

## Development of a Decision Support Tool for Analyzing the Avian Conservation Measures in Semi-Arid Region

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**Abstract:** With the increasing loss of bird species, worldwide, Aves conservation and management has become a great concern for researchers. This has become very important because of scientific value of the birds, and being indicators of environment conditions. Avian conservation and management is a complex decision making problem as it includes monitoring the birds, determining the reasons for decline in bird species, and then devising conservation strategies. The use of a computer-based decision support system can help in making decisions for effective conservation and management of Aves. This paper documents the design and development of an intelligent tool, the Avian Conservation Support System (AC-DSS), to analyze the avian diversity and then suggest decision measures for effective conservation and management of avian fauna in a semi-arid region. The framework of the system involves measuring and mapping the biodiversity, collecting data of the Aves population, analyzing the avian diversity, identifying and analyzing the threats, and formulating conservation and management strategies.

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**Keywords:** Avian diversity; Decision support system; conservation, management; multi-criteria decision making; Intelligent.

### 1. Introduction

Birds are one of the best known and most highly valued groups of species. These have been demonstrated to serve as good indicators of biodiversity and environmental change and thus can help in making strategic conservation planning decisions for the wider environment.

Continental and local declines in numerous bird populations have led to concern for the future of migratory and resident bird species. The reasons for declines are complex like habitat loss, habitat

fragmentation and modification, loss of wintering habitat, and excessive predation. Several bird conservation planning efforts are underway across the world and are likely to continue to evolve. Ruth et al. (2003) outlined the U.S. Geological Survey's planning for research in support of bird conservation efforts and identified five priority research areas.

Bird conservation plans have also been discussed by researchers worldwide (Hughes, Daily, & Ehrlich, 2002; Marini & Garcia, 2005; Brandes, 2008; Araújo et al., 2011; Garnett, Szabo, & Dutson, 2011; Buechley et

al., 2015; Arbeláez-Cortés et al., 2016). In India, Islam and Rahmani (2004) and Islam (2006) identified Important Bird Areas as priority sites for conservation of birds. Acharya and Vijayan (2010) collected information on endemic and threatened birds of Sikkim using point count method. The number of species and their density at five elevation zones were calculated.

Avian conservation and management is a complex decision making problem as it includes evaluating avian life history and ecology; and communicating ecological information of Aves. The use of a computer-based decision making system can help in effective conservation and management of Aves.

A Decision Support System (DSS) provides an effective process for organizing existing geographical, physical, and biological data for conservation planning (Prato, 1999). It is an interactive and computer-based tool that uses information and models to improve the process or outcome of decision-making. The decision support systems manage very large data efficiently and are used to assemble historical information, store new information for the future, and make both readily available for use in assessing environmental change. Geneletti (2004), Rao et al. (2007), Nelson et al. (2009), Bottero et al. (2013), Guisan et al. (2013), Bird et al. (2014), and Junior et al. (2015) have used decision support system for environment conservation, soil conservation, and biodiversity conservation. This paper documents the design and development of an intelligent and multi-criteria decision making decision

support tool, the Avian Conservation Support System (AC-DSS), to solve decision tasks for effective Conservation of Aves and Management of their Habitats (C&M) in semi-arid regions.

The paper is organized as follows: Section 2 describes the Material and Method to develop the system. Section 3 presents components of the developed system. Section 4 presents a case study of Agra where this AC-DSS is applied to show its applicability in real-life. The computations are given in Appendices. Section 5 is devoted to conclusion.

## 2. Material and Methods

The main aim of this study was to develop a tool which could help in assessing the avian diversity and identifying the threats of the avian diversity. To achieve this the conceptual framework is as shown in Figure 1.

### 2.1 Development of AC-DSS

The development of AC-DSS was achieved using the component-based software engineering approach with the following steps:

- I. *Identification of system components*: Total 5 components of the AC-DSS were identified: Database Management Sub-system (DBM-SS), Knowledge base Management Sub-system (KBM-SS), Model-base Management Sub-system (MBM-SS), Central Vision Exhibit Board (CVE-Board), and Dialog Management Sub-system (DiM-SS).

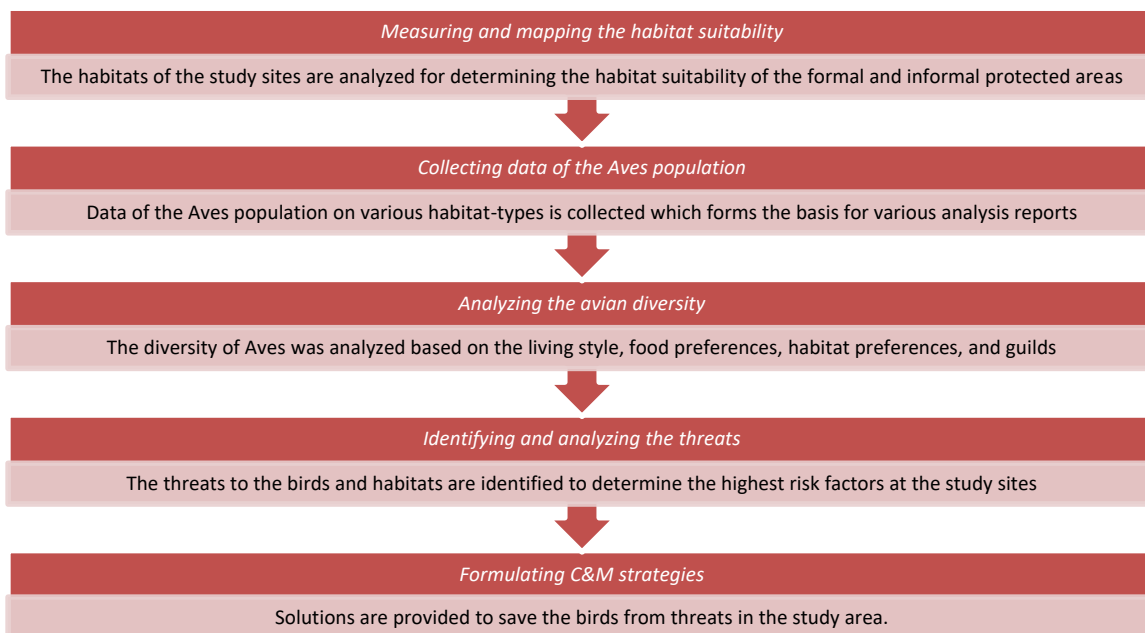


Figure 1: Conceptual framework for the system

II. *Designing system architecture*: Three-tier server-side architecture was adopted for developing AC-DSS. The architecture of the system comprises of:

- **The presentation tier**: implements DiM-SS and CVE-Board components of the AC-DSS. The DiM-SS communicates with the decision-makers through C&M User Desk in order to view the decision support information in graphical environment.
- **The business tier**: accesses the data tier for data retrieval and manipulation, and sends the results to presentation tier. It implements MBM-SS and KBM-SS as a means to business logic related to decision-making process.
- **The data tier**: implements DBM-SS and KBM-SS components of AC-DSS. It provides the business layer with required data and knowledge when needed; and stores data and knowledge when requested. The database and knowledge base are managed with an object-relational database management system.

The three-tier organization of AC-DSS results in improved security, availability, data integrity, and effective usability.

III. *Development of independent components and integration of components*: The development of AC-DSS is achieved with the open-source software packages: Microsoft Visual Web Developer (2008) Express Edition, SQL, and Quantum GIS.

## 2.2 Survey Design

### Habitat

Habitats of the study sites were visited multiple times to conduct an immense field work. Study site was divided into quadrates to calculate the ecological data of the habitat. A total of 8 quadrates of one square kilometer were analyzed in the habitat. The quadrates were compared to analyze different environmental variables (landscape structure, landscape heterogeneity, resources, and biotic information) in the habitat. The areas within the quadrates were then divided into strata, which were first individually counted and later was summed for the entire area.

### Birds

The birds were surveyed using direct count, focal and 1-0 scan sampling methods. The habitats of study site were stratified into  $1 \times 1$  km grids using standard point count method. Birds were recorded in four grids, each grid of 50 m. A total of 8 sampling sites were laid down randomly within the grids of each study site. Samplings were also made on seasonal basis and the field characteristics were noted down on ornithological

sampling data sheet which included species, number of individuals, activities, micro-habitat, threats to birds and other details.

Sampling points were selected either at the edges of core zones or in buffer zones of the study site based on their importance level. Observations were also made according to the generic and species level. In case of line transect method observation was performed through a straight line (50 m breadth and 500 m length). Random and direct counting was performed for several times.

The spatial data was collected using a GPS device. The collected data is stored in the shape files which helped in generating the maps of the study areas.

Discussions with experts was also considered an important source of information. An *Expert Assessment (EA) Team* was formed for this purpose. The team includes 9-10 experts from different fields (academicians, policy makers, ornithologists, and field experts). Their responsibilities include:

- rating and ranking the questionnaires; and
- giving their valuable opinions to ensure the reliability of the data

### 2.3 Habitat Suitability Analysis (HSA)

The Habitat Suitability Analysis is performed to determine habitat aptness and species distributions at the study site by computing Habitat Suitability Value (HSV). The  $HSV^z$  of the study site  $z$  is computed by combining Modified Delphi Method, Analytical Hierarchy Process (AHP) and Weighted Linear Approach. The analysis provides habitat information which can be used for impact assessment and habitat management. This analysis is performed on the basis of biological surveys of the green reserves and the management priorities within the habitat.

The inputs (species data and biotic-abiotic parameters), habitat variation (natural spatial and temporal variability), and sampling variation (average, relative importance and habitat scores) were quantified for accuracy in HSVs results.

To compute the HSV, first the hierarchy of the habitat-scales is developed. Modified Delphi exercise is performed next to score the habitat scales taking into consideration the environmental variables (measures of climate, landscape structure, landscape heterogeneity, resources and biotic information). Next the relative importance of the habitats was evaluated. Pairwise comparison between all habitat factors was performed using a 9-point scale (Table 1) to calculate the Habitat

Suitability Weights ( $HW_h^{z_i}$ ) for habitat scale h using AHP.

**Table 1:** Scale for pairwise comparison (Saaty, 1980)

<b>Intensity of importance</b>	1	3	5	7	9	2, 4, 6, 8
<b>Definition</b>	Equal	Moderate	Strong	Very Strong	Extreme	Intermediate Value

A weighted linear combination was then used to evaluate the suitability value:

$$SV_h^{z_i} = \sum_i HW_h^{z_i} \cdot x_h^{z_i} \quad (1)$$

Where  $x_h^{z_i}$  is the score of habitat-scale h for the study site(s) ( $z_i$ ),. Finally the Habitat Suitability Value was calculated using equation (2), n is types of habitats.

$$HSV^{z_i} = \sqrt[n]{\prod_{h=1}^H SV_h^{z_i}} \quad (2)$$

## 2.4 Assessing the risk impact to the avian diversity

The disturbance gradients at the study site are identified on the basis of bio-geographical classification of birds, site-monitoring, vegetation structure, dietary habits, and population trend. This helped in identifying the threats to birds and their habitats.

The risk assessment of the threats was done by developing the Risk Impact Assessment (RIA) Method. The steps of the methodology are:

Step 1: Identifying the threat classes for each category  $c_j$  (j is the category).

Step 2: Scoring the threats classes for each  $c_j$  by EA Team using 5-point scale (High-5, Middle-3,

and Low-1) to get the Threat Influence Score ( $TI_{c_j}^{z_i}$ ) at each study site ( $z_i$ ),  $i= 1, 2, \dots, 5$ .

Step 3: Fuzzy pairwise comparison (Table 2) of threat class for each  $c_j$  to determine Threat Influence Weights ( $TW_{c_j}$ ) using following steps:

Step 3.1: Conversion of fuzzy scale in triangular fuzzy number  $\tilde{a}_m = (a_{1m}, a_{2m}, a_{3m})$  using 9-point fuzzy scale (Table 2). The triplet  $(a_{1m}, a_{2m}, a_{3m})$  represents the lower, middle and upper triangular fuzzy number, m represents the threat class

**Table 2:** 9-point fuzzy scale

Fuzzy Scale	Triangular fuzzy scale	Description
$\tilde{1}$	(1,1,1) if diagonal (1,1,3) for equal importance	Equal importance
$\tilde{3}$	(1, 3, 5)	Moderate importance of one over another
$\tilde{5}$	(3, 5, 7)	Strong importance of one over another
$\tilde{7}$	(5, 7, 9)	Very strong importance of one over another
$\tilde{9}$	(7, 9, 9)	Extreme importance of one over another
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	(1, 2, 4), (2, 4, 6), (4, 6, 8), (6, 8, 9)	Intermediate values

Step 3.2: Formation of Fuzzy Decision Matrix to compute Fuzzy Decision Weights ( $\tilde{F}_m$ )

$$\tilde{F}_m = \left( \frac{v_{1m}}{\sum_{i=1}^p v_{3m}^L}, \frac{v_{2m}}{\sum_{i=1}^p v_{2m}}, \frac{v_{3m}}{\sum_{i=1}^p v_{1m}} \right) \quad (3)$$

where  $\tilde{v}_m = \left( \prod_{m=1}^M \tilde{a}_m \right)^{1/M}$

Step 3.3: Computation of Decision Weights ( $D_m$ ) for the Fuzzy Decision Weights using the equation  $D_m = [\beta c_\alpha(F_{lm}) + (1 - \beta) c_\alpha(F_{rm})]$ ,  $0 \leq \beta \leq 1$ ,  $0 \leq \alpha \leq 1$  (4)

Where

$c_\alpha(F_{il}) = [(F_{2m} - F_{1m})\alpha + F_{1m}]$  represents the left value of  $\alpha$ -cut for  $\tilde{F}_m$ , and

$c_\alpha(F_{ir}) = [F_{3m} - (F_{3m} - F_{2m})\alpha]$  represents the right value of  $\alpha$ -cut for  $\tilde{F}_m$ .

Step 3.4: Determining the Threat Influence Weights ( $TWC_j$ ) by normalizing  $D_m$

Step 4: Determining the Site-Risk Impact Weights ( $ZRW_{c_i}^{z_j}$ ) for the sites using the equation

$$ZRW_{c_i}^{z_j} = TI_{c_j}^{z_i} \times TW_{c_j} \quad (5)$$

Step 5: Scoring the threat classes for each category by the EA team according to their timing, range and severity, in relation to how likely they 'trigger' the bird species mortality at the study

sites, to get Threat Trigger Scores (TS, RS, SeS) of sites for each category. The scores are given in Table 3, Table 4, and Table 5.

**Table 3:** Timing of threat

Timing of threat	Timing score (TS)
Happening now	5
Likely in short term (within 4 years)	3
Likely in long term (beyond 4 years)	1
Past (and unlikely to return) and no longer limiting	0

**Table 4:** Range of threat

Range of threat	Range score (RS)
Whole population/area (>90%)	5
Most of population/area (50-90%)	3
Some of population/area (10-50%)	1
Few individuals/small area (<10%)	0

**Table 5:** Severity of threat

Severity of threat	Severity score (SeS)
Rapid deterioration (>30% over 7 years)	5
Moderate deterioration (10-30% over 7 years)	3
Slow deterioration (1-10% over 7 years)	1
No or imperceptible deterioration (<1% over 7 years)	0

Step 6: Scoring the threat classes using the 5-point scale by the EA Team to get the Species Threat Influence Score ( $STI_{c_{1k}}^{z_i}$ ) and ( $STI_{c_{2l}}^{z_i}$ ); k is the number of species, and l is the number of the habitat sub-types.

Step 7: Computing the total species threat impact score ( $TSTI_{c_{1k}}^{z_i}$ ) using the equation

$$TSTI_{c_{1k}}^{z_i} = STI_{c_{1k}}^{z_i} \times (TS + RS + SeS) \quad (6)$$

and total habitat threat impact score ( $TSTI_{c_{2l}}^{z_i}$ ) using the equation

$$TSTI_{c_{2l}}^{z_i} = STI_{c_{2l}}^{z_i} \times TS_{c_i}^{z_i} \quad (7)$$

Step 8: Calculating the overall Risk Impact Score ( $ORI_{c_j}^{z_i}$ ) for each category using the equation

$$ORI_{c_1}^{z_i} = TSTI_{c_{1k}}^{z_i} \times ZRW_{c_j}^{z_i} \quad (8)$$

and

$$ORI_{c_2}^{z_i} = TSTI_{c_{2l}}^{z_i} \times ZRW_{c_j}^{z_i} \quad (9)$$

### 2.5 Determining conservation status

The global conservation status of the birds of the study site is determined as per the IUCN guidelines. The local conservation status of the birds is determined on the basis of population trend, and average risk impact score (Figure 2). The species are categorized as Least Concern (LC), Vulnerable (VU), Near Threatened (NT), Endangered (EN) and Critically Endangered (CR) for local status.

The developed SFS Method is a combination of SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, Fuzzy AHP, and Simple Additive Weighted (SAW) Analysis that helps in identifying and prioritizing the strategies for a goal. The proposed methodology is developed to identify the internal and external parameters required for analyzing a problem quantitatively. These parameters are used to form a TOWS matrix to develop offensive strategies (SO: including strengths to exploit opportunities), reactive strategies (SW: aims to overcome the weakness by taking advantages of opportunities),

### 2.6 SFS (SWOT-FAHP-SAW) Methodology for C&M

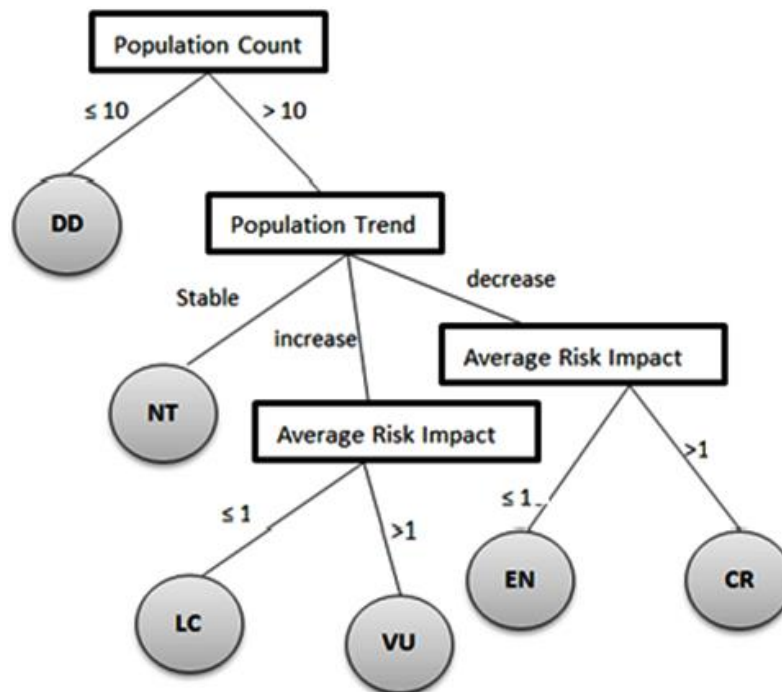


Figure 2: Criteria for determining local conservation status

defensive strategies (ST: strengths to avoid threats), and adaptive strengths (WT: reduce the weakness to avoid threats). Action Plans were then generated to implement the strategies.

The phases of the methodology are:

*Phase I: Identification of SWOT parameters and alternative strategies*

Step 1: Identification of SWOT parameters ( $p_m$ ,  $m = 1, \dots, M$ )

Step 2: Organizing these parameters in a SWOT matrix under each group ( $g_d$ ,  $d = 1, 2, 3, 4$ )

Step 3: Establishment of TOWS Matrix to develop  $s$  strategies ( $A_s$ ).

*Phase II: Prioritization of SWOT groups and parameters*

Step 1: Rating and ranking of  $g_d$  and  $p_m$  using pairwise-comparison (PC) questionnaire

Step 2: Generation of PC Matrix for each  $g_d$  and their corresponding  $p_m$  using the equations

$$g_d^R = \left( \prod_{q=1}^Q x_{dq} \right)^{1/Q} \quad (10)$$

$$p_m^R = \left( \prod_{q=1}^Q y_{mq} \right)^{1/Q} \quad (11)$$

Where  $x_{dq}$  is pairwise rating of the  $d^{\text{th}}$  group by  $q^{\text{th}}$  respondent, and  $y_{mq}$  is pairwise rating of the  $m^{\text{th}}$  parameter by  $q^{\text{th}}$  respondent

Step 3: Computation of Group Judgment Weights ( $gW_d$ ) and Parameter Judgment Weights ( $pW_m$ ).

Step 4: Computation of Global Judgment Weights ( $pJ_m^w$ ) using the equation.

$$pJ_m^w = gW_d \times pW_m \quad (12)$$

*Phase III: Rating alternative strategies  $A_s$  using following steps*

Step 1: Linguistic ranking of  $A_s$  based on the  $p_m$ .

Step 2: Conversion of linguistic terms in triangular fuzzy number  $\tilde{a}_m$  using 9-point fuzzy scale (Table 2).

Step 3: Formation of Fuzzy Decision Matrix to compute Fuzzy Decision Weights ( $\tilde{F}_m$ ) using equation (4)

Step 4: Computation of the Decision Weights ( $D_m$ ) using formula (5)

Step 5: Computation of SWOT weights using the equation

$$SW_m = pJ_m^w \times D_m \quad (13)$$

*Phase IV: Computation of Strategy Judgment Weights ( $SJ_s^w$ )*

The Strategy Judgment Weights ( $SJ_s^w$ ) are computed using the following equation

$$SJ_s^w = \sum_{m=1}^M SW_m \quad (14)$$

### 3. Results: The Avian Conservation Decision Support System (AC-DSS)

The developed AC-DSS is a computer-based conservation and management tool which implements various scientific methods and approaches that helps in

analyzing the avian diversity and generating strategies for effective Conservation of Aves and Management of their Habitats (C&M) in a semi-arid region. AC-DSS has been designed and developed with symbiotic approach to provide the necessary information and

analysis for interaction among conservationists and to enable them to make effective C&M decisions.

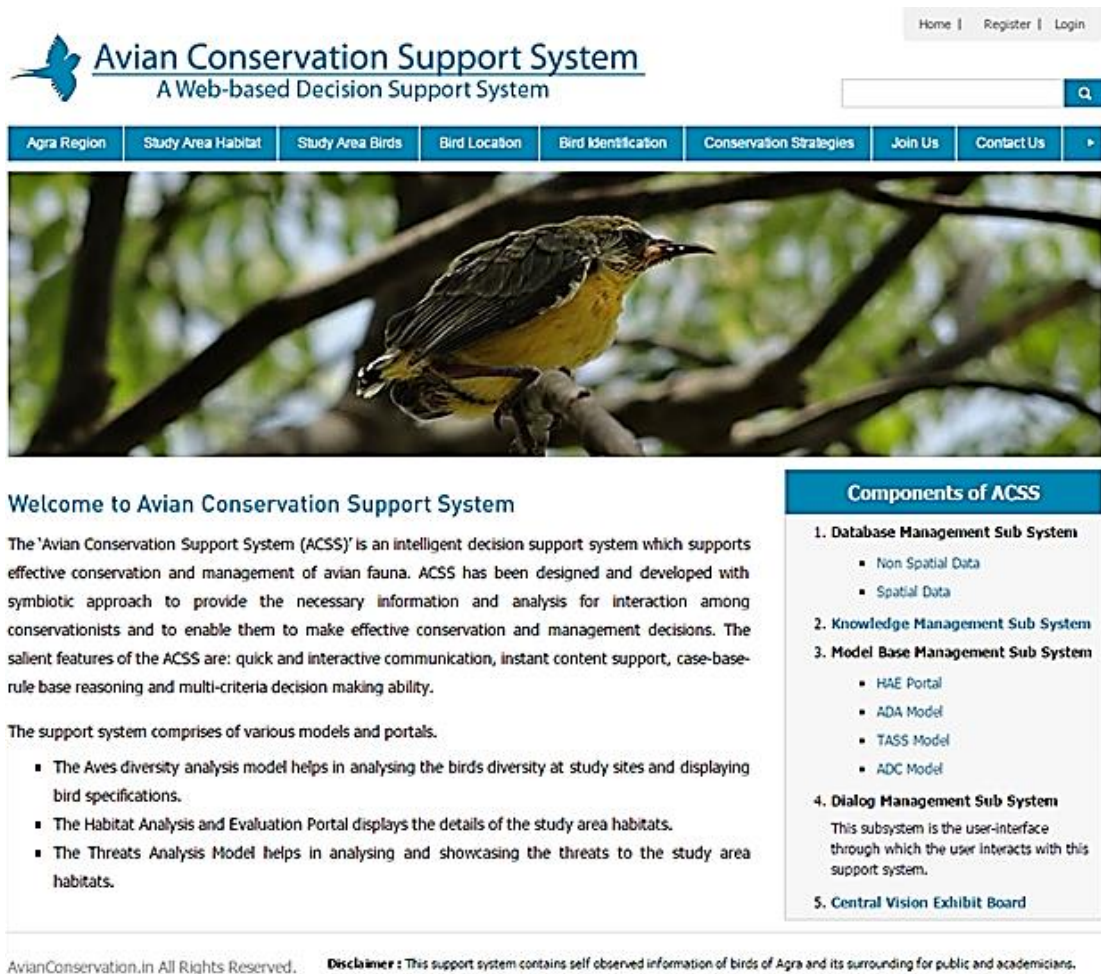


Figure 3: Opening Screen of the AC-DSS

The block diagram of AC-DSS architecture is presented in Figure 4. It describes the structure of individual components and relationships between different components of AC-DSS. The decision maker interacts with the DiM-SS which interacts with MBM-SS, DBM-SS, and KBM-SS either in isolation or in integration to facilitate decision support information. The results are then displayed on DiM-SS through CVE-Board.

The MBM-SS component provides the analytical capabilities to the system by making the use of C&M Decision Tools. The KBM-SS component of AC-DSS is responsible for rule-base, case base manipulation and provides knowledge and experience to MBM-SS to make decision-making process intelligent.



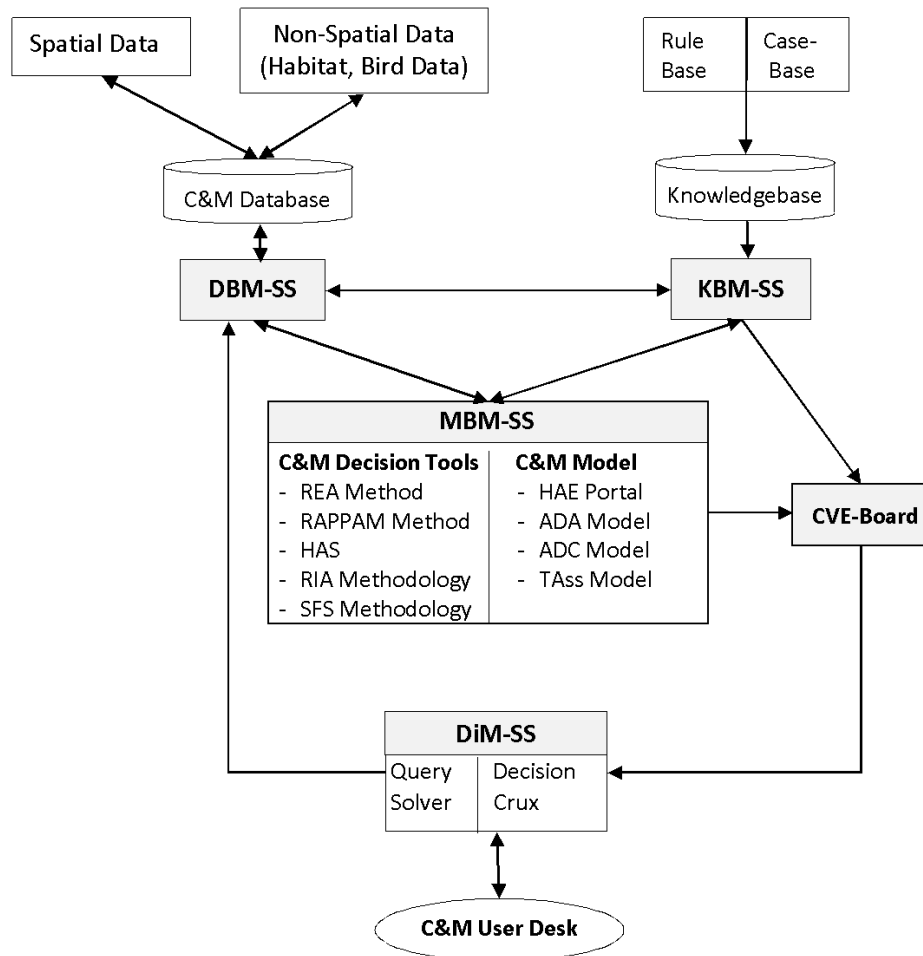


Figure 4: Architecture of AC-DSS

**3.1. Data Base Management Sub-System**

The DBM-SS is the fundamental part of the AC-DSS that provides the spatial and non-spatial data for analysis and evaluation. This sub-system consists of spatial (geometric location of sites) and non-spatial

data (Bird data and Habitat Data). The E-R model of the database used in this study is established in Figure 5 for representing the modeling parameters. Table 6 displays additional parameters considered in this study:

Table 6: Modeling parameters and their attributes

Parameters	Their Attributes
Population count	Number of sites, years, and number of counted individuals
Birds Demography	Population abundance, living status
Presence/Absence Data	Occurrence at site, occurrence in month
Threats	Threats to birds, threats to habitats

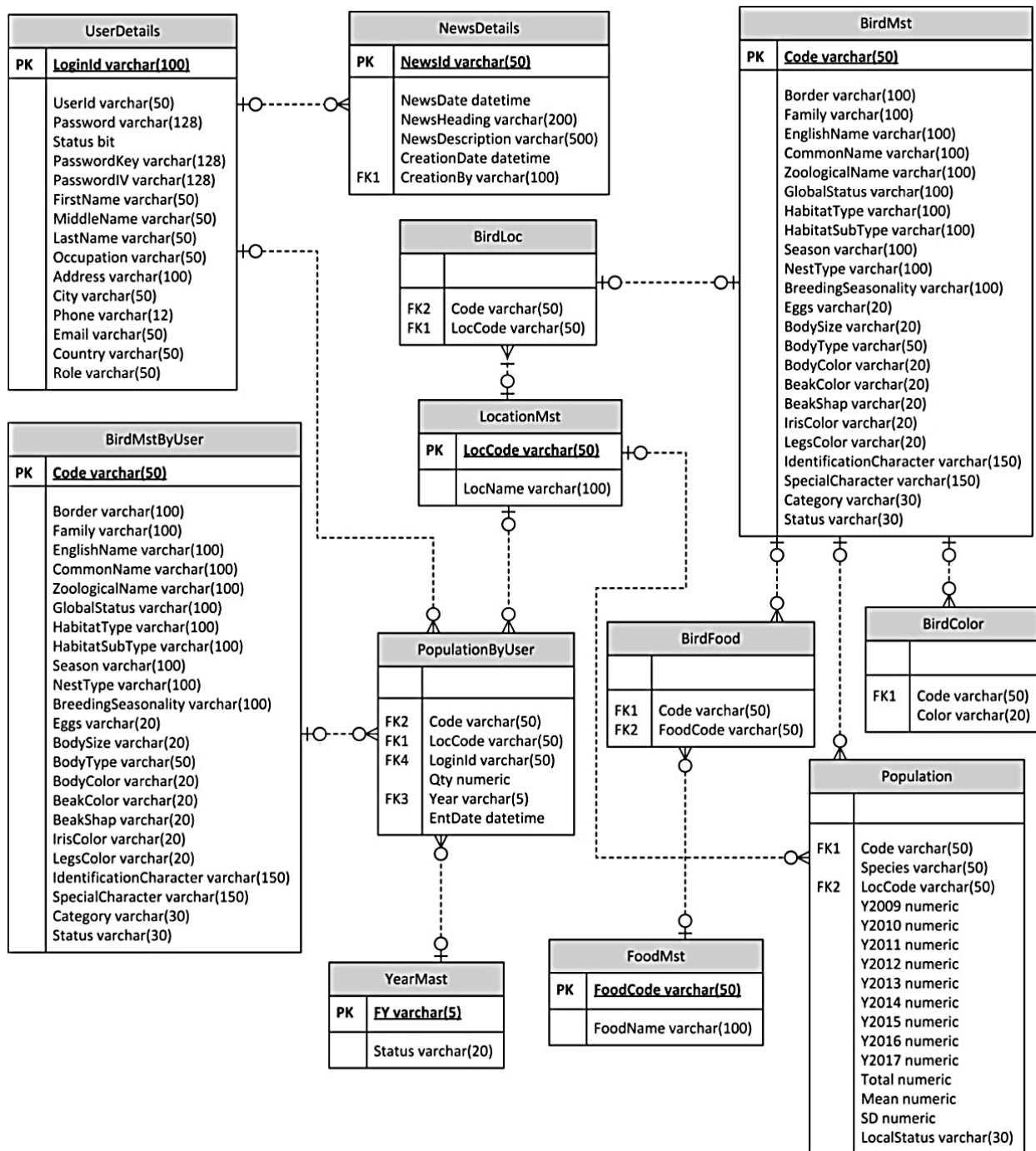


Figure 5: Normalized E-R model of the database

## 2.4 Knowledge Base Management Sub-System (KBM-SS)

The function of KBM Sub-System is knowledge retrieval, updation, deletion and reasoning. It utilizes its internal Knowledge base for reasoning, and communicates with the Database Management Sub-System via Model-base Management Sub-System for knowledge updation. The Knowledge Base holds representations of descriptive, procedural and/or

reasoning. Rule base and case-base are the two components of the sub-system.

### The Rule base

The C&M rules in the rule base specify a relation, and recommendation. C&M Rules are in the form of  
**if** <antecedent clauses> **then** <consequent clauses>

Sample rules are:

- Rule 1:*           if (BodyColor='LB')  
                          and if (BodySize='SM')  
                                  and if (BeakShap = 'SB')  
  then EnglishName = 'Common Kingfisher'  
  or EnglishName = 'Blue Throat'
- Rule 2:*           if (EnglishName= 'Peacock')  
                          and if (Season = 'Winter')  
                                  and if (HabitatType = 'Forest')  
  then LocName = 'SBS'
- Rule 3:*           if (HabitatType= 'Forest')  
                          and if (Season = 'Summer')  
                                  and if (LocName = 'KNP')  
  then Total =12

### 2.3 The Case base

The case-base allows to express the decision makers experience and knowledge, and thus uses it by comparing new case(s) with previously stored indexed cases, to retrieve those similar to the new situation. The process of solving a target case involved:

1. *Retrieving a Case:* The Retrieve task starts with the C&M problem description, and ends when a best matching previous case has been found.

When a new problem occurs it is compared with each case and most similar case is selected. Similarity can be assessed based on similarity of each feature, which depends on the feature value. If the degree of similarity of the feature ( $d_c$ ,  $c$  = number of cases) is 0 (not similar) or 1 (very similar), and priority weight of the feature is  $w_c$  (value ranges from 0 to 1) then the similarity is computed as

$$\text{Similarity} = \frac{\sum_{c=1}^C w_c \times d_c}{\sum_{c=1}^C w_c} \quad (15)$$

2. *Reusing a Case:* The case in the case-base, which is similar to the new case, is reused as the solution to the problem.
3. *Revising the Case:* The solution which was presented by utilizing the retrieved cases is evaluated according to its level of success. If the solution is fully successful then there remains no need for revision. If however, the solution failed to achieve its required goal, then it is revised according to certain rules.
4. *Retaining the Case:* In this phase the useful information has to be retained from the problem which was presented to it.

### 3.3 Model Base Management Sub-System (MBM-SS)

The Model Base Management Subsystem comprises of 4 model for effective C&M decision-making. The model uses the developed C&M-Decision Tools for analysis, and evaluation of Aves data. The models accept the data from Data Base Management Sub-system and Knowledge Base Management Sub-System and suggests a feasible solution.

- I. C&M-Decision Tools of the Model-base Management Sub-System are:

→ **REA (Rapid eco-regional Assessment) Method**

The REA Method (Carr et al., 2013) synthesizes exiting information for examining the ecological values, conditions, and trends within large connected areas that have similar environmental characteristics.

→ **Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) Methodology**

RAPPAM method (Ervin, 2003) is used for analyzing and comparing the importance, and the management effectiveness of the protected areas.

→ **Habitat Suitability Analysis**

The computed values can be used to measure the effects of land-use change on the habitats, and design inventories of Aves habitats which forms the basis for moderating plans.

→ **Risk Impact Assessment (RIA) Method**

The Risk Impact Assessment (RIA) Method is developed to compute the overall risk impact of the study site based on the threat classes. The developed method can be used by policy makers to analyze the risk impact of threats at the study site.

→ **SFS (SWOT-FAHP-SAW) Method**

The developed method is a foundation for evaluating the internal potentials and limitations, and the likely opportunities and threats from the external environment quantitatively. These strategies can help in predicting the changing trends and also in decision-making process of the organization.

II. The developed four models are:

**i. Habitat Analysis and Evaluation (HAE) Portal**

The Portal uses habitat suitability value to display the overview and the habitat suitability of the study area habitats. The Portal presents the optimal relationship between species distribution and the influential variables explaining presence/absence, abundance and breeding success of birds. The inputs to the portal are *geometric locations, habitat patch scores and pairwise comparison of each habitat type and sub-types*, and the output is *thematic maps of the sites and the habitat suitability value* which can be used to predict the presence of the Aves. The C&M Decision tools used in this model are REA, RAPPAM and HSA Methodologies.

The portal also helps in identifying the environmental variables that restrict the distribution of the birds. The environmental variables considered in this study are: measures of climate, landscape structure (for example connectivity indices), landscape heterogeneity (such as eco-tone cover), resources (such as food availability) and biotic information (like co-occurring competitors). These variables are chosen to reflect the following main influences on the bird species:

- Limiting factors: These are the factors that control the eco-physiology of the bird species (such as minimum winter temperature), or appearance (such as competition) and facilitation;
- Disturbances: These are all types of perturbations affecting the environment systems, for example fire frequency; and
- Resources: These are all materials that can be assimilated by organisms (e.g. availability of insects, or seeds).

**ii. Avian Diversity Analysis (ADA) Model**

Based on the sample-wise *population (individual and species) count* as input, the developed ADA Model analyses the *avian abundance*, classifies the *species* of the *habitat bio-geographically*, displays the

*community composition and species composition* of Aves, determines the *population trend* and helps in identifying the *dominant species*, and calculates the *diversity indices*, as outputs.

Taking *foraging, nesting and breeding seasonality behaviors* as input, *relative abundance* is calculated as output. *Month-wise distribution* was taken as input to get the *season preference* of birds as output. *Focal categories* of the birds were taken as input to get the *focal species* as output.

The model has analytical capability of answering C&M questions like: “Which bird is the most diverse at a particular site?”, or “Which site should be visited to see a peacock?” by providing on-line access to the textual and tabular data.

**iii. Threat Assessment (TAss) Model**

The TAss Model takes *threat impact scores* of threat classes for sites, habitats and for birds; *timing score* for site habitat and birds, *range score* for site habitat and birds and *severity score* for site habitat and birds; and *fuzzy pairwise comparisons* of the threat classes as input, and determines *risk impact to bird, habitat, and bird guilds* as the output. This model utilizes RIA Method for generating the output.

The model is able to answer the questions like:

- What are the main threats affecting the formal/informal protected areas, and how serious these are?
- What are the important management gaps in the Protected Area system?
- What are the most strategic interventions to improve the entire system?

which can provide the policy makers and wildlife authorities with a relatively quick and easy tool to compute the risk impact based on the identified threats that need to be addressed for improving management effectiveness in a protected area (formal/informal).

**iv. Avian Diversity Conservation (ADC) Model**

The ADC Model provides scientific analysis that supports conservation and management of birds. Based on the population count, threats, and management effectiveness, the strategies are generated for conserving the Aves. The

inputs to the model are *pairwise comparison of SWOT groups together with their parameters*, and *linguistic ranking of strategies* on the basis of SWOT parameters. The outcome of the model is *prioritized strategies*. SFS methodology is utilized to generate the output. The Model facilitates the policy framework for C&M decision making and helps in adjusting environmental policies and practices to maximize the sustainability.

### 3.4 Central Vision Exhibit Board

The CVE-Board is basically communication medium that enables information to be shared among the users. The board provides facility for viewing output in multimedia format (Text, Table, Chart or Image format).

### 3.5 Dialog Management Sub-System

The Dialog Management Sub-system is an important component that provides user-friendly graphical user interface for the users.

The Sub-system capabilities are broadly classified into two categories: Query Solver and Decision Crux due to the variety of C&M-Users with different decision making tasks. While Query Solver allows *ad hoc* retrieval of Conservation and Management information, Decision Crux supports the decision-making tasks using the C&M decision tools and allows the system users to generate a number of displays from the data available in the system, in a pre-defined format.

## 4. Case Study: Agra, a semi-arid region

This DSS was applied to the real-life conservation problem taking Agra, a city in Uttar Pradesh, India for case study. Agra is a highly biota-sensitive zone. The wildlife here is very rich, which is preserved at many formal and informal protected areas in and around Agra. The 4 major formal bird hotspots are: Keoladeo National Park (KNP), National Chambal Sanctuary (NCS), Patna Bird Sanctuary (PBS) and Soor Sarovar Bird Sanctuary (SBS). The informal bird hotspot, Dayalbagh Ecovillage (DEV), also provides a good number of wildlife inventories. In spite of the increasing urban pressure all around the area, these sites are able to sustain the Aves up to some extent due to a mix of aquatic habitat, forests, semi-arid zone, river and cultivations. This section shows how the AC-DSS is used to assess the conservation and management of Aves in Agra.

The semi-arid landscapes and their various environmental aspects (Water Quality, Habitat

Fragmentation by Barriers, Presence of Buffers Zones, Habitats and Biota of Special Concern), (as discussed with the EA Team, comprising of tropical dry deciduous vegetation and humid subtropical climate, are evaluated using the Rapid Eco-regional Assessment (REA) Methodology. The overarching environmental changes within the habitats was also assessed which includes climate change, invasive species, and urban growth. The habitats were also assessed to understand their ecological condition, floral trends, and prospects for green reserves conservation and restoration. Habitats of the study site were categorized into second and third-levels (Table 7).

Table 7: Hierarchy of habitat at study sites

Level 1	Level 2	Level 3
Grassland	Dry Savanna, Moist Savanna	
Scrubland	Xeric Shrubs	Dense foliage cover, Mid-dense foliage cover, Sparse foliage cover
Forest	Tropical Dry Forest	Saplings, Mature tree, Old-growth
	Tropical Seasonal Forest	Saplings, Mature tree
	Tropical thorn forests	Saplings, Mature tree
Bare Ground	Sand Dunes, Semi-arid Plains	
Urban Landscape	Farms, Gardens	
Wetlands	River	Upstream, Low stream, River Bank
	Lake/Pond	Perennial, Annual, Seasonal
	Marshes	Seasonal marshes, Permanent marshes
	Canal	Perennial, Annual, Seasonal

Habitat suitability analysis was performed to compute the habitat suitability values. Suitability of above habitats was analyzed on the basis of the following criteria (Calculations are given in Appendix 1).

**Table 8:** Description of the selected criteria

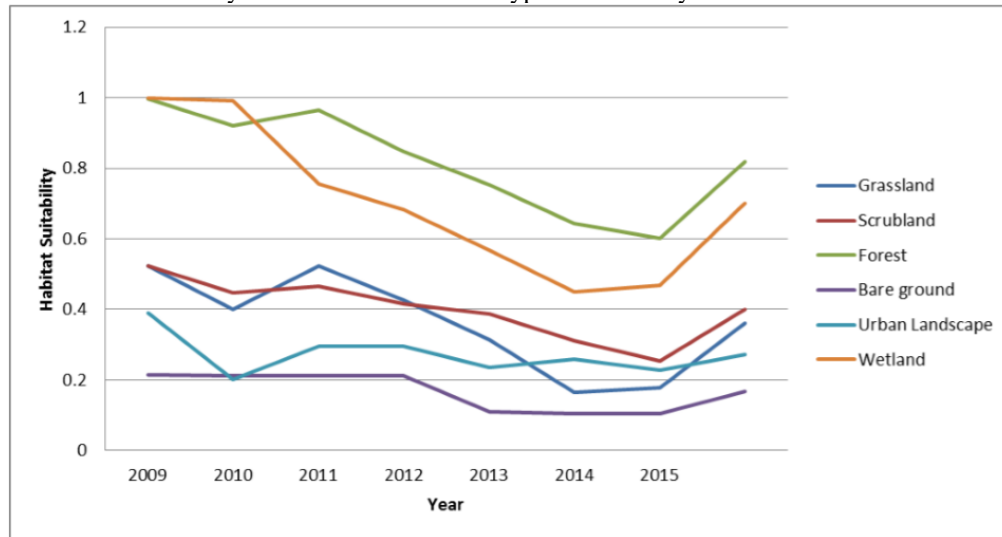
S.No.	Criteria	Description
1.	Demographic conditions of the habitat	The present absent data of the species and frequency of rare species
2.	Temporal geography	It concern the periodic geography of the pre and post habitat fragmentation
3.	Habitat quality	Considers habitat types that are suitable for a species
4.	Seasonal habitat change	
5.	Food availability	Considers availability of food for the species considered in the patch
6.	Nesting availability	Considers availability of food for the species considered in the patch
7.	Proximity to water	Considers stagnant or running freshwater sources, e.g., ponds, lakes, rivers in the patch or within the travel distances of an organism
8.	Arbitrary threats to the habitat	Pressure and threats due to land use change and development activities, and all other unwanted activities impacting wildlife (In RAPPAM)

Using the method discussed in Section 2.4, the computed  $HSV^{z_i}$  are:

**Table 9:** HSV for the study site

Grassland	Scrubland	Forest	Bare ground	Urban Landscape	Wetland	$HSV^{z_i}$
0.3858	0.4084	0.7252	0.2778	0.3188	0.7976	0.4444

Figure 7 illustrates the suitability index for all the habitat types of the study site from 2009-2015.



**Figure 7:** Habitat Suitability

As can be seen from the figure, the habitats of the study site were initially deteriorating, but gradually are improving.

After analyzing the habitats, the ADA model was used to assess the avian diversity of Agra. The outcomes are:

**a. Bio-geographical Classification of Birds**

The Bio-geographical classification of birds was examined according to their spatial presence in the study area. The study of bio-geography was performed in two phases. First the unbiased samples were taken and birds range was marked. In second phase, the ideal locations were studied

where the chances of bird occurrence was better. Bird dispersion throughout the habitat was observed to understand changes in their habitat preferences and their living styles due to the complexity of different climates, food availability, and presence of other species and predators.

**b. Species Composition of Aves at Agra**

A total of 305 bird species belonging to 22 orders and 59 families were observed at the study area. The sample sites of the study area is divided in to three complex habitat units– Terrestrial (n=188 birds), aquatic-terrestrial (n=85 birds), and aquatic (n=32 birds), where n is the number of counted birds. The bird population at different habitats of Agra is: Grassland (387), Scrubland (307), Forest (605), Bare ground (268), Urban Landscape (334), and Wetland (484) (The number shows overlapping of birds among different habitats).

The dominant order in this semi-arid region is Passeriformes. The living status at Agra includes native, migratory, local migratory and trespasser birds.

On the basis of the food habits, the birds were divided in 6 guilds: Carnivores, Carnivores-Herbivores, Carnivores-Scavenger, Herbivores, Omnivores, and Scavenger.

The diversity indices were calculated for the sample sites, the habitats, and the birds using Shannon Index and Pielou’s measure. The calculated diversity indices showed that the sites are quite diverse. The diversity index *H'* for sample sites show that terrestrial is the most diverse habitat type at all study sites. The water bodies are not able to sustain a large number of birds. Similarly *H'* for habitats shows that forest of

the study site and wetland are the most diverse habitat types. In general the forests have high diversity because of tree species composition and the wetland have high diversity because of varieties of food sources and varied sources of foraging.

**c. Identified Population Trend**

Decreasing trend was determined in 51% birds of Agra and increasing trend was observed in 42%, whereas 5 % birds were observed stable, and 2% were considered as data deficient. Further, gradual decreasing trend was found only in about 40% birds.

**d. Dominant Birds**

Dominant birds were identified on the basis of their relative abundance which was used to check their population trend. It was found that in Agra out of 16 dominant birds, only one 1 (House Crow) is either increasing or is stable.

**e. Recognized Focal Species**

On the basis of computed focal score, 35 birds were identified focal in Agra. This listing helped in making specific strategies for the birds that need immediate protection.

Next the TAss Model is used to analyze the threats at the study site.

A list of possible disturbance gradients to the study sites was compiled and was presented to the EA Team for analyzing the applicability of each disturbance gradient to the birds at the study sites. The disturbance gradients were grouped into threat classes. The resulting list displayed in Table 10, as agreed by the Team, formed the basis for the risk assessment.

Table 10: Threat classes (Few classes are shown)

Threat Class	Disturbance gradient	Type	Population components affected
Wildlife Crime	Poaching	Direct	Eggs, Juveniles, Adults
	Trading	Direct	Eggs, Juveniles
	Hunting	Direct	Adults
Pollution	Vehicular Pollution	Indirect	Juveniles
	Chemical run off	Indirect	Eggs, Juveniles
	Sewage and drain water	Indirect	Eggs, Juveniles

The threat classes were divided into two categories:

1. Threats direct to the birds (*c*<sub>1</sub>): These are the threats that are directly affecting the birds.

2. Threats to the habitats (*c*<sub>2</sub>): These are the threats affecting the habitats and thus are affecting the birds also.

Table 11: Threat Categories

Bird Threats	Habitat Threats
Wildlife Crime (WC)	Pollution (Pol)
Collision (C)	Habitat fragmentation (HF)
Emerging infectious disease (EID)	Human intervention (HI)
Human intervention (HI)	Tourism (T)
Tourism (T)	Over exploitation (OE)
Natural threats (NT)	Natural threats (NT)

The computation of  $ORI_{c_2}^{z_1}$  weights is given in Appendix 2.

### Threats to Habitats

Mature tree, old growth, dry and moist savanna, dense foliage cover, gardens, low stream, upstream, annual and perennial canals are among constant threat of **Habitat Fragmentation** ( $ORI_{c_2}^{z_1}$ : 52.56), **Human Intervention** ( $ORI_{c_2}^{z_1}$ : 66.09) and **Over Exploitation** ( $ORI_{c_2}^{z_1}$ : 43.61) with significant level of risk impact. Sand dunes, saplings, mid dense foliage cover, river bank and seasonal canal, lake and ponds and marshes are under pressure.

### Threats to Birds

**Human Intervention** ( $ORI_{c_2}^{z_1}$ : 74.12) and **Wildlife Crimes** ( $ORI_{c_2}^{z_1}$ : 65.50) are the main risks to the birds at this site.

### Management Effectiveness

Management effectiveness of the site was also evaluated using RAPPAM method. The protected areas of the study site are biologically important as it

possesses all the important factors like rich taxa, diverse vegetable, and strong food chain.

The relatively high market value of the protected area land and the ease of access make the site vulnerable. Law enforcement is needed, along with the intensive monitoring of the site for abolition of illegal activities (Figure 9). Degree of efforts for site restoration and mitigation should also be taken in account. The protected areas are suffering from laxity of staff and habitat negligence. Infrastructure development, related to wildlife protection and conservation are also needed.

### Determined relationship between the HSV and the bird population and threats

The relationship between HSV and the bird population is shown in Figure 11. The analysis demonstrates that there is a rapid deterioration in the suitability value of all the habitats of the study site.

Based on the HSV, the bird population can be predicted using the following equation, where habitat types were treated as independent variable (x) and the total population as dependent variable (y):

$$y_{SBS} = 120x_{scrub} + 119.10x_{forest} + 302.43$$

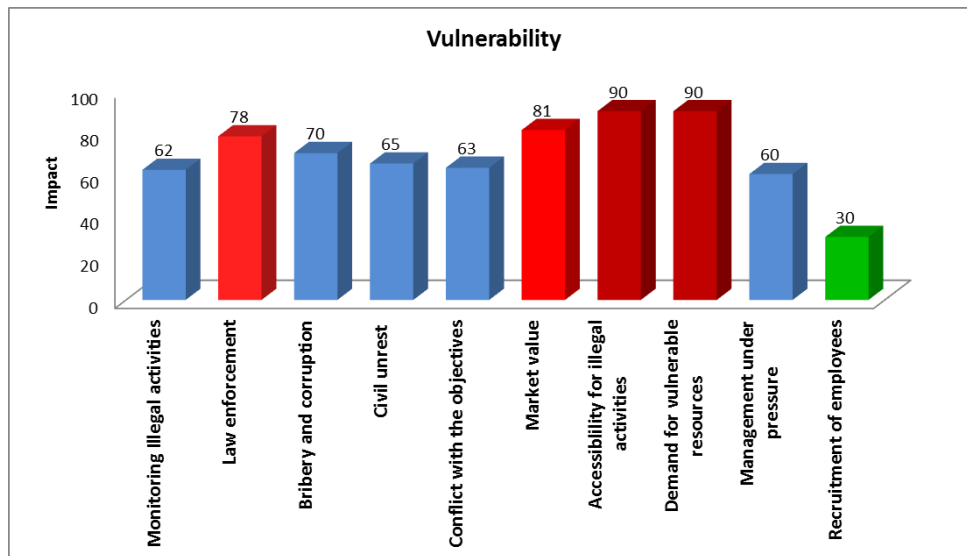


Figure 9: Vulnerability at the study site



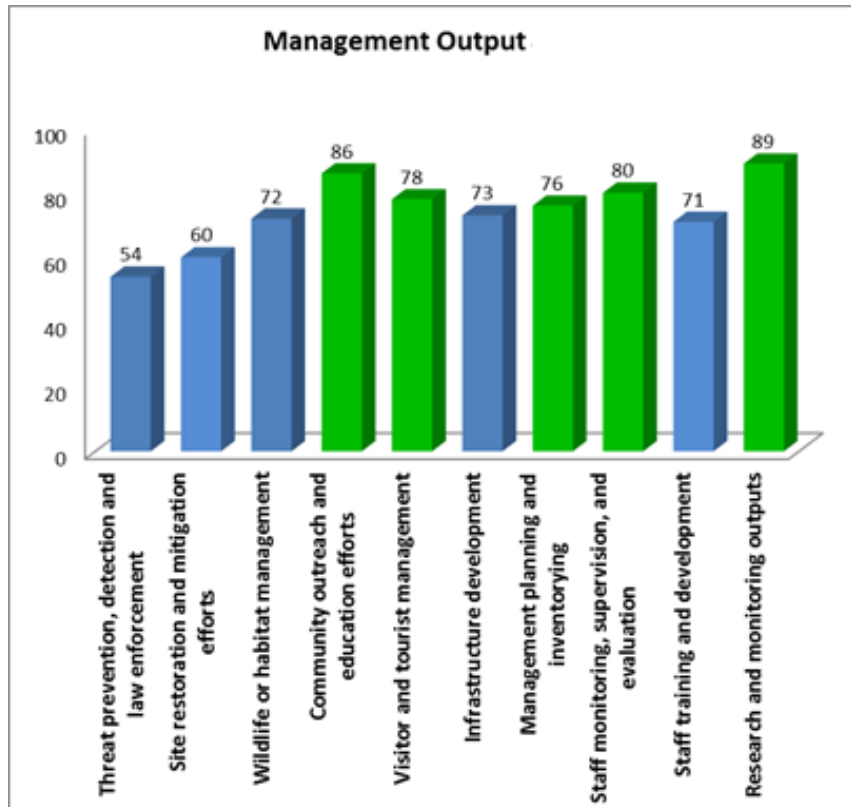


Figure 10: Management output

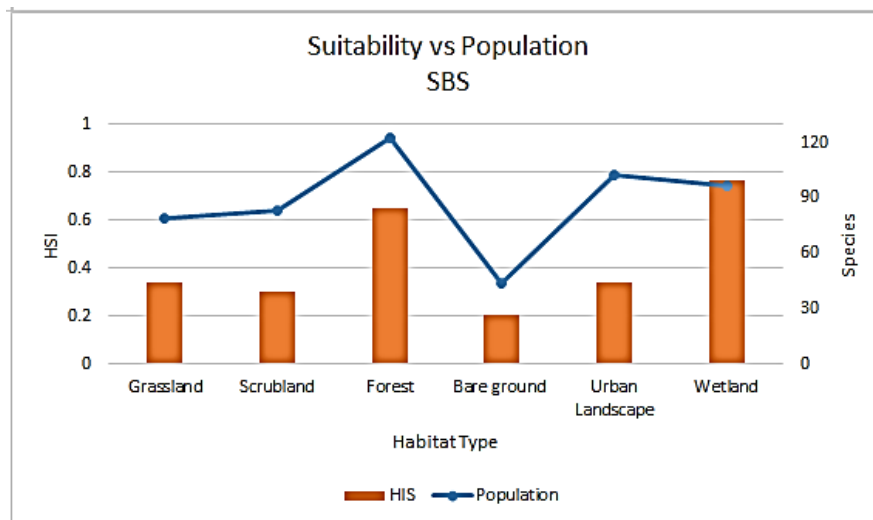


Figure 11: The Suitability vs. Population relation

Once the suitability and the threats were analyzed, the ADC model was used to generate the strategies for effective C&M. The computations are specified in Appendix 3.

Table 12 displays SWOT matrices for the study site. The identified SWOT parameters were grouped for making computation simple. This helped in generating the TWOS Matrix (Table 13).

Table 12: SWOT matrices

<b>Strengths (<math>g_1</math>)</b>		<b>Weaknesses (<math>g_2</math>)</b>	
(p1)	<i>Dynamic habitat</i> : Productive vegetation structure; Controlled natural disturbance	(p7)	<i>Crowded</i> : Mismanaged tourist crowd, surrounded by human habitations
(p2)	<i>Rich bird diversity</i> : Diverse species; Good number of native species population; Good number of migratory birds	(p8)	<i>Drained water body</i> : Problem of water fluctuation; Issues of continuous water stodgy source
(p3)	<i>Mixed Vegetation</i> : Long spread grassland, forest cover; Aquatic plantation mosaic habitat	(p9)	<i>Encroachment</i> : Teeming buffer zone; Rapid development around PA
(p4)	<i>Satisfactory infrastructure</i> : Well boundary, gradient landscape; Acceptable zoning research		
(p5)	<i>Knowledge Oriented</i> : Community schools for children; Training centre for staff; Base for wildlife research		
(p6)	<i>Tourist friendly</i> : Lodging facility; In park; Eco guide facility		
<b>Opportunities (<math>g_3</math>)</b>		<b>Threats (<math>g_4</math>)</b>	
(p10)	<i>Area expansion</i> : Chances to expend the area of lake; Prospective forestation; Increasing chance of boundary expend	(p13)	<i>Rapid development</i> : Increasing urbanization; Pacing industries
(p11)	<i>Strong food pyramid within PA</i> : Availability of fruit bearing trees; Rich aquatic fauna and flora	(p14)	<i>Pollution</i> : Chemical runoff from nearby agricultural land; noise pollution from nearby highway
(p12)	<i>Better tourism</i> : Chances to generate better tourism planning; Area available for night safari	(p15)	<i>Habitat disturbance</i> : Timber cutting; Livestock grazing
		(p16)	<i>Misbalanced ecosystem</i> : Species drift; Reduction in vegetation

Table 13: TOWS Matrix

	<b>Strengths</b>	<b>Weaknesses</b>
<b>Opportunities</b>	<p><i>SO: "Maxi-Maxi" Strategies</i>  <i>A1: Strategy of Restoration and reconciliation of the Habitat</i>: Examining the relationship between avian diversity population and habitat, this will generate the supportive data to identify suitable habitat for the species with precise habitat requirements of the bird.</p>	<p><i>WO: "Mini-Maxi" Strategies</i>  <i>A2: Strategy of Formulate and enact wildlife laws</i>: Emphasizing on new species that are recently fall under threatened bird list and generating critical laws for protecting neglected species.  <i>A3: Strategy of Conceptualize Sustainable Tourism Approach</i>: Redefining terms of sustainability in the area by over-arching paradigm, which incorporates new range of approaches for feasible tourism system</p>
<b>Threats</b>	<p><i>ST: "Maxi-Mini" Strategies</i>  <i>A4: Strategy of Maintaining large volume bird diversity</i>: Bird diversity should be maintained by landscape management, driven by the novelty research efforts</p>	<p><i>WT: "Mini-Mini" Strategies</i>  <i>A5: Strategy of Improvising water policies for water birds protection</i>: Integrating bird conservation concern to form dynamic wetland protection policy framework for better conservation and management</p>

Finally the computed Strategy Judgment Weights are:

Strategy Judgment Weights:

A1	0.2266
A2	0.197
A3	0.2027
A4	0.1802
A5	0.1935

Thus the C&M Strategies and Action plans are:

- *Restoration and reconciliation of the Habitat:* Examining the relationship between avian diversity population and habitat, this will generate the supportive data to identify suitable habitat for the species with precise habitat requirements of the bird.
- *Conceptualize Sustainable Tourism Approach:* Redefining terms of sustainability in the area by over-arching paradigm, which incorporates new range of approaches for feasible tourism system
- *Formulate and enact wildlife laws:* Emphasizing on new species that are recently fall under threatened bird list and generating critical laws for protecting neglected species.

## 5. Concluding Remarks

In this paper, Avian Conservation Support System is designed and developed for conservation and management of avian diversity. The main components of the DSS are discussed in this paper. The tool is innovative as it:

- combines three fields (Decision Support System, Operations Research, and Wildlife)
- gives decision based on the spatial and non-spatial data of a semi-arid region
- can be applied to analyze the avian diversity and suggest conservation measures for any semi-arid region.

The formulation of policies, goals, planning, coordination, balancing, prioritizing different initiatives and actions regarding conservation and management can only be done by bringing C&M stakeholders at a common platform, thus bridging the existing gap and facilitating effective decision making. The AC-DSS is an effort in this direction.

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**Appendix 1**

Suitability of above habitats was scored (linguistically) on the basis of the criteria specified in Table 6. For example the demographic condition of grassland was scored *Very High*, and so on. This scoring was then converted to numeric data as shown in Table A.1 to get  $x_{h_j}^{z_i}$  (Table A.2).

**Table A.1:** Scoring scheme for the criteria

1	.75	.5	.25	.1
Very High	High	Medium	Low	Not suitable

**Table A.2:**  $x_{h_j}^{z_i}$  scoring (example shows the scoring of 2 types only due to space limitation)

Grassland	1	Dry Savanna	0.75		
		Moist Savanna	1		
Scrubland	1	Xeric Shrubs	1	Dense foliage cover	1
				Mid-dense foliage cover	0.75
				Sparse foliage cover	0.75

Next the relative importance of the habitats was scored and was averaged to find the Habitat Suitability

weights ( $HW_h^{z_i}$ ) as shown in Table A.3. Similarly the matrices for all the scales were developed.

**Table A.3:** The Relative Importance Matrix for first scale habitats (after averaging)

	Grassland	Scrubland	Forest	Bare ground	Urban Landscape	Wetland	HS Weights
Grassland	1.00	0.42	0.15	3.43	1.86	0.16	0.076
Scrubland		1.00	0.22	3.71	0.45	0.20	0.087
Forest			1.00	6.43	5.14	1.29	0.361
Bare ground				1.00	0.22	0.16	0.032
Urban Land					1.00	0.15	0.09
Wetland						1.00	0.354

These weights were then used to calculate Habitat Suitability Values ( $HSV^{z_i}$ ), using equation (3) (Table 9).

**Appendix 2**

The Threat categories (Table 11) are scored for each category (Table B.1), which resulted in Threat Influence Score ( $TI_{c_j}^{z_i}$ ) as shown in Table B.2.

Table B.1: Threat classes scored of all sites for category 1 (i.e. bird)

	<b>KNP</b>	<b>NCS</b>	<b>PBS</b>	<b>SBS</b>	<b>DEV</b>
<b>WC</b>	M	H	H	H	L
<b>C</b>	M	L	M	M	M
<b>EID</b>	L	L	M	M	M
<b>HI</b>	M	L	H	H	M
<b>T</b>	H	L	M	H	L
<b>NT</b>	M	H	M	H	M

Table B.2:  $TI_{c_j}^{z_i}$  at sites for category 1

	<b>KNP</b>	<b>NCS</b>	<b>PBS</b>	<b>SBS</b>	<b>DEV</b>
<b>WC</b>	3	5	5	5	1
<b>C</b>	3	1	3	3	3
<b>EID</b>	1	1	3	3	3
<b>HI</b>	3	1	5	5	3
<b>T</b>	5	1	3	5	1
<b>NT</b>	3	5	3	5	3

Then Threat Influence Weights ( $TW_{c_j}$ ) were determined as specified in step 3.4.

$TW_{c_j}$  for threat category 1

<b>WC</b>	0.2911
<b>C</b>	0.0821
<b>EID</b>	0.1035
<b>HI</b>	0.3294
<b>T</b>	0.1177
<b>NT</b>	0.0762

The Site-Risk impact weight ( $ZRW_{c_i}^{z_j}$ ) was computed using equation (6) as

Table B.3:  $ZRW_{c_i}^{z_j}$  for threat category 1

	<b>WC</b>	<b>C</b>	<b>EID</b>	<b>HI</b>	<b>T</b>	<b>NT</b>
<b>KNP</b>	0.873	0.246	0.104	0.988	0.588	0.229
<b>NCS</b>	1.456	0.082	0.104	0.329	0.118	0.381
<b>PBS</b>	1.456	0.246	0.311	1.647	0.353	0.229
<b>SBS</b>	1.456	0.246	0.311	1.647	0.588	0.381
<b>DEV</b>	0.291	0.246	0.311	0.988	0.118	0.229

Next the threat classes were scored by the EA Team to get the Species Threat Influence Score ( $STI_{c_{1k}}^{z_i}$ ) which

was used to calculate Total species threat impact score ( $TSTI_{c_{1k}}^{z_i}$ ) using equation (7).

Table B.4:  $TSTI_{c_{1k}}^{z_i}$  for few birds

<b>Bird Code</b>	<b>Species</b>	<b>WC</b>	<b>C</b>	<b>EID</b>	<b>HI</b>	<b>T</b>	<b>NT</b>
PSAc247	Bank Myna	11	7	9	39	75	7
AAAn001	Bar headed Goose	33	35	9	13	15	35
PHHi193	Barn Swallow	11	7	27	13	15	7
TTTu295	Barred Buttonquail	55	7	9	13	15	7
PPPI222	Baya Weaver	11	7	9	13	15	7
FAAc116	Besra	11	7	9	13	75	7

Then the Overall Risk Impact Score ( $ORI_{c_j}^{z_i}$ ) was calculated for category 1 using the equation (9).

Table B.5:  $ORI_{c_j}^{z_i}$  for few birds

Bird Code	Species	WC	C	EID	HI	T	NT
PSAc247	Bank Myna	9.607	1.723	0.932	38.545	44.130	1.600
AAAn001	Bar headed Goose	28.822	8.615	0.932	12.848	8.826	7.998
PHHi193	Barn Swallow	9.607	1.723	2.795	12.848	8.826	1.600
TTTu295	Barred Buttonquail	48.036	1.723	0.932	12.848	8.826	1.600
PPPI222	Baya Weaver	9.607	1.723	0.932	12.848	8.826	1.600
FAAc116	Besra	9.607	1.723	0.932	12.848	44.130	1.600

Similarly the  $ORI_{c_j}^{z_i}$  was computed for all habitats and all bird guilds. These values helped in determining the major threats to habitats and bird of Agra.

### Appendix 3

#### Phase I: Identification of SWOT parameters and alternative strategies

The opinion of EA Team helped in identifying parameters ( $p_m$ ) relevant to internal and external C&M environment. These parameters were categorized into four groups ( $g_d$ ): strengths, weaknesses, opportunities and threats. A SWOT matrix was formed using  $g_d$  together with their corresponding  $p_m$ . Table 12 displays SWOT matrices for the study site. The

identified SWOT parameters were grouped for making computation simple.

Next the EA Team investigated the alternative strategies based on TOWS matrix (Table 13) to identify offensive strategies, reactive strategies, defensive strategies, and adaptive strengths.

#### Phase II: Prioritization of SWOT groups and parameters

Pairwise-Comparison (PC) ranking was performed for the  $g_d$  and  $p_m$ . These were then averaged to find the PC matrix for each group:

Table C.1: PC Matrix for  $g_1$

	p1	p2	p3	p4	p5	p6	Weights
p1	1.000	2.250	3.000	4.880	5.000	3.130	0.375
p2		1.000	1.000	3.880	2.880	5.000	0.219
p3			1.000	2.000	3.000	4.750	0.182
p4				1.000	2.880	2.500	0.102
p5					1.000	3.130	0.073
p6						1.000	0.049

Similarly the PC Matrices were generated for  $g_2$ ,  $g_3$ , and  $g_4$ . These gave the local weights for all the SWOT parameters (Table C.2).

Table C.2:  $pJ_m^w$  of SWOT parameters

SWOT Groups	Weights	SWOT parameters	Local weights	Global Weights
$(g_1)$ Strengths	0.469	(p1) Dynamic habitat	0.375	0.1759
		(p2) Rich bird diversity	0.219	0.1027
		(p3) Mixed Vegetation	0.182	0.0854
		(p4) Satisfactory infrastructure	0.102	0.0478
		(p5) Knowledge Oriented	0.073	0.0342
		(p6) Tourist friendly	0.049	0.0229
$(g_2)$ Weaknesses	0.132	(p7) Crowded	0.532	0.0702
		(p8) Drained water body	0.331	0.0437
		(p9) Encroachment	0.137	0.0181
$(g_3)$ Opportunities	0.284	(p10) Area expansion	0.553	0.1571
		(p11) Strong food pyramid within PA	0.292	0.0829
		(p12) Better tourism	0.155	0.0440
$(g_4)$ Threats	0.114	(p13) Rapid development	0.478	0.0545
		(p14) Pollution	0.157	0.0179
		(p15) Habitat disturbance	0.095	0.0108
		(p16) Misbalanced ecosystem	0.270	0.0308

Phase III: Rating alternative strategies  $A_s$

Linguistic ranking of  $A_s$  based on the  $p_m$  was performed which were converted into triangular fuzzy number, for example the linguistic term VH will be converted to triangular fuzzy number  $\tilde{9} = (7, 9, 9)$ . The terms in the triplet  $(a_{1m}, a_{2m}, a_{3m})$  represent the

lower, middle and upper triangular fuzzy number respectively. Fuzzy Decision Matrix was formed to compute Fuzzy Decision Weights (Table C.3). These were then used to calculate  $c_\alpha(F_{il})$ ,  $c_\alpha(F_{ir})$ .

Table C.3: Fuzzy Decision Matrix for KNP

	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	p15	p16
<b>A1</b>	0.073	0.100	0.127	0.086	0.086	0.100	0.046	0.023	0.023	0.117	0.100	0.100	0.046	0.023	0.046	0.046
<b>A2</b>	0.049	0.049	0.049	0.024	0.024	0.024	0.128	0.108	0.128	0.108	0.108	0.128	0.049	0.024	0.024	0.049
<b>A3</b>	0.048	0.048	0.048	0.024	0.024	0.024	0.126	0.107	0.126	0.126	0.107	0.126	0.048	0.024	0.024	0.048
<b>A4</b>	0.059	0.116	0.072	0.085	0.116	0.099	0.045	0.023	0.023	0.045	0.045	0.023	0.099	0.085	0.085	0.116
<b>A5</b>	0.112	0.112	0.070	0.082	0.095	0.095	0.044	0.044	0.023	0.023	0.044	0.023	0.095	0.112	0.082	0.112

Next Global Judgment Weights are multiplied by Decision Weights using equation (14) to get SWOT weights. Finally the Strategy Judgment Weights are

computed using equation (15). Next the strategies were also generated.

Strategy Judgment Weights:

- A1 0.2266
- A2 0.197
- A3 0.2027
- A4 0.1802
- A5 0.1935

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