# METHODOLOGY FOR REMOTE SENSING OF WATERBIRD HABITATS IN AN INLAND WETLAND

KETAN TATU*, M.M. KIMOTHI** AND J.S. PARIHAR**

## Introduction

Wetlands are the areas of marsh, fen, peatland or water, whether natural or artificial; permanent or temporary with water that is static or flowing, fresh, brackish or salt; including areas of marine water, depth of which does not exceed six meters at low tide (Ramsar Convention 1971). It is estimated that 8.56 million km$^2$ i.e. 6.4 per cent of the land surface of the world comprise wetlands (Mitsch and Gosselink, 1986). In India, 40,493.73 km$^2$ i.e. about 1.23 per cent of the land surface, excluding 5,049.99 km$^2$, of mangrove forest, comprise wetlands (Narayanan, 1992).

These are one of the most productive ecosystems which perform a variety of ecological and socio-economic functions. Fulfilling the food and habitat requirements of various waterbirds is one of the most important functions performed by the wetlands as it helps in maintaining the biodiversity on the earth. Unfortunately existence of wetlands all over the world is threatened and waterbirds are under pressure from increasing human population, man's socio-economic activities and man-induced adverse natural phenomena.

Destruction or deterioration of habitats is a major reason for threat to waterfowl conservation all over the world and population of various waterbird species has dwindled. Some species of waterbirds have become rare whereas some others are pushed to the edge of extinction. This may further lead to loss of biodiversity and hampering of the ecological balance. In Indian subcontinent, waterbirds like Spot-billed Pelican (*Pelecanus philippensis*), Dalmatian Pelican (*Pelecanus crispus*), White-billed Heron (*Ardea imperiallis*), Lesser Adjutant (*Leptoptilos javanicus*), Greater Adjutant (*Leptoptilus dubius*), Darter (*Anhinga rufa*), Bar-headed Goose (*Anser indicus*), White-winged Wood Duck (*Cairina scutulata*), Marbled Teal (*Marmaronetta angustirostris*), Pink-headed Duck (*Rhodonessa caryopyllacea*), Ferruginous Duck (*Aythea nycora*), Black-necked Crane (*Grus nigricollis*), Siberian Crane (*Grus leucogeranus*), Indian Skimmer (*Rynchops albicollis*), Eastern White Stork (*Ciconia ciconia*), Osprey (*Pandion heliatus*), Palla's Fishing Eagle (*Haliaeetus leucoryphus*), White-tailed Eagle (*Haliaeetus albicilla*) etc. are considered to be threatened.

Such being the case, it is very important to see that the wetland habitats of various waterbirds are properly conserved through scientific management. Sound management of such habitats is only possible with the use of information regarding existing habitat components. However in countries like

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India, such data is often not available to the satisfactory level. This is because, ecological studies on wetland ecosystems of India have been of preliminary and fragmentary nature (Mahajan, 1986).

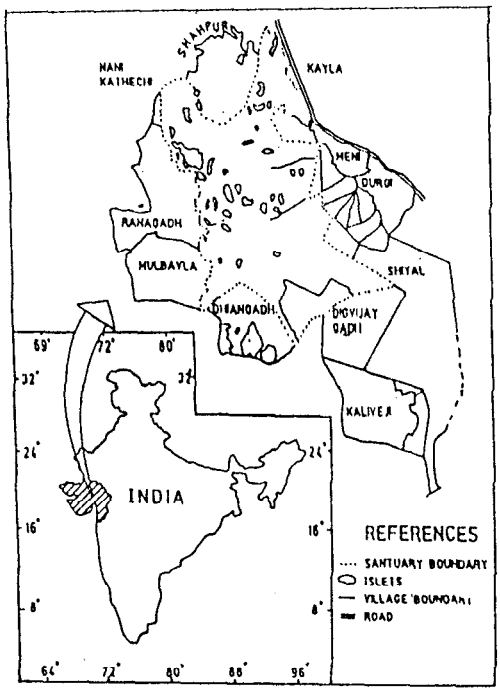
Satellite remote sensing can be very useful for filling the gaps of information on the extent, status and spatial patterns of waterbird habitats in Indian wetlands. With remote sensing, multi-date habitat mapping can be possible through synoptic and repetitive coverage. It further facilitates inventorying and change monitoring of waterbird habitats. However, till date no attempt has been made in India to develop an appropriate methodology for mapping, monitoring and quantitative evaluation of waterbird habitats in an inland wetland using satellite remote sensing technique. Hence a detailed study has been carried out at the Space Applications Centre of ISRO, to qualitatively and quantitatively characterise waterfowl habitats in one of the important inland wetlands in Gujarat viz. Nal Sarovar. The wetland was studied by considering the critical drought period in the State, i.e. 1985-86 to 1987-88 as the 'reference period'. By keeping in mind this reference period, the satellite data was selected for the pre-drought years (1984-85), drought years (1985-86, 1986-87, 1987-88) and the post-drought years (1989-90, 1990-91). For the aforesaid time-frame, wetland based waterbird habitats and other ecological conditions were studied using remotely sensed data for the mid-winter (January, February), summer (April) and early post-monsoon (September, October) seasons by quick-look-analysis. As mid-winter season is known to be the critical period of waterbird migrations and waterbird censuses in India, higher preference was given to the data of the mid-winter seasons.

The objective of this paper is to discuss various aspects of methodology developed for remote sensing based delineation and mapping of waterbird habitats in an inland wetland. Suitability and limitations of important aspects of the methodology like selection of mapping period and seasons, mapping scale, sensors etc. are also evaluated. The paper can provide a guideline/direction for studying other wetlands of the country as waterbird habitats using remote sensing technique.

## Study Area

Nal Sarovar is located in Gujarat State between 71° 92' E and 72° 08' E and 22° 40' N and 22° 55' N (Fig. 1). This is a natural lake with associated marshes (Wolstencraft

**Fig. 1**




Location of Nal Sarovar

*et al.*, 1989). It is mainly shallow; having maximum depth of 3 m (Johri *et al.*, 1990). The rain water run-off is poured into it from the northern and North-eastern uplands falling in Surendranagar, Ahmedabad and Mehsana Districts of the State. Being located in the semi-arid tract, the rainfall is usually low and erratic. The mean annual rainfall in the region has been found to be 584.2 mm. It may be noted that the wetland went completely dry during the mid-winter season of 1986-87 (January 1987) as a result of the severe drought. There are several islands in the lake having varied size and shape.

Nal Sarovar supports rich avian wildlife. Hence about 120.82 km$^2$ area of this wetland is being protected as bird sanctuary by the State Forest Department. A large number of migratory and resident waterbirds congregate at the wetland in the winter. A total number of 113 waterbird species with the population of 2,24,245 individuals were recorded during mid-winter waterfowl census conducted by the State Forest Department in the year 1992.

## Data Used

Following remote sensing and collateral data were used for this study : (i) Multi-temporal satellite images (False Colour Composites) of Landsat MSS (79 m resolution), Landsat TM (30 m resolution) and IRS LISS II (36 m resolution) as listed in Table 1; (ii) Survey of India (SOI) topographical maps at 1:50,000 scale; (iii) 'Management plan of Nal Sarovar Bird Sanctuary 1990-2000' prepared by Gujarat State Forest Department; (iv) Waterfowl census data for the year 1991-92 from Gujarat State Forest Department; (v) Field data on species diversity, population dynamics and habitat preferences of different waterbirds occurring at Nal Sarovar.

**Table 1**

*Satellite data used for remote sensing based mapping of Nal Sarovar as waterbird habitat*

| Satellite | Sensor | Date of acquisition |
|---|---|---|
| Landsat | MSS | 24-01-1985 |
| Landsat | TM | 17-02-1986 |
| Landsat | MSS | 06-04-1986 |
| Landsat | TM | 29-09-1986 |
| Landsat | TM | 19-01-1987 |
| Landsat | TM | 27-04-1988 |
| Landsat | TM | 11-01-1990 |
| IRS | LISS II | 28-04-1990 |
| IRS | LISS-II | 21-10-1990 |

## Methodology

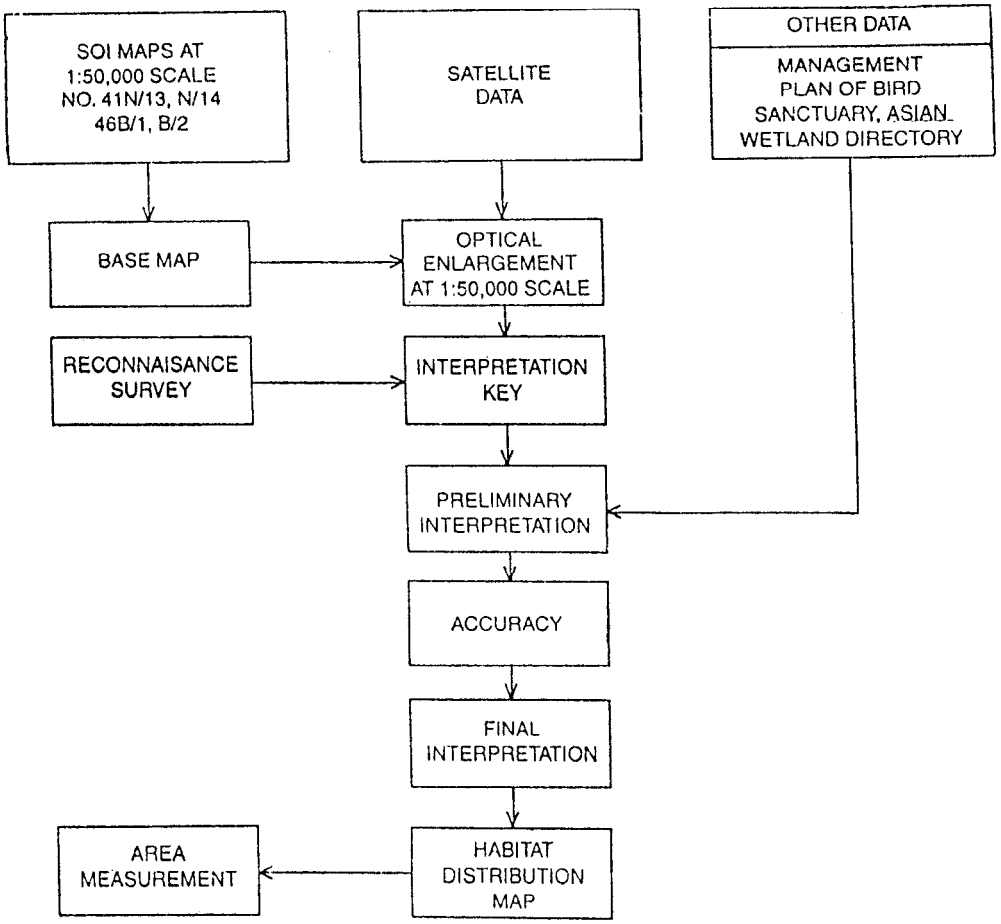
The methodology developed for mapping the waterbird habitats in the wetland of Nal Sarovar and its environs is depicted in Fig. 2. Step-by-step procedure adopted for the habitat distribution mapping, is described below.

*Demarcation of the wetland boundary for the preparation of the base map* : The boundary of the wetland ecosystem is often transitory in nature. Hence it had been an essential step to delineate the boundary of this wetland for carrying out further study. It was demarcated by taking into account the combination of different features given below :

* Maximum expanse of the wetland shown as lake and muddy area surrounding the lake in Survey of India (SOI) topographical map.

* Maximum expanse of open water and emergent aquatic vegetation during the early post-monsoon season of the excessive rain year 1990-91 (October 1990).

**Fig. 2**




Methodology flow-chart for remote sensing Nal Sarovar

* Location of villages whose boundaries are known to determine the legal boundary of Nal Sarovar Bird Sanctuary as per the 'Management Plan' of the sanctuary.

*Selection of the mapping scale* : The scale of 1:50,000 has been considered to be appropriate for the present habitat study in relation with the waterbirds. It may be noted that the topographical maps at 1:50,000 scale are commonly used for most of the field work. The smallest mapping unit has been taken as 3 x 3 mm which is equivalent to 150 x 150 m (2.25 ha) on ground.

*Analysis procedure* : Visual analysis had been carried out for the present study. The analysis had been done by first developing the interpretation key. The key formed the basis of delineation and identification of various habitat components in the wetland and its environs. The inherent elements like tone, texture, size, shape, pattern, location and association were examined by

enlarging the FCCs to 1: 50,000 scale using an optical instrument viz. High Magnification Enlarger (HME). Legends were also developed based on various habitat features identified in the wetland and its environs. Classification system for structural components of the wetland providing waterbird habitats has been developed.

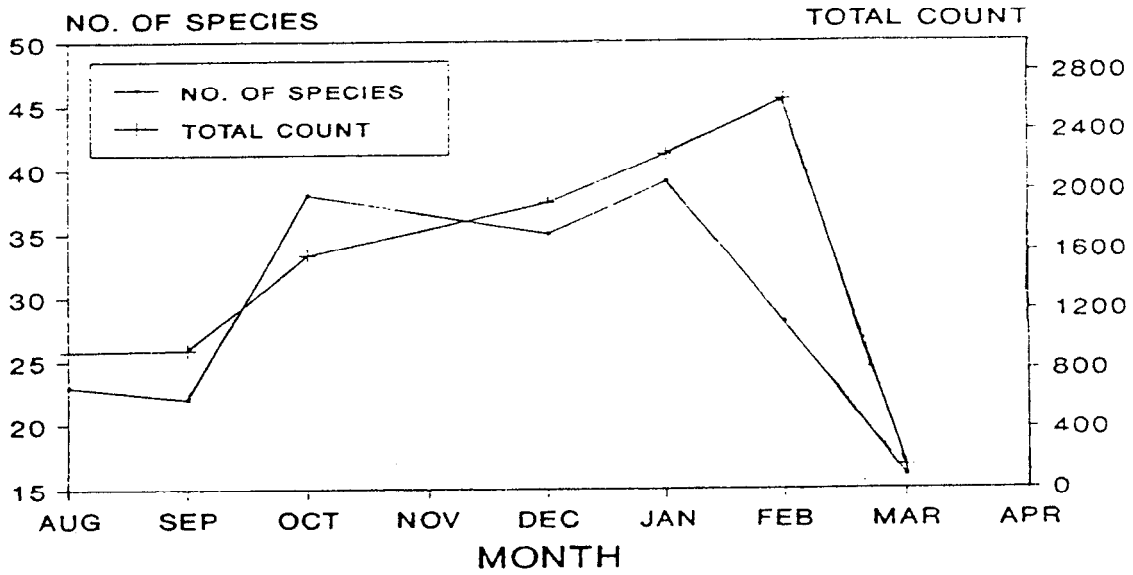
*Ground truth and accuracy checks* : Field data was collected during the year 1990-91. In addition, an intensive ground truth survey was conducted in 1993. To carry out the survey, a Ground Truth Design Map was prepared at 1:50,000 scale for the verification of the accuracy. Areas were identified from the preliminary interpretation maps for ground verification. Random samples were generated and plotted on the map.

Sample points field details were transferred on ground truth maps during field visit. Various habitat information including that of avifauna, flora and socio-economic activities were also recorded from 50 sampling points distributed randomly both in the wetland and its environs. Using the technique developed by Arnoff (1982), the interpretation accuracy is tested on a sample basis assuming a binomial distribution for the probability of success or failure of sample points.

*Preparation of the final Habitat Distribution Maps (HDM)* : After carrying out ground truth, necessary corrections and modifications have been incorporated in the preliminary interpretation key and maps for their finalisation.

*Habitat Inventory* : Habitat inventory has been carried out by measuring the area of important habitat components in the habitat distribution maps using dot grid template. Apart from facilitating the area determination of the entire wetland and its

**Fig. 3**




Species diversity and population of Waterfowl for the migration season 1991-92

different structural components, it has also provided the bases of quantitative change monitoring in conjunction with the pictorial change monitoring.

## Results and Discussion

Various aspects of the methodology developed for the remote sensing based mapping of wetlands as waterbird habitat has been assessed to judge their suitability. The suitability assessment of each of the methodological aspects is discussed here.

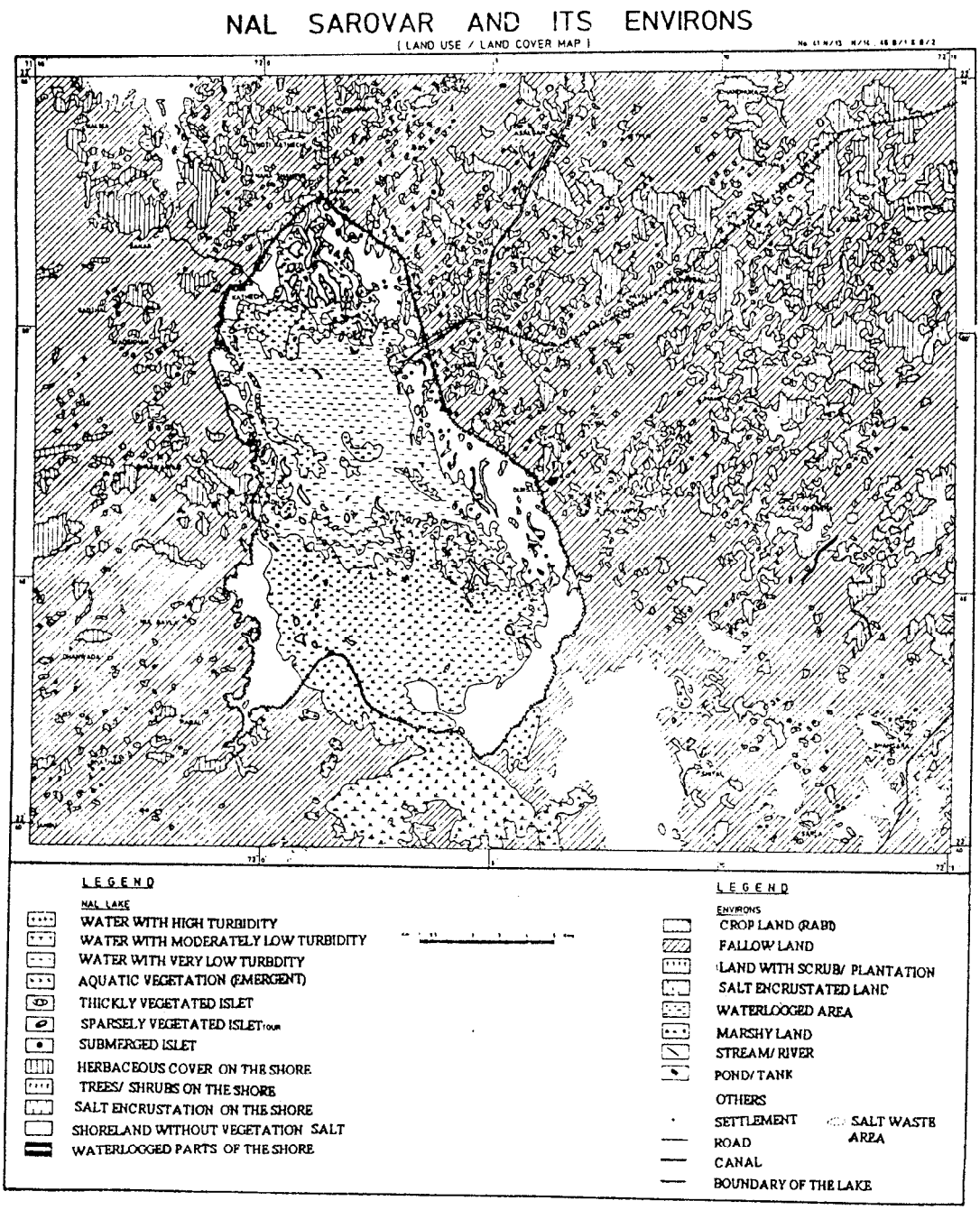
*Selection of data sets* : Selection and analysis of the satellite data for the period from 1984-85 (January 1985) to 1990-91 (October 1991) has been found to be very useful. This is because it had been the recent time-frame with erratic weather (rainfall) conditions. There was drought in the study area between 1985-86 and 1987-88, whereas it received excess rainfall during the year 1990-91. It may be noted that an erratic pattern of the rainfall causes drastic fluctuations in the water levels of the wetland. In turn the internal character and biodiversity of the wetland may be severely influenced because wetland ecosystems, unlike deep water habitats are sensitive to water-level fluctuations (Kusler *et al.*, 1994).

*Mapping Seasons* : Multi-year analysis has brought out habitat distribution changes for the mid-winter seasons of the years 1984-85, 1985-86, 1986-87 and 1989-90. Seasonal analysis was also done for the different consecutive seasons (mid-winter, summer and early post-monsoon) of the years 1985-86 to 1986-87 (February 1986, April 1986 and September 1986) and 1989-90 to 1990-91 (January 1990, April 1990 and October 1990).

Meyer (1978) has reported that the satellite data should be selected in such a way that it can best be correlated with important short-term habitat dynamics such as water level variation, plant growth stage, animal activity pattern etc. In this connection, it may be noted that the use of the mid-winter season satellite data (January/February) has been found appropriate in studying the wetland as waterbird habitat from the view point of bird activity. This is because the utilization of different habitat components in Nal Sarovar and its environs by the waterbirds has been maximum as judged from the high waterbird diversity and population during January and mid-February, respectively (Fig. 3). The fact is further strengthen from the observation that about 113 waterbird species with the total population of 2,24,245 have been recorded in mid-January (Waterfowl Census 1991-92). The use of the satellite data of the mid-winter season has been found appropriate from the data quality point of view also. It provided optimum contrast between different waterbird habitats and in turn the delineation and mapping of the edges of the waterbird habitats become convenient.

In addition to the mid-winter season satellite data, use of September/October and April months data have been found useful from the view-point of the water level changes. This is due to the fact that large fluctuation in the water spread (water level) occur during these months. Thus water spread may be maximum during September/October under the influence of the monsoon. On the contrary, the water spread may be very low during April. The data of the months of September/October and April has also been found useful to some extent from the bird activity point of view. This is because, several early winter migrants are found using Nal Sarovar and

**Fig. 4**




Habitat Distribution Map - January, 1985

its environs as early as from August and remain there till April. Waterbirds like Flamingos have been found in thousands as late as in April/May due to brackish to saline character of the water during summer.

The satellite data of the early post monsoon season of the excessive rain year (October 21, 1990) has provided good contrast due to the perpetuity of water and fresh vegetation (aquatic and terrestrial). Though the Landsat MSS/TM data of summer season of the drought years (April 6, 1986 and April 27, 1988) have provided comparatively poor contrast between different structural components of the wetlands, such contrast has been found good in the non-drought period (IRS LISS II data of April 28, 1990).

*Sensors* : Comparison of HDMs prepared by the analysis of mid-winter season satellite data has shown that 12 habitat classes/ structural components in the wetland ecosystem have been detected both on Landsat MSS (January 1985) and Landsat TM (January 1990) data. IRS LISS II data of the mid-winter season was not available and hence similar comparison could not be made for it. However, with IRS LISS II data of early post-monsoon season (October 21, 1990), ten habitat classes have been detected which was nearly same as those detected by the other two sensors employed. Comparison of the HDMs for the summer season shows that nine habitat classes/structural components in the wetland ecosystems have been detected both in the Landsat MSS (April 6, 1986) and IRS LISS II (April 28, 1990) images. The map prepared through the use of Landsat TM data of the April 27, 1988 revealed very few habitat classes but that has been due to the severity of the drought conditions in the area. Thus it can be said that all the sensors employed for the study have shown nearly equal capability of habitat detection during the similar season/ weather conditions.

Comparison of HDMs prepared from the mid-winter season Landsat MSS data with that of mid-winter season Landsat TM data of the year 1984-85 and 1989-90 respectively, has shown that micro-habitats like thin reed-belts on the edges of barren islets and stretches of mud on the edges of some barren islets could be seen on the Landsat TM images but not on Landsat MSS images (at 1:50,000 scale). This was due to limitation of lower resolution of Landsat MSS data. Fraser (1980) had found that Landsat MSS data have been less useful in the evaluation of the waterfowl habitat. It has limitation of detecting habitat features having size of 0.4 ha (0.004 $km^2$) or smaller (Gilmer *et al.*, 1978).

In the present study the capability of the Landsat MSS in detecting barren islets in Nal Sarovar during the mid-winter season was found to be equally good as other two sensors if they exist within the open water zone. The islets as small as 0.02 $km^2$, could be detected, due to contrast created by the high reflectance from the sandy/saline soil of the islets and high absorption by the near-transparent water of the lake. It may be noted that the islets appeared white whereas the water appeared dark blue or black. It may not be improper to state here that multi-spectral satellite data employed in the present study (bands 1, 2, 4 in MSS and bands 2, 3, 4 in TM and LISS II data) have played important role in effectively delineating various waterbird/habitats structural components in the wetland and its environs.

It has been found that the tonal

characteristics of IRS LISS II FCC for the emergent aquatic vegetation during the early post-monsoon period (October-end) has been very effective in distinguishing it from terrestrial herbaceous cover (including crops, grasses etc.) even if both exist side-by-side at the margin of the wetland.

It was interesting to find that though the submerged aquatic vegetation (including species like *Potamogeton, Nitella, Chara, Najas, Hydrilla* and *Vallisnnaria*) usually occurs in perpetuity in the open waters of the wetland during winter season, it could not be detected by any of the sensors if the lake holds perpetual water. If, however, the water-spread is reduced as seen in LISS-II image of April 1990, the vegetation appears in the form of dull/dark brown dots. Non-detectability of submerged aquatic vegetation in good water condition may be a shortcoming of the remotely sensed data in assessing the wetland as waterbird habitat. Whereas this vegetation forms important food item for various migratory ducks (anatids) and ever-abundant winter migrant at Nal Sarovar, viz. Coot (*Fulica atra*).

*Classification Accuracy* : Classification accuracy was estimated by working out commission and omission errors through the confusion matrix. The classification accuracy as high as 92 per cent at 90 per cent confidence level has been achieved for both, the wetland and its environs. Multi-date analysis and monthly visits for the field work to the study area has helped in achieving higher classification accuracy (Table 2).

*Habitat Distribution Mapping*: Preparation of a series of maps from the analysis of multi-date (multi-year and seasonal) satellite data, each depicting habitat distribution over the time-span of 1984-85 to 1990-91 is referred to as habitat distribution mapping.

In all, analysis of Landsat MSS, Landsat TM and IRS LISS II images has resulted in the availability of nine 'Habitat Distribution Maps' (HDM). Each of these maps has represented at 1:50,000 scale, the spatial distribution of various waterbird habitFats (along with other ecologically/ socio-economically significant structural components of the wetland ecosystem) The distribution has been pictorially revealed for either mid-winter or summer or the early post-monsoon seasons of the normal/ scarce (drought)/excessive rainfall years (Fig. 4).

Apart from pictorially revealing the spatial status of different waterbird habitats, these HDMs have also provided the basis for the habitat inventorying (i.e. area measurement of waterbird habitat using dot grid template). The HDMs have also provided the basis for preparation of the thematic 'Habitat Change Monitoring Maps' and developing the 'Waterbird Habitat Assessment Models'.

## Conclusions

Landsat (MSS/TM) and IRS LISS II data have been found to facilitate development of classification system upto level III through visual analysis approach. The system could include total 21 structural components of the wetland ecosystem and its environ; 19 of which having direct relevance to various life requisites of waterbirds.

IRS LISS II and Landsat TM data are found more suitable for mapping waterbird habitats in an inland wetland than Landsat

**Table 2**

*Confusion matrix for Nal Sarovar (1:50,000 Scale) for IRS LISS II*

| | Class | Verified | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ovlt/ omlt | oht | av | tvi | bi | hcsl/b | tssl | stsl/ b | bsl/ b | Total | Omm. (%) | Correct (%) |
| O | ovlt/omlt | 9 | | | | | | | | | 9 | 0 | 100 |
| B | oht | | 6 | | | | | | | | 6 | 0 | 100 |
| S | av | | | 9 | | | | | | | 9 | 0 | 100 |
| E | tvi | | | | 1 | | | | | | 1 | 0 | 100 |
| R | bi | | | | | 7 | | | | | 7 | 0 | 100 |
| V | hcsl/b | | | | | | 5 | 1 | | | 6 | 17 | 083 |
| E | tssl | | | | | | | 2 | | | 2 | 0 | 100 |
| D | stsl/b | | | | | | | | 5 | | 5 | 0 | 100 |
| | bsl/b | | | | | | | | | 5 | 5 | 0 | 100 |
| | Total | 9 | 6 | 9 | 1 | 7 | 5 | 3 | 5 | 5 | 50 | | |
| | Comm.(%) | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 0 | 0 | | | |

Notes : ovlt/omlt: Open water with very low to moderately low turbidity
oht: Open water with high turbidity
av: Aquatic vegetation
tvi: Thickly vegetated islet
bi/svi: Barren or sparsely vegetated islet
hcsl/b: Herbaceous cover on shoreland/basin
tssl: Trees/Shrubs on shore
stsl/b: Salt encrustation on shoreland
bsl/b: Barren shoreland/basin

Total no. of samples= 50, No. of failures=01
Overall accuracy at 90% confidence level=92%

MSS. Thus, comparison of the wild-winter season Landsat MSS and TM data has shown that micro-habitats of waterbirds like the reed-belts on the edges of some of the small islets as also muddy stretches on edges of such islets could not be delineated with Landsat MSS data. However, they could be delineated in Landsat TM images. Moreover, in detecting and delineating islets as small as 0.02 $km^2$ existing amidst the extensive and thick cover of the emergent aquatic vegetation, IRS LISS II data has been found to have an edge over the Landsat (MSS/TM) data. IRS LISS II FCC of the early post-monsoon season (October, 1990) has been found to be effective in distinguishing emergent aquatic vegetation from the nearby terrestrial herbaceous cover.

Mid-winter season (January/February) data has been found especially appropriate for the multi-year mapping of the wetland as waterbird habitat. It is during this period that the utilisation of the habitats in the wetland by various resident and migratory waterbirds is at peak.

## Acknowledgements

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## SUMMARY

**Waterbird (Waterfowl) habitats in wetlands are deteriorating due to variety of human activities threatening the survival of waterfowl. Sound management of such habitats is possible if information regarding them is available. Satellite remote sensing can be very useful in providing such information through delineation, mapping and inventorying of habitats. The methodology developed for delineation, mapping and inventorying waterbird habitats in an inland wetland viz. Nal Sarovar (Gujarat State) has been discussed in the present paper. Suitability and limitations of important aspects of the methodology adopted for preparing 'Habitat Distribution Maps' are also revealed and discussed. Mid-winter season (January/February) data of Landsat (MSS/TM) and IRS LISS II has been found very appropriate for studying waterbird habitats. Classification system upto level III has been developed. IRS LISS II FCC has been found to be more effective in distinguishing habitat of emergent aquatic vegetation from the nearby terrestrial herbaceous cover during early post-monsoon period. Mapping scale of 1: 50,000 was found appropriate with respect to the resolution of the Landsat (MSS/TM) and IRS LISS II images employed in the study. Accuracy of the 'Habitat Distribution Maps' was tested on the sample basis assuming a binomial distribution for the probability of success/failure of sample points. It was found to be 92 per cent at 90 per cent confidence level.**

## अन्तर्देशीय आद्र भूमि में जल कुक्कुट प्राकृतावासों के दूर संवेदन का रीति-विज्ञान

केतन टाटु, एम०एम० किमोथी व जे०एस० परिहार

### सारांश

आर्द्रभूमियों में जल कुक्कुटों के प्राकृतावास कई तरह की मानव क्रियाओं के कारण विनष्ट होते जा रहे हैं जिनसे जल कुक्कुटों की अतिजीविता ही संकट में पड़ रही है । ऐसे प्राकृतावासों का अच्छा प्रबन्ध तभी किया जा सकता है जब उनके बारे में पूरी जानकारी उपलब्ध रहे । प्राकृतावासों का सीमा निर्धारण, मानचित्र और तालिकायन करके ऐसी जानकारी प्रदान करने में उपग्रह दूर संवेदन बहुत उपयोगी सिद्ध हो सकता है । एक अन्तर्देशीय आर्द्रभूमि अर्थात् नल सरोवर (गुजरात राज्य) में जल कुक्कुट प्राकृतावासों के निर्धारण, मानचित्रण और तालिकायन के लिए विकसित रीति विज्ञान का विवेचन प्रस्तुत अभिपत्र में किया गया है । "प्राकृतावास वितरण मानचित्र" तैयार करने के लिए अपनाए गए रीति विज्ञान के महत्वपूर्ण पक्षों की उपयुक्तता और सीमाओं को भी यहां प्रकट एवं विवेचित किया गया है । लैंडसेट (एमएसएस/टीएम) तथा आइआरएस एलआइएसएस II के मध्य शीत ऋतु (जनवरी/फरवरी) आंकडे जल कुक्कटों के प्राकृतावासों का अध्ययन करने के लिए बहुत उपयुक्त पाए गए । स्तर III तक की वर्गीकरण प्रणाली विकसित करली गई है । उग रही जलीय वनस्पतियों के प्राकृतावास को मानसूनोत्तर अवधि में आस-पास के भोम साकीय आवरण से पृथक बताने के लिए आइआरएस एलआइएसएस II एफसीसी अधिक प्रभावकारी पाया गया है । अध्ययन में अपनाए गए लैंडसेट (एमएसएस/टीएम) और आइआरएस एलआइएसएस II बिम्बों को साथ मिलाने की दृष्टि से 1 : 50,000 अनुमाप उपयुक्त पाया गया । "प्राकृतावास वितरण मानचित्रों" की सुतथ्यता की नमूना आधार पर जांच नमूना बिन्दुओं की सफलता / विफलता की संभाव्यता द्विपद वितरण पर होती मानकर की गई । 90% विश्वास्य स्तर पर यह 92% पाई गई ।

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