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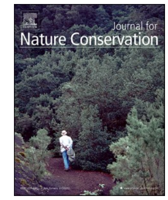

To a charismatic rescue: Designing a blueprint to steer Fishing Cat conservation for safeguarding Indian wetlands

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A R T I C L E I N F O

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A B S T R A C T

Wetland conservation in the Indo-tropics can benefit from the protection of the charismatic Fishing Cat. India, supporting ~ 40% of its known range, is a stronghold for the species. Here, using multiple information sources we outline a framework to safeguard fishing cats in India. Specifically, we a) estimated district-level Conservation priority scores (using presence records, and habitat suitability and habitat connectivity) to identify ecologically important habitats, b) estimated state-level Conservation likelihood scores assessing the success potential of any conservation intervention, c) collated district-level Conservation initiative information identifying ongoing efforts for species and/or habitat conservation. We consecutively assessed the spatial congruence between (a), (b) and (c) to delineate species' conservation areas and corresponding action goals (blueprint). Using information on habitat suitability, we also delineated survey landscapes. Although Fishing Cat records were found in 12 Indian states, only a small proportion of the state area was identified harbouring optimal habitat for the species. Three broad habitat clusters - Terai arc, Eastern coast, and Brahmaputra floodplains - were identified, with overall high habitat connectivity. Most districts ranking high in Conservation priority scored low in Conservation likelihood. Districts with Fishing Cat presence (n = 60) were delineated into four tiers of action landscapes and the majority of districts classified as survey landscapes (n = 156) were found in the Terai arc. We use our results to recommend and discuss conservation actions for districts identified in our blueprint. Flagship species conservation approach has substantial potential to enrich wetland conservation, for which our blueprint can act as a baseline.

1. Introduction

Wetlands, including mangroves, rivers, lakes, and floodplains are areas where the ground-water table is at or near the land surface. Besides supporting numerous rare and threatened species, tropical wetlands also provide crucial ecosystem services like freshwater supply, fisheries support, and carbon sequestration, thereby also supporting livelihoods of several communities globally (Junk et al., 2006). Yet these systems are stressed from intrusive anthropogenic activities resulting in their rapid shrinkage and degradation (Junk et al., 2013; Gardner and Finlayson, 2018). The importance of these ecosystems in helping build climate resilience has also gained global attention (Gokce, 2019), with a call to act for their protection and restoration at the Glasgow CoP26 meeting in 2021. While protecting such large ecosystems can be complex, promoting flagship species conservation may be a more efficient alternative to safeguard them (Senzaki et al., 2017). In this regard, charismatic species have previously been used as flagships for ecosystem conservation (Xiang et al., 2011; Thompson and Rog, 2019). Here, we propose that promoting a habitat specialist predator, the Fishing Cat *Prionailurus viverrinus* as a flagship species for wetlands, can help conserve these dwindling ecosystems in the Indo-tropics.

The Fishing Cat is a threatened medium-sized felid found in at least eight countries across South-East Asia. Although it has a wide geographical distribution, most of its populations are reported to be fragmented (Mukherjee et al., 2016), which has been attributed to the strong association of the species with wetlands. Classified as Vulnerable by the IUCN, Fishing Cat populations are considered to be declining on account of shrinking wetland habitats and serious threat of direct

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persecution in the form of retaliatory killings as a result of economic losses to locals (Adhya et al., 2011; Mukherjee et al., 2016). Despite its threatened status, basic information on populations vital for their conservation is scarce. Surviving in rapidly degrading wetlands across South-East Asia, this little-known felid exemplifies the problems faced by many species in the developing economies of the Indo-tropics.

Often, conservation efforts targeted to halt the loss of spaces and species in the Indo-tropics, are fraught with challenges including over-hunting and over-harvesting of resources, spread of invasive species, etc. (Bradshaw et al., 2009). Socio-political challenges such as insufficient funding for conservation, non-recognition of ecosystem services and limited interests in maintenance of current and creation of new protected areas (Adenle et al., 2015; Ghosh-Harihar et al., 2019), only add to these complexities as they stand in contrast to the long-term conservation needs of tropical biomes. This multidisciplinary and complex nature of conservation demands the creation of a well-planned blueprint to safeguard species survival. While a typical approach involves ranking areas in terms of their Conservation priority based on species population parameters and availability of suitable habitat, it is oblivious to socio-political factors like availability of funds, stakeholder willingness, political outlooks, and ongoing conservation efforts, that may act as proxies for implementation and success of applied conservation actions. In a nuanced approach, the spatial congruence of ecological as well as socio-political measures can help in determining area-specific conservation actions needed to safeguard species. This concept of incorporating relevant socio-economic factors that are likely to affect conservation success is termed as Conservation likelihood (Dickman et al., 2015).

In this paper, we have collated and analysed information from multiple sources on the habitat and ecology of the Fishing Cat. Incorporating socio-economic and political details to this data, we identify key conservation areas in India and outline broad research and conservation goals for the species. Harbouring around 15 known areas of its distribution, comprising $\sim$ 40% of the total known range area of the species, India is an important stronghold for the Fishing Cat (Mukherjee et al., 2012; Silva et al., 2020). These areas are widely distributed along the Himalayan foothills, Brahmaputra floodplains and Eastern coasts with isolated records from Central India (Mukherjee et al., 2016), most of which fall outside the boundaries of protected areas in the country (Duckworth et al., 2014). The widespread yet fragmented distribution of the Fishing Cat in India presents unique challenges for understanding and conserving the species, where conservation actions often limited by funds can benefit from science-based prioritization. In a large and multicultural country like India, factors driving the success of conservation actions can differ greatly across the country based on landscape, demography and/or governmental policies. This heterogeneity and complexity accentuates the need for a strategic multi-dimensional blueprint of conservation strategies for the Fishing Cat in India at the scale of appropriate administrative units.

The generation of such a Conservation blueprint however, is difficult due to unavailability of detailed information, more so for a species of limited understanding. In such cases, information gathered remotely and from diverse sources (Groves, 2003; Srivathsa et al., 2020), e.g., satellite data, newspaper reports, etc. becomes crucial to understand species ecology and conservation priorities. In this paper, assessing the spatial congruence between a) Conservation priority scores, b) Conservation likelihood scores, and c) ongoing conservation efforts, we identify important areas and potential actions for conservation of the species in the country, while also identifying districts where exploratory surveys for the species should be targeted. We use our results to discuss the present ecological and conservation status of the Fishing Cat in India and draw broad yet tangible research and conservation goals for different areas to efficiently safeguard the survival of the species in the country. With limited data, we demonstrate the use of a framework that could be employed to understand and conserve the many elusive and data scarce species that occupy not only wetlands but various tropical ecosystems all over the world.

2. Materials and methods

To construct a Conservation blueprint for the Fishing Cat in India, we estimated and compared scores of Conservation priority and Conservation likelihood at relevant spatial scales, broadly following an established framework (Dickman et al., 2015; Srivathsa et al., 2020).

2.1. Conservation priority

To identify key areas of conservation importance for the Fishing Cat, we used available information on species presence and ecology. With most knowledge on the distribution of the Fishing Cat emerging from sporadic surveys (Mukherjee et al., 2012; Mukherjee et al., 2016; Rana, 2021), our first objective was to identify areas with key habitats for the species across the entire country. To achieve this, we constructed a habitat suitability map for the species using MaxEnt modelling (Phillips et al., 2006), which was then used to generate an omnidirectional habitat connectivity map (Pelletier et al., 2014) to understand how the identified habitats may be connected.

2.1.1. Habitat suitability modelling

Habitat suitability models have been used extensively to understand species-habitat relationships and predict current and future occurrence ranges for species (Gebrewahid et al., 2020). With the ability to work with most commonly available ecological data (presence only records and environmental variables), these models have been widely regarded as important tools for conservation (Guisan et al., 2013; Swan et al., 2021).

We collected occurrence records of the Fishing Cat from the year 2000 onwards, from across the Indian sub-continental mainland using various sources including peer reviewed papers, published theses, and government reports (Table A1, Appendix A). We first removed duplicate records and then spatially filtered out points in close proximity, by applying a circular buffer with a radius of 2 km, corresponding to a home-range size of $\sim$ 12 km^2 (Cutter, 2014), around each point to minimise bias induced by uneven sampling effort (Kramer-Schadt et al., 2013). We selected environmental variables to explain the habitat suitability of the species based on information from previous studies and known ecology of the Fishing Cat (Adhya et al., 2011; Mukherjee et al., 2012; Silva et al., 2020).

We used Maximum Entropy (MaxEnt) models to understand how environmental factors may affect fishing cats and consecutively predict their distribution. MaxEnt models work by minimising relative entropy between occurrence locations and the landscape in the covariate space (Elith et al., 2010). These models provide robust predictions at large spatial scales based on limited data and have been widely used in the field of species conservation (Kaky et al., 2020). MaxEnt modelling requires both presence and absence data, but when the latter is not available, pseudo-absence or background data are explicitly generated (Phillips et al., 2006). Methods used to sample background points can greatly affect MaxEnt results (Phillips et al., 2009, Merow et al., 2013), and therefore must be appropriated by the question of interest. One approach is to select areas within a specified distance from known presence locations of a species and sample points randomly from within the areas. This typically leads to better model sensitivity and hence is suitable for rare and elusive species (Barbet-Massin et al., 2012). The buffer distance around each presence location is selected such that it may reflect areas that are accessible to the species via dispersal, yet lack species presence (Merow et al., 2013). However, since our knowledge of Fishing Cat distribution in India is nascent, with several recent and sporadic records (Talegaonkar et al., 2018; Dutta et al., 2021), we chose a large buffer size of 1 degree ($\sim$111 km) around each filtered presence location to sample 10,000 background points (Barbet-Massin et al., 2012) for further analysis.

To avoid model overfitting, we retained only uncorrelated variables that could provide a parsimonious explanation to the distribution of the species. We estimated pairwise correlation between all 19 bioclim variables and filtered out the ones showing high correlation (Pearson's r >= 0.7) with more than 6 other variables. Additionally, we checked for the degree of spatial autocorrelation for each variable and retained only the ones with low spatial autocorrelation (<1000 km). The final set of variables used to model Fishing Cat distribution across the Indian subcontinent are provided in Table 1.

MaxEnt allows for the modelling of complex response curves using various feature classes, but this can also make it difficult to separate non-linear signals from noise (Merow et al., 2013), and therefore may not be suitable for predicting species distribution across a large geographic space. Withstanding this we only ran models using three feature classes i.e., Linear (L), Linear Quadratic (LQ), and Linear Quadratic Product (LQP). We ran three separate models for each feature class with regularisation multipliers set to 1, 1.5 and 2, to avoid overfitting. We ran 5 replicates of each model with 5000 iterations to allow for model convergence. Conventional data partitioning methods to create training and test datasets for MaxEnt can often lead to overestimation of the 'area under a relative operating characteristic curve' or AUC value (Valavi et al., 2019), which is widely regarded as a metric of model performance (Baldwin, 2009). Therefore, we partitioned our presence-background data into spatial blocks, where the extent of each block was defined using information on spatial autocorrelation of predictor variables, assessed using the *blockCV* package (Valavi et al., 2019) in R v 4.0.5 (R Core Team, 2022). Five folds were assigned to these blocks randomly and for each replicate, data from four of the folds were used to train the model while that from the remaining fold was used to test it. Results from all replicates were averaged for further inference and analyses, including the assessment of the importance of variables in predicting species distribution. All models were run using the *dismo* package in R v4.0.5 (Hijmans et al., 2021).

To select the best performing model, we first chose models with high test AUC values (greater than0.8). Amongst these, we selected a single model based on a) low AUC difference between training and test datasets (high values may indicate overfitting), b) high True Skill Statistic (TSS) value, and c) low omission rates based on 10th percentile presence, and equal sensitivity and specificity thresholds, upon which we based our further inferences.

Table 1
A list of environmental factors used to model the habitat suitability of the Fishing Cat.

Predictors of Fishing Cat habitat suitability	Description	Prediction
Bioclimatic variables (mean diurnal temperature range, mean precipitation of the driest, warmest, and coldest quarters)	Uncorrelated measures of temperature and precipitation	Habitat suitability would be greater in wet areas with moderate temperatures
Elevation	Mean height above the sea level	Habitat suitability would be greater in low lying areas
Land use land cover (2012)	Includes different land cover types such as agriculture, forests, built-up areas, etc.	Habitat suitability would be greater in wetlands, grasslands, and agricultural fields
Human population density	Projected number of people per sq. km for the year 2020	Habitat suitability would be greater in areas with low human density
Soil water content	Total moisture content in the soil after accounting for evapotranspiration and soil water loss	Habitat suitability would be greater in areas with greater soil water content

Note: All environmental rasters were resampled to the coarsest available resolution of 5 km in the software QGIS v3.16 for further analysis.

2.1.2. Habitat connectivity modelling

Electrical circuit theory has been commonly used to model connectivity across habitats within a landscape (Rayfield et al., 2011). As per this theory, organisms (current) move across habitat patches (focal nodes) through paths with differing movement probabilities (voltage) based on habitat permeability (resistance) (McRae et al., 2008). This approach identifies probabilities of movement as opposed to a single least cost path, and therefore provides a precise overview of connectivity across habitats (Urban et al., 2009). Most connectivity models, however, are designed to understand connectivity across pairs of points or patches (Walpole et al., 2012), limiting their scope in mapping landscape-level connectivity across large areas. A recent development by Pelletier et al. (2014) has overcome this problem by estimating omnidirectional connectivity using the software *Circuitscape* (McRae and Shah, 2009). This approach includes passing current across the surface of resistance raster tiles in orthogonal directions and deriving the product of the two output rasters to estimate landscape level omnidirectional connectivity.

Considering that we were mainly interested in understanding how identified suitable habitats were interconnected, we used the output from our MaxEnt model for the omnidirectional connectivity analysis. Keeley et al. (2016) suggested that dispersing animals may be more tolerable to low quality habitats. So, instead of linearly transforming habitat suitability values to habitat resistance values, we used a c8 negative exponential transformation function to generate the resistance raster (Keeley et al., 2016). This function specifies high resistance values to only the lowest habitat suitability areas, and thus may account for dispersing individuals. To model connectivity using this resistance layer, we followed the approach detailed in Pelletier et al. (2014). Further details on this analysis can be found in Appendix B.

2.1.3. Estimating conservation priority scores

Habitat suitability maps may not represent the occupancy or abundance of animals but rather potential habitats they may occupy (Phillips et al., 2006; Araujo and Guisan, 2006). While our best selected model may have a certain average predictive accuracy, uncertainty around its performance across the range of habitat suitability values may not be known, potentially leading to erroneous inferences (Hirzel et al., 2006). To account for this, we estimated the ratio of the predicted to expected frequency of evaluation points (P/E ratio; Boyce et al., 2002) across habitat suitability values using the *ecospat* package (Di Cola et al., 2017) in R v 4.0.5. Only habitat suitability values where predictive accuracy was high (fishing cats likely to be present at least 5x more than by chance) were used to calculate Conservation priority scores to minimize false positives in further inferences. We refer to these as optimal habitats. To draw a map of Conservation priority, representing areas of ecological importance, we averaged and summed indices of habitat suitability and predicted connectivity with presence records (1/0 for presence/absence) of the species, at a district level.

2.2. Conservation likelihood

We define Conservation likelihood as the potential for action by government organisations to protect the Fishing Cat, which in turn may affect the success of any future conservation initiative. To identify regions with high likelihood of conservation success, we collated information on relevant socio-political factors to use as proxies for the willingness and potential of the government in aiding Fishing Cat conservation. Given the complexity associated with socio-political drivers of conservation which are closely associated with this rare species, measuring true estimates of Conservation likelihood is difficult. Based on previous studies and available information, we used three predictors - a) Gross Domestic Product (GDP), b) Conservation budget, and c) Fisher population at state-level, which we believed helped assess the willingness and capacity of states to undertake conservation efforts effectively. Economic state of the governing unit is a major factor determining initiation and implementation of conservation efforts in general and more so in developing countries, with larger economies being more inclined towards investing in conservation actions (Baynham-Herd et al., 2018). Hence, we used data on net GDP as a positive predictor for Conservation likelihood of each state. Though general economic strength of the state is important, sector-specific expenditure of the state budget could provide a more accurate assessment of conservation intent and ability of the state. We defined conservation budget as the sum total of the budget allocated to the forest department for management purposes by the state government, and the budget allocated for research and conservation of sympatric species like tigers, under the Project Tiger. This measure of conservation budget also provided a positive predictor for measuring likelihood as a larger budget would translate into a greater scope for conservation interventions (Wilson et al., 2007). Although information on the proportion of funds available exclusively for the Fishing Cat or wetland conservation could have been more useful, in its absence, we believe the above information to be a good proxy for the same. Lastly, for a wetland specialist species like the Fishing Cat which experiences large overlap in terms of habitat and resources with humans (Mekherjee et al., 2016), resulting in direct and indirect conflict, incorporating socio-economic factors linked to wetland dependency or human tolerance is important. Due to lack of such detailed information, the population of inland fishers, which may reflect a state's dependency on wetland habitats, provides a rough proxy affecting Conservation likelihood by challenging conservation efforts (McIntyre et al., 2016; Sarkar et al., 2020; Table D1, Appendix D).

We collated all this information at a state level, since state is the principal governing body responsible for major management activities like budget allocation in India. Additionally, most of this information was available only at a state level. Data for all these measures were scaled independently from 0 to 1. Data on the population of inland fishers was transposed (subtracted from 1) after scaling to account for its inverse relationship with Conservation likelihood. We scored the Conservation likelihood for each state by summing up these values. To avoid false positives in our inferences, we only included states with confirmed Fishing Cat presence in this analysis.

2.3. Conservation initiative

Ongoing conservation actions for the Fishing Cat (Adhya, 2011), even at a local scale may aid directly in the conservation of the species (Sodhi et al., 2011). Conservation initiative represents active conservation actions as opposed to conservation proxies, like in the case of Conservation likelihood. We collated data on existing conservation efforts by government and private organisations for the Fishing Cat and/or wetland conservation (presence of protected areas and Ramsar sites) through organisational websites and published articles (Table E1, Appendix E). Since the scope of such initiatives was local, it was more relevant to map them at the district level. To avoid false positives, presence of protected areas and Ramsar sites was only recorded for districts with confirmed Fishing Cat presence.

2.4. Conservation blueprint

2.4.1. Identifying action landscapes and interventions

To build the final Conservation blueprint for the Fishing Cat in India, we incremented Conservation likelihood scores of districts with any form of Conservation initiative by '1' to account for the presence of ongoing research and conservation activities. Consecutively, we classified only districts with confirmed Fishing Cat records into four distinct tiers based on Conservation priority, Conservation likelihood and Conservation initiative. Areas with greater than the median Conservation priority score, with greater or less than the median Conservation likelihood score were classified as Tier A and Tier B districts respectively. While areas below the median Conservation priority score, along with greater or less than the median Conservation likelihood score were classified as Tier C and Tier D districts respectively. This classification helped us summarise broad research/conservation actions potentially required in these areas. Since our increment value for Conservation initiative and cut-off thresholds for Conservation priority and Conservation likelihood scores were arbitrary, we conducted a sensitivity analysis to test for the impact of varying these values on our results. Details on this analysis can be found in Appendix F.

2.4.2. Identifying survey landscapes

To guide further exploratory work on the little-known fishing cats of India, using information on habitat suitability, we identified districts where surveys investigating the presence and the extent of occurrence of the species could be prioritised. Excluding areas with confirmed Fishing Cat records, we identified districts with optimal habitats for the species (refer to Fig. C1, Appendix C) throughout the country. Districts adjacent to the ones with Fishing Cat records were also included because such populations, especially near districts with few or sporadic records, may be small and isolated, and therefore in urgent need of assessment (Gilpin and Soule,1986). Additionally, recent records outside the known regions of occurrence of the species suggests that our understanding of its ecology is incomplete, highlighting the need for extensive surveys.

3. Results

3.1. Conservation priority

We found presence records of fishing cats in 12 Indian states, to which we limited our subsequent analyses. Despite a wide range of occurrence, most states only harboured a small area of high priority habitat for the species (Fig. 1c). Nearly 50% (n = 183) of all assessed districts (n = 367) across the assessed states, scored values greater than the median Conservation priority score.

3.1.1. Fishing Cat habitat suitability

All nine habitat suitability models that we ran had test AUC values greater than 0.8. As both AUC difference and true skill statistic values were comparable for all models (Table 2), we selected our best model based on low omission rates for both 10th percentile presence and equal sensitivity and specificity thresholds. Under these criteria, the model with LQP features and regularisation multiplier set to 2 was ranked as the top model.

Using P/E ratios (section 2.1.3) we found optimal habitats for fishing cats to be areas with habitat suitability greater than 0.44 (out of 1) (refer to Fig. C1, Appendix C). These regions broadly included areas in northern India, along the eastern coast, and the north-eastern floodplains. Most of the identified optimal habitats were found in the regions with confirmed Fishing Cat presence. Although optimal habitats were also predicted to occur in the states of Punjab, Haryana and Tamil Nadu, we found no prior records of fishing cats in these areas. In the Terai arc i.e. in the states of Uttarakhand, Uttar Pradesh and Bihar these habitats were limited, and confined to a narrow belt, whereas similar habitats were more evenly distributed across the Brahmaputra floodplains in Assam and along the Eastern coast in West Bengal, Odisha and Andhra Pradesh. Central India also seemed to contain a few patches of optimal habitats (Fig. 1a). In general, predicted optimal habitats were found to mostly exist in linear patches with transboundary habitats in Nepal and Bangladesh (Fig. A1, Appendix A).

3.1.2. Fishing Cat habitat connectivity

We found connectivity to be high across and within all habitats identified above (Fig. 1b.). Within the country, habitats in the Terai arc seemed to be connected more to those in the Eastern coast, via the Gangetic delta, when compared to the Brahmaputra floodplains (Fig. 1b). However, connectivity between these habitats may exist through transboundary habitats in Bangladesh (Fig. B1, Appendix B). Similarly, habitats in Nepal may also aid in connecting populations within the Terai arc.

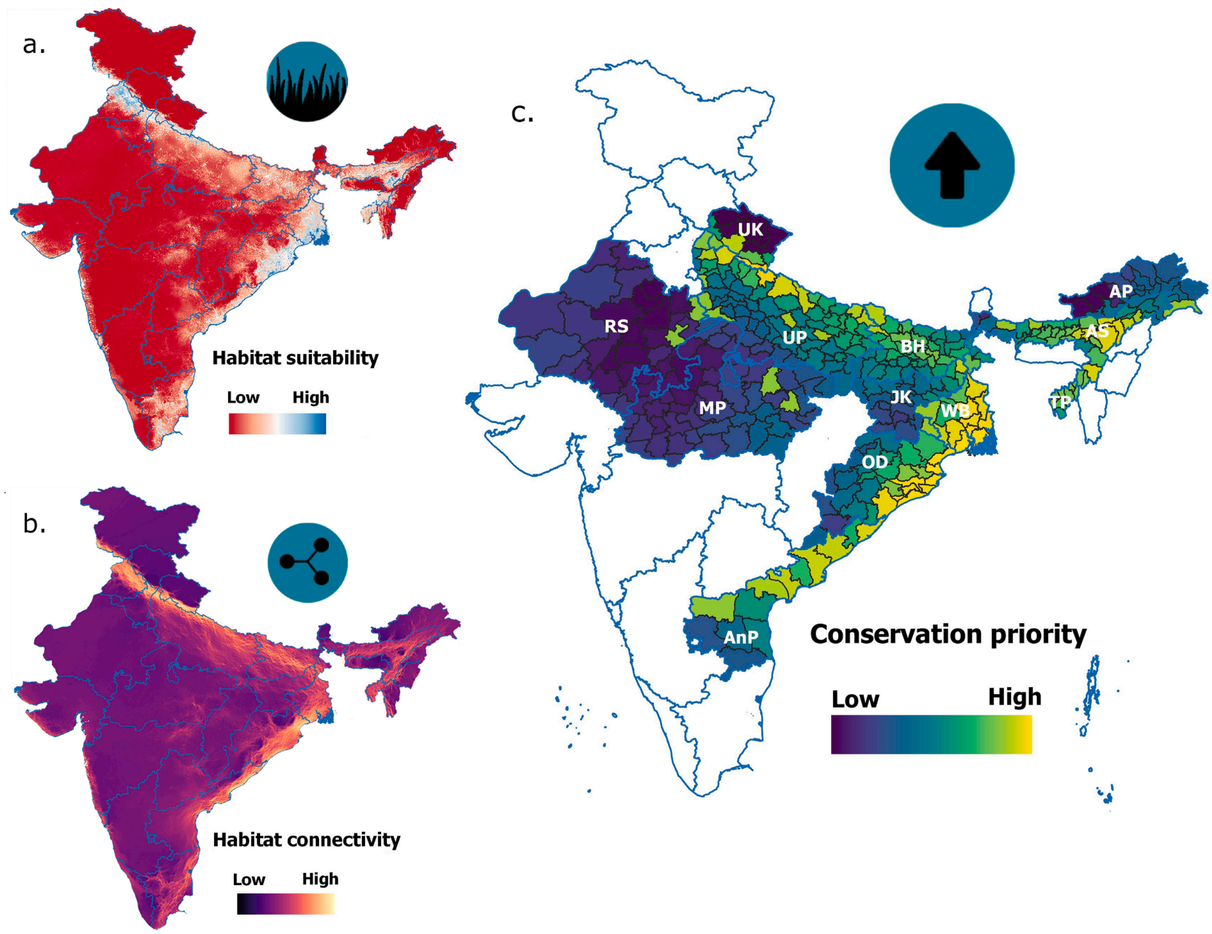

Fig. 1. Map denoting a) Habitat suitability b) Habitat connectivity c) Conservation priority scores. All analyses were conducted at a district level. The letters on Map (c) represent Indian states as follows: Uttarakhand (UK), Rajasthan (RS), Madhya Pradesh (MP), Uttar Pradesh (UP), Bihar (BH), Jharkhand (JK), West Bengal (WB), Odisha (OD), Andhra Pradesh (AnP), Assam (AS), Tripura (TP), and Arunachal Pradesh (AP).

Table 2
A summary of various performance parameters used for evaluating different models.

Feature class	Beta Multiplier	AUC (train)	AUC (test)	AUC difference	TSS	Omission rate (p10)	Omission rate (ESS)
LQP*	2	0.9	0.84	0.06	0.34	0.03	0.08
LQP	1.5	0.9	0.84	0.06	0.34	0.03	0.09
LQP	1	0.91	0.84	0.07	0.34	0.04	0.09
LQ	2	0.89	0.8	0.09	0.31	0.03	0.11
LQ	1.5	0.89	0.8	0.09	0.31	0.04	0.11
LQ	1	0.89	0.8	0.09	0.3	0.04	0.12
L	1.5	0.88	0.83	0.05	0.33	0.03	0.12
L	2	0.88	0.83	0.05	0.34	0.03	0.12
L	1	0.88	0.83	0.05	0.33	0.04	0.13

* Top model used for further analysis. p10 and ESS refer to 10th percentile presence and equal sensitivity and specificity thresholds.

3.1.3. *Conservation priority scores*

Based on habitat suitability, habitat connectivity, and species presence records, district-level Conservation priority scores (n = 367) across 12 Indian states are shown in Fig. 1c. Districts of highest Conservation priority were primarily restricted to the states of West Bengal and Odisha, with few isolated districts in Assam, Uttar Pradesh, and Uttarakhand. States with isolated presence records like Madhya Pradesh, Rajasthan, Jharkhand, Uttarakhand, and Arunachal Pradesh harboured regions with the least Conservation priority, while several districts in Uttar Pradesh, Bihar, Andhra Pradesh, Assam and Tripura showed intermediate levels of Conservation priority.

3.2. *Conservation likelihood*

Conservation likelihood was found to be highest in Uttarakhand followed by Madhya Pradesh and Rajasthan (Fig. 2). In contrast, the states of Bihar, Uttar Pradesh, Odisha, Jharkhand, and West Bengal showed the least potential for conservation success. Andhra Pradesh and the north-eastern states of Assam, Arunachal Pradesh and Tripura ranked moderately on this index.

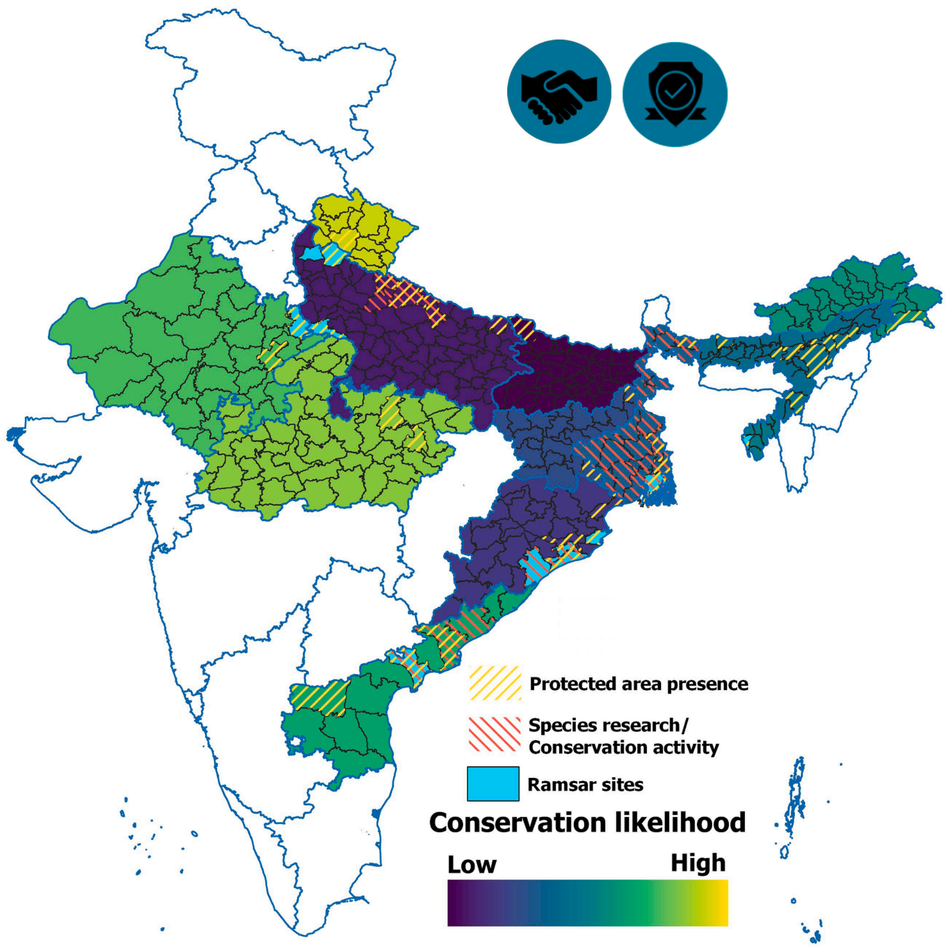

Fig. 2. Map denoting the Conservation likelihood scores for the Fishing Cat in India. Dashed districts represent areas with Conservation initiative (Protected area presence, Species research/conservation activity, and Ramsar sites).

3.3. Conservation initiative

Our search revealed sporadic species-specific research/conservation actions, limited to a few districts (n = 27) primarily distributed along the eastern Indian coast. In the districts with confirmed Fishing Cat presence (n = 60), existence of protected areas (n = 12) and Ramsar sites (n = 6) aiding in wetland conservation was found to be sparse (Fig. 2). While most of the districts containing protected areas that could aid in conservation of the species, were found in the Terai arc and the Brahmaputra floodplains, Ramsar sites harbouring fishing cats were primarily distributed along the Eastern coast and in the state of Uttar Pradesh.

3.4. Conservation blueprint

Analysis for defining action landscapes was limited to the districts with confirmed Fishing Cat records (n = 60). Based on our classification, districts were nearly equally distributed in the four tiers (Fig. 3 and Table G1, Appendix G). Tier A districts (n = 15) were restricted to the states of Assam and West Bengal while Tier B districts (n = 15) were majorly distributed in Uttar Pradesh and Odisha. The Tier C districts (n = 17) occurred across Andhra Pradesh and Assam and in areas with sporadic records of the species. The Tier D districts (n = 13) were mostly concentrated along the Terai arc, in the states of Uttar Pradesh and Bihar (Fig. 4).

156 districts were identified as survey landscapes that could potentially harbour unknown Fishing Cat populations (Fig. 4). Most of these districts occurred in the Terai arc, extending to regions with known records of fishing cats in Rajasthan. Additionally, districts neighbouring identified optimal habitats in Eastern coast and Brahmaputra floodplains, were also highlighted as areas that could potentially harbour Fishing Cat populations. Apart from these, our results suggest that few districts in Madhya Pradesh and Punjab may also harbour undiscovered populations.

4. Discussion

Using an objective and replicable framework, we have not only identified key areas in need for research and conservation on a data deficient species, but we have also drawn broad, yet tangible area-specific conservation approaches for districts across the country. Our results find scope in ensuring long-term conservation of the species and advocating targeted exploration in areas where it may be found.

4.1. Ecological status of the Fishing Cat in India

The results of our habitat suitability model are in consonance with the known distribution of the Fishing Cat in India. Apart from these areas, our model also predicted suitable Fishing Cat habitats in Punjab and Haryana in the northern region, and Tamil Nadu in the southern region of the country (Fig. 1a). Although no records of fishing cats exist from these regions, they could have been important historically, facilitating connectivity between populations in India and Pakistan in the north, and between India and Sri Lanka in the south. The results of our habitat suitability model delineating three broad clusters of optimal

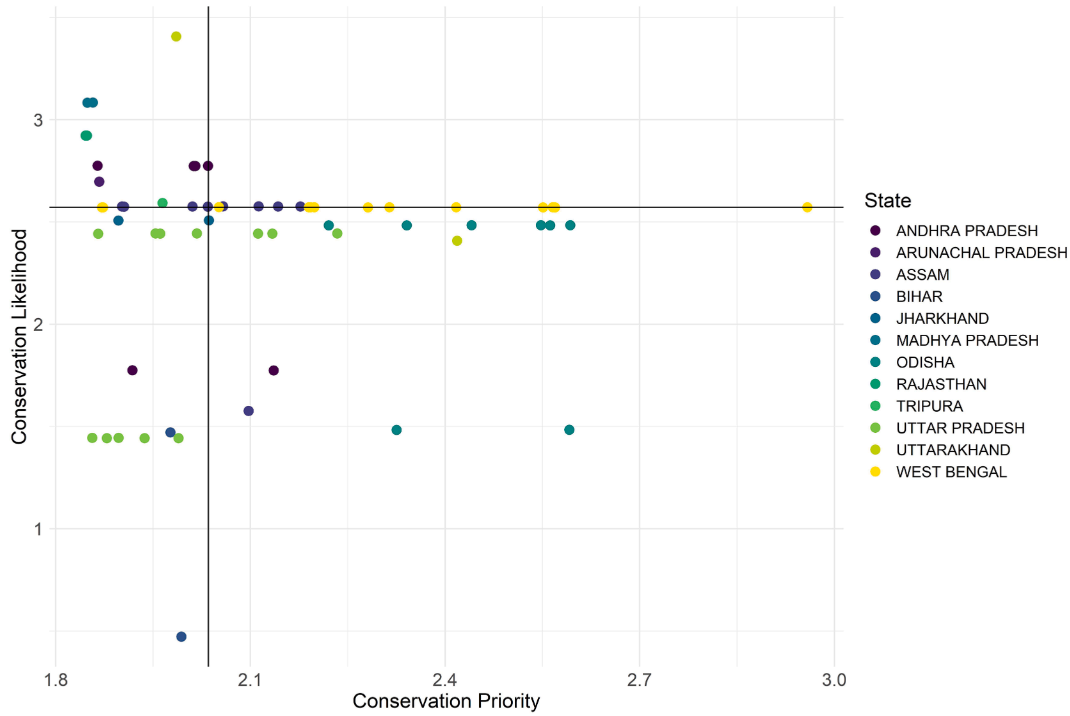

Fig. 3. Partitioning of Conservation priority and Conservation likelihood scores to delineate districts with varying needs for Fishing Cat conservation. The horizontal and vertical lines denote median Conservation likelihood and Conservation priority scores respectively.

habitats for fishing cats in the country, namely - the Terai arc (Uttarakhand, Uttar Pradesh, and Bihar), the Eastern coast (West Bengal, Odisha, and Andhra Pradesh) and the Brahmaputra floodplains (Assam and Tripura), are broadly in line with the findings of Silva et al. (2020). Within these clusters, the states of West Bengal, Odisha, and Assam harboured some of the most suitable habitats for the species, which were predominantly defined by low elevation, high precipitation of the driest quarter, and the presence of wetlands, croplands, and forests (for further details refer to Table A3 and Fig. A2, Appendix A). These relationships are consistent with our own predictions and the findings of previous studies (Silva et al., 2020; Jhala et al., 2021).

While identified patches of linear habitats overall were found to be connected, paucity of predicted suitable habitats in the regions of North Bengal and western Assam resulted in weaker connectivity to habitats in the Brahmaputra floodplains. This lack of suitable habitats is also mirrored by lack of records of the species in the region despite documentation efforts (Tempa et al., 2013; Dey et al., 2015). However, these areas may be connected to the Brahmaputra floodplains through transboundary habitats in Bangladesh. Analysing genetic connectivity of the Fishing Cat populations across predicted habitats within the country and in these transboundary regions would help in revealing nuanced details about the population status and ecology of the species.

Increased wildlife monitoring efforts across the country may have led to discoveries of the Fishing Cat in isolated districts resulting in high Conservation priority scores for districts in Jharkhand, Madhya Pradesh, and Rajasthan (Talegaonkar et al., 2018; Dutta et al., 2021). These records exist sporadically in otherwise low predicted habitat suitability and connectivity regions, underscoring our limited understanding of the species' ecology and biogeography, and of how local and site-specific factors may affect its distribution. Dedicated ecological studies on the species are of paramount importance to fill these knowledge gaps.

4.2. Conservation needs of the Fishing Cat in India

Our analysis revealed that states that harboured districts with highest Conservation priority in the country, like Uttar Pradesh, West Bengal, and Assam, ranked low in their likelihood to conserve the species. To identify district-level actionable goals to strengthen Fishing Cat conservation in the country, we divided areas with confirmed fishing cat records into four tiers (see section 2.4.1 and Fig. 3). With high priority and likelihood scores, Tier A districts (Fig. 4) delineate areas with an urgent demand for conservation and are accompanied by factors that could boost conservation success. In such districts, we propose that conservation actions, implemented through local, on-ground initiatives should be focused upon, since they can greatly benefit from existing governmental and infrastructural support. Such support in West Bengal for example, that has declared the Fishing Cat as their State Animal, has aided in campaigns to generate awareness about the species which could ultimately help in conserving them (García-Cegarra and Pacheco, 2017). The presence of most of these habitats outside protected area boundaries, however, amplifies the impact of anthropogenic activities like expansion of human settlements, creation of aquaculture farms, declaration of wetland habitats as 'waste dumping' sites and even periodic hunting, on this habitat specialist species. Therefore, Tier A districts in Assam, with an extensive protected area network present great potential to safeguard species survival within these areas.

In Tier B districts (Fig. 4), that signify regions of high Conservation priority but low Conservation likelihood, large scale efforts to institutionalise long-term organisational support in terms of finances or even policy related changes are crucial. Any conservation efforts in such districts of western Uttar Pradesh and Odisha, could vastly benefit from the support of governmental and/or non-governmental organisations. Recently, the Fishing Cat has been declared as a flagship of the Chilika lagoon in Odisha which has helped in establishing long-term community-driven monitoring projects in the lagoon area. Such coordinated and institutionalized efforts in Tier B districts with high Conservation priority are predicted to boost conservation of the species.

The districts scoring low on Conservation priority harbour fewer optimal habitats with weaker connectivity between them. Such districts with high Conservation likelihood (Tier C, Fig. 4), including regions in Andhra Pradesh and Assam, represent areas with dwindling habitats in urgent need of protection. Many Tier C districts of Andhra Pradesh and

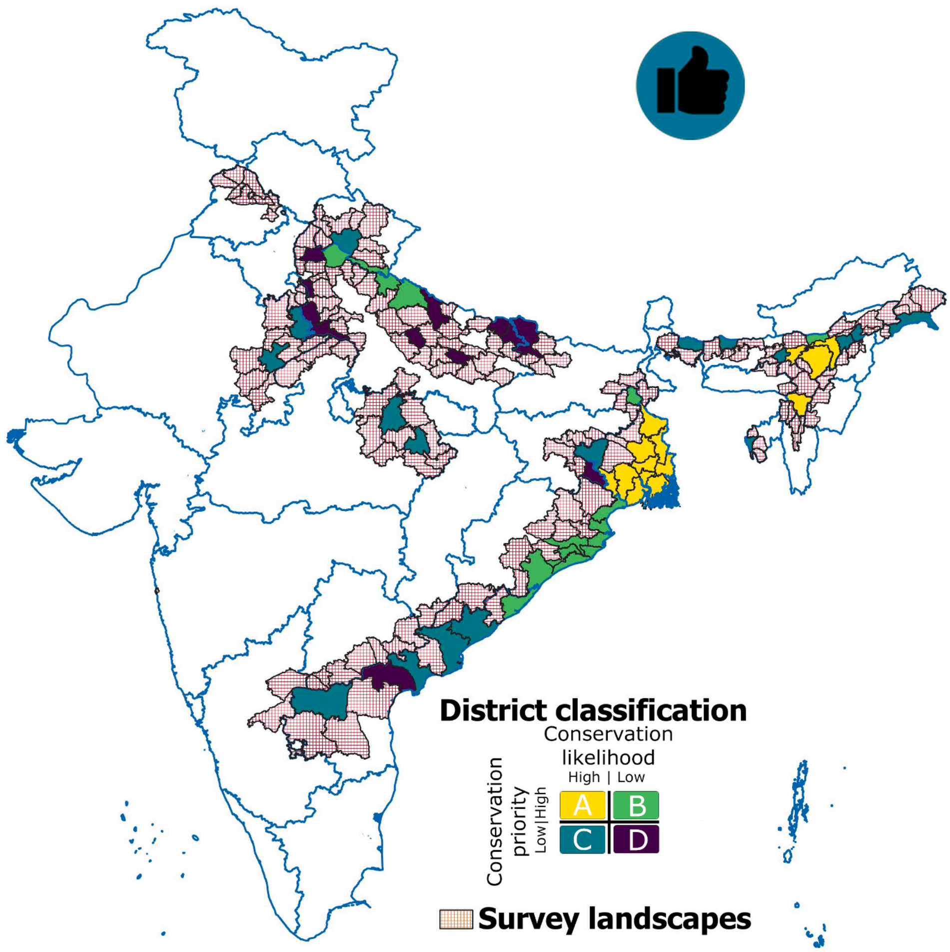

Fig. 4. Conservation blueprint map for the Fishing Cat in India.

Odisha face localised threats in the form of rampant wetland conversion for aquaculture farming (Jayanthi et al., 2018). Other Tier C districts distributed in Madhya Pradesh, Rajasthan and Uttarakhand represent areas with isolated records of the species. These areas require urgent need for localized wetland conservation and threat assessment to safeguard the survival of remnant Fishing Cat populations. The remaining areas classified as Tier D (Fig. 4) rank low in both Conservation priority and likelihood and may require further exploratory measures instead of action-oriented conservation. Primarily distributed in Uttar Pradesh, these districts comprise areas with very little information on the species and therefore, actions here should aim to investigate the current status of fishing cats which could lead to localised conservation efforts in future.

The conservation actions proposed above are however limited to a handful of districts with confirmed species presence, restricting their scope in safeguarding the elusive Fishing Cat across the country. Understanding and conserving this species would also require systematic, large-scale exploratory surveys for the species. Delineation of survey landscapes has been helpful in understanding the distribution and occurrence of large and relatively well-known species like tigers (Sanderson et al., 2010; Bista et al. 2021), and so could be even more crucial for smaller, lesser-known species like the Fishing Cat. The districts we have identified, based on habitat suitability, could be prioritised for such exploratory surveys (Fig. 4).

Lastly, conflict with humans is a major and direct threat to this species which needs targeted solutions to assist successful conservation measures. In modified habitats like near aquaculture farms, fishing cats have been known to utilise resources of importance to humans, causing economic losses that may lead to retaliatory actions against the species. Alarmingly, a significant number of such direct threats which included recorded incidents of conflict and anecdotal evidence of hunting, were concentrated in Tier A districts of West Bengal and Assam (Adhya et al., 2011; Mukherjee et al., 2012). Beyond international borders too, fishing cats may face similar threats. Retaliatory killings, for example, are not limited to parts of West Bengal in India but are also reported from neighbouring habitats in Bangladesh and Nepal (Chowdhury et al., 2015; Timilsina et al., 2021). This coupled with the fact that highly suitable habitats are mostly transboundary (with Nepal and Bangladesh; Fig. A1, Appendix A), could add to the complexity of conserving the Fishing Cat (Rahman, 2017; Mishra et al., 2018). Yet, it could also provide extensive opportunities for strong international cooperation and transboundary conservation projects (Appel and Duckworth, 2016). Conservation interventions, whether international or local, should nevertheless be tailored to local threats that the species faces. Conflict reports however, provide only a biased snapshot of the level of threat the species faces in the country. Hence, targeted assessment of conflict is required in synchrony with the outlined blueprint for protecting fishing cats in the country.

4.3. Significance of Fishing Cat conservation in safeguarding Indian wetlands

Despite their important ecosystem services being recognised globally, wetlands in India are synonymous with "wastelands" (Adhya et al., 2011), and therefore receive little conservation attention from the government. As a result, very few of these ecosystems are conserved under the country's protected area network. Instead, such areas are readily converted to agricultural land, and are allocated for industrial and developmental projects (Bassi et al., 2014).

We believe that efforts to conserve fishing cats could also garner discussions on, and actions to protect their habitats - wetlands, which is crucial in the country. Threatened and charismatic status of this small cat has led to its recognition as the State Animal of the fourth most populous state of India, the ambassador of Asia's largest lagoon and the mascot for a mangrove sanctuary in India. However, similar appreciation for the intrinsic values of their habitat is absent. Therefore, we suggest that there is great scope in portraying the Fishing Cat as a flagship species for the conservation of wetlands across its wide range in India. Protecting fishing cats to save wetlands could entail restoring degraded areas and gradually reducing human dependency on them and can benefit from recent advances in the field of wetland restoration ecology (Kumari et al., 2019; Renzi et al., 2019).

To conclude, although information on species parameters like population size or species occupancy would have been useful in designing more robust interventions, we believe our approach highlights the importance of the most commonly available data for a rare and lesser-known species, to help understand and conserve them. Similarly, the socio-economic predictors used to measure the Conservation likelihood of the states may not find complete overlap with conservation interests of the species. However, given the dearth of socio-political understanding of Fishing Cat conservation, we believe the assessed predictors (see section 2.2 and Table D1, Appendix D) provide generic proxies to broadly assess the likelihood of conservation success for a wetland specialist predator. Given the current state of knowledge on fishing cats, our blueprint provides a concise and coherent scheme to understand and conserve the species across the country. However, our understanding of even the basic ecology and occurrence of the Fishing Cat, like many other lesser-known species, is being constantly updated with new and unique information. The periodic translation of this knowledge along with information on the effects of subsequent conservation actions as updates for our blueprint, would be important to keep it relevant for continued on-ground conservation of the species.

Data accessibility statement

All data used in the manuscript will be made available through Dryad upon successful acceptance of the manuscript. The corresponding data used in the manuscript is available at: https://doi.org/10.5061/dryad.qz612jmj7.

CRediT authorship contribution statement

Divyashree Rana: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Imran Samad:** Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Sankarshan Rastogi:** Conceptualization, Data curation, Methodology, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2022.126225.

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