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Discrete generation cycles in the tropical moth *Opisina arenosella*

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Insect populations with discrete generation cycles (DGCs), have been rarely encountered in the tropics. Among the few known species, spatially segregated coastal populations of *Opisina arenosella*, the coconut caterpillar, have been shown to follow DGCs during outbreaks in Sri Lanka. Climatic parameters are known to be important in regulating generation cycles in insect populations. But, unlike temperate conditions, the tropics are characterized by high spatial heterogeneity in climate, which prompted the present investigation on generation cycles of populations of *O. arenosella* occurring in interior dry landscapes of the Indian peninsula. Two spatially isolated populations were regularly sampled for two years and data were subjected to time series analysis to determine periodicity, if any, in the occurrence of different developmental stages of the population. Results showed that populations followed DGC with a periodicity of approximately one generation, and further, correlations showed that there was a definite lead/lag in the peaks of different developmental stages, which closely correspond to the developmental period of different stages of the insect. The findings suggest that discrete cycles of *O. arenosella* may not be related to seasonality. The importance of generation cycles with respect to pest management has also been discussed.

Keywords: Coconut black-headed caterpillar, generation cycles, host-parasitoid dynamics, insect seasonality.

INSECT populations are known to either cycle with a period of approximately one generation (discrete or non-overlapping generation cycles, DGCs) or all age-classes of the population can occur simultaneously (continuous or overlapping generation cycles). DGCs are common in temperate environments characterized by extensive winters, where populations hibernate through the winter months in a particular developmental stage – as egg, larva or pupa. In other words, winter conditions 'select' a particular developmental stage, which creates uniformity in the surviving population with respect to age, causing the subsequent spring populations or summer populations to follow 'discrete' cycles. In the tropics, however, it is generally believed that lack of such 'selection' can lead to continuous generation cycles in insect populations. Interestingly, certain multivoltine tropical insect species that are active throughout the year are also known to follow DGC. Godfray and Hassell[1] have listed several such species. In India, only *Andraca bipunctata* (Lepidoptera, Bombycidae) has been speculated to be following DGC[1,2].

Populations of *Opisina arenosella* Walker (Lepidoptera, Oecophoridae), commonly called the 'coconut black-headed caterpillar', have been shown to follow partially DGC during outbreaks in Sri Lanka[3]. This species is the major leaf-feeding pest of coconut palms in the entire Indian subcontinent. Surprisingly, earlier studies from India do not refer to generation cycles[4]. *O. arenosella* breeds all year round on coconut palms without undergoing diapause. Although the species infests coconut groves almost throughout peninsular India, it has never been found to occur as a large contiguous population in coconut-growing areas. Infested areas are always interspersed with un-infested ones, suggesting the existence of spatially segregated populations. In India, such populations are distributed over different agro-climatic zones – from high-rainfall coasts[5] to interior dry landscapes[6], which considerably vary from the coastal climate of western Sri Lanka from where an earlier study concluded that the species followed DGCs. Unlike temperate situations, the high spatial heterogeneity of climatic parameters in the tropics would expose different populations of *O. arenosella* to different climatic conditions. These could, directly[7] or indirectly (through their influence on natural enemies)[8], have a differential influence on generation cycles of different populations. Such variation is well illustrated by gypsy moth (*Lymantria dispar*) populations, where the oscillations in periodicity of populations separated by distances of over 1000 km have been shown to be asynchronous[9]. A study was therefore carried out to determine generation cycles with particular reference

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*For correspondence. (e-mail: yb@iwst.res.in) to two populations of *O. arenosella* in dry agro-climatic zones of peninsular India.

O. arenosella typically has four stages in its life-cycle – egg, larva, pupa and adult. Eggs are laid in small batches among the larval frass of the previous generation. They hatch in about 7 or 8 days into larvae that pass through seven instars in case of males, and eight instars in case of females, in 33 to 39 days before metamorphosing to pupae. Moths emerge from pupae in about ten days; the total life cycle thus is completed in approximately 55 to 59 days[10]. Larvae stay within galleries constructed out of their own faecal pellets and silk while feeding on the leaflets and pupate there. The life cycle is generally prolonged during winters and shortened during summer months. Adults live for approximately a week and a female lays about 80% of her ~200 eggs within two nights after emergence[11].

In order to determine generation cycles, two spatially segregated populations of *O. arenosella* were sampled for two years (July 1999 to July 2001). The first population was sampled from a coconut garden at Srirampura village, Bangalore North, while the second population was from Tittamaranahalli village, Channapatna taluk, Bangalore rural district. Both places are situated in the interior plains of the peninsula and fall in the low-rainfall zone. The selected garden at Srirampura had 125 palms aged between 15 and 20 years. It was situated near the Srirampura Lake and isolated from other gardens by a distance of over 100 m in all directions. The garden at Tittamaranahalli was part of a ~100 acre stretch along the banks of the Kanva River. This garden was a multi-aged stand (15 to 40 years) of over 2000 palms. Both gardens had a history of harbouring *O. arenosella* population for 3 months before the sampling began, which corresponded to approximately 1.5 generations. The age-structure and population density of *O. arenosella* was recorded from both gardens through fortnightly sampling. [Insects like *O. arenosella* have three development stages (egg, larva and pupa) followed by a reproductive stage (moth). In this study the development stages were sampled. As each larva lasts for ~35 days and as pupae are available in the field for more than 15 days in a generation, generation cycles, if any, could be detected at the larval and pupal stage by drawing fortnightly samples. In order to cover the egg stage, which is available for a short period in the field, it would be necessary to increase the sampling effort by almost three times, which is logistically demanding. Moreover, as periodicity indicated in larval and pupal stages would obviously entail existence of periodicity in the egg stage also fortnightly samples were expected to satisfactorily answer the question on whether populations of *O. arenosella* followed discrete generation cycles.] During each sampling, ten palms were randomly selected and twenty leaflets showing approximately 50% damage were picked from each of the ten palms at both the locations. Every leaflet was labelled and examined under a stereo-binocular microscope for the number of different stages of the population (eggs, larvae and pupae). Based on growth, larvae were classified into three groups – small, medium and large. The 'small' group constituted of larvae in 1 to 3 instars (<4 mm in length), the 'medium' group had larvae in 4–6 instars (4–11 mm in length), while larvae in 7 or 8 instars (>11 mm in length) were categorized under 'large' group.

Figure 1 *a* shows that populations at Srirampura and Tittamaranahalli were characterized by distinct periods when eggs and pupae were not available, which is a pattern that is usually consistent with populations following DGC (a population with overlapping or continuous generations was most likely to have eggs and pupae available throughout the sampling period). If beginning of a generation was marked by the presence of eggs and the end by the presence of pupae, then ten generations over a period of two years could be easily demarcated at both locations. Larval population also had distinct peaks, although the population appeared to be available throughout the sampling period. This, probably, was because the sampling interval of 15 days was not able to demarcate the overlap that the larval populations had with eggs at one end and pupae at the other. Interestingly, there were distinct peaks for small, medium and large larvae, which followed the same order within each generation (Figure 1 *b*). The above pattern remained same at both locations suggesting that the populations were, perhaps, following DGC. A time series analysis was carried out to determine if there was periodicity in the appearance of different stages of the populations. First, Fourier analysis was carried out to determine periodicity in the time series. Periodicity is reflected in a Fourier spectrum by a sharp peak in the amplitude of a time series for that particular period. The spectra for populations at Srirampura (Figure 2 *a*) and Tittamaranahalli (Figure 2 *b*) showed a distinct peak for both larvae and pupae, indicating that there was periodicity in the appearance of the stages. The peak at Srirampura was at ~75 days, while at Tittamaranahalli the peak was at ~65 days for both larvae and pupae; no definite peak was noticeable for eggs at both locations. The discrepancy between locations with respect to time when the peak appeared was <15 days, which is within one sampling interval, and such oscillations of the peaks within a sampling interval are possible. Eggs were available for a short period of time within each generation, which meant that a sampling interval of once every 15 days was not able to capture the periodicity in eggs. However, the definite periodicity in the appearance of larvae and pupae clearly suggested that the populations of *O. arenosella* under study followed DGC. Total life cycle of *O. arenosella* takes ~60 days, which approximates the periodicity shown by Fourier spectra.

As the spectra suggested periodicity, a time lag was expected between appearances of peaks in different stages of the population. This was tested by lead/lag correlations between different developmental stages of *O. arenosella*. The expected lead/lag between the stages depended on the time taken for the development of the stages. As moths

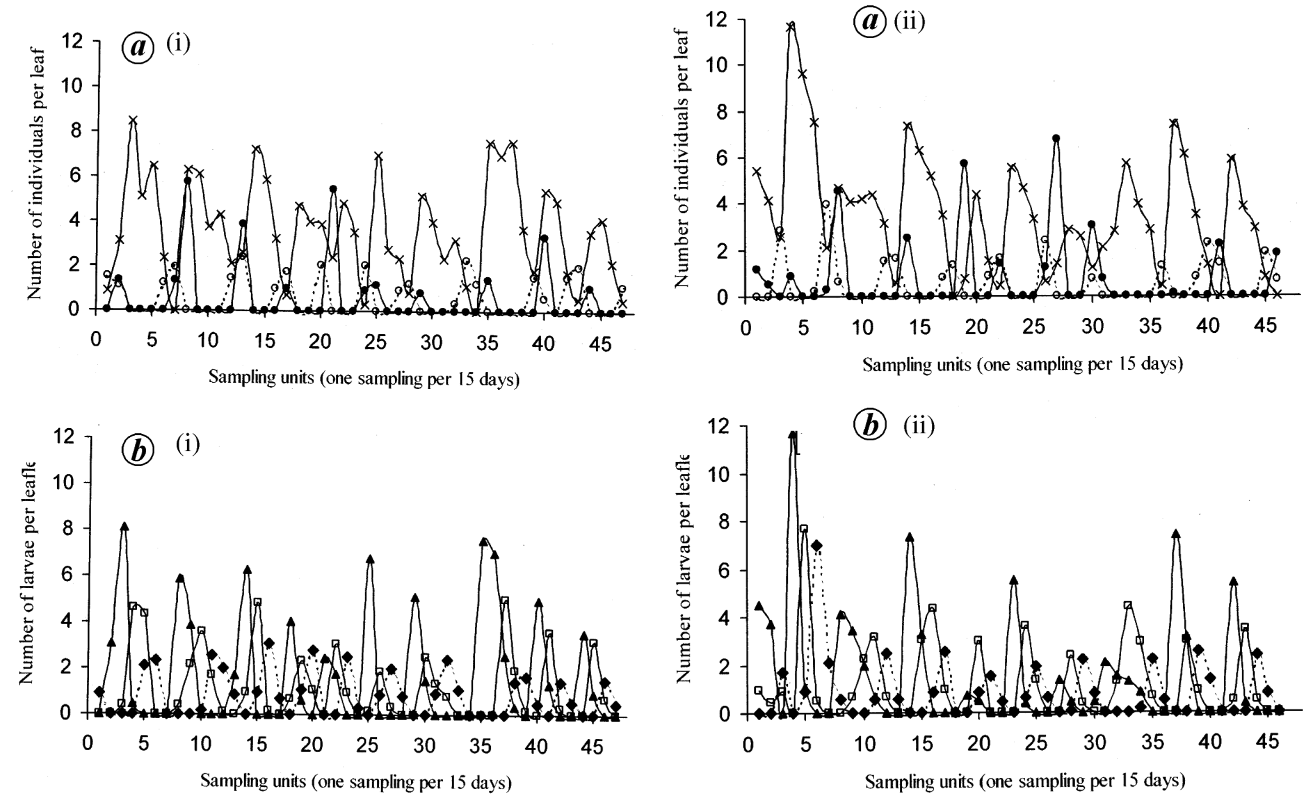

Figure 1. Population dynamics of different developmental stages of *Opisina arenosella* (***a***) eggs (●), total larvae (x) and pupae (○); and (***b***) small (▲), medium (□) and large (◆) sized larvae at (i) Srirampura and (ii) Tittamaranahalli. Data were obtained from samples of 200 infested coconut leaflets drawn at 15-day intervals for two years starting from July 1999.

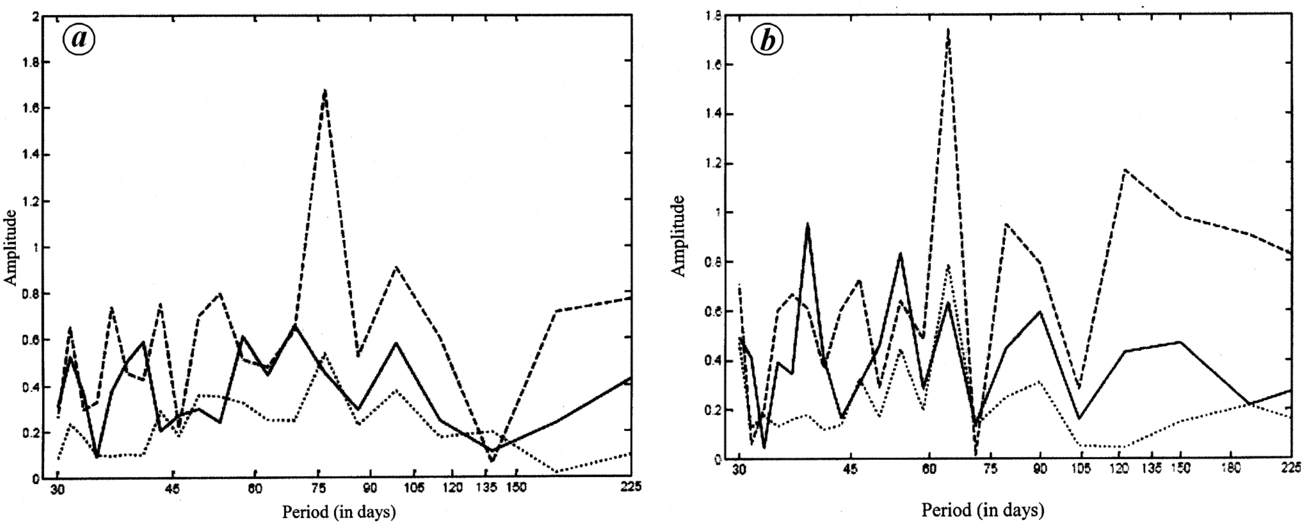

Figure 2. Fourier spectrum of the time series for different developmental stages (eggs – solid line, larvae – broken line, pupae – dotted line) of *O. arenosella*. Samples were drawn at 15-day intervals for a period of two years (July 1999 to July 2001) from (*a*) Srirampura and (*b*) Tittamaranahalli.

emerge in about ten days after pupation and lay most of their eggs in the next two days, the expected difference in the appearance of peaks of pupae of the previous generation and eggs of the current generation was ~12 days. As larvae hatch in seven or eight days, the difference in the peaks of eggs and larvae of the current generation was expected to be ~8 days, and as the larval duration ranges from 33 to 39 days, the peaks of larval and pupal densities were expected to be separated by approximately the same duration. As expected, there were significant correlations

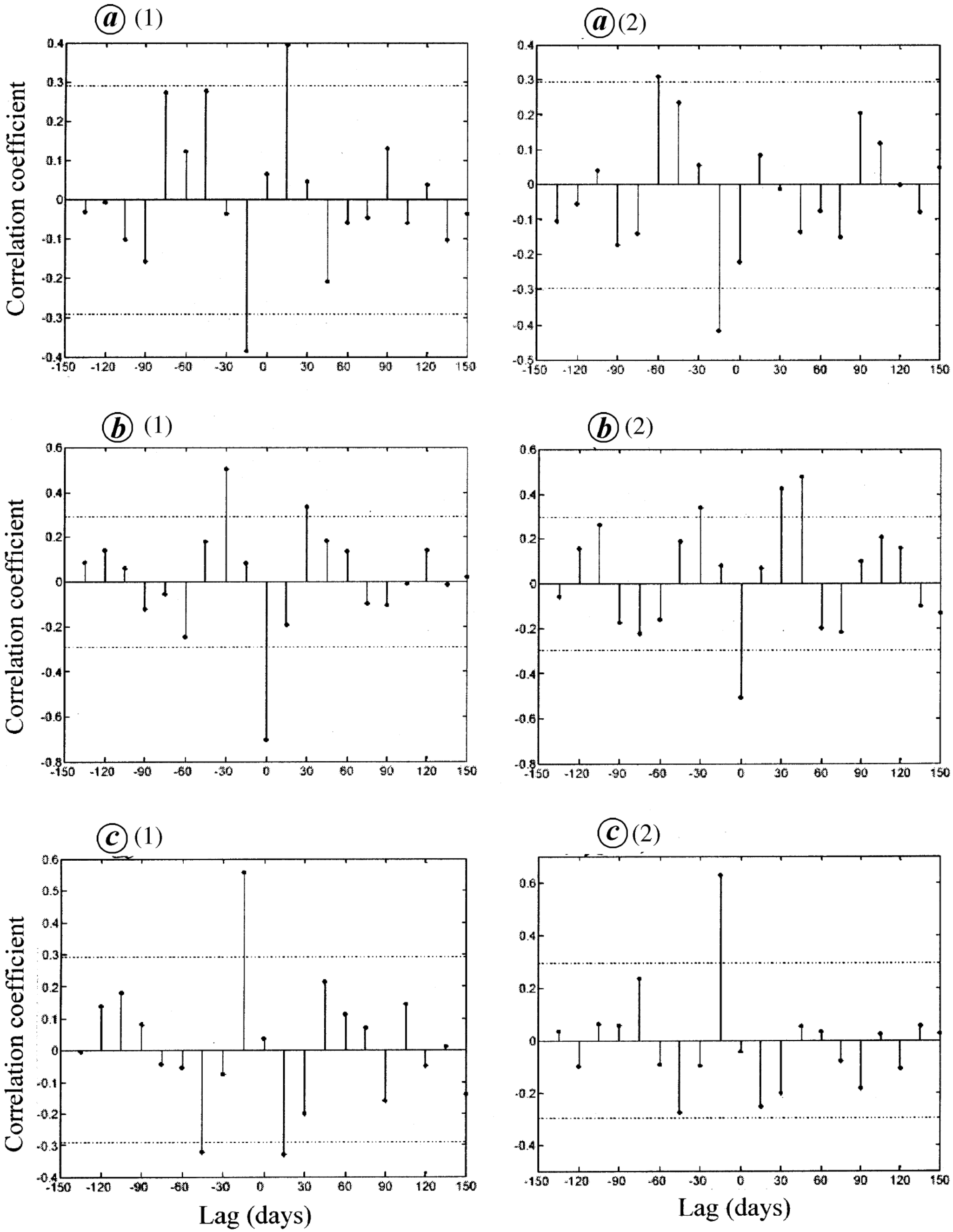

Figure 3. Lead/lag correlations between different developmental stages of *O. arenosella*. 1, Srirampura; 2, Tittamaranahalli. Correlation between (*a*) egg – larvae; (*b*) larvae – pupae and (*c*) egg – pupae. Points between the dotted lines are not significantly different from 0.

between peaks of the developmental stages at certain time lags (Figure 3) and the results agreed with the expected values. [It must be noted with caution that the period of lead/lag between any two successive stages suggested by the correlations is influenced by the sampling frequency. Since samples have been drawn at 15-day intervals, significant correlations, if any, would mean that peaks between two successive stages are separated by 15 days or by multiples of 15 days, although in several cases the expected lead/lag may be less than 15 days or not in multiples of 15 days. However, a 15-day interval approximates most of the expected differences between peaks of successive stages.] The negative correlation between eggs and larvae at a lag of 15 days at both locations (Figure 3 *a*) indicated that 15 days prior to the peak of eggs, larval population was the least. In other words, the larval population of the previous generation reached a minimum 15 days before the peak in eggs. At Srirampura (Figure 3 *a*(i)), the positive correlation between eggs and larvae at a lead of 15 days indicated that 15 days after the peak in eggs there was a peak in larvae, which corresponds to the larvae of the current generation. The simultaneous negative correlation (the negative correlation at lag 0) between larvae and pupae at both locations (Figure 3 *b*) suggested that the two could not co-occur. The same is also reflected in Figure 1, where the appearance of pupae coincided with the decline in larval population at all times at both locations. The positive correlations between the two at a lead/lag of 30 days at both locations (Figure 3 *b*) suggested that 30 days before and 30 days (30–45 days in case of Tittamaranahalli) after the peak in larvae, there was a peak in pupae. The pupal peak appearing before the larval peak refers to the pupae of the previous generation, while the pupal peak appearing after the larval peak refers to pupae of the current generation. The positive correlation between the peak in eggs and pupae at a lag of 15 days at both locations (Figure 3 *c*) suggested that 15 days before the peak in eggs there was a peak in pupae, which refers to the pupae of the previous generation. At Srirampura (Figure 3 *c*(i)), the negative correlations between eggs and pupae at a lead of 15 days and lag of 45 days, indicated that pupal populations were at minimum 15 days after and 45 days before the peak in eggs. These results strengthened suggestions of DGC among populations of *O. arenosella* and matched the developmental biology of the species convincingly.

Thus, it is clear that generation cycles in *O. arenosella* are discrete and that there is definite periodicity in the appearance of different stages of the population. The periodicity may be prolonged during winters (November to January) and shortened during summers (March to June). There is a definite time lag in the appearance of different developmental stages of the species, which has important implications in pest management as discussed later.

DGC in phytophagous and largely monophagous tropical insect populations may be regulated by seasons and host–parasitoid dynamics. Wolda[7] suggested that tropical seasons, especially the onset of rains, could play an important role in generation cycles of insect populations. But, as populations of *O. arenosella* occurring in the coastal climates of Sri Lanka[3] and dry zones of India are shown to follow DGC, and since periodicity in the occurrence of different developmental stages does not appear to be related to any season (Figure 1), the influence of season on generation cycles of this species can be ruled out. This strengthens the claim of aseasonality in generation cycles of *O. arenosella*[1] and eight other tropical insect species listed by Godfray and Hassell[1]. Wolda[7], however, concedes that most multivoltine species tend to have discrete generations in the beginning of the season only to have overlapping generations with time. The results of the study reported here fail to support Wolda's[7] argument since population cycles of *O. arenosella* appeared to remain discrete even during the tenth generation at both locations. Mathematical models[1,8] have demonstrated that parasitoids could lead host populations to DGC under tropical conditions. This has been empirically demonstrated only with one species, namely *Prokelisia marginata* (Homoptera: Delphacidae), where the egg parasitoid *Anagrus delicatus* (Hymenoptera: Mymaridae)[12] has been shown to regulate populations of its host leading to DGC. The spatially segregated populations of *O. arenosella* in different climatic conditions can thus serve as an excellent model system to investigate the role of natural enemies in maintaining discrete generations of the host populations.

The demonstration of discrete generation cycles in *O. arenosella* has significant implications for the management of this insect that causes considerable economic losses to coconut growers[5]. Information on periodicity and lead/lag in appearance of different developmental stages will not only provide new opportunities in pest management, but also assist in refining the existing management plans. First, this information will be a key input for modelling population growth rates, host–parasitoid population dynamics, severity of attack, etc. Secondly, it would provide necessary information for accurate timing of different management strategies, such as timing inundative releases of larval and pupal parasitoids for more effective management. Similarly, stomach poisons ingested during feeding would be effective only if administered when the host is in its larval stage and not when it is in pupal or moth stage, and trapping adults using light or pheromone traps would be effective only when the population is in its moth stage. Thirdly, the effectiveness of management strategies can considerably differ between populations that follow discrete and those that follow continuous generation cycles. A management strategy targetting a particular developmental stage, if accurately timed, may be effective against populations with DGC; while repeated interventions of the same kind or simultaneous adoption of different strategies targetting different developmental stages would be more effective against populations with continuous generation cycles.

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Change detection studies in coastal zone features of Goa, India by remote sensing

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Digital remote sensing data of SPOT-1 (Nov. 1990), IRS-1C (Jan. 2001) and IRS-1D (Jan. 2003) have been subject to maximum likelihood classifier (MLC) to carry out change detection studies in the coastal zone of Goa. The classified images were evaluated on both homogeneous and heterogeneous regions in terms of confusion matrix as well as by field validation. The classification results of these multi-temporal data reveal that MLC gives an average accuracy of 85.69, 77.66, and 88.43% for 1990, 2001 and 2003 images respectively, and the corresponding kappa coefficients are 0.89, 0.84 and 0.86 respectively. Results of MLC indicate that there is an increase in urban land, vegetation and water body reduction in barren land and sandy beach along the coastal zone of Goa. The urbanization is attributed to tourism boom-related activities.

Keywords: Coastal zone of Goa, land cover, land use, maximum likelihood classifier, kappa coefficient.

GOA, the smallest state in India with an area of 3702 km^2, lies in the west coast. Goa is the prime tourist destination of India, and the tourism industry is growing rapidly. Associated with this growth, changes could be detected in the land-use, especially along the coastal belt such as construction of buildings, environment-friendly industries, resorts, breakwaters, minor harbours, expansion of a major port, etc. Goa has been experiencing a lot of changes in its land-use patterns. It has become necessary to detect the changes happening around this region as this may help determine the level of stress that the coastal zone of Goa is facing. Literature review points out that no study had been carried out to detect the changes that have occurred along the coastal zone of Goa other than the environment and sustainable local development of coastal area study[1]. Increasing tourism appears to drive land-use/land-cover changes in Goa[2]. Coastal geomorphic features, sediment transport and coastal vegetation (mangroves) have been studied using remote sensing data[3,4]. As Goa is one of the global tourist destinations of the world, more development is expected along the coastal zone, and subsequently there will be changes in the land-use/land-cover pattern in the coming years.

In the present study, an attempt has been made to carry out change detection analysis for the coastal zone of Goa. For this purpose, available cloud-free remote sensing data have been subjected to digital image processing techniques as they provide a wealth of information due to synoptic coverage and repetivity. Change detection involves the use of multi-temporal datasets to derive land-cover changes between the dates of imaging. Types of change vary from short term to long term. Change detection procedures require data of the same or similar sensors. Influencing environmental factors should be considered in change detection procedures. Spatial and spectral resolution of recent satellite sensors gives high-quality satellite images. Remote sensing data having good spectral and spatial resolution are extremely useful for mapping land use and land cover[5]. Areas surrounded by aquatic systems are important for their contribution to the hydrological cycle[6]. Several image processing techniques have been developed in the last three decades to process and analyse remote sensing images and extract meaningful information[7]. Different land-cover types in an image can be classified using image-classification algorithms having spectral features. Methods based on spectral variations are robust when dealing with data captured at different times of the year[7]. The most common means of expressing classification accuracy is preparation of a classification confusion matrix[8]. These matrices compare the relationship between known reference and classified data on category-by-category basis. The classification procedures can be supervised or unsu-

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