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ORIGINAL PAPER

Habitat selection of smooth-coated otters (*Lutrogale perspicillata*) in the peri-coastal, urbanised landscape of Goa, India

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Abstract

Human development can have detrimental impacts on the environment and its contained ecosystems. However, several species have adapted to thrive in human-modified landscapes. This study was aimed to assess habitat selection of threatened smooth-coated otters (*Lutrogale perspicillata*) in the peri-coastal landscape of Goa, India. In the Indian context, there are significant gaps in knowledge pertaining to factors that influence otter occurrence in such environments. Otter presence/absence in 78 1 km^2 plots across two river catchments was modelled against several habitat variables including measures of agricultural pollution, salinity, mangrove cover, and fishing presence. The effect size and direction of relationships between the probability of otter occurrence and the habitat variables were analysed by building a set of candidate generalised linear models. The models were subsequently ranked using small-sample Akaike's information criterion (AICc). Analysis indicated that water salinity, mangrove cover, and fishing presence had a significant positive influence on otter occurrence. However, the concentrations of agricultural pollutants (nitrates, phosphates, and sulphates) were not contributing factors in influencing otter occurrence in the surveyed landscape. The metrics used in this study can be applied for preliminary assessments of presence and occupancy of otters in other coastal landscapes of India, and aid in the conservation of the species.

Keywords Smooth-coated otter · Human-wildlife coadaptation · Habitat selection · Khazan · Mangroves · Fishing · Salinity

Introduction

Human development and associated habitat fragmentation can exert a catastrophic negative influence on the natural world. This can impede animal movement, distribution, and dispersal. In addition, it can lead to population decline as well as local and global extinctions (Andrén 1994; Dirzo et al. 2014; Mullu 2016; Shende et al. 2015). The periodically fluctuating environment that occurs in estuarine mangrove ecosystems is caused by changes in water levels, salinity, oxygen concentration, and the movement of nutrients and sediments (Bayen 2012; Saddhe et al. 2016). This results in the formation of a brackish environment characterised by high productivity (Nixon et al. 1986). These ecosystems act as feeding, breeding, and shelter grounds for a rich assemblage of organisms, represented in complex and intricate food webs. In addition, mangroves provide several ecosystem services such as shoreline stabilisation, coastal protection, pollution control, and carbon sequestration (Carlton 1974; Das and Vincent 2009; Dhargalkar et al. n.d.; Kathiresan and Bingham 2001; Kathiresan and Rajendran 2005; Maiti and Chowdhury 2013; Ray and Jana 2017). In Goa, rapid development, land reclamation, sand and iron ore mining, and other factors relating to human population growth have led to the degradation of mangrove forests (Dhargalkar et al. n.d.; The Navhind Times 2017).

The smooth-coated otter (*Lutrogale perspicillata*) is a social, nocturnal, piscivorous mustelid occurring throughout South and Southeast Asia, and Iraq (Blanford 1890; Hussain and Choudhury 1997; Medway 1969). On the Indian peninsula, this species is primarily found in plains, deserts, semi-arid areas, and the highlands of the Deccan, inhabiting

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canals, and irrigation tanks, using flooded fields, estuaries, coastal belts, and the open sea as hunting grounds (Prater 2005). Fish, crabs, shrimp, insects, and amphibians constitute its diet (Anoop and Hussain 2005; Foster-Turley 1992). The species is classified 'Vulnerable' on the IUCN Red List of Threatened Species and listed under 'Schedule-II' of the Indian Wildlife Protection Act, 1972 (DeSilva et al. 2015; Wildlife Protection Act 1972). In Goa, *L. perspicillata* generally occurs in large rivers characterised by brackish water and mangrove forest patches (Borker et al. 2016).

Habitat selection is a hierarchical process that influences varied behaviours causing a non-random use of available habitat (Johnson 1980). Since the environment is not static, several organisms exhibit a dynamic response which results in the variation in distribution and abundance across habitable landscapes (McGarigal et al. 2016). Habitat selection assessments give an insight into the behavioural responses of organisms that subsequently affect distribution and persistence across habitats of varying ecological quality (Arlt 2007; Morrison et al. 1992). Habitat selection studies on *L. perspicillata* in India have largely been carried out in protected areas. In Periyar Tiger Reserve, Kerala, South India, Anoop and Hussain (2004) studied habitat selection of this species with the help of an ordination technique using parameters such as defecating areas, holts, footprints, and grooming sites as indicators for presence. The study concluded that several environmental factors such as shallow water depth, gradually sloping mud, number of streams, distribution of potential holt sites, sandy substratum, vegetation cover, grooming sites, and latrine sites influenced habitat selection. Similarly, Khan et al. (2014) studied habitat use pattern of smooth-coated otters in the upper Gangetic basin. This study indicated the preference for sandy substrates in some regions of the study area and muddy substrates in another. The authors also concluded that calmer regions of the rivers influenced otter occurrence as it increased prey capture rate. However, a significant part of the species' range occurs in areas that have a dense human population (DeSilva et al. 2015). Hence, studying population parameters chiefly in protected areas may not be indicative of the full picture. Therefore, habitat selection assessments of otters in rapidly urbanising, coastal regions that contain important natural and modified environments is an useful additional component to understand landscape use for future management and conservation of this threatened species.

Published literature on *L. perspicillata* suggests that this species thrives in estuarine environments characterised by mangrove forests and elevated salinity concentrations (Abdul-Patah et al. 2014; Kamjing et al. 2017; Palei et al. 2020; Sivasothi and Nor 1994; Theng et al. 2016). Furthermore, estuarine environments are characterised by high productivity (Day et al. 2013). This ensures a diverse prey base for otters. In Goa, these ecosystems harbour a wide variety of fish and crustacean stock resulting in an extensive modification of the estuarine environment to support the rural fishery of the state (De Sousa 2007). The presence of otters in these areas implies an overlap between the resources harvested from the estuaries and their prey-base. In addition, agriculture is a predominant activity carried out around the major river systems of Goa (Directorate of Agriculture n.d; Kamat 2004). Hence, it is important to consider the impacts of agricultural pollutants when studying selection parameters of bioindicator species such as otters. In this study, we focused on aquatic pollutants originating from fertiliser use by analysing the concentrations of three inorganic components of fertilisers namely nitrates, phosphates, and sulphates. Several studies have highlighted the negative impacts of elevated concentrations of these ions in aquatic ecosystems, particularly by impacting the food web, resulting in a decline in fish populations that are crucial for the survival of apex predators such as otters (Bedford 2009; Camargo and Alonso 2006; Minnesota Pollution Control Agency 2008; Kroupova et al. 2005; Brown and Sadler 1989; Sprague et al. 2007).

In this study, we assessed habitat selection of *L. perspicillata* in the peri-coastal, estuarine environments of Goa in relation to a range of environmental variables: salinity, mangrove cover, concentrations of agricultural pollutants (nitrates, phosphates, and sulphates), and fishing presence. Based on our pilot study and existing literature, we hypothesise that mangrove cover and the salinity concentration of the aquatic environment play an imperative role in influencing otter occupancy. We also hypothesise a positive relationship between otter occurrence and fishing presence in the estuarine areas of Goa and a negative association between otter presence and agricultural pollutants with an emphasis on nitrates, phosphates, and sulphates.

Material and methods

Study area. Goa is a state located along the western coast of the Indian peninsula (28° 38′ N latitude and 72° 12′ E longitude). The central and eastern regions of the state contain a section of the Western Ghats mountain range that runs along the western coast of India and separates the Deccan Plateau from the Konkan Coast. In Goa, the Western Ghats create a catchment system that empties into the Arabian Sea through seven estuaries. As the distance between the mountain range and the ocean is relatively small (~ 40 km), the coastal influence extends throughout most of the inland rivers resulting in brackish water environments. Historically, this influence has favoured the growth of mangrove forests along the banks of the rivers in the central and western regions of the state. The high productivity of these ecosystems has been extensively exploited by humans and these areas have been modified into the ‘Khazan system’. Khazans are community managed areas that are used for paddy cultivation, salt extraction, and pisciculture (Ansari et al. 2012; De Sousa 2007). A typical Khazan consists of the following: (a) Bundhs: 2–2.5-m-high and 1–1.5-m-wide embankments constructed from clay soil which help protect the Khazans from the saline waters of the estuary during high tides; (b) Manas (Sluice Gates), which are gate-like structures that aid in the exchange of water between Khazans and neighbouring estuaries during tidal fluctuations; (c) Poiin, which are the internal water bodies within the Khazans (see Fig. 1). Dense mangrove growth is typically seen along the outer bundhs of the Khazans. Historically, the primary use of the poiin was to provide irrigation water for agriculture but today they also serve as traditional fishing pools (De Sousa 2007). This study was carried out in the Khazans and associated non-Khazan landscapes of two major rivers of Goa, namely, the Mandovi and the Zuari.

Data collection. Data collection was carried out between 15th January 2018 and 16th March 2018 following a pilot study conducted in December 2017. Based on literature review and field observations made during the pilot study, variables that had an apparent influence on otter presence were identified. An arbitrary grid system of 1 km^2 squares was generated as a shapefile and imported into QGIS (QGIS Development Team 2018). Using the GEarthView plugin, this grid system was transferred onto a map of Goa in Google Earth Pro (Google LLC 2018). A major portion of the study (72 km^2, 90%) was carried out in areas that experienced a tidal influence. In addition, a small portion of the study (8 km^2, 10%) was carried out in a man-made irrigation canal system that originates and runs parallel to the Zuari river. For logistical reasons, we selected eighty 1 km^2 squares to sample from. We used a stratified random sampling approach, such that we would sample equally from each river system. Selected squares are shown in Fig. 2a.

For each sample square, a 400-m transect was carried out, based on prior surveys. Due to logistical constraints, a single survey was carried out along a single bank of the selected grid. The constraints primarily occurred due to spatial hindrances such as the inaccessibility of adjacent banks of the survey grids due to the river width and lack of connectivity via bridges. This decision was made based on an assumption that the study species utilises both riverbanks as there is a limited variation in landscape characteristics within the confinement of each survey grid. The probability of detection of otter signs was assumed to be similar across 95% ($n = 76$) of the 78 surveyed grid squares as the surveys were carried out along a comparable terrain. Sixty-eight of the 78 surveys were conducted along man-made bundhs that are regularly maintained by the fisherfolk. The bundhs are typically constructed from soil obtained from the adjoining river and are composed of hardened sand, silt, and clay. In addition, some bundhs are constructed using red lateritic soil (Souza et al. 2016). In either case, the topography of the bundh was fairly uniform and characterised by negligible vegetation cover during the study period. Furthermore, eight surveys were carried out along the banks of a man-made irrigation canal. These banks were also primarily characterised by a fairly even topography composed of lateritic soil and sparse vegetation cover. 2.5% ($n = 2$) of the surveys were conducted along rocky riverbanks, and 2.5% ($n = 2$) grid squares could not be surveyed due to inaccessibility

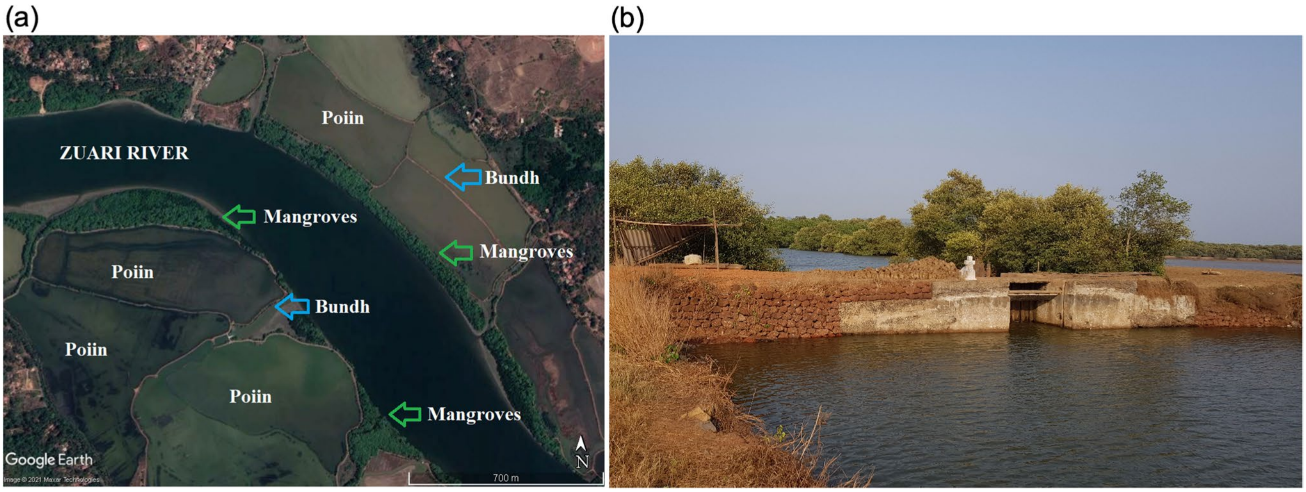

Fig. 1 An example of the Khazan system in Goa: (**a**) An aerial image of a section of the main river system showing mangrove forests, bundhs (mud embankments), manas (sluice gates), and poiin (internal water bodies) that make up the Khazans (Google LLC, 2021); (**b**) A manas and a bundh separating a poiin from the channel that leads to the main river

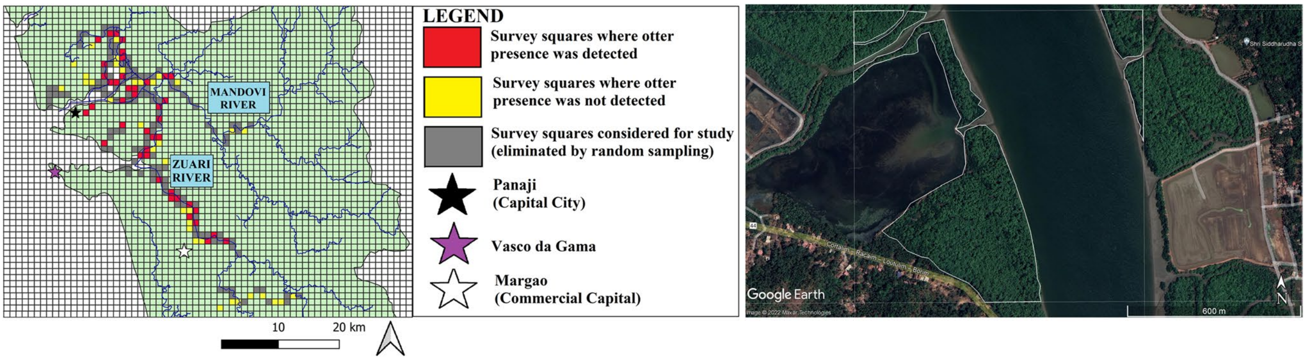

Fig. 2 Grid system of 1km^2 grid squares over the map of Goa (Left); Map indicating an example of the grids assessed for mangrove cover. Regions marked around the mangroves depict the estimation of mangrove cover using the polygon-area estimation function in Google Earth Pro, Source: Google LLC 2022 (Right)

and heavy human development in the area. Furthermore, the study was conducted between winter and early summer where the precipitation is low (India Meteorological Department- Goa 2021). This results in persistence of otter signs in the environment for relatively longer periods of time.

During each survey, the 400-m transect was extensively searched for otter signs (spraint, latrine sites, and tracks), which were subsequently recorded using a GPS device (Garmin etrex-10, Garmin International Inc., Olathe, KS, USA). Presence of otters in a survey grid square was determined based on whether such signs were observed during the surveys. In addition, water samples were collected from accessible locations along the transects and stored in 750-mL plastic bottles. These samples were used for the assessment of salinity and agricultural pollutant concentrations derived from fertilisers (nitrates, sulphates, and phosphates). The water samples were stored in a dark environment overnight and quickly analysed the next day (see below). Several fishing variables such as number of fishers, nets, boats, and sluice gates were also noted to determine 'Fishing Presence'. The final variable estimated was 'Estimated Mangrove Cover (ha)', which was assessed using the polygon-area estimation function using Google Earth Pro (Google LLC 2018) (see Fig. 2b).

Generation of calibration curves and analysis of water samples. Nitrate, phosphate, and sulphate concentrations from the water samples were assessed by employing a colorimetric technique using a Visible Spectrophotometer (Chemito-215D, Chemito Technologies Pvt Ltd, Mumbai, India). The assessments were carried out in the Chowgules Human Genetic Research Lab at Parvatibai Chowgule College of Arts and Science (Autonomous), Gogol, Margao- Goa. Prior to the analysis of water samples acquired from the field, nitrate, phosphate, and sulphate calibration curves were constructed using standard solutions. Using the line equations generated from the calibration curves, the concentrations of pollutants in the water samples obtained from the field were analysed.

Data analysis Analysis was carried out in R Studio (RStudio Team 2018). Otter Presence (1)/Absence (0) for each square was taken as a binary response variable, with nitrates, phosphates, sulphates, salinity, fishing presence, and estimated mangrove cover as the predictor variables. Multicollinearity across all the six explanatory variables was tested by creating a global generalised linear model with binomial errors and logit-link function. This global model consisted of otter presence as a response variable, and each explanatory variable. A Variance Inflation Factor (VIF) was then calculated for each explanatory variable, using the 'car' package in R (Fox and Weisburg 2019). A generally accepted threshold for VIF is that a value >2.5 indicates 'considerable collinearity', with some using a less conservative threshold (Johnson et al. 2018). A conservative approach was taken and the lower threshold of 2.5 was used in this study. All VIFs in the global model were between 1.03 and 1.36, so multicollinearity was assumed to be low in the explanatory variables and not biasing the interpretation of our models. In addition, all Pearson correlation coefficients between pairs of explanatory variables were $\leq |0.42|$. Then, a set of ten a priori hypotheses were used to build a set of candidate generalised linear models with binomial errors and logit-link function (Table 1). This was done to explain smooth-coated otter distribution, based on the six pollution, habitat, and management variables collected from the surveys. A null (no terms) and a global model (all terms) was also included. However, we did not include any interaction terms, only main effects.

All candidate models were ranked by their small-sample Akaike information criterion (AICc) and inferences were taken from models with $\Delta\text{AICc} \leq 2$. In addition, to account for model selection uncertainty, we calculated

Table 1 Candidate set of a priori hypotheses and associated models for smooth-coated otter distribution. Models are all generalised linear models with binomial errors and logit-link functions, with Otter Presence (1)/Absence (0) as a response variable. Explanatory variables are estimated mangrove cover, fishing presence, salinity, nitrates, sulphates, phosphates, and null model

Model	Explanatory variables	Hypotheses. Otter distribution is predicted by…
1	(Null model)	… none of the variables measured
2	Nitrates	… concentration of nitrates
3	Phosphates	… concentration of phosphates
4	Sulphates	… concentration of sulphates
5	Nitrates + phosphates + sulphates	… concentrations of a combination of agricultural pollutants
6	Salinity	… water salinity
7	Estimated mangrove cover	… mangrove cover
8	Fishing presence	… presence of fishing
9	Salinity + estimated mangrove cover + fishing presence	… a combination of habitat and management factors
10	Nitrates + phosphates + sulphates + salinity + estimated mangrove cover + fishing presence (global model)	… a combination of agricultural pollutants, habitat and management factors

model-averaged parameter estimates and 95% confidence intervals, weighted by each model's Akaike's weight (w_i) The 95% confidence intervals were estimated by taking model-averaged standard errors and multiplying by 1.96. Model comparison and averaging were carried out in the R package 'MuMIn'(Barton 2018). Marginal effects (i.e. effects when other covariates are held constant) of any model(s) in the confidence set were calculated and plotted using the R package 'sjPlot' (Lüdecke 2021).

Results

Otters were detected in 42 of the 78 squares surveyed. The mean nitrate, phosphate, and sulphate concentrations of the water samples collected in this study were estimated to be 2.1 mg/L (SD = ± 1.6 mg/L; range = 0.3–14.0), 0.4 mg/L (SD = ± 0.3 mg/L; range = 0.1–1.2), and 6221.8 mg/L (SD = ± 3341.6 mg/L; range = 340.0–17,443.9) respectively. The mean salinity concentration of the water samples collected was estimated to be 13.8 g/L (SD = ± 7.3 g/L; range = 0.02–24.5). Furthermore, the mean mangrove cover across the surveyed grid squares was estimated to be 9.9 ha (SD = ± 12.0 ha; range = 0.0–45.4). Lastly, fishing activity was observed in 34.6% ($n = 27$) of the surveyed grid squares. The thematic representations of variations in the predictor variables across all sampled grid squares in the study area are depicted in Fig. 3.

No models apart from that with the lowest AICc had a ΔAICc ≤ 2, with the next best model having a ΔAICc of 5.6, i.e. the global model (Table 2). The top model contained the following variables: salinity concentrations, estimated mangrove cover, and fishing presence. The effect of all three variables in that model on probability of otter presence were positive, and 95% confidence intervals did not overlap zero, either in the top model or when estimated from model-averaging (Table 3). In contrast, none of the agricultural pollutants (nitrates, sulphates or phosphates) appeared in the confidence set and their model-averaged parameter estimate 95% confidence intervals overlapped with zero (Table 3). The marginal effects with 95% confidence intervals of each of the variables in the top model are plotted in Fig. 4.

Discussion

L. perspicillata largely occurs in developing nations where intensive agriculture contributes to a significant component of aquatic pollution (Atapattu and Kodituwakku, 2009; DeSilva et al. 2015). Large-scale use of fertilisers in agricultural areas has significantly contributed to aquatic pollution on a global scale (Chandini et al. 2019; Choudhury and Kennedy 2005; Savci 2012; Singh and Craswell, 2021). In Goa, agriculture is primarily practiced in close proximity to the rivers (Directorate of Agriculture n.d; Kamat 2004). Therefore, these river systems are highly susceptible to aquatic pollution of agricultural nature. In this study, we assessed the concentrations of three inorganic ions, i.e. nitrates, phosphates, and sulphates that are present in fertiliser complexes used in agriculture (Chandini et al. 2019; Food and Agriculture Organization of the United Nations 2005). The negative impacts of these pollutants on aquatic ecosystems are many fold. High concentrations of nitrates and phosphates can cause eutrophication of the water bodies by inducing an accelerated growth rate of plant matter resulting in unavailability of dissolved oxygen for fish species (Bedford 2009; Camargo and Alonso 2006; Minnesota Pollution Control Agency 2008). At the physiological level, nitrate accumulation can also result in the oxidation of haemoglobin and methaemoglobin comprising blood oxygen transport in fish (Kroupova et al. 2005). Increased concentrations of

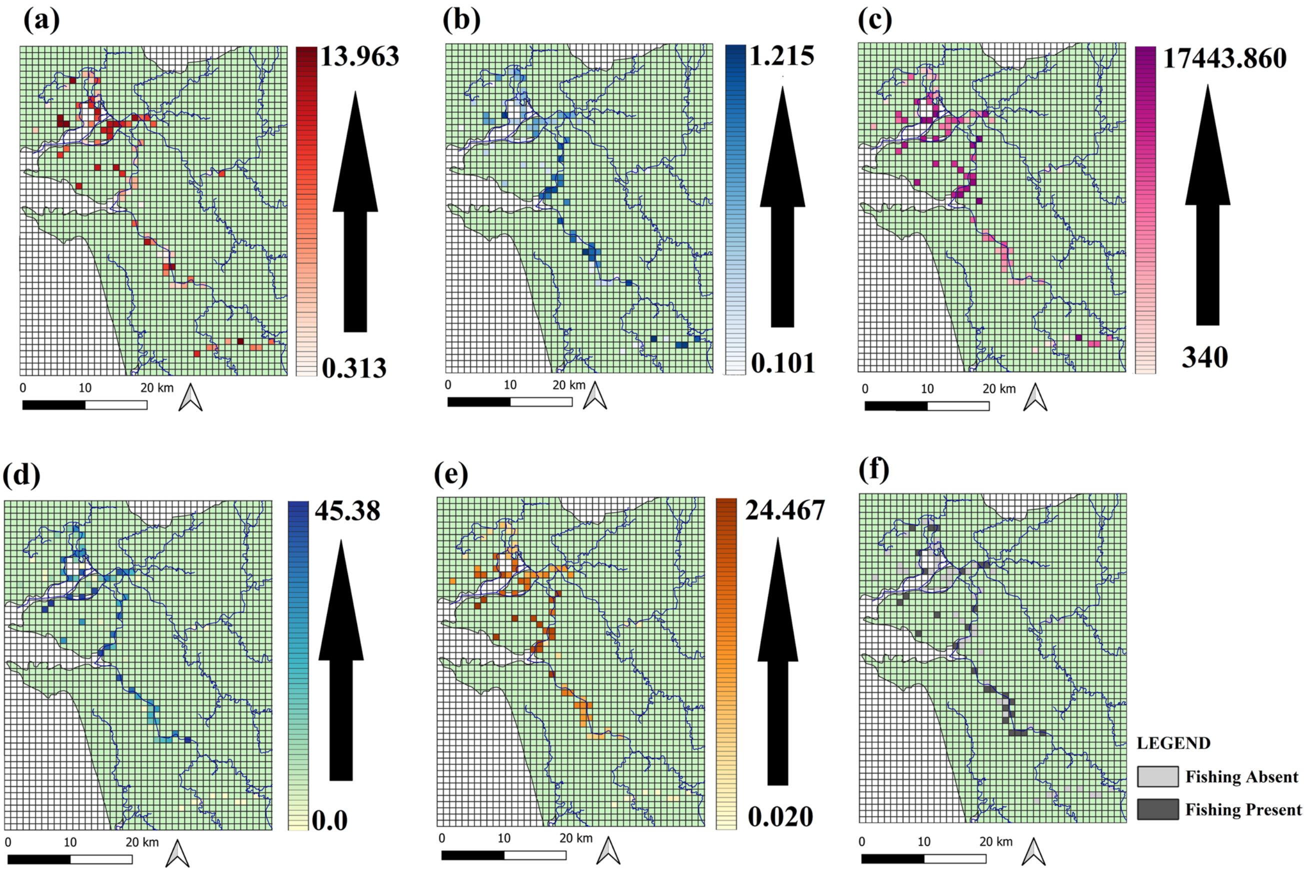

Fig. 3 Variation in the predictor variables across the study area. (**a**) Nitrate concentration (mg/L); (**b**) Phosphate concentration (mg/L); (**c**) Sulphate concentration (mg/L); (**d**) Estimated mangrove cover (ha); (**e**) Salinity concentration (g/L); (**f**) Fishing presence

Table 2 Model comparison results for candidate models in Table 1. *k*, number of estimated parameters; *−ln(L)*, negative log-likelihood of model; *AICc*, small-sample Akaike's information criterion; *ΔAICc*, difference between the AICc for given model and best model; w_i, Akaike's weights. The model in the confidence set (ΔAICc ≤ 2) is shown in bold. Explanatory variables are estimated mangrove cover, fishing presence, salinity, nitrates, sulphates, phosphates, and the null model

Model	Explanatory variables	*k*	− ln(*L*)	AICc	ΔAICc	w_i
9	**Salinity + estimated mangrove cover + fishing presence**	**4**	**− 31.7**	**71.9**	**-**	**0.94**
10	Nitrates + phosphates + sulphates + salinity + estimated mangrove cover + fishing presence	7	− 30.9	77.5	5.6	0.06
7	Estimated mangrove cover	2	− 39.0	82.1	10.2	0.00
6	Salinity	2	− 44.2	92.6	20.7	0.00
8	Fishing presence	2	− 45.0	94.2	22.3	0.00
4	Sulphates	2	− 52.5	109.2	37.3	0.00
1	Null model	1	− 53.8	109.7	37.8	0.00
5	Nitrates + phosphates + sulphates	4	− 50.6	109.8	37.9	0.00
2	Nitrates	2	− 53.2	110.5	38.6	0.00
3	Phosphates	2	− 53.2	110.5	38.6	0.00

sulphates can affect fish species that are not tolerant to high pH levels. In addition, sulphate pollution can also increase fish mortality by causing a reduction in the sodium and oxygen levels of the blood (Sprague et al. 2007). Therefore, in sufficient concentrations, nitrates, phosphates, and sulphates have the potential of drastically affecting fish populations, thereby affecting otter occupancy in the landscape. Our analysis indicates that the concentrations of nitrates, phosphates,

Table 3 Parameter estimates and 95% confidence intervals (1.96*SE) for model parameters from (a) the top model based on AICc (and the only model in the confidence set of ΔAICc ≤ 2, see Table 2), and (b) model-averaged parameter estimates across all models in Table 2, weighted by Akaike's weights. Parameter estimates for which the 95% confidence intervals do not overlap zero are shown in bold

Parameter	(a) Top model		(b) Model-averaged	
	Estimate	**95% CI**	**Estimate**	**95% CI**
(Intercept)	**−3.33**	**−5.28, −1.38**	**−3.33**	**−5.37, −1.29**
Salinity	**0.14**	**0.03, 0.25**	**0.14**	**0.03, 0.25**
Estimated mangrove cover	**0.12**	**0.03, 0.20**	**0.12**	**0.03, 0.21**
Fishing presence/absence	**1.91**	**0.43, 3.39**	**1.92**	**0.41, 3.43**
Nitrate concentration	-	-	−0.16	−0.85, 0.53
Phosphate concentration	-	-	1.29	−1.54, 4.12
Sulphate concentration	-	-	0.00	0.00, 0.00

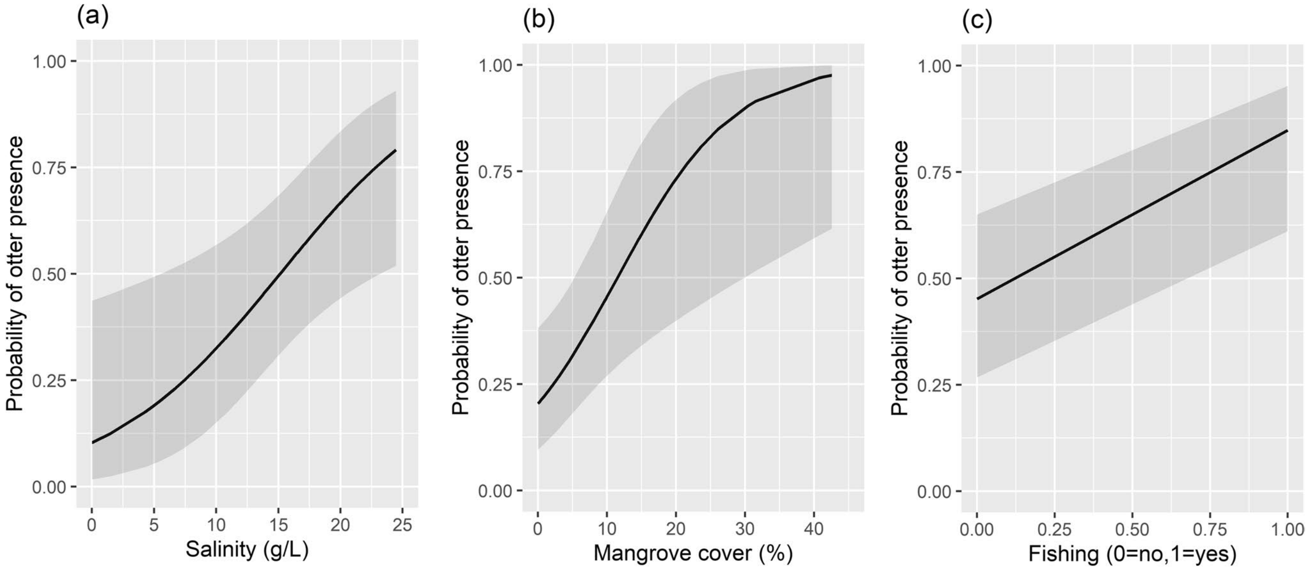

Fig. 4 Predicted marginal effects, with 95% confidence regions, of the three variables included in the top model based on AICc (and only model in the confidence set of AICc ≤ 2, see Table 2). Fishing presence was a binary variable dummy coded as 0 = absence and 1 = presence. The response variable has been back transformed from the logit scale to probabilities

and sulphates in the study area were not associated with otter occurrence, thereby indicating that these concentrations are likely to be below the threshold levels to affect the prey-base and limit otter occupancy.

The smooth-coated otter is a river otter that primarily inhabits freshwater systems across its geographical range (DeSilva et al. 2015). However, this species also thrives in estuarine environments (Abdul-Patah et al. 2014). High salinity concentrations can have negative impacts on otters. A study conducted by Kruuk and Balharry (1990) indicated that a constant exposure to salinity can have detrimental impacts on otters such as a loss in thermal capacity of the coat, hypothermia, and a decreased oxygen carrying capacity under water. Therefore, otters that inhabit coastal environments require freshwater for drinking and bathing purposes (Abdul-Patah et al. 2014). Although there are records of smooth-coated otters in estuarine ecosystems, there is no scientific literature that indicates a preference for brackish water environments as compared to upstream environments of the same river within a contiguous landscape. In the context of the present study, it is evident that the salinity gradually decreases upstream in both the river systems (see Fig. 3e). Surveys carried out in the upstream extremities of Mandovi river did not give any indication of otter presence. Furthermore, no otter signs were recorded from the eight surveys carried out along the man-made irrigation canal. The preference to estuarine ecosystems may be linked to the high productivity of these environments. The rural fishery sector of Goa is extensively reliant on the estuaries. The khazan areas which were historically used for agriculture are now primarily used for aquaculture. A wide variety of fish species belonging to Mugilidae, Cichlidae, Clariidae, and Chanidae families, as well as shrimp and crabs, are harvested in the Khazans. This implies a high density of fish and crustacean stock in the relative confinement of the khazan pools (De Sousa 2007). Therefore, the khazans serve as good hunting and breeding grounds for otters (Abdul-Patah et al. 2014). As per our analysis, the parameters salinity and fishing presence were present in the top model thereby indicating that they were associated with occurrence of otters in the study area. Therefore, our assessment implies that otter occurrence and landscape use is influenced by factors linked to high salinity concentrations and fishing prevalence, both of which are characteristic features of khazans.

Mangrove forests are another characteristic feature of the Khazan landscape of Goa (see Fig. 1a). In coastal environments, mangrove forests and associated rice fields are crucial environments for otters (Abdul-Patah et al. 2014; Foster-Turley 1992). However, there are limited studies that delve into the importance of mangroves for the species in India. Observations made in this study indicate that mangrove cover correlated with otter occurrence. As the khazans of Goa exhibit similar landscape characteristics as those studied by Abdul-Patah et al. (2014) and Foster-Turley (1992) in Malaysia, this study gives further validity to the importance of mangroves for otters in human-modified, coastal landscapes. In terms of global species distribution, *L. perspicillata* occurs throughout South and Southeast Asia in several countries namely Pakistan, India, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, Vietnam, Malaysia, Singapore, Indonesia, Cambodia, Brunei, and Laos. In addition, an isolated population of the species persists in Iraq. The species is considered to be possibly extinct in China owing to its demand in the pelt trade (Khoo et al. 2021). Mangrove ecosystems are found throughout the tropical and subtropical regions of the world (Giri et al. 2010). Mangroves forests occur in 11 countries where extant populations of *L. perspicillata* persist with the exception of Nepal, Bhutan, Laos, and Iraq (Giri et al. 2010; Wilkie and Fortuna 2003). In Goa, the importance of mangrove ecosystems for otters may be an indirect result of the high productivity that by nature, also influences mangrove growth.

However, based on the results of this study and existing published literature, certain hypotheses arise that require further evaluation. Habitat preference within the estuary could be dynamically stratified based on the distribution of freshwater sources. Therefore, identification of freshwater sources within the landscape would help delve further into the stratification of habitat preference within the limits of the estuary. Furthermore, the increased occurrence of the species in the khazans and surrounding areas could lead to conflict between fishers and otters as reported in published literature from various regions where *L. perspicillata* occurs (Foster-Turley 1992; Kamjing et al. 2017; Kloskowski 2011; Rosas-Ribeiro et al. 2011; Václavíková et al. 2011). However, data on human-otter conflict in Goa is unavailable. The spraint samples obtained from the khazans regularly contained pieces of nets indicating that otters actively procured fish from gill nets deployed by the fisherfolk. Thus, extensive research on the perceptions of fisherfolk towards otters in Goa is crucial in terms of management aspects. In addition, mangrove cover and salinity are characteristic features of estuarine ecosystems. Our analysis indicated that otters preferred such environments. Mangrove cover and salinity may influence otter occupancy in an indirect manner as these variables could act as possible drivers for supporting a high density of prey base for otters due to the high productivity nature of estuarine environments that they represent. Furthermore, as otter signs were largely recorded in areas that were exploited by fisherfolk, this could be another indication of sufficient prey base for otters and an overlap between the prey species and resources harvested by the fisherfolk. Therefore, future studies on prey availability would add an additional aspect in understanding otter occupancy and landscape preference in Goa and other areas of India with similar environmental characteristics.

Our analysis indicated that salinity, mangrove cover, and presence of fishing positively influenced the occurrence of *L. perspicillata* in the Mandovi and Zuari estuaries of Goa. Therefore, it can be concluded that within the confinements of the selected variables, salinity, mangrove cover, and presence of fishing cumulatively influence otter occupancy. In addition, it can also be concluded that there are other factors (e.g. conflict and freshwater availability) that could possibly also influence occupancy, and this warrants further investigation to better understand and conserve the populations of smooth-coated otters in Goa. Furthermore, it can be concluded that aquatic pollution from agricultural sources did not significantly affect otter occurrence in this study area. The smooth-coated otter is a social species that requires large stretches of river and estuarine ecosystems for its survival. Thus, management of this species becomes increasingly difficult in human-modified environments. The current study gives an insight into the habitat preference of the species in Goa. This species favours an estuarine environment that is characterised by brackish water, mangrove cover, and extensive fishing effort. This study was conducted primarily due to the gap in knowledge with reference to factors that influence habitat selection in coastal, urbanised ecosystems, particularly in India. However, these results may not indicate all possible variables that may influence selection.

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Code availability https://github.com/stephendias46/Habitat-Selection-of-Smooth-coated-Otters

Declarations

Ethics approval This is an observational study. The Edinburgh Napier University Research Ethics Committee has confirmed that no ethical approval is required.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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