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REVIEW

Assessing the threats facing wetland mammals in India using an evidence-based conservation approach

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ABSTRACT

1. Environmental change and anthropogenic pressure are primary drivers of biodiversity loss, particularly in wetland ecosystems that have been modified significantly. Among wetland specialists, mammals may be particularly vulnerable to extinction. We aimed to increase understanding of threats and knowledge gaps faced by 11 mammal species inhabiting wetlands throughout India.
2. We adopted a systematic literature search protocol following an evidence-based conservation approach to obtain information on conservation threats and identify knowledge gaps for each species. Each species received threat scores based on the occurrence and magnitude of ecological and anthropogenic threats, a score based on its International Union for Conservation of Nature (IUCN) Red List category, and a knowledge gap score. A cumulative conservation threat score based on the four individual scores was calculated for each species to assess overall conservation threats.
3. Only about 10% of the literature search results were relevant. Of the major research categories, ecology was the most well-studied, whereas the impact of anthropogenic pressure on wetland mammals was the least studied. Pressing ecological and anthropogenic threats, scientific knowledge gaps, and conservation needs contributed to a high cumulative threat score for the sangai *Rucervus eldii eldii* (cumulative threat score = 34), followed by the wild Asian buffalo *Bubalus arnee* (threat score = 33) and the Bengal marsh mongoose *Herpestes palustris* (threat score = 32). Poaching/hunting, habitat loss due to development, and changes in land-use practices were found to be the major anthropogenic threats resulting in decreasing population trends. We identified knowledge gaps concerning the ecology of wetland mammals (e.g. population abundance). It is essential that these knowledge gaps are filled for effective conservation planning.
4. We identified important areas (population ecology, disease ecology, human–wildlife conflict, changes in land use) that should be considered as research priorities for wetland mammals in India, in order to make conservation efforts more effective and enable management planning, to ensure the long-term survival of these mammals.

Schlüsselwörter
Bestandsbedrohungen, Feuchtgebiete, Indien, Säugetiere, Schutz- und Managementstrategien, systematische Literaturrecherche, Wissenslücken

ZUSAMMENFASSUNG AUF DEUTSCH

1. Umweltveränderungen und anthropogener Druck sind Haupttreiber für den Verlust der biologischen Vielfalt, insbesondere in Feuchtgebieten, die erhebliche ökosystemare Veränderungen erfahren haben. Unter den Feuchtgebietsspezialisten sind Säugetiere möglicherweise besonders vom Aussterben bedroht. Ziel unserer Studie war es, das Verständnis von Bedrohungen und Wissenslücken für 11 Säugetierarten in Feuchtgebieten Indiens zu verbessern.

2. Wir haben eine systematische Literaturrecherche anhand von evidenzbasierten Schutzansätzen durchgeführt, um Informationen über Bestandsbedrohungen zu erhalten und Wissenslücken für Arten zu identifizieren. Jede Art erhielt Gefährdungsbewertungen basierend auf dem Auftreten und dem Ausmaß ökologischer und anthropogener Bedrohungen, eine Bewertung auf Grundlage der Roten Liste der Internationalen Union für Naturschutz (IUCN) sowie eine Bewertung der Wissenslücken.Für jede Art wurde eine kumulative Bewertung der Schutz Bedrohung basierend auf den vier Einzelbewertungen berechnet, um die Gesamtbedrohungen für die Erhaltung zu bewerten.
3. Nur etwa 10% der Ergebnisse der Literaturrecherche waren relevant. Von den wichtigsten Forschungskategorien war die Ökologie am besten untersucht, der Einfluss des anthropogenen Drucks auf Säugetiere in Feuchtgebieten am wenigsten. Der ökologische und anthropogene Gefährdungsdruck, wissenschaftliche Wissenslücken und Schutzbedürftigkeit trugen zu einem hohen kumulativen Gefährdungswert für den Sangai Rucervus eldii eldii (kumulativer Gefährdungswert = 34) bei, gefolgt vom wilden asiatischen Büffel Bubalus arnee (Gefährdungswert = 33) und dem Bengalischer Sumpfmungo Herpestes palustris (Gefährdungswert = 32) bei. Wilderei/Jagd, Verlust des Lebensraums aufgrund der regionalen Entwicklung sowie Änderungen der Landnutzung erwiesen sich als die größten anthropogenen Bedrohungen, die zu negativen Trends der Populationsentwicklung führten. Wir konnten Wissenslücken hinsichtlich der Ökologie von Säugetieren der Feuchtgebiete (z.B. Bestandszahlen) identifiziert. Für die Entwicklung von effektiven Schutzstrategien müssen diese Wissenslücken geschlossen werden.
4. Wir haben wichtige Gebiete (Populationsökologie, Krankheitsökologie, Mensch–Wildtier Konflikt, Landnutzungsänderungen) identifiziert, die als Forschungsprioritäten für Säugetiere der Feuchtgebiete in Indien betrachtet werden sollten, um die Schutzbemühungen effektiver zu gestalten und eine Managementplanung zu ermöglichen, die ein langfristiges Überleben dieser Säugetiere sichert.

INTRODUCTION

The loss of biodiversity is among the major environmental problems threatening ecosystem function and the long-term survival of wildlife species (Dirzo & Raven 2003, Ceballos et al. 2010). Terrestrial mammals around the world are highly vulnerable to environmental change and face diverse anthropogenic threats, including habitat destruction, habitat degradation, and harvesting for food and medicine (Schipper et al. 2008). Among the mammalian species, those specialised for life in various ecosystems, such as wetlands, may be particularly vulnerable to extinction (Singh 2004, Sanjit et al. 2005).

Wetlands are known as 'the kidneys of the landscape' because they perform a range of hydrological functions (e.g. groundwater recharge, gross water balance, flood control, and influence on downstream river flow) and chemical functions (e.g. regulating the flow of nutrients and acting as sinks for nutrients; Mitsch & Gosselink 1993, Bullock & Acreman 2003, Hansson et al. 2005, Bassi et al. 2014). Wetlands are the most productive ecosystems due to their contributions to the food web, and they are also effectively known as 'biological supermarkets' (Mitsch & Gosselink 1993, Barbier et al. 1997). Wetland plants in India (e.g. water hyacinth *Pontederia crassipes*, water spinach *Ipomoea aquatica*, Bermuda grass *Cynodon dactylon*) purify water and soil contaminated by heavy metals through phytoaccumulation processes (Chatterjee et al. 2011). Globally, the area of natural wetland habitat declined by 35% between 1970 and 2015, which caused the loss of 81% of inland wetland species and 36% of marine and costal wetland species (Ramsar Convention on Wetlands 2018). According to the National Wetland Atlas 2013 (Murthy et al. 2013), India has 26 Ramsar Sites (e.g. east Kolkata Wetland, Loktak Lake) in 15 states (in all, India has 28 states and eight union territories; Nagabhatla et al. 2009, Bassi et al. 2014). Additionally, due to its geographic variation, India has diversified inland and coastal wetland ecosystems (Bassi et al. 2014).

Wetlands in India provide habitats for more than 300 bird species and diverse mammalian taxa, which play important ecological roles (Prater & Barruel 1971, Kumar & Gupta 2009, Mallick 2009, Gray et al. 2015). Often considered as wastelands, wetlands have been subjected to conversion to agriculture, industry, fish farming, and road building (Barbier et al. 1997, Bassi et al. 2014, Mukherjee et al. 2016). The Deepor Beel, an important freshwater flood plain lake and Ramsar Site in north-east India, is reported to face significant pollution due to dumping of solid waste materials in the wetland water by the local municipal authority (Choudhury & Gupta 2017). Over time, wetlands are being decimated due to deforestation, defoliation, hydrological alterations, water-quality degradation, wetland consolidation, global climate change, introduction of exotic species, and groundwater depletion (Foote et al. 1996, Mallick 2013).

The latest International Union for Conservation of Nature (IUCN) Red List report (version 2020-1; Tables 5 and 6a; IUCN 2020) indicated that a total of 93 mammal species found in India, including eight species which inhabit wetland, are threatened with extinction. Increased human populations and associated development activities are known to affect a range of wildlife habitats, including highly biodiverse wetlands, throughout India (Bassi et al. 2014). Mammals in wetland have restricted abilities to traverse large human-dominated landscapes, are under high anthropogenic pressure, and may be particularly vulnerable to extinction (Schloss et al. 2012). Therefore, in the present study, we adopted an evidence-based conservation approach to increase understanding of conservation threats operating on selected mammalian species that are closely associated with wetlands in India.

Evidence-based conservation is known to be an effective tool that is systematically prepared using web-based information databases in an accessible form to help in the formulation of effective conservation policies (Pullin & Knight 2001). It reduces the implementation of conservation practices that are primarily based on guesses and anecdotes, and improves the scientific information flow to decision-makers or policymakers to enable conservation planning (Pullin & Knight 2003, Sutherland et al. 2004, Pullin & Stewart 2006, Pullin & Knight 2009).

We adopted a systematic search protocol following the evidence-based conservation approach to obtain information on conservation threats and identify knowledge gaps for 11 mammal species, *viz*., fishing cat *Prionailurus viverrinus*, (Indian) smooth-coated otter *Lutrogale perspicillata*, Eurasian otter *Lutra lutra*, Asian small-clawed otter *Aonyx cinereus*, Bengal marsh mongoose *Herpestes palustris*, crab-eating mongoose *Herpestes urva*, (Indian) hog deer *Axis porcinus*, swamp deer or barasingha *Rucervus duvaucelii*, sangai, brow-antlered deer or Eld's deer *Rucervus eldii eldii*, wild Asian buffalo or wild water buffalo *Bubalus arnee* and Indian rhinoceros or greater one-horned rhinoceros *Rhinoceros unicornis*. Published literature (Prater & Barruel 1971, Mallick 2009, Gray et al. 2015) has identified these species as wetland specialists that are closely associated with wetland ecosystems in India.

The primary objectives of the study were as follows: 1) to identify threats (ecological and, anthropogenic) to wetland mammal species based on a systematic review of the published literature; 2) to increase understanding of the current state of knowledge for each species and identify knowledge gaps to aid future conservation research; and 3) to use ecological and anthropogenic threat scores, scores based on each species' IUCN Red List category, and knowledge gap scores to calculate a cumulative conservation threat scores for each of the selected mammal species, in order to identify priority species for immediate conservation action. Additionally, we explored funding agency contributions, locations of studies conducted on wetland mammals, and accessibility of scientific information, in order to understand ongoing conservation efforts. Our overall aim was to contribute towards the long-term survival of the selected wetland mammals.

METHODS

Search strategy for relevant data collection

Using an evidence-based conservation approach (Pullin & Knight 2001, Sutherland et al. 2004, Pullin & Stewart 2006), we obtained data on species' ecology, conservation threats, and information that can aid species' conservation, using the published literature in peer-reviewed journals and reports. We undertook a systematic search of online information repository databases, such as the Web of Science (clarivate.com/products/web-of science/), Google Web (www.google.com/), and Google Scholar (www.scholar.google.co.in/). The information search was conducted between 21 January and 14 February 2018, using common names and scientific binomials of each mammal species as the search strings.

A specific set of inclusion and exclusion criteria (e.g. only information and studies focused on selected wetland mammals and published in English were considered relevant) were applied to screen the available information. Information (from e.g. popular articles, web blogs) that was not the direct outcome of primary research or research syntheses on the selected mammal species was not included for further evaluation. No specific timeframe for publication of information was specified, to incorporate all possible information available for each species. One of our primary objectives was to increase understanding of the current state of knowledge for each species, in order to aid future conservation of the

selected wetland mammals. Some of the species are endemic to India (e.g. the sangai), whereas some have large global geographic ranges (e.g. the Eurasian otter). We included all relevant studies from India as well as from outside India, in order to capture spatial variation in research effort. We divided the search results into six major research categories: ecology, evolution, physiology and reproductive biology, disease, conservation challenges, and conservation efforts. Within these categories, we placed papers in 22 subcategories in order to understand research trends in various subject areas (Appendix S1). To ensure the quality of information incorporated in this study, we constructed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagrams (Moher et al. 2009) for each species, documenting information flow at each step of the systematic mapping process (see Appendix S2 for an example).

Estimating the reliability of assessment criteria

Based on the inclusion and exclusion criteria used, each search result was assessed using its title and abstract to select the most relevant information. As the decision for inclusion of a particular study and exclusion of others can be subject to assessor bias, two independent assessors assessed the title and abstract. Following the standard method for systematic reviews (Collaboration for Environmental Evidence 2013), kappa values were estimated to evaluate the reliability of inter-assessor agreement relevance for each search result (Cohen 1960, Landis & Koch 1977). The kappa score was calculated following Cohen (1960) and Landis and Koch (1977) as:

$$K = \left(\frac{\text{observed agreement} - \text{expected agreement}}{1 - \text{expected agreement}} \right).$$

'Observed agreement' was calculated as the proportion of agreement where both assessors agreed that a paper was relevant, or both assessors agreed that a paper was irrelevant. 'Expected agreement' was estimated as: [(proportion of papers considered relevant by assessor 1 × proportion of papers considered relevant by assessor 2) + (proportion of papers considered irrelevant/rejected by assessor 1 × proportion of papers considered irrelevant/rejected by assessor 2. Kappa scores above 0.4 were considered as moderate to good agreement and indicated that the decision on paper relevance was repeatable (Collaboration for Environmental Evidence 2013). All papers for which there was a disagreement at the title and abstract level were retained for full-text assessment. A kappa score above 0.6 indicates high agreement between assessors (Cohen 1960, Landis & Koch 1977, Collaboration for Environmental Evidence 2013).

Estimation of ecological threats for wetland mammals

Information on current population abundance, long-term abundance trends, patterns of population and habitat fragmentation, geographic range, body weight and generation lengths of selected wetland mammals were obtained via the published literature search to estimate ecological threat scores (Appendix S3). For example, a species with a low population number has an elevated chance of extinction (Mace et al. 2008, Di Marco et al. 2014), and thereby obtained a high threat score (Appendix S3). Since the absence of estimated population abundance information impedes conservation efforts, species with no population estimates received high ecological threat scores (Appendix S3). Similarly, larger body size and long generation time increase species extinction probability (Mace et al. 2008, Di Marco et al. 2014), so species with these attributes were given high threat scores (Appendix S3).

Estimation of anthropogenic threats for wetland mammals

Information on common anthropogenic threats (e.g. human–wildlife conflict, poaching/hunting) that are known to impact selected wetland mammals was obtained from the published literature in order to calculate anthropogenic threat scores (Appendix S2). The presence of a threat incurred a score of one, while the score in the absence of threat was zero (Appendix S3).

Threats to wetland mammals indicated by IUCN category

The IUCN category was used to incorporate overall conservation requirements of wetland mammals into the cumulative score. As IUCN categories indicate conservation threats, wetland mammals in the IUCN Endangered category received a score of 4, Vulnerable species received a score of 3, Near Threatened species had a score of 2, and species of Least Concern had a score of 1. Species that were Not Evaluated or Data Deficient also received a score of 4, as the absence of a systematically estimated conservation status could hinder effective planning for any future conservation action protocol (Appendix S4).

Estimation of knowledge gaps for wetland mammals

The lack of detailed research information on various aspects of species' ecology and conservation threats hamper effective conservation measures for mammalian species (Costa et al. 2005). Therefore, the total number of papers for each

species was compiled from the literature database, to provide an estimate of the knowledge gap for this species. For example, a wetland mammal species with fewer than ten published scientific papers got a high knowledge gap score, indicating the lack of information that is essential to enable species conservation, whereas a species with more than 200 papers got a low knowledge gap score (Appendix S3).

Understanding cumulative conservation threats and research trends for wetland mammals

We estimated the overall conservation threat for each species as the cumulative impact of ecological threats, anthropogenic threats, IUCN category, and knowledge gaps. A high cumulative conservation threat score for a species indicates that higher conservation priority is required to ensure its long-term survival.

The trend in the recent scientific papers for a species can be considered an indicator of ongoing conservation efforts by the scientific community aiming to ensure the long-term survival of the species (Griffiths & Dos Santos 2012). Hence, the total number of primary papers on the species published during 2010–2018 was used as a score to help understand recent research trends (Appendix S3). We explored temporal patterns in papers in four time periods (pre-1990, 1990–1999, 2000–2009 and 2010–2018). Additionally, information on the geographic locations of study sites, and the involvement of government and non-government funding agencies in conservation work for the 11 wetland mammal species was recorded, to improve understanding of the current research patterns, assess accessibility of information, and determine future conservation needs.

Data analysis

Variation in ecological threat scores, anthropogenic threat scores, and knowledge gap scores in the wetland mammal species were analysed by the Kruskal–Wallis test (Zar 2014). We used Dunn's test in the R software package *dunn.test* to identify significant pairwise differences between means (Dunn 1964, Dinno 2017). The R software package *ggplot2* (Wickham 2016) was used for graphic visualisation of the data and to explore the trends. All analyses were conducted with R version 3.3.3 software (R Foundation for Statistical Computing, http://www.r-project.org/).

RESULTS

The initial information search for 11 selected wetland species through various online databases produced a large amount of information (n = 11867 papers). The mean kappa estimate (0.66 ± 0.13 – mean ± SE) indicated high levels of agreement among the assessors in determining the relevance of search items (Appendix S5). After a careful assessment using our inclusion and exclusion criteria, only 10% (n = 1217) of the papers were found to be relevant (Appendix S6). The number of scientific papers varied among species. The Eurasian otter was the most studied (n = 557 papers), while the Bengal marsh mongoose had the least amount of information available (n = 5). Though 1217 papers were found to be relevant, only 979 could be accessed online for complete assessment (Appendix S7). The search results indicated significant variation in the availability of information in the six major research categories (Kruskal–Wallis χ^2 = 28.88, d.f. = 5, P < 0.001) and in the 22 subcategories (Kruskal–Wallis χ^2 = 66.81, d.f. = 21, P < 0.001). Of the major categories, ecology was found to be most well-studied (n = 484) followed by physiology and reproductive biology (n = 184), whereas conservation challenges due to anthropogenic pressures were found to be the least studied (n = 69; Table 1).

Patterns of ecological threat to wetland mammals

Ecological threat scores for the 11 species of wetland mammal ranged from 9 to 15 (Appendix S8). We gave herbivores higher ecological threat scores (12.6 ± 0.67 – mean ± SE) than carnivores (10.33 ± 0.71 – mean ± SE; Appendix S8). We found that basic ecological information that is essential for conservation planning, such as population density estimates, is not available for 45% (mostly carnivores) of the selected wetland mammal species (Appendix S8). Other ecological characteristics, such as high levels of population fragmentation and life-history traits (e.g. long gestation period, large body weight), made the wetland mammals prone to ecological threats. The sangai had the highest ecological threat score (15) due its low population abundance (<200 individuals), small geographic range and fragmented habitat, followed in rank order by the Indian smooth-coated otter and the Indian rhinoceros (Appendix S8). Except for the Indian rhinoceros, all wetland mammals had decreasing trends in the abundance of mature individuals. The ecological threat scores varied significantly across subcategories of ecological threats (Kruskal–Wallis χ^2 = 26.64, d.f. = 5, P < 0.001).

Patterns of anthropogenic threats to wetland mammals

Poaching/hunting, human–wildlife conflict and habitat loss due to development activities were found to be the primary anthropogenic threats for all the selected wetland mammals (Appendix S9). The anthropogenic threat scores were relatively elevated (range: 4–6) in herbivores (e.g.

Table 1. Numbers of papers included in the review, in various major research categories and subcategories, for 11 wetland mammal species found in India. The codes in parentheses are the species name abbreviations

Major categories	Subcategories	Fishing cat (FC)	Indian smooth-coated otter (SCO)	Eurasian otter (EO)	Asian small-clawed otter (ASCO)	Bengal marsh mongoose (BMM)	Crab-eating mongoose (CEM)	Swamp deer (SD)	Indian hog deer (HD)	Sangai (SG)	Wild Asian buffalo (WAB)	Indian rhinoceros (IR)
Ecology	Demography and habitat	9	36	168	12	4	4	8	8	2	3	22
	Food habit and foraging	1	4	127	2	0	1	1	2	2	0	11
	Ecosystem service	0	0	0	0	0	0	0	0	0	0	3
	Ethology and cognition	1	3	27	12	1	0	1	3	0	0	6
	Molecular biology	2	1	44	0	0	0	2	7	4	5	20
Evolution	Phylogenetic and speciation	0	3	7	6	0	1	0	1	0	0	2
Physiology and reproductive biology	Ecophysiology	3	1	29	6	0	0	0	1	0	0	18
	Ecotoxicology	0	0	57	1	0	0	0	0	0	0	0
	Veterinary application	0	0	6	4	0	0	0	2	0	0	13
	Reproductive anatomy and physiology	2	0	6	1	0	0	1	0	0	0	12
	Reproductive genetics	0	0	0	0	0	0	0	0	0	0	2
Disease	Microbial	1	0	10	2	0	0	0	1	0	1	5
	Parasitic	0	0	29	0	0	0	0	1	0	0	1
	Genetic disorder	3	0	2	2	0	0	0	0	0	0	1
	Physiological	0	0	4	4	0	0	1	1	0	0	7
Conservation challenges	Habitat loss and fragmentation	0	0	2	1	0	0	0	1	0	1	5
	Human-mediated mortality and illegal wildlife trade	0	2	14	6	0	0	0	0	0	1	19
	Human–wildlife conflict	0	0	8	0	0	0	0	0	0	1	3
	Impact of climate change	0	0	0	0	0	0	0	0	0	0	2
	Impact of invasive species	0	0	0	0	0	0	0	0	1	0	2
Conservation efforts	In situ conservation	2	3	16	3	0	0	1	1	0	1	24
	Ex situ conservation	3	2	1	5	0	0	1	0	1	2	14

swamp deer, Indian hog deer, wild Asian buffalo) in comparison with carnivores (range: 3–4, Appendix S9). All herbivores other than sangai reportedly experienced threats from habitat degradation driven by introduced invasive plant species. Nine out of the 11 wetland species considered in this study are reportedly vulnerable to infectious disease and pollution in wild and captive conditions (Appendix S9). Evidence of hybridisation between domestic and wild populations was found only in the case of the wild Asian buffalo. The overall anthropogenic threat scores varied significantly across the subcategories (Kruskal–Wallis $\chi^2 = 38.95$, d.f. = 6, $P < 0.001$). The scores differed significantly between categories of anthropogenic threats: hybridisation with domestic animals, diseases, and pollution (Z value = 3.35, $P < 0.001$), human–wildlife conflict (Z value = 3.99, $P < 0.001$), habitat loss due to anthropogenic activity (Z value = −4.43, $P < 0.001$), poaching/hunting (Z value = −4.32, $P < 0.001$), habitat loss due to anthropogenic activity, impact of invasive species (Z value = 3.10, $P < 0.01$).

Knowledge gaps, research trends, funding, and research priorities for the conservation of wetland mammals

We found that 42% of the scientific papers ($n = 411$) were published from 2010 to 2018 (Fig. 1). Most papers on the well-studied Eurasian otter were published a decade earlier: $n = 207$ for the period 2000–2009; $n = 180$ for the period 2010–2018 (Fig. 1). The Bengal marsh mongoose ($n = 5$) and the crab-eating mongoose ($n = 6$) were the least studied, while the Eurasian otter ($n = 557$) and the Indian rhinoceros ($n = 192$) were the most well-studied species. We found knowledge gaps for the fishing cat, Bengal marsh mongoose and sangai prior to 1990, due to a lack of published scientific literature (Fig. 1). The total number of published papers varied significantly across various time periods (Kruskal–Wallis $\chi^2 = 10.03$, d.f. = 3, $P < 0.001$) and across species (Kruskal–Wallis $\chi^2 = 27.31$, d.f. = 10, $P < 0.001$).

We found that 76% of the papers were available open access (Fig. 2). The percentage of papers that were freely accessible was lowest for the wild Asian buffalo (60%) and highest (87%) for the Indian smooth-coated otter (Fig. 2). Information accessibility did not vary significantly across species (Kruskal–Wallis $\chi^2 = 16.91$, d.f. = 10, $P > 0.05$) or accessibility categories (Kruskal–Wallis $\chi^2 = 3.39$, d.f. = 1, $P > 0.05$).

We found that 92% of the papers were published in peer-reviewed scientific journals (Fig. 2). For the crab-eating mongoose, <30% of papers were published in peer-reviewed journals, whereas most papers (78–97%) relating to other wetland species were published in prominent peer-reviewed journals. Similarly, 90% of the papers were published in indexed journals and hence were readily

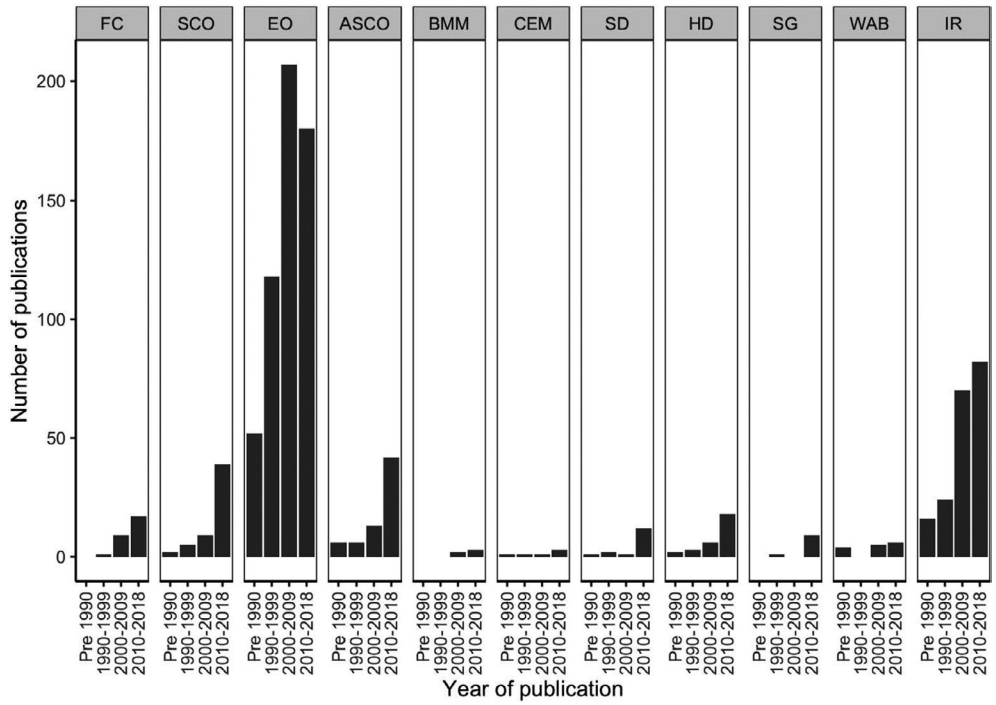

Fig. 1. Publication trends for 11 wetland mammal species in India over time (species codes are explained in Table 1).

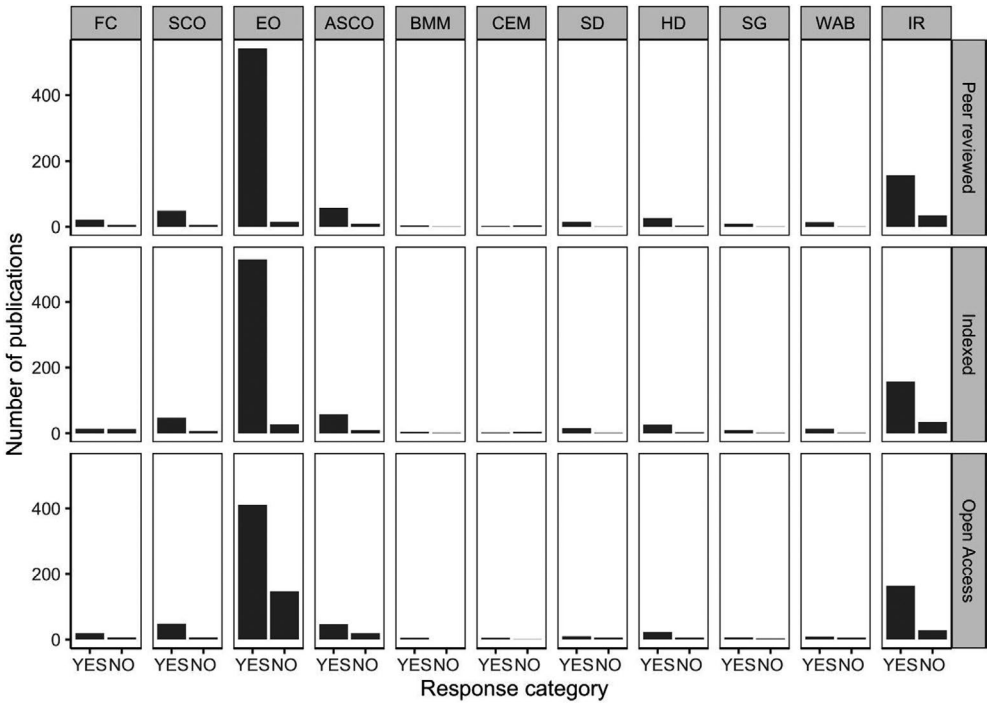

Fig. 2. Patterns of knowledge quality assessment and accessibility for the wetland mammals (species codes are explained in Table 1). Each paper was assessed based on whether or not it was published in peer-reviewed scientific journals, in indexed journals, and open access.

traceable for easy verification (Fig. 2). The number of peer-reviewed studies on wetland mammals varied significantly across peer-review categories (Kruskal–Wallis $\chi^2 = 6.95$, d.f. = 1, $P < 0.001$) and indexing (Kruskal–Wallis $\chi^2 = 5.78$, d.f. = 1, $P < 0.01$).

Government agencies were the primary funders for nearly 32% of the studies, while non-government agencies funded 12% of the studies (Fig. 3); 8% of studies received financial support from both governmental and non-government agencies. A large percentage (48%) of studies did not provide any information about funding sources. The number of studies funded by different types of funding agencies varied significantly across types of agency (Kruskal–Wallis $\chi^2 = 9.00$, d.f. = 3, $P < 0.05$) and across species (Kruskal–Wallis $\chi^2 = 28.95$, d.f. = 10, $P < 0.001$).

The majority (87%) of studies included in the review were conducted outside of India, except studies on the sangai and Bengal marsh mongoose, which are endemic to India (Appendix S10). We found only two papers on the Eurasian otter that reported results for India, but 555 reporting results outside of India (Appendix S10). A few (19%) studies were long-term (>3 years; Appendix S10). We found that 40% of papers did not include the study duration; 24% of studies were of 1–3 years duration (Appendix S11).

Cumulative conservation threat scores in wetland mammals

High ecological and anthropogenic threats, knowledge gaps, and high conservation needs according to the IUCN Red List assessment contributed to a high cumulative threat score for the sangai (threat score = 34), followed, in rank order, by the wild Asian buffalo (threat score = 33) and the Bengal marsh mongoose (threat score = 32; Fig. 4). In general, the cumulative threat scores were higher for large herbivores such as the Indian rhinoceros (30.6 ± 1.24 – mean ± SE) than for small carnivores such as the Asian small-clawed otter (24.5 ± 1.96 – mean ± SE). Even-toed ungulates (order Cetartiodactyla), such as the sangai and swamp deer, had higher cumulative threat scores (range = 31–33) than other ungulates living in wetlands. The cumulative threat score varied significantly among the different types of threats faced by wetland mammals (Kruskal–Wallis $\chi^2 = 29.82$, d.f. = 3, $P < 0.001$). The scores differed significantly between anthropogenic threats and ecological threats (Z value = −3.68, $P < 0.001$), ecological threats and IUCN category (Z value = 5.11, $P < 0.001$), and knowledge gap and IUCN category (Z value = −3.32, $P < 0.001$). Sympatric mammal species (e.g. Indian hog deer and swamp deer) with similar ecological requirements were found to face similar anthropogenic and ecological

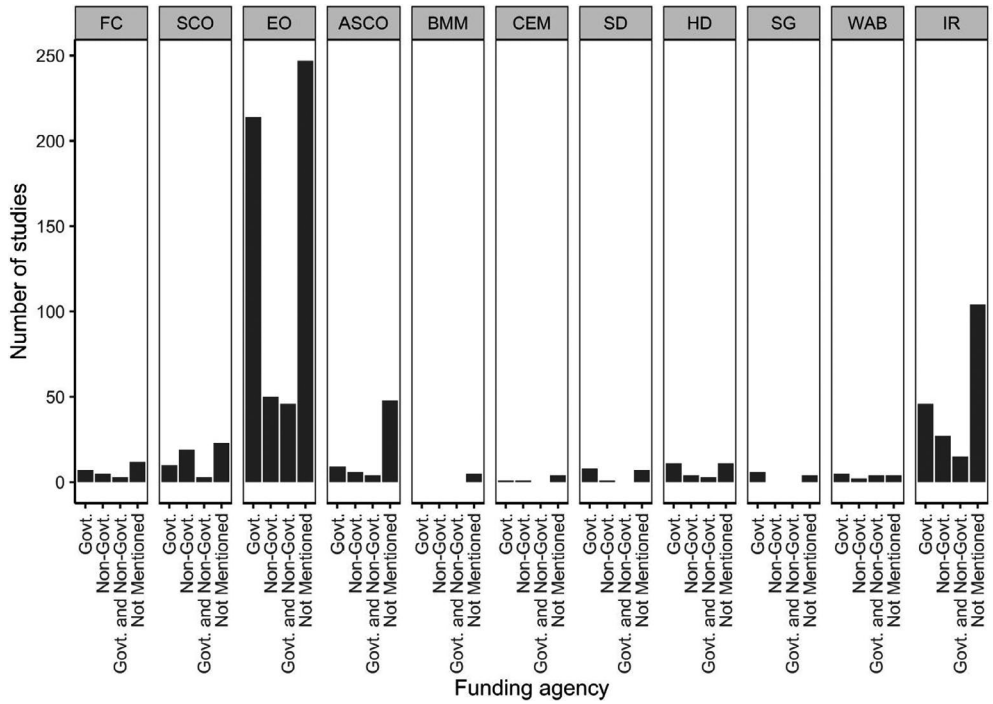

Fig. 3. Contributions of government and non-government funding agencies to scientific research on selected wetland mammals (species codes are explained in Table 1). In many published papers, the source of funding was not mentioned.

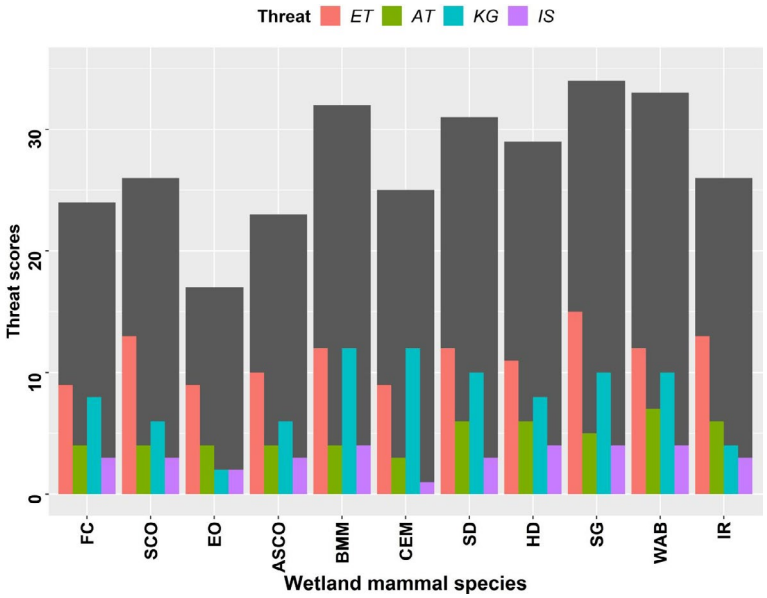

Fig. 4. Cumulative threat scores for each of the 11 selected wetland mammal species in India. Cumulative threat scores were calculated by adding the four individual threat scores, which were based on the occurrence and magnitude of ecological threats (ET) and anthropogenic threats (AT), an evaluation of knowledge gaps (KG), and the species' International Union for Conservation of Nature (IUCN) Red List category (IS); species codes are explained in Table 1. [Colour figure can be viewed at wileyonlinelibrary.com]

threats (Fig. 4). Overall, different threats operating on wetland mammals did not vary significantly among species (cumulative threat: Kruskal–Wallis $\chi^2 = 4.46$, d.f. = 10, $P = 0.85$; anthropogenic threat: Kruskal–Wallis $\chi^2 = 9.12$, d.f. = 10, $P = 0.52$; ecological threat: Kruskal–Wallis $\chi^2 = 3.56$, d.f. = 10, $P = 0.96$).

DISCUSSION

The success of species or habitat conservation efforts is enhanced by the systemic collection of evidence-based data and their use in formulating conservation strategies (Sutherland et al. 2004, de Lima et al. 2011). We adopted a systematic search protocol to obtain information on conservation threats and identify knowledge gaps for selected wetland mammal species.

Influence of ecological threats on wetland mammals

Accurate population estimations, which are key to conservation management due to their direct link to ecology (e.g. habitat selection) and long-term survival of populations (Kelt et al. 2019), were not available for five out of the 11 wetland mammals. Populations of all species other than the Indian rhinoceros were found to be declining (Appendix S8). Population fragmentation, which is known to reduce gene flow and subsequent genetic drift, may result in inbreeding depression, Allee effects and population bottlenecks (Lamont et al. 1993, Keitt et al. 2001, Charlesworth & Willis 2009). Similarly, small populations of wild animals become susceptible to extinction through environmental or demographic stochasticity due to severe habitat fragmentation (Fahrig 1997, 2003). We found that populations of many wetland mammal species (e.g. swamp deer, Indian hog deer, sangai and Indian rhinoceros) and their habitats were severely fragmented, and species were often confined to small geographic ranges, which might hinder population emigration and immigration, result in the loss of genetic diversity, and increase inbreeding depression. Wetland mammals with large geographic ranges (such as the Eurasian otter which is found throughout Asia, Europe, and Africa) may encounter fewer ecological threats due to their wide distribution and may therefore have a better chance of survival in the future than species with restricted ranges. The sangai and Bengal marsh mongoose, which are endemic to small geographic regions of India, may face comparatively high conservation threats due to habitat fragmentation and lack of knowledge. Thus, these two species, along with wild Asian buffalo, should be considered as high priority taxa for future conservation actions.

Studies have shown that large body sizes in mammals are proportional to slow population growth rates, which increase the probability of extinction, especially due to poaching/hunting practices (Price & Gittleman 2007). We found that four of the five most threatened wetland mammal species (sangai, swamp deer, wild Asian buffalo, and Indian hog deer) were herbivores with body weights >100 kg (Appendix S8). Long generation times also make some species (e.g. Indian rhinoceros, wild Asian buffalo) more vulnerable to extinction and challenging to conserve. Species such as the sangai and wild Asian buffalo face greater conservation threats than carnivores (e.g. fishing cat, Eurasian otter) in Indian wetlands. To formulate effective conservation policies for wetland mammals, more basic ecological research should be encouraged.

Impact of habitat loss and degradation on wetland mammals

Habitat destruction and the exploitation of vertebrate species are considered to be primary 'twin extinction threats' around the globe (Ripple et al. 2016). Hunting and poaching directly slow the population growth rate and accelerate the mortality rate of a species, while habitat destruction indirectly reduces the carrying capacity of the environment (Price & Gittleman 2007). Our extensive literature review showed that habitat loss and fragmentation due to various development activities were the primary anthropogenic threats for all 11 wetland mammals. The absence of detailed long-term studies on the amount and magnitude of habitat loss affecting many wetland mammals (e.g. crab-eating mongoose) hampers accurate assessments of conservation threats for these species. Our systematic literature search identified the conversion of wetlands for food production (i.e., agriculture; Foote et al. 1996, Bassi et al. 2014, Mukherjee et al. 2016), industrial zone establishment (Rao et al. 1999, Prasad et al. 2002, Bassi et al. 2014), and road construction (Foote et al. 1996, Prasad et al. 2002, Bassi et al. 2014, Mukherjee et al. 2016) as important drivers making wetland habitats more isolated and fragmented.

In Kaziranga National Park, where 70% of the wild Indian rhinoceros population occurs, the lands are severely threatened by annual floods caused by heavy monsoonal rain (Kushwaha et al. 2000, Ellis & Talukdar 2019). Alterations of the water drainage system due to unplanned development activates have increased the overall impact of the flooding in Kaziranga National Park (Kushwaha et al. 2000, Kotoky et al. 2005). Additionally, dams and barrages, constructed for flood control and hydroelectric projects, have changed patterns of water flow and water quality in the wetlands and associated riverine ecosystems, and may have had significant impacts on the ecology and long-term survival of related wetland and riverine species, including mammals (Singh 2004, Sanjit et al. 2005). For example, the endangered sangai habitat 'phumdis' (floating islands in Loktak Lake, Manipur) was found to face significant negative impacts from a hydroelectric project nearby (Singh 2004, Sanjit et al. 2005, Gray et al. 2015). The swamp deer, Indian hog deer, sangai and Indian

rhinoceros are also threatened by habitat loss due to flooding (Duckworth et al. 2015, Gray et al. 2015, Timmins et al. 2015, Ellis & Talukdar, 2019). Although the Ministry of Environment, Forest and Climate Change of the Government of India, working in close collaboration with state Governments under the National Wetland Conservation Programme (NWCP 1985–1986), identified 115 wetlands, including 26 Ramsar Sites, across the country for urgent conservation action, the overall quality of wetlands has not improved (Nagabhatla et al. 2009, Bassi et al. 2014).

Wetland mammals, particularly herbivores (e.g. Indian hog deer, swamp deer), face significant threats due to the range expansion of unpalatable low nutritive-value invasive plants (e.g. *Sesbania* spp., *Cymbopogon* spp., *Lantana camara*, *Tiliacora acuminate*, *Mimosa* sp., *Mikania micrantha*, and *Ipomoea* sp.) which has resulted in the decline of habitat quality (Duckworth et al. 2015, Timmins et al. 2015, Ellis & Talukdar 2019). Unfortunately, information on the impact of invasive plants on other herbivores that are specialist wetland-dwellers is not available, which hampers the formulation of holistic conservation plans for these species. Extensive grazing by livestock around wetland habitats has also been found to have negative impacts on herbivorous wetland mammals throughout their geographic ranges (Duckworth et al. 2015, Gray et al. 2015, Timmins et al. 2015, Ellis & Talukdar 2019, Kaul et al. 2019).

Impacts of poaching/hunting and human–wildlife conflict on wetland mammals

Poaching and hunting are considered to be the primary extinction threats for more than 300 mammal species around the globe (Ripple et al. 2016). As well as reducing the population, poaching/hunting may affect wild populations genetically by altering population subdivisions and reducing genetic variation (Allendorf et al. 2008). We found evidence that the poaching/hunting of the wetland mammal species for food and for their body parts (e.g. antlers, horns, skins, hides, hair) reduced long-term survival (Mallick 2013, Duckworth et al. 2015, Gray et al. 2015, Timmins et al. 2015, Mukherjee et al. 2016, Ellis & Talukdar 2019). Indian rhinoceroses were previously (late 1800s to early 1900s) hunted for sport, but in recent years they have been poached for their horn, which is believed to have medicinal values in traditional Chinese medicine (Ellis & Talukdar 2019). It is estimated that 1 kg of rhinoceros horn is worth USD 65000, which may promote poaching practices (Lopes 2019). Of Bengal marsh mongooses killed in the state of West Bengal, India, around 50 are required to collect 1 kg of hair to make paint brushes (Mallick 2013).

Our literature search also identified human–wildlife conflict as a prominent threat for the survival of all the wetland mammals except the sangai, for which there is paucity of data. Human–wildlife conflict often leads to retaliatory killing of wetland carnivores (e.g. Bengal marsh mongoose, Indian smooth-coated otter, Eurasian otter, crab-eating mongoose), as they occasionally raid poultry farms and fisheries (Mallick 2013, Choudhury et al. 2015, de Silva et al. 2015, Roos et al. 2015, Mukherjee et al. 2016). Thus, future conservation policies for wetland mammals, especially carnivores, should address effective human–wildlife conflict mitigation measures.

Increased disease susceptibility and the impacts of environment pollution on wetland mammals

Disease and pollution effects (e.g. heavy metal toxicity) are among the significant drivers that can threaten the long-term survival of wild animals (Scott 1988, Sánchez-Chardi 2007, 2009a, b). Rapid urbanisation can increase the human–wildlife interaction interface, exposing wild mammals to infectious diseases (Bradley & Altizer 2007). The presence of diseases was previously reported for all the wetland mammals we selected, except for the Indian smooth-coated otter and the crab-eating mongoose (Landolfi & Terio 2006, Park et al. 2007, Schaftenaar et al. 2011). Hybridisation with domestic animals (considered to be a conservation threat) has been reported only for the wild Asian buffalo in this study (Kaul et al. 2019). As wetland habitats in India are changing very fast due to rapid urbanisation, wetland mammals may become more vulnerable to disease and hybridisation with domestic animals. Recent research has shown that the three sympatric otter species are threatened by pesticide pollution throughout their geographic ranges (de Silva et al. 2015, Roos et al. 2015, Wright et al. 2015). Eurasian otters are threatened by pollution caused by industrial chemical contamination, acidification and oil spills in rivers and on sea shores of Europe (Baker et al. 1981, Mason & Macdonald 1987, Boscher et al. 2010, Roos et al. 2015). Although India and other South Asian countries experience high levels of environment pollution, information on its impact on wetland species, especially otters, is limited. Thus, we have demonstrated a requirement for future studies that will improve understanding of the impacts of environment pollution on wetland mammals. Disease and hybridisation threats should be considered as priority topics for future scientific studies.

Using modern conservation tools to promote the survival of wetland mammals

Successful implementation of ex situ conservation techniques, such as conservation breeding and associated assisted reproductive technologies, is known to improve

degenerated populations of threatened wild animals (Songsasen & Comizzoli 2019). Though recent research has indicated that conservation breeding programmes in captivity could be an important strategy for conserving threatened wetland mammal species (e.g. the fishing cat, Indian rhinoceros, and wild Asian buffalo), we found scant information on the conservation breeding of other wetland mammal species in India (Schaffer et al. 1990, Zschokke et al. 1998, Thiangtum 2005, Thiangtum et al. 2006, Priya et al. 2014, Houwald & Pagan 2017). Conservation breeding has been reported for three otter species in different zoos: the Indian smooth-coated otter in Jaipur Zoo, India (Yadav 1967), the Asian small-clawed otter in Adelaide Zoo, Australia (Lancester 1975) and in Chester Zoo, UK (Timmis 1971), and the Eurasian otter in the Hunawihr breeding centre in France (Capber 2007).

The Wildlife Trust of India and the Chhattisgarh State Forest Department jointly initiated a five-year action plan, the Central India Wild Buffalo Recovery Project in the Udanti-Sitanadi Tiger Reserve, which successfully increased the wild Asian buffalo population in 2015 using ex situ (e.g. conservation breeding) and in situ techniques (https://www.wti.org.in/projects/central-india-wild-buffalo-conservation-project/). This indicates the potential for conservation breeding as an important strategy for increasing the population of vulnerable wetland mammals, such as the sangai and the Bengal marsh mongoose in India.

Recent advances in conservation genetics and endocrinology have helped conservation efforts to manage both captive and free-ranging populations of threatened species more effectively (Tubbs et al. 2014, Benestan et al. 2016). Our detailed literature search revealed that some of the wetland mammals, namely the fishing cat (Santymire et al. 2011, Khonmee et al. 2016, Suksai et al. 2016), Eurasian otter (Kalz et al. 2006, Seignobosc et al. 2011, White et al. 2013), Asian small-clawed otter (Bateman et al. 2009, Rosli et al. 2014), Indian hog deer (Durrant et al. 1996, Abbas et al. 2017, Pinthong et al. 2017), and Indian rhinoceros (Schwarzenberger et al. 2000, Stoops et al. 2004, 2016), have been used as model systems for conservation genetics and endocrinological studies. These disciplines should be prioritised in future studies to improve future conservation measures for threatened mammals.

Knowledge gaps in wetland mammal conservation

Conservation initiatives based on limited knowledge about species' ecology, unscientific anecdotes and myths have led to the implementation of ineffective conservation practices (Sutherland et al. 2004, Costa et al. 2005, Songsasen & Comizzoli 2019). We found significant variation in the amount of research on different wetland mammals. The Eurasian otter was the best-studied species (n = 557 papers), followed by the Indian rhinoceros (n = 192); other species have generally received little attention from scientific researchers. For example, in spite of the severe conservation threats identified by the present study, published information on the Bengal marsh mongoose (n = 5), crab-eating mongoose (n = 6), and sangai (n = 10) is limited; most of the studies were undertaken post-1990. We also found that most studies on wetland mammals had been undertaken outside India, except for two Indian endemic species (Bengal marsh mongoose and sangai). Although the Eurasian otter is a well-studied species, only two papers on it were based on studies within India. Clearly, there is a knowledge gap concerning Eurasian otter ecology and survival threats in its Indian habitat. Being a mega-diverse country, India contains many different types of habitats and associated wetlands (Bassi et al. 2014). In spite of the availability of potential wetland habitats for the Eurasian otter, a lack of information on its population trends and habitats in India hampers the accurate assessment of conservation threats for the species and the formulation of effective conservation policies.

We found that a significant number of papers (n = 469) did not include information on funding agencies, making it difficult to understand the participation of various stakeholders (e.g. government and non-government agencies) in the conservation of wetland mammals in India. Future studies should clearly acknowledge the participation of stakeholders in conservation activities.

Policy intervention for wetland conservation in India

Wetlands cover 4.3% of geographic area of India and support one fifth of India's biodiversity. As a signatory of the Ramsar Convention, the Indian Government developed policies and programmes, such as the National Wetland Conservation Programme (1985–1986), the National Lake Conservation Plan (2001), the National Plan for Conservation of Aquatic Ecosystems (2013), the National Wetland Atlas (2013), and the Wetlands (Conservation and Management) Rules (MoEF 2010), to conserve its wetland ecosystems and associated biodiversity. Despite government legislation on wetland regulation, a significant amount of wetland continues to be ignored in the policy process, which has resulted in the loss of one-third of natural wetlands to various development activities (e.g. urbanisation, agricultural expansion) and pollution between 1970 and 2014 (Bassi et al. 2014, Wetland International South Asia 2019). New habitat-centric conservation programmes exist, such as the Integrated Development of Wildlife Habitats in 2007 (MoEF 2014), which aims to improve habitat quality for threatened animal species and

increase their overall population, and has listed four wetland mammal species (sangai, swamp deer, Indian rhinoceros, and wild Indian buffalo). However, similar programmes are not available for carnivores inhabiting wetland. The current wetland conservation efforts are only focused on a small fraction of total wetland areas, and, as threats to wetland ecosystem functions increase, it is essential to identify more ecologically important wetlands and to implement regulations strictly.

CONCLUSIONS

The wetland ecosystems in India are distributed across various topographic and climatic regimes, support diverse habitats with significant amount of biological diversity, and provide a wide variety of ecosystem services [Wetlands (Conservation and Management) Rules (MoEF 2010)]. Thus, our study is timely and relevant, as it assessed available information on the conservation of 11 wetland mammals in India through a rigorous evidence-based conservation process, identified knowledge gaps and priority species (sangai, wild Indian buffalo, Bengal marsh mongoose) for immediate conservation action and required for monitoring the health of wetlands. Furthermore, this study identified the need for a holistic conservation approach for wetland mammals and highlights the need for trans-boundary conservation efforts, such as regular population estimations and habitat monitoring exercises. We emphasise important issues (e.g. disease ecology, human–wildlife conflict, changes in land use) that should be considered as future priority research areas and will allow the effective conservation and management plans that are needed to ensure the long-term survival of wetlands and wetland mammals in India.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Appendix S1. Classification of literature on wetland mammals in different categories.

Appendix S2. Schematic representation of information flow for the Eurasian otter (*Lutra lutra*) using a PRISMA flow diagram.

Appendix S3. Assessment of conservation threats for wetland mammals of India.

Appendix S4. Assessment of IUCN conservation status.

Appendix S5. Kappa estimates for inter-assessor agreement on the relevance of search results; species codes are explained in Table 1.

Appendix S6. Availability of information at various search stages for eleven selected wetland mammals in India. Codes in parenthesis are species abbreviations.

Appendix S7. Literature search results which have been used to identify relevant studies on wetland mammals.

Appendix S8. Details of ecological threats faced by selected wetland mammals in India (ABD: Population Abundance; PT: Population Trend; Pop. Frag. = Population Fragmentation; GD = Global Distribution; BW = Body Weight in kg, highest body weights were considered for assessment; GL = Generation Length in years, longest generation length was considered for assessment). Numbers in superscripts indicate corresponding literature references; species codes are explained in Table 1.

Appendix S9. Details of anthropogenic threats operating on selected wetland mammals in India. HAC: Human Animal Conflict; HLAA: Habitat Loss due to Anthropogenic Activity; IIS: Impact of Invasive Species; PH: Poaching Hunting; HAD: Hybridization with Domestic Animal; HLNP: Habitat loss due to Natural Processes; DIS. POL.: Diseases and Pollution. Numbers in superscripts indicate the corresponding literature references; species codes are explained in Table 1.

Appendix S10. Locations of studies found during literature search for selected wetland mammals; species codes are explained in Table 1.

Appendix S11. Duration of studies found during literature search for selected wetland mammals; species codes are explained in Table 1.