OCEANOGRAPHY DETERMINANTS OF THE OCCURRENCE OF DOLPHINS AND WHALES IN SOUTHERN SRI LANKA

P.L.N.Lakmali [*] ***and D.D.G.L. Dahanayaka***

Department of Zoology, Faculty of Natural Sciences,

The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka

Sri Lanka occupies a unique location within the equatorial belt in the Northern Indian Ocean. The southern waters of Sri Lanka is biologically abundant in cetacean species such as whales and dolphins due to the deep waters found quite close to the southern shore. The presence of cetaceans have been influenced by certain oceanographic conditions. The oceanographic determinants such as the Sea Surface Temperature (SST) and Chlorophyll-a (CHL-A) concentration, which could influence the richness and distribution of cetacean species in the southern coastal area of Sri Lanka, were investigated and their relationships were studied in the present study.

The SST and CHL-A concentration were obtained from satellite data from the Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) NASA Level-3 (L3). Numerical simulations were made using MODIS/Aqua to investigate the coastal upwelling of the area.

The major upwelling region is located along the southern coast, in both the Northwest and Northeast monsoon periods, resulting from the southward flow converging along the southern coast. However, higher surface chlorophyll concentrations were observed during the Southwest monsoon. The region of the flow convergence and hence, the upwelling centre was dependent on the relative strengths of wind-driven flow along southern and western coasts. The elevated CHL-A concentrations persisted for several subsequent months and was attributed to coastal upwelling. In such situations, the nutrient availability of the Southern offshore is high during the Southwest monsoon. Therefore, the abundance of the cetaceans in the southern waters is high during the Southwest monsoon period and thus, directly correlates with the availability of nutrients.

The study has opened a space for oceanographic determinants for whale and dolphin forecasting, and it could assist the sector in the scheduling of whale and dolphin watching operations to minimize the cost while bringing high economic gain to the country.
Keywords: Chlorophyll-a concentration , MODIS, satellite data, Sea Surface Temperature,

*Corresponding Author: *lakshijayarathne1113@gmail.com*

OCEANOGRAPHY DETERMINANTS OF THE OCCURRENCE OF DOLPHINS AND WHALES IN SOUTHERN SRI LANKA

P.L.N.Lakmali [*] ***and D.D.G.L. Dahanayaka***

Department of Zoology, Faculty of Natural Sciences,

The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka

INTRODUCTION

Sri Lanka is located between the latitudes 5.55 N and 9.51 N, and the longitudes 79.41 E and 81.53E. It lies near the equatorial belt in the Northern Indian Ocean (NIO) and has a comparatively narrow continental shelf (5-25 km). Travelers and historians have documented cetaceans like whales and dolphins in the waters around the island as far back as the 14th century. The Southern coastal area of Sri Lanka has some of the best hotspots from which to observe whales and dolphins in their natural habitat (Abeysinghe & Dahanayaka, 2021). Most involved in the Sri Lankan whale and dolphin-watching industry usually spend lengthy durations at sea, in a single trip, looking for these mammals. The occurrence and abundance of whales and dolphins directly relates to the seasonal upwelling. Along the uplifting slope, the cooler water of the sea bottom rises up to make the upper high nutrient water layer. This condition has highly affected the ocean food web. The periodical heating and cooling of the continental land mass and the ocean result in the southwest and northeast monsoon winds. Throughout the southwest monsoon, higher growth of phytoplankton (CHL-A concentration > 5mgm^{-3}) has been recorded in the southern offshore of Sri Lanka (Vinayachandran et al., 2004). Upwelling regions are cooler and have a high density of Chlorophyll-a (CHL-A). The high abundance and occurrence of whales and dolphins could be observed in these regions (de Voz, 2014). Those two variables were correlated to each other to satisfy the upwelling phenomena. Variations in marine environmental conditions affect the distribution, abundance, and availability of marine mammal populations. Remote Sensing (RS) plays an important role in marine mammal research and management by providing synoptic views of the ocean's environmental effects on the abundance and availability of populations (Bestley, 2020). Satellite sensors provide information on water colour and temperature, chlorophyll, Sea Surface Heights (SSH), and winds in NRT.

METHODOLOGY

There were two major types of data that were used: Satellite remotely sensed oceanographic data and data related to the occurrences of whales and dolphins in relation to time and location. The MODIS satellite sensor was well suited for investigating and monitoring the ocean surface properties for real-time applications. It offered the combined advantage of large spatial coverage, high spectral resolution, and frequent repeatability of coverage at short intervals. Analysis System (SeaDAS) software was developed by the NASA OCEAN Biology Processing Group (OBPG) for the processing, display, analysis, and quality control of remote sensing Earth data. The MODIS provided SST and CHL-A concentrations with 4 km spatial resolution. The SST and CHL-A are relevant to the occurrences of whales and dolphins because of the temperature preferences of individual marine mammal species. MODIS data products helped to improve the understanding of productivity and circulation, and their seasonal changes, which control the marine mammal habitats and migration patterns. SST and CHL-A concentrations were processed and analysed between the latitude of 5 and 5.9°N and longitude of 79.5 and 80.5°E. Oceanography data from MODIS has been used to make maps and estimate the SST and CHL-A concentrations. The analysis of SST and CHL-A concentrations in the study area in southern Sri Lankan waters was based on MODISAQUA L3 monthly data products during years the from 2019 to2021. The monthly mean SST and CHL-A concentrations were tabulated by averaging all the data

from January to December from 2019 to 2021 to characterize the SST and CHL-A distribution in the study area in Southern Sri Lanka.

RESULTS

Distribution of the Sea Surface Temperature (SST) and CHL-A concentration (2019-2021)

The results of the monthly SST analysis of the year 2019 using MODIS AQUA data found that the lowest mean SST detected was recorded in January, with a mean temperature of 28.37°C. The lowest mean SST value of years of 2020 and 2021 were analysed using MODIS Aqua data that was recorded in the month of August as 27.57°C and 27.63°C, respectively.The highest mean CHL-A concentration value for the year 2019 was analysed using MODIS Aqua data that was recorded in the month of May as 0.92mgm^{-3}. For te year 2020, the highest mean CHL-A concentration was recorded in the month of August as 7.14mgm^{-3}**.** The results of the monthly CHL-A concentration analysis for the year 2021, using MODIS Aqua data, found that the highest mean CHL-A concentration detected was recorded in October with a mean CHL-A concentration of 3.74mgm^{-3}.

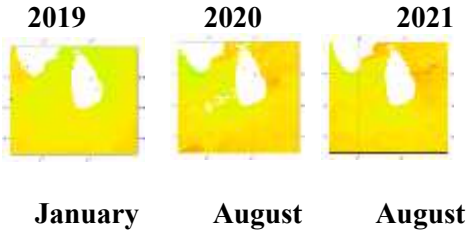

Figure1: The lowest monthly composites of SST maps for 2019-2021.

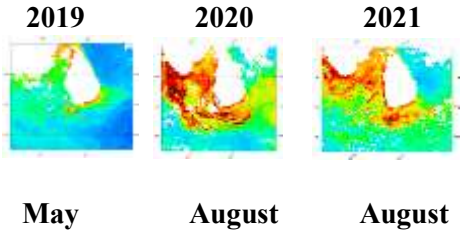

Figure 2: The highest monthly composites of CHL-A concentration maps for 2019 -2021.

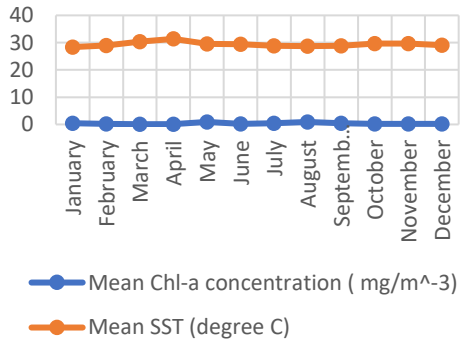

Figure 3: Variations of the mean SST and mean CHL-A (January-December 2019) derived from MODIS satellite

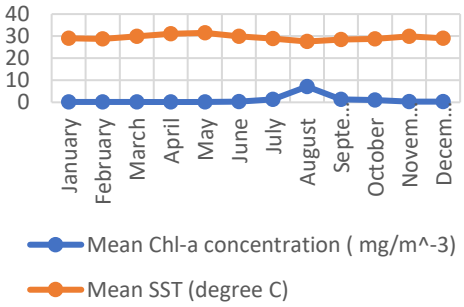

Figure 4: Variations of the mean SST and mean CHL-A (January-December 2020) derived from MODIS satellite data.

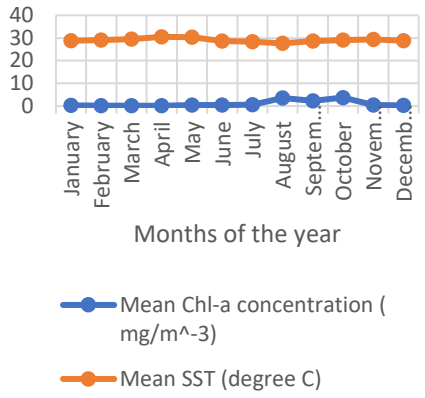

Figure 5: Variations of the mean SST and mean CHL-A (January-December 2021) derived from MODIS satellite data.

Species Diversity and relative abundance

During the study period, marine mammal data related to their occurrences was not collected as planned due to the prevailing conditions of the country including the implications of the economic crisis. Therefore, this study relies on the data collected from researchers and other institutes. The relevant data on marine mammals was extracted from published information. Blue whales should occur in the area of high productivity from about June to October or November and be absent or rare when productivity is low during the NEM season in the southern off shore (Anderson et al., 2012).

Date	Time at start of encounter (UTC)	Location of sightings	Bearing	Range (m)	Number of individuals	Water depth (m)	Certainty
12 July 2017	10:55 11:24	5°43.92'N, 80°03.84'E 5°38.92'N, 80°08.93'E	170 200	2,000 1,500	1 1	2,730 3,205	Probable Probable
13 July 2017	2:08 2:22	5°40.68'N, 80°50.69'E 5°38.80'N, 80°50.69'E	225 210	2,000 2,000	1 1	2,253 2,424	Probable Definite
22 July 2017	2:00 3:40 4:25	5°52.18'N, 81°03.27'E 5°52.07'N, 81°00.67'E 5°53.41'N, 80°59.05'E	240 280 120	2,000 2,500 3,000	2 1 2	524 608 84	Definite Probable Definite
25 July 2017	11:53 11:55	4°16.27'N, 81°00.76'E 4°16.27'N, 81°00.76'E	10 12	4,000 4,000	2 2	4,300 4,300	Probable Probable

		5°49.16'N, 81°01.49'E					
26 July 2017	11:18	5°52.65'N, 81°01.49'E	60	2,000	3	372	Probable
	11:25		300	4,000	2	372	Probable
	11:30	5°52.65'N, 81°01.49'E	270	4,000	2	372	Probable
	11:43		325	2,000	1	372	Definite
	12:40	5°52.65'N, 81°01.49'E	210	2,000	1	372	Definite
31 July 2017	9:15	5°52.73'N, 81°00.33'E 5°58.46'N, 81°27.87'E	300	1,000	1	367	Probable
14 August 2017	6:55	6°14.33'N, 81°55.82'E 6°14.33'N, 81°55.82'E 6°17.18'N, 81°55.82'E 6°16.46'N, 81°53.44'E	270	1,500	1	3,678	Probable
	6:58		240	4,000	1	3,678	Probable
	7:15	6°16.46'N, 81°53.44'E	300	1,500	1	2,189	Probable
	7:25		255	2,000	1	1,400	Probable
	7:27	6°16.46'N, 81°53.44'E	240	3,500	2	1,400	Definite
	7:28		210	2,000	1	1,400	Definite
	7:30	6°17.18'N, 81°55.82'E	160	300	1	2,189	Definite
	7:35		165	400	1	2,189	Definite
	7:36	6°17.18'N, 81°55.82'E	170	150	1	2,189	Definite
	7:36		330	700	1	2,189	Definite
	8:29	6°17.18'N, 81°55.82'E	105	1,000	1	3,288	Definite
	8:35		175	4,000	1	3,288	Probable
	8:59	6°17.18'N, 81°55.82'E 6°05.98'N, 81°46.52'E 6°05.98'N, 81°46.52'E 6°02.21'N, 81°46.52'E	295	2,500	1	3,170	Probable
Total		28 sightings			37	Ave. 1960.8	

Table 1: Blue whale sightings recorded throughout the scientific geophysical survey in the south of Sri Lanka during the southwest monsoon season, July–August 2017.

Month	Jan	Feb	Mar	Apr	May	Sep	Oct	Nov	Dec
No.of whales	32	71	46	66	2	37	17	28	19

Table 2: No. of blue whales recorded during the year 2019 (NARA, 2019).

DISCUSSION

The spatial and temporal variability of oceanographic determinants of the marine waters of Sri Lanka, including the CHL-A concentration and SST, were analysed in the present study using the satellite RS approach. MODIS AQUA data between 2019 and 2021 was used as the RS data source while, further, the study focused on determining the influence of the SW and NEM on these parameters. Possible upwelling periods around the southern coast of Sri Lanka were also studied. Ocean colour imageries were used to determine the CHL-A as an indicator of biological production.

Distribution, abundance, and availability of marine mammal populations also depend on the variations of the CHL-A and SST in marine environment. Thus, information is required on the "changing ocean," on near real time (NRT) observations rather than the "average ocean" to predict the potential areas of marine mammal aggregation. RS data can be successfully applied in marine mammal research and management by providing synoptic views of ocean environmental variations on the abundance and distribution of marine mammal populations, which was targeted by the present study.

The oceanographic conditions that could influence the richness and distribution of whales and dolphins in the southern coastal area of Sri Lanka were investigated to a considerable extent throughout this research. It is clearly concluded that prominent upwelling was detected during August in 2020 and 2021. High productivity waters with the highest mean CHL-A concentrations, along the southern region during the months August to October, were accompanied by the lowest SST corresponding to regions where high CHL-A concentration were detected. Moreover, the CHL-A concentration in the month of August indicate the relationship between the lowest SST, which influence the occurrence of upwelling. MODIS imagery data indicate the strong relationship between higher CHL-A concentration and cooler SST, which influenced the upwelling and causes the occurrence of Whales and Dolphins in the study area. During SWM, there are different distinct high Chlorophyll patches in the south coast. The variations detected in the CHL-A matched with the thermal features of the SST maps. Cooler temperatures indicate nutrient-rich waters, and these areas are high biological production areas. The high abundance of Whales and Dolphins in the southern coastal area might be due to the narrow continental shelf and steep continental slope, which are associated with upwelling. As shown in Table 2, Blue whale sightings could be observed from January to December except in the months of June, July, and August, which are the months which are SWM occurring periods. However, thirty-seven Blue whale sightings were obtained in seven days in

July to August in 2017, which belongs to the SWM period (Table 1). Usually, the whales and dolphins aggregate in the places where high nutrient content is available. As per the previous surveys, whale watchers# data shows the NEM period as the peak season for observing these mammals. According to this study, the high nutrient availability in the Southern coast during SWM was observed. Nevertheless, there was a lack of marine mammal data during the SWM period.

CONCLUSION

This study attempts the long-term monitoring of ocean status, and its relation to the whales and dolphin occurrences and the monsoon effects on them. It is improper to mention the NEM period as the peak season for whale and dolphin aggregation in Southern offshore due to consequences of rough sea conditions lead by strong Southwest winds. According to this survey, the SWM period correlates with high abundance and diversity of cetaceans, and the high nutrients availability in the southern coast.This data represent an important contribution to the pool of limited observations of cetaceans during this period of the years. There was no fully or never developed forecasting system on marine mammals in Sri Lanka, especially in relation to the oceanographic determinants. Therefore, capacity building in the application of technology and methodology development is an essential need to cope with the world trend. Whales and dolphin forecasting will assist the sector in the scheduling of whale/ dolphin watching operations to minimize the cost and bring high economic gain.

ACKNOWLEDGMENT

The authors acknowledge with gratitude, Department of Zoology, Faculty of Natural Sciences, The Open University of Sri Lanka.

REFERENCES

1.Abeysinghe, J S & D D G L Dahanayaka. (2021). Development of Marine Mammal Stranding and Mortality Database Using GIS as a Forensic Tool. *WILDLANKA,* Vol. 9, No. 3, pp. 340-360.

2. Andersen, R. C., Branch, T. A., Alagiyawadu, A., Baldwin, R., & Marsac, F. (2023). Seasonal distribution, movements and taxonomic status of blue whales (Balaenoptera musculus) in the northern Indian Ocean. *J. Cetacean Res. Manage.*, *12*(2), 203–218. https://doi.org/10.47536/jcrm.v12i2.578

3.Bestley, S., Ropert-Coudert, Y., Bengtson Nash, S., Brooks, C. M., Cotté, C., Dewar, M., Friedlaender, A. S., Jackson, J. A., Labrousse, S., Lowther, A. D., McMahon, C. R., Phillips, R. A., Pistorius, P., Puskic, P. S., Reis, A. O. D. A., Reisinger, R. R., Santos, M., Tarszisz, E., Tixier, P., … Wienecke, B. (2020). Marine Ecosystem Assessment for the Southern Ocean: Birds and Marine Mammals in a Changing Climate. *Frontiers in Ecology and Evolution*, *8*, 566936. https://doi.org/10.3389/fevo.2020.566936

4. De Vos, A., Pattiaratchi, C. B., & Wijeratne, E. M. S. (2014). Surface circulation and upwelling patterns around Sri Lanka. *Biogeosciences*, *11*(20), 5909–5930. https://doi.org/10.5194/bg-11-5909-2014

5. Minton, G., Reeves, R., Collins, T., & Willson, A. (n.d.). *Report on the Arabian Sea Humpback Whale Workshop: Developing a collaborative research and conservation strategy*.

6. Performance Report, National Aquatic Resources Research and Development Agency (2019). 49-52.

7. Russell, G., Bridge, M., & Nimak-Wood, M. (2020). Blue whales off the Southern coast of Sri Lanka during the Southwest Monsoon Season. *IWC Journal of Cetacean Research and Management*, *21*(1), 1–7. https://doi.org/10.47536/jcrm.v21i1.189

8. Vinayachandran, P. N. (2004). Biological response of the sea around Sri Lanka to summer monsoon. *Geophysical Research Letters*, *31*(1), L01302. https://doi.org/10.1029/2003GL018533

9.Wright, D J & D J Barlett (Eds). (1999). *Marine and coastal geographical information systems*. CRC press.