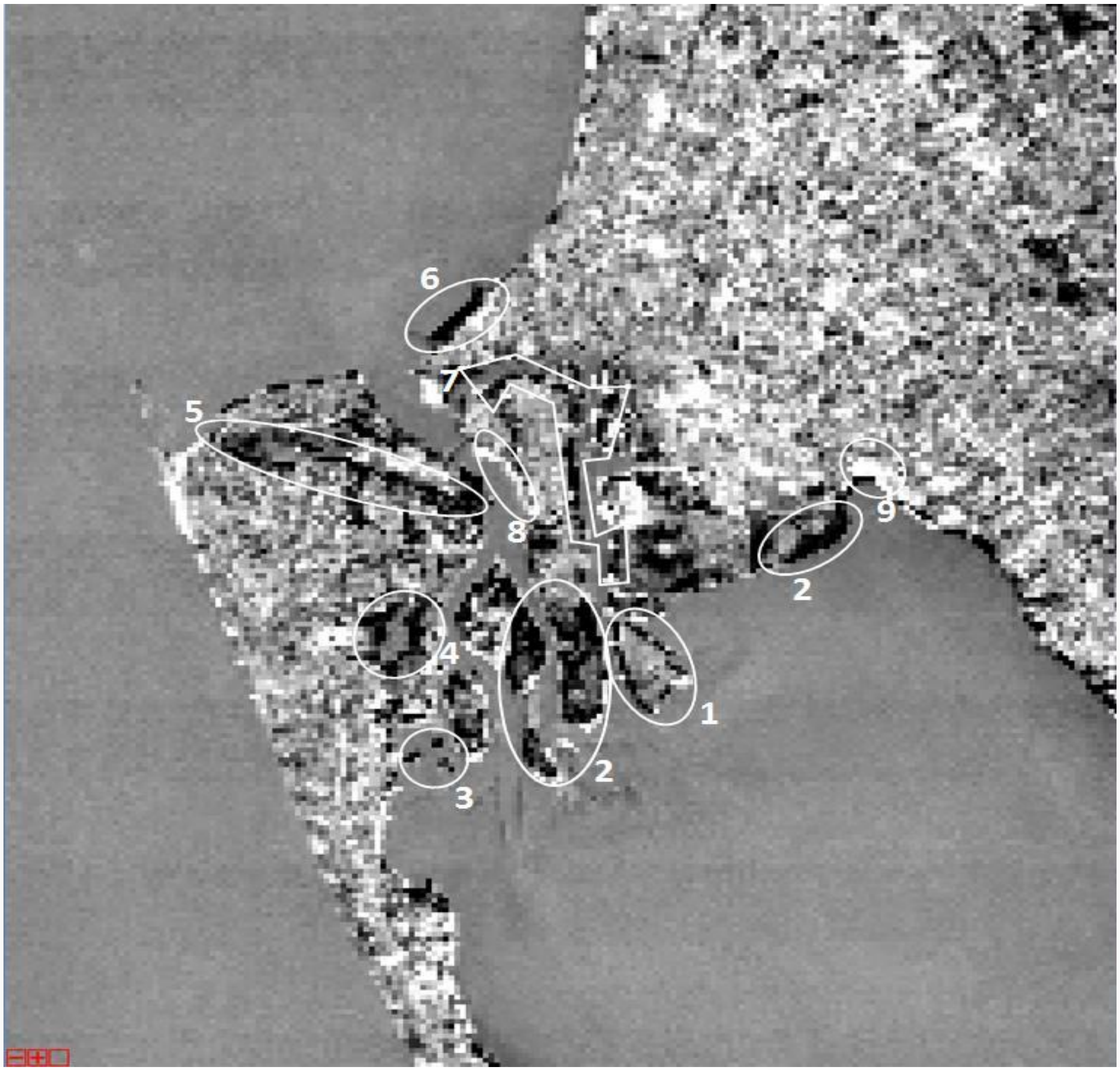

Fig. 3 Two decadal changes of the channel segment of Negombo Estuary (comparison between Landsat TM 19 February 1987 image with ASTER 16 February 2009 image using Multivariate Change Detection Technique); Maximum change areas are given as black and white pixels. Grey pixels shown areas with no change (Dahanayaka et al. 2012). The major causes for the changes in areas 1-9 are as follows: 1. Expansion of the islet area due to mangrove vegetation; 2. Increase density and area of mangrove vegetation; 3. Formation of new islets; 4. Decrease of water area due to increase of land area and vegetation; 5. Narrowing of outlets and decrease of area of Kuda ela; 6. Sand depositions (seasonally change); 7. Narrowing of east channel due to increased land area and vegetation; 8. Soil erosion and vegetation area convert to land; and 9. Vegetation area converts to land.

An attempt was made by Piratheepa and Suthakar (2012) for mapping wetlands in the Jaffna peninsula using high resolution satellite data. GIS and RS were applied to develop maps of selected coral reefs in the southern coast of Sri Lanka. Freely available Landsat7 ETM+ satellite images were used for the mapping and due to the limited resolution of the Landsat imagery, study was confined to large reef areas (Warnasuriya et al. 2014). Dahanayaka and Pahalawattaarachchi (2017) incorporated field observations and high spatial resolution WorldView-2 (WV-2) imagery processing techniques to provide an assessment of shallow coastal marine seagrass beds in Palk Bay, North-Western coast of Sri Lanka. Study concluded that eight-band high resolution multispectral WV-2 satellite imagery has great potential for mapping and monitoring seagrass beds in shallow coastal waters with large-scale coverage. Seagrass distribution map of 0.5 m resolution estimated from WV-2 satellite imagery using the in-situ seagrass data with atmospherically corrected WV-2 satellite imageries is shown in Fig. 4. After image pre-processing, supervised image classifications were performed using maximum likelihood, minimum distance to means, and spectral angle mapper methods to compare relative accuracies in mapping seagrass coverage. The primary results of the study provide useful baseline information that is necessary for marine conservation strategic planning to be incorporated to protect feeding grounds of dugongs and commercially important fish species around the North-Western coast of Sri Lanka.

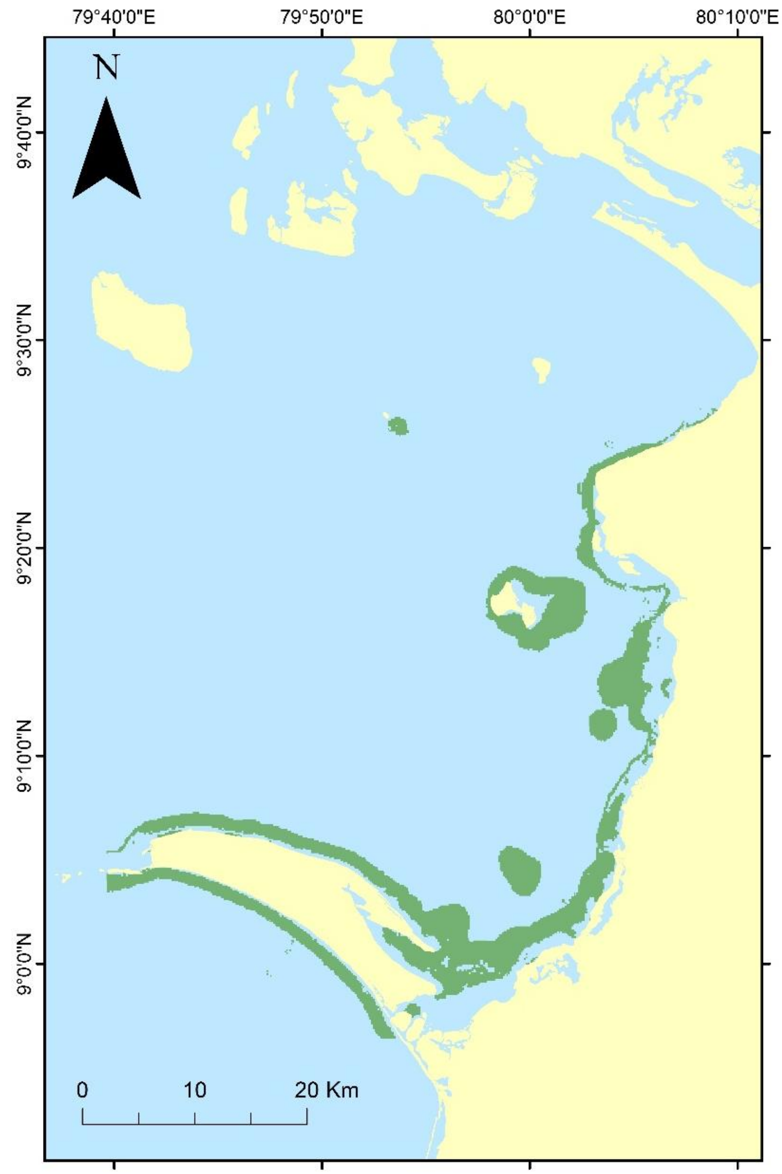

Fig. 4 Seagrass distribution map of Palk Bay derived from the WV-2 satellite data (Dahanayaka and Pahalawattaarachchi 2017)

CONTROL OF IUU FISHING USING REMOTE SENSING

Illegal, Unreported and Unregulated (IUU) fishing around Sri Lankan waters has escalated rapidly as the chance for profit outweighs concerns about the health and sustainability of Sri Lankan marine fisheries sector. Reported incidents of disputes between shrimp trawling fishermen of South India and Northern Sri Lanka are getting increased recently and these encroaches of shrimp and fish resources of Sri Lanka will create severe social and economic issues of the country (Jayakody 2017). Meanwhile, they also affect the bilateral relationships of the two countries. This issue will be more serious in future unless an appropriate fishery monitoring system is established soon in the region. RS techniques exhibit great potential for supporting to develop fisheries monitoring system and VIIRS Boat Detection system of NOAA and *Global Fishing Watch* can be effectively used for the development of such a system to ensure sustainable use of marine fisheries sector of the country.

VIIRS Boat Detection (VBD)

SNPP is the Suomi National Polar Partnership satellite flown by NASA and NOAA. It is the next generation polar orbiting satellite, collecting both daytime and nighttime data worldwide each day. The primary imager on SNPP is the Visible Infrared Imaging Radiometer Suite (VIIRS). At night, the VIIRS day / night band (DNB) collects low light imaging data in the visible images to enable detection of moonlit clouds. In addition to clouds, the DNB detects lights sources present at the earth's surface. This includes the detection of boats, especially those using light to attract fish. The service started in South East Asia and has now been expanded to global (Elvidge et al. 2015). Data on Sri Lankan EEZ added to the system recently on request and VBD will be benefited in future for the management of marine fishery of the country. VIIRS boat detection data are available at http://ngdc.noaa.gov/eog/viirs/download_boat.html. Fig. 5 shows an example of boat detection results of Sri lankan waters on the 14th December 2017.

VBD data for combatting IUU fishing in Sri Lanka

- The daily basis VBD data could be used in future to check proposed marine protected areas of Department of Wildlife Concervation (DWC), Sri Lanka where there should be no fishing or limited fishing activities.
- Boat activity at EEZ lines can be tracked for incrusions.
- Temporal analysis can be identify boats that are stationary. These may be factory boats collecting catch from multiple fishing boats.
- The data can indicate where clusters of boats are present, to target inspections in the ares with high probability of IUU boats.

Limitations of VBD

- VBD detection is based on single sprectral band. Therefore, it is not possible to distinguish different type of lighting based on spectral signatures.
- Data do not provide any information on the ownership of the detected boats.
- It is not possible to track individual boats throughout the time.
- Algorithms performs well under the low lunar illuminance.
- Not all fishing boats are lit enough to be detected.
- The most effective detection case is for boats using lights to attract catch. Other fishing boats may be detected while lighting their decks for safety reasons during operations.
- All the detections do not represent fishing boats. VBD appears to be detecting other types of boats that are well lit, such as pleasure cruise ships or freighters.

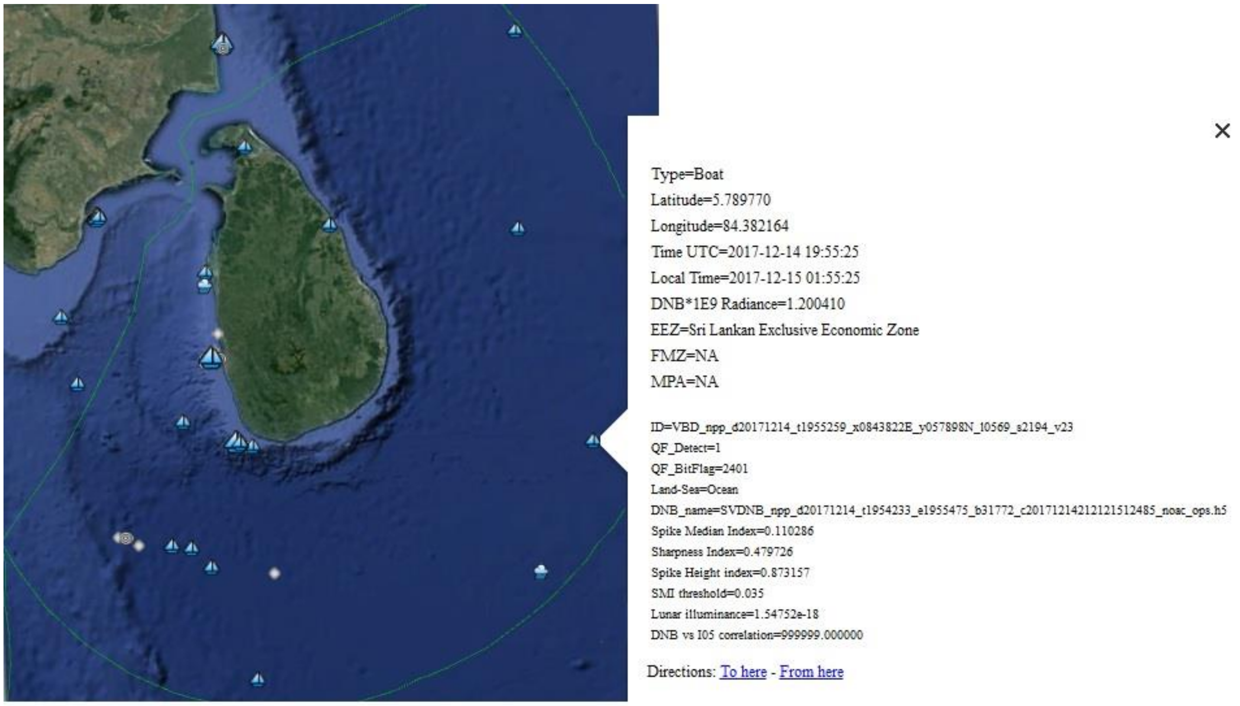

Fig. 5 Boat Detection results of Sri lankan EEZ on the 14th December 2017. Offshore Boats = sailing Ships; near shore boats = anchors; blurry = cloud (Placemarks are size based on radience and have information on Panels)

Global Fishing Watch

Global Fishing Watch is a Vessel Monitoring System (VMS) which analyzes data from the Automatic Identification System (AIS). Data collected by satellites and terrestrial receivers are used to identify apparent fishing behaviour based on the movement of vessels over time and it is the first effective tool to track commercial fishing around the world. It enables anyone with an internet connection to see fishing activity anywhere in the ocean in near real time for free. The system can help put an end to the massive overfishing that is decimating fisheries everywhere and can help authorities protect precious marine ecosystems. Observed fishing patterns and activity determined by *Global Fishing Watch* are based on vessel position, course and speed as derived from AIS broadcasts. It provides tools for governments, fishery management organizations, scientists, private industry and NGOs to implement rules and regulations that will ensure a sustainable fishery. *Global Fishing Watch* will be able to take advantage of any improvements that make to satellites, data, Application Programming Interfaces (APIs), and analytics offerings, which means they have an immediate impact on efforts to improve the sustainability of fisheries and protect an important resource that feeds millions of people. Recently, *Global Fishing Watch* supported by Nano-satellite technology and that doubled their resolution and identify and track nearly 60,000 commercial fishing vessels on the world's oceans. Hence, *Global Fishing Watch* take advantage of the latest space-based earth monitoring technology and increase the power of platform to create transparency in the oceans. The technology can support to control overfishing, illegal fishing and habitat destruction in Sri Lankan marine waters. Further, it can be used to monitor and track changes in fishing pressure in areas of special biological or commercial interest or vulnerability.

Global Fishing Watch could also be used as a supplementary tool that allows the Sri Lankan Government, especially with limited resources, to monitor the extent and nature of fishing in our national waters. It will enable to enforce fishing restrictions such as trawling bans and no-take zones or use *Global Fishing Watch* to assess the characteristics of the vessels to help enforce areas set aside for small-scale or local fishermen. In addition, it will allow governments requiring AIS to track and assess the behaviour of vessels registered in Sri Lanka. *Global Fishing Watch* could enhance the ability of the country to block imports of fish from vessels flagged in countries that fail to enforce fishery laws. *Global Fishing Watch* data are available at http://globalfishingwatch.org/. The tracking results of the selected vessel and informations of the vessel can be obtained with popup panels (Fig. 6).

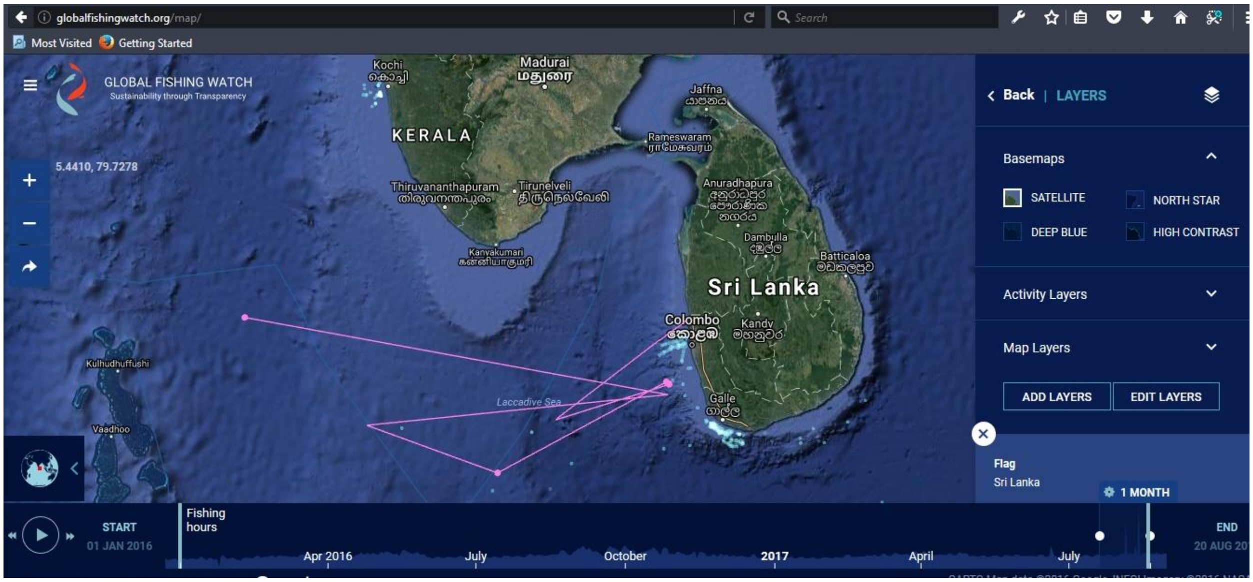

Fig. 6 Snap shot of tracking results of the selected vessel around Sri Lanka (http://globalfishingwatch.org/)

Global Fishing Watch for combatting IUU fishing in Sri Lanka

- Identifying vessels that may be fishing illegally or fishing without a license
- Identifying vessels that may be fishing in ways that involve under-reporting or false reporting of catches
- Measuring and tracking apparent fishing activity
- Identifying places where large numbers of vessels gather and may be breaking the rules, therefore indicating ocean areas where increased NAVY and other enforcement patrolling are needed
- Monitoring the current activities of “blacklisted” vessels previously identified by governments or NGOs as engaged in illegal or suspicious fishing activity.

Limitations of Global Fishing Watch

Publicly broadcast AIS messages received by satellites and ground-based receivers comprise the largest source of data in the *Global Fishing Watch* platform, but gaps in AIS signals can occur in areas where satellite coverage is sparse, or between satellite passes.

DISCUSSION AND CONCLUSION

Marine fisheries production is an important contributor to Sri Lankan economy and had become an important food source, livelihood development, employment and foreign exchange of the country. As a growing requirement of the sector, RS coupled with a GIS is a promising way to develop and expand the sector with a sustainable nature. The satellite RS provides valuable information which is useful in the management of fisheries, fishery ground selection and expansion and assessment, monitoring of fisheries related ecosystems. Four decades of RS data from different satellites offer sufficient opportunities to establish standards for many environmental issues related to the sector. The information, which is thus derived, can be precious in the fisheries management and significantly vital for the development, sustainable use and conservation and management of the fishery resources. Mapping and monitoring of fisheries related ecosystems such as wetlands including coastal ecosystems with their ecosystem services will provide essential understanding of the inter-related ecological and socio-economic factors that influenced the sector. Those factors will help identifying the interrelationships within the various components that encompass the marine fisheries and that support to development of livelihoods. Continuous monitoring of fishery resources will be a valuable candidate for the widespread use of RS data and technologies to safeguard that conservation strategies are being effectively implemented. These are vital in the essence of sustainable development and management, mainly in developing countries such as Sri Lanka, which are frequently susceptible to environmental degradation. Thus, RS combined with GIS technologies can be widely used today in the fisheries and aquaculture management in Sri Lanka and also imperative to collect and integrate data from different disciplines of the sector. However, the level of these technologies that is being used falls far short of their potential, with a range of technical and financial reasons, which are the likely the causes of the deficit of Sri Lanka. The main limitation of some of the new RS technologies such as high-resolution satellite data is their commercial nature, and the comparatively high prices charged prevent the Sri Lankan scientific community to access RS data. Therefore, most of the RS studies related to fisheries and aquaculture management in Sri Lanka were confined to freely available medium resolution satellite data with low accuracy rate. Even though, based on this type of RS research, there is a great potential to provide management guidelines for immediate action, or to construct a long-term management strategy to sustainable management of fisheries sector in Sri Lanka. Less expensive and easier to deploy and update than traditional satellites, nano-satellites are becoming increasingly important tools for fisheries research and management around the globe and hopefully will play major role in conservation of marine fisheries sector of Sri Lanka in near future. Further, satellite data can be used to empower and propel forward a new era of spatially ambitious marine governance and research in Sri Lanka. By helping to manage fisheries more sustainably, spatial data will help bring back fishery abundance, protecting and enhancing the livelihoods of the people of Sri Lanka, who depend on ocean fisheries for food and income.

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