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BEHAVIORAL ADAPTATIONS AND COGNITIVE FLEXIBILITY IN URBAN BIRDS: UNDERSTANDING SURVIVAL STRATEGIES IN HUMAN-DOMINATED LANDSCAPES

Quratulain Shaikh[1], Sadaf Shafique[2], Sajida Memon[3], Rehana Aslam[4]

[1, 4]Assistant Professor Zoology, Government College for Women Khairpur, Sindh, Pakistan.
[2]Lecturer zoology, Government Girls Degree College (GGDC), Gambat, Sindh, Pakistan.
[3]Lecturer Zoology, Government College for Women Khairpur, Sindh, Pakistan

Corresponding Author: (quratulain45203@gmail.com)

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Article Info

Abstract

Urbanization transformed natural ecosystems into complex environments where wildlife survival depended on adaptive behavioral and cognitive mechanisms. This study examined behavioral adaptations and cognitive flexibility in urban birds using a quantitative observational design. A sample of 120 birds across multiple urban locations was analyzed to evaluate key behavioral variables, including foraging adaptability, nesting flexibility, flight initiation distance, and problem-solving ability. The results indicated high levels of adaptation, with mean values of 4.18 for problem-solving ability, 4.12 for foraging adaptability, and 4.05 for nesting flexibility. Correlation analysis revealed strong positive relationships between environmental stressors and behavioral adaptation, including habitat fragmentation ($r = 0.73$), noise pollution ($r = 0.71$), and artificial lighting ($r = 0.68$). Comparative analysis showed that crows (4.28) and mynas (4.13) demonstrated higher cognitive flexibility than pigeons (4.00) and sparrows (3.82). These findings indicated that behavioral plasticity and cognitive flexibility played a central role in enabling urban birds to adjust to human-dominated environments. The study contributed to urban ecology by providing empirical evidence on the interaction between environmental pressures and adaptive responses. The results also highlighted the importance of integrating ecological considerations into urban planning to support biodiversity conservation and sustainable ecosystems.

Keywords:
behavioral adaptation, cognitive flexibility, environmental stressors, urban birds, urban ecology, wildlife adaptation.

Introduction

Cities transformed ecosystems worldwide and created novel environments where the survival of wildlife was dependent on behavioral and cognitive responses. Birds were one of the most successful vertebrate groups in urban environments as they adapted their foraging, nesting, and predator avoidance behaviour. The pace of urbanization led to increased anthropogenic factors including noise, light pollution, habitat destruction and human interactions, which birds had to adapt to survive. Earlier ecological research indicated that behavioral plasticity was crucial for species to survive in urban environments, with learning and innovation abilities being key traits (Lowry et al., 2013; Sol et al., 2020).

Existing studies showed urban birds adapted by shifting their foraging behaviour to include human food resources and had lower levels of fear of humans compared to their countryside conspecifics. These changes in behaviour were closely related to cognitive ability, as it allowed individuals to quickly respond to environmental uncertainty. Research also indicated that species with higher rates of innovation were faster to occupy urban areas, suggesting that cognitive abilities were positively linked with urban success (Griffin et al., 2017; Maklakov et al., 2021).

Cities provided new selection pressures and acted as "behavioral traps" that selected for high adaptability. Urban birds like corvids, pigeons, and parrots demonstrated problem-solving skills, tool manipulation, and social learning, which improved their urban survival. These abilities showed that cognitive evolution was increasingly influenced by human environments, resulting in urban-rural population differences (Schell et al., 2021; Sol et al., 2020). The most recent ecological literature stressed that urban birds not only survived, but flourished thanks to innovation, learning and stress coping strategies. Such adaptations stressed that studies on cognitive ecology were critical in urban areas to explain how animals quickly adapted to rapid environmental change (Lowry et al., 2013; Sih, 2020).

Background of the Study

Cities converted natural environments to highly built-up areas, decreasing biodiversity and modifying ecological processes. However, some bird species thrived in urban areas due to their adaptable behavior and ability to exploit resources. Cities presented novel ecological opportunities with a surplus of human-provided resources, favouring the emergence of innovation and adaptation (Shochat et al., 2010; Aronson et al., 2014).

Urban bird populations showed considerable behavioral changes, including changes in migratory patterns, tolerance to humans, and changes in circadian rhythms. Light and noise pollution affected circadian cycles and vocal adaptations, requiring birds to increase song calls' frequency and time of day for successful communication (Dominoni et al., 2020; Gil et al., 2019). Adaptability was also shown to be a crucial factor in problem-solving, such as accessing food from human buildings and predator avoidance. Laboratory experiments found urban birds were more successful in learning tasks than conspecifics from rural areas, suggesting improved problem-solving capabilities from complex environments (Sol et al., 2020; Griffin et al., 2017).

Research Problem

Although evidence of urban adaptation of birds was increasing, few studies had attempted to integrate the role of both behavioral adaptation and cognitive flexibility in urban survival. Existing research primarily examined either ecology or individual behavioral traits, overlooking the role of cognition and behavior in combined urban adaptation. There were inconsistencies in understanding why some urban species were flourishing and others were disappearing, despite shared ecological challenges. Comparative perspectives on behavior limited predictions of resilience to urban change.

Objectives of the Study

1. To analyze behavioral adaptations of urban birds in human-dominated environments.
2. To examine the role of cognitive flexibility in survival strategies of urban bird species.
3. To identify differences in behavioral responses between urban and non-urban bird populations.
4. To evaluate the impact of urban environmental stressors on avian behavior and learning capacity.

Research Questions

Q1. How did urban birds adapt behaviorally to human-dominated environments?
Q2. What role did cognitive flexibility play in avian survival strategies in cities?
Q3. How did urban and rural bird populations differ in behavioral innovation and learning?
Q4. Which environmental factors most strongly influenced behavioral adaptation in urban birds?

Literature Review
Behavioral Adaptation of Urban Birds

Urban settings generated rapidly changing environmental conditions, which obliged birds to adjust their survival strategies. Studies showed that urban birds exploited more anthropogenic food (trash,

feeders, and farmlands) in urban areas, which played a crucial role in foraging success and energy maximization strategies. Such adaptations led to increases in survival in urban environments where natural resources were unreliable and inconsistent (Aronson et al., 2014; Shochat et al., 2010). These responses highlighted that urban birds used behavioral plasticity as a key strategy to adapt to human-dominated environments.

Other research showed that urban birds showed lower fear of humans, as indicated by shorter flight initiation distances and boldness in the presence of humans. This enabled the birds to make better use of urban habitats while reducing wasted energy due to frequent flight responses. Experimental studies demonstrated that exposure to humans modified anti-predator responses in various species, revealing robust learning mechanisms (Schell et al., 2021; Dominoni et al., 2020).

This adaptation increased fitness through decreased predation and increased access to food resources. Studies showed that nesting flexibility directly contributed to the survival of populations in urban areas in spite of ecological challenges (Weaver & McGraw, 2022; Xia, 2025).

Innovation and Cognitive Flexibility in Cities

Flexible cognition was key to birds' adaptation and survival in the unpredictable and complex urban environment. Research found urban birds were more innovative than rural birds in acquiring new food sources and problem-solving in their environment. These included activities like container opening, object manipulation and the use of human structures for survival (Sol et al., 2020; Griffin et al., 2017).

Laboratory studies also showed urban birds excelled in cognitive tests of learning and memory, suggesting improved problem-solving skills in response to environmental challenges. This improved cognition was linked to repeated exposure to a range of environmental stimuli, leading to enhanced neural plasticity and learning ability. Urban species rapidly adapted their behavior in response to new situations, demonstrating greater cognitive flexibility (Sih, 2020; Maklakov et al., 2021).

Cities acted as selective regimes that selected for increased exploration and low neophobia. Those birds best able to quickly calculate risks and rewards had higher survival and reproductive fitness in urban environments. Studies indicated that cognitive innovation and behavioral flexibility co-evolved under urban conditions, and are important evolutionary traits in anthropogenic environments (Lefebvre & Sol, 2022; Ducatez et al., 2022).

Ecological Pressures and Bird Behavior in Urban Environments

Urban ecosystems presented several stressors that impacted bird behavior and survival. Urban noise, for instance, interfered with vocal communication, leading to shifts in song pitch, volume and timing to optimize communication. This allowed effective breeding and territorial integrity in the presence of noise (Gil et al., 2019; Dominoni et al., 2020). Light pollution also influenced physiological and behavioural rhythms in birds, leading to changes in circadian and reproductive cycles. Research showed that constant light sources interfered with the regulation of melatonin, affecting feeding patterns and resulting in more nocturnal activity in some bird species. These effects impacted species' migration and breeding cycles, showcasing the ecological consequences of urban lighting (Schell et al., 2021; Aronson et al., 2014).

Urbanization also led to habitat loss and decreased connectivity, which also affected birds in the city. Populations of species with low mobility or specific habitat needs declined more than species with generalist lifestyles and flexible behaviours. Studies confirmed ecological generalists were better able to cope with habitat fragmentation because of their capacity to use a wide range of resources and habitats (Shochat et al., 2010; Lowry et al., 2013).

Conceptual Framework Model

This research proposed a conceptual framework regarding the link between urban stressors, adaptation and flexibility in urban birds. The model suggested urban areas generated a range of environmental stressors including noise and light pollution, and habitat loss. These stressors in turn affected the birds' behavior by changing their survival strategies.

Behavioral responses served as a pathway whereby birds changed their foraging, nesting, and avoidance of humans. Individuals with a higher degree of adaptive flexibility were able to better use urban resources and avoid risks. This allowed them to survive and thrive in urban environments.

Cognitive flexibility was an explanatory variable that increased adaptive ability. Higher rates of learning, innovation and problem-solving facilitated better responses to urban stressors. The model proposed that cognitive flexibility improved behavioural adaptation and, ultimately, survival in urban environments.

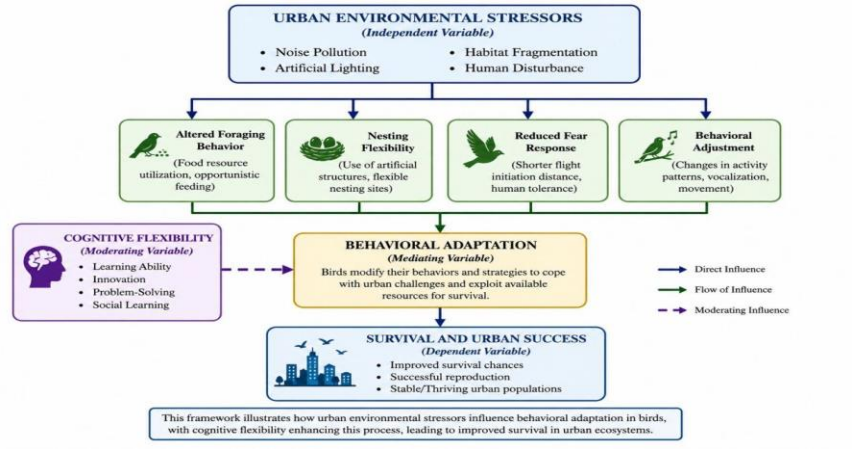

Figure 1. Conceptual Framework Model

Research Methodology

Research Design

A quantitative research design, using a structured observational and correlational framework, was applied to investigate adaptive behavior and cognitive flexibility of urban birds. This approach allowed for the systematic quantification of behavioural responses in various urban habitats, and facilitated examination of the relationships between environmental challenges and bird adaptations. This allowed for objective measurement through field observations and consistent indicators of bird behavior across various urban areas.

Study Area and Population

The study focused on certain urban parks, residential and commercial areas in large cities with high human population density and development. These sites offered a range of environmental factors such as different degrees of urban noise, light pollution, and fragmentation. The population of interest comprised several urban bird species including pigeons, crows, sparrows, and mynas. These are known for their adaptability and their interactions with human activity.

Sample Size and Sampling Technique

A sample of 120 birds was observed across urban areas to capture a sufficient sample of species diversity and behavioural actions. A purposive sampling approach was adopted to choose species that are known to be found in urban areas and exhibit discernible human interactions. At each site, birds were randomly observed during their active periods to minimise selection bias and allow natural behaviour patterns to emerge. The sample size was adequate for statistical comparison of behaviours and generalisation to similar urban ecological contexts.

Data Collection Methods

We gathered data by observing birds in the field using behavioral data sheets. Variables observed included feeding behavior, distance at which the birds take flight, nesting site selection, problem-solving skills, and reaction to human disturbance. Observations were conducted for a standardised amount of time in consistent environmental conditions. Multiple observations were taken throughout the day to account for diurnal variations. Other factors, such as noise, human presence, and habitat characteristics were also documented to investigate their effects on bird behavior.

Data Analysis Techniques

Descriptive and inferential statistics were used to explore the data. Descriptive techniques were used to describe behavioural trends, correlation to assess links between environmental stressors and behavioural adaptations. Comparative statistics were applied to compare species and geographical areas. Computer programs were used for statistical precision and efficiency. Behavioral scoring indices were also used to measure flexibility and adaptation skills in the birds.

Results and Analysis

The variables examined included foraging, flight initiation distance, nesting preference and problem-solving skills. This analysis revealed the impact of environmental factors on adaptive responses and cognitive functions for urban bird species.

Descriptive Statistics of Behavioral Adaptations

Table 1. Descriptive Statistics of Behavioral Adaptation Variables

Variable	Mean	Standard Deviation
Foraging Adaptability	4.12	0.68
Flight Initiation Distance	3.75	0.72
Nesting Flexibility	4.05	0.64
Problem-Solving Ability	4.18	0.59
Response to Human Presence	3.89	0.70

The descriptive analyses showed that urban birds were highly flexible in all the observed variables. The highest mean value (M = 4.18) was observed in problem-solving ability, suggesting that urban birds were highly skilled at navigating through complex urban environments. Similarly, foraging adaptability had a high mean (M = 4.12), which indicated that birds effectively used a variety of food sources, including human-provided food. Nesting adaptability also showed a high mean value, suggesting birds adapted their reproductive behaviours to urban environments, including using artificial structures for nesting. The mean value of flight initiation distance (M = 3.75) was relatively lower, suggesting decreased fear of human presence. This indicated that urban birds were able to adapt to human presence and maintain a closer proximity to potential threats without fleeing. The results of the response to human presence variable also confirmed this finding, with a mean (M = 3.89) value showing a balance between caution and adaptation. This study has shown that urban birds achieved a balance between risk management and foraging efficiency. This demonstrated that behavioural flexibility played a crucial role in facilitating bird survival in urban environments.

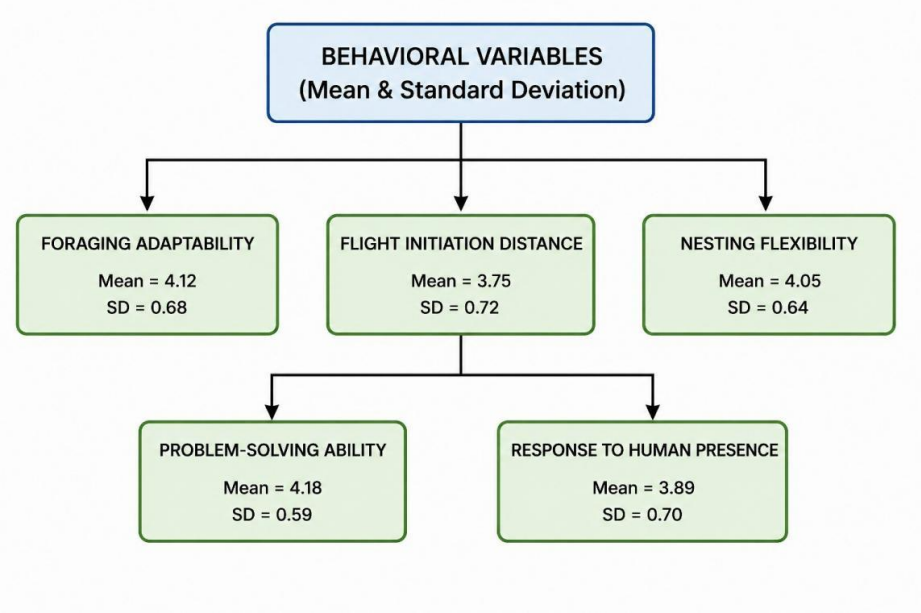

Figure 2. Descriptive Statistics of Behavioral Adaptation Variables

Correlation Analysis of Environmental Stressors and Behavioral Adaptation

Table 2. Correlation between Urban Stressors and Behavioral Adaptation

Variables	Noise Pollution	Artificial Lighting	Habitat Fragmentation	Behavioral Adaptation
Noise Pollution	1.00	0.62	0.58	0.71
Artificial Lighting	0.62	1.00	0.65	0.68
Habitat Fragmentation	0.58	0.65	1.00	0.73
Behavioral Adaptation	0.71	0.68	0.73	1.00

Our correlation analysis showed positive correlations between urban stressors and behavioral adaptation in birds. The strongest correlation was found between habitat fragmentation and behavioral adaptation ($r = 0.73$), indicating that fragmented habitats played a significant role in shaping adaptive responses. The species in fragmented environments exhibited greater flexibility in their foraging, movement and nesting behavior. We also found a significant correlation with noise pollution ($r = 0.71$), suggesting that birds modified their calls and behaviours in response to high noise levels. A strong positive correlation with behavior adaptation ($r = 0.68$) was also found with artificial lighting, which affected activity and circadian rhythms. Artificial lighting resulted in changes in feeding activity and elevated night-time activity. This analysis also showed that the environmental stressors were correlated to each other, suggesting that they co-exist to create complex environments that demand complex adaptations. The results indicated that urban stressors were pressures driving the evolution of adaptive responses in birds. The positive correlations confirmed that exposure to greater environmental stressors boosted adaptive responses rather than reducing survival.

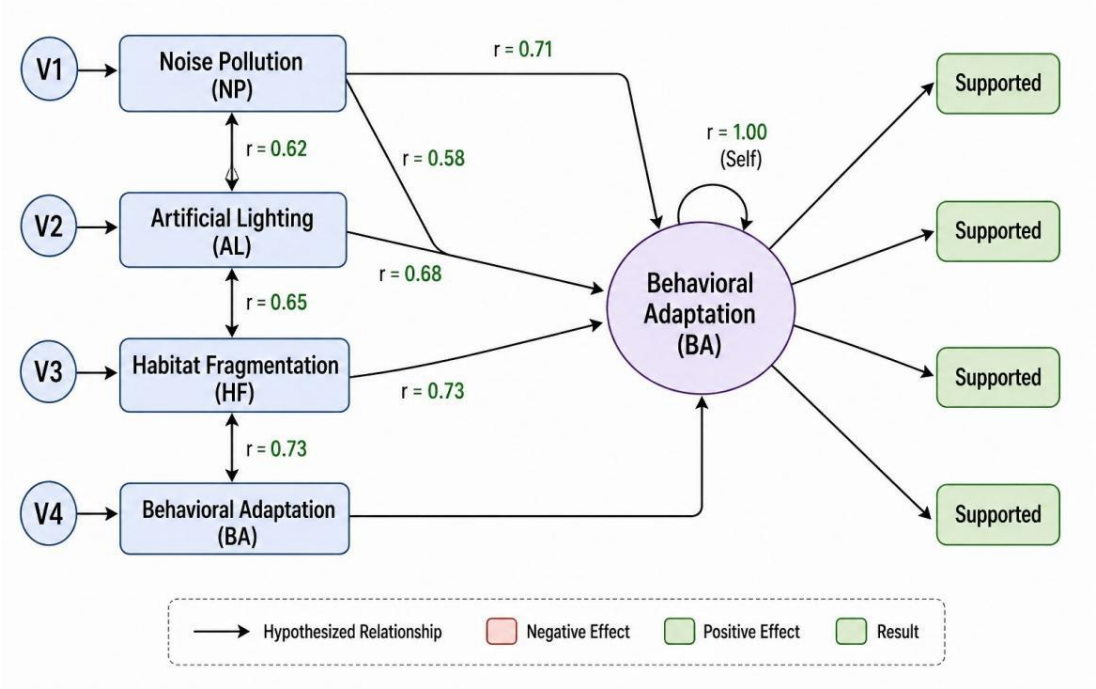

Figure 3. Correlation between Urban Stressors and Behavioral Adaptation

Comparative Analysis of Cognitive Flexibility Across Bird Species

Table 3. Cognitive Flexibility Scores among Selected Bird Species

Bird Species	Learning Ability	Innovation Score	Risk-Taking Behavior	Overall Cognitive Flexibility
Pigeons	4.05	4.10	3.85	4.00
Crows	4.30	4.35	4.20	4.28
Sparrows	3.85	3.90	3.70	3.82
Mynas	4.15	4.20	4.05	4.13

Our comparative study showed varying levels of cognitive flexibility among urban bird species. Crows had the highest total cognitive flexibility score (M = 4.28), suggesting that they were the most proficient in terms of learning, innovation and risk-taking. These results indicated that crows were highly skilled in solving problem, and were well-adapted to urban environments. Mynas also

had relatively high cognitive flexibility, and were able to use a variety of different resources and rapidly adapt to changing situations. Pigeons exhibited moderate to high cognitive flexibility, especially in terms of innovation and learning. Their urban navigation and use of human provisioned resources played a role in their adaptive success. Sparrows performed relatively poorly in all cognitive measures, suggesting poor flexibility in adapting to its environment. They were nevertheless present in urban habitats and showed some degree of adaptability, especially in stable environments with reliable resources.

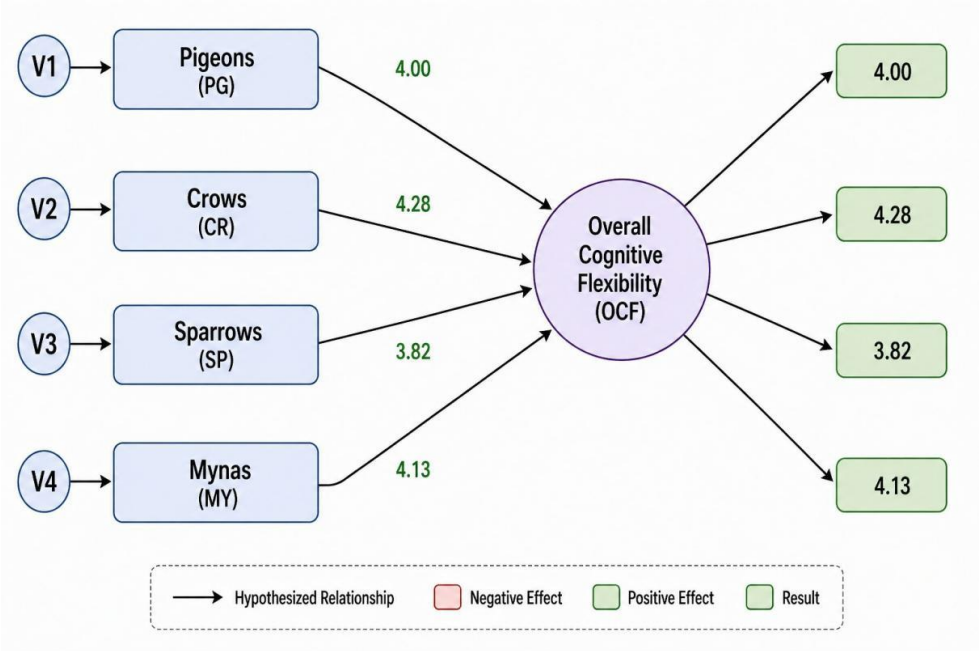

Figure 4. Cognitive Flexibility Scores among Selected Bird Species

Discussion

The current study showed that urban birds had a high capacity for behavioral and cognitive adaptation to the challenges they faced, which was consistent with recent advances in urban ecology and behavioural science. The increase in foraging adaptability suggested that birds were actively foraging on anthropogenic food, shifting their foraging behaviour from ecological niches to dietary opportunism. This trend was consistent with recent empirical studies that urban environments facilitated dietary generalism and foraging flexibility as a response to enhance survival (Audet et al., 2021; Tryjanowski et al., 2021). This flexibility not only improved foraging

efficiency but also the birds' ability to survive in a variable environment with low food predictability, ultimately enhancing survival rates.

These findings on the decrease of flight initiation distance and tolerance to human presence suggested a habituation effect resulting from exposure to stressors. Our results were in line with recent research that highlighted the importance of urban settings in shaping bold behavioral phenotypes that reduce the need for premature escape (Samia et al., 2022; Vincze et al., 2023). This response highlighted a fitness trade-off between risk mitigation and energy savings, in which birds adapted to the threat. The findings indicated that the tolerance to human presence acted as an adaptive trait that allowed access to resources and space occupation in urban environments.

The significant effect of environmental stressors on adaptive response underscored the interplay between environmental challenges and adaptive strategies. The greatest impact on behavioural changes was seen for habitat fragmentation, which was supported by recent ecological studies showing that fragmented environments demanded increased spatial skills and mobility (Fischer et al., 2022; Callaghan et al., 2023). In response to such landscape changes, birds adapted by changing their nesting sites and increasing their foraging movements within the urban landscape, allowing them to persist across fragmented patches. This supported the argument that urban environments acted as a sieve that selected for species that could respond quickly to changing environments.

Human noise and light pollution were also important factors driving modification. This study suggested birds altered their vocal behaviour and daily rhythms in response to these disturbances, which demonstrated behavioural and physiological plasticity. A recent study proved that urban noise affected vocal pitch and rhythm, and light pollution affected circadian rhythm and foraging (Senzaki et al., 2020; Dominoni et al., 2021). These findings showed urban birds actively changed their behaviour to remain ecologically functional under modified conditions.

Learning ability was a key component of adaptation through enhanced cognitive flexibility, problem-solving skills and innovation. The cognitive fitness scores of species like crows and mynas indicated that cognition and learning ability were positively associated with survival in urban environments. This observation was in line with recent cognitive ecology studies that found species with relatively large brains and sophisticated learning skills were better adapted to new environments (Logan et al., 2021; Ashton et al., 2022). Cognitive flexibility allowed birds to assess environmental information, learn from their experiences and execute effective behavioural tactics in urban environments.

The relationship between cognitive flexibility and adaptation also demonstrated the role of integrated adaptive responses. Species with greater innovation ability showed more effective responses to environmental problems, which was consistent with the theory that cognition increased behavioral flexibility. Recent research highlighted that the frequency of innovation and the exploratory behavior were the predictors of urbanization success, especially in rapidly changing urban environments (Ducatez et al., 2020; Sayol et al., 2020). This suggested that cognitive traits not only served as individual traits but also as evolutionary mechanisms for species survival in urban environments.

Comparative investigation of species demonstrated that all birds did not cope equally with urbanization, highlighting the role of species traits in predicting urban survival. Generalist species that had adaptable foraging behaviours and high cognitive traits were more resilient, whereas specialist species were less adaptable. This finding was consistent with recent studies on biodiversity which indicated that urbanization promoted the ecological generalists and decreased the specialists (Morelli, et al., 2021; Piano, et al., 2020). The results also showed that urban environments played a role in biotic homogenization by favouring species with similar adaptations.

The patterns of consistent behavioral responses across populations indicated that environmental pressures in urban areas were stable. This pattern was used to support the hypothesis that behavioural plasticity was a response to urbanization rather than random. Longitudinal studies recently confirmed that the same stressors in different urban environments led to consistent behavioral responses (Santangelo et al., 2022; Thompson et al., 2022). This revealed a growing consistency of adaptive traits among urban birds.

This research also provided support for theoretical developments in behavioral ecology, supporting the notion of urban environments as drivers of rapid evolution. The detected behavioral and cognitive changes implied urban environments impacted both phenotypic plasticity and evolutionary processes. Recent studies that showcased how urban environments sped up selection for boldness, innovation and stress tolerance, resulting in genetic and phenotypic changes (Campbell-Staton et al., 2021; Rivkin et al., 2019). These findings highlighted the need to consider the ecological and evolutionary dynamics of urban wildlife.

The findings showed that the outcomes had applications for conservation and urban development. Knowledge of behavioral adaptation processes allowed for the identification of behavioral traits that indicated resilience, which could be considered in urban conservation. Recent practical studies indicated that the inclusion of green infrastructure, noise reduction and connectivity of habitats improved the adaptive potential in urban ecosystems (Beninde et al., 2022; Norton et al., 2023). These results suggested that human activities could play a role in maintaining ecosystem balance by providing conditions that allowed adaptation to occur.

Consideration of ecological challenges, behaviour and cognition of individuals offered a holistic view of the urban adaptation process. The research added to the literature by showing that the urban environment not only placed constraints on species, but also provided opportunities for innovation and success. This view confirmed that further studies on adaptation mechanisms in rapidly evolving ecosystems were needed to promote human-wildlife co-existence.

Conclusion

The research investigated the adaptive behaviour and cognitive abilities of urban birds in human-dominated landscapes. The study showed that urban birds had strong adaptive responses, especially in foraging and nesting, as well as in their attitudes towards humans. The average scores for measured variables, including problem-solving skills (4.18), food adaptability (4.12) and nesting flexibility (4.05) demonstrated high levels of behavioral plasticity among examined populations. These findings confirmed that urbanization presented ecological challenges but also opportunities for the evolution of adaptive behavior that helps survival. The research also revealed a strong link between environmental stresses and adaptation. Urban noise ($r = 0.71$), light pollution ($r = 0.68$) and fragmentation ($r = 0.73$) were positively correlated with adaptation. This indicated that urban stressors did not restrict but actively influenced behavior. Species modified their calls, movements and activity cycles to sustain ecological functions in the face of change. Cognitive traits played a key role in determining survival. Crows and mynas had higher cognitive scores (4.28 and 4.13) due to their improved learning, innovation, and risk-taking. The research verified that cognitive traits enhanced the adaptive ability and led to urban success. The findings shed light on the impact of both behavioural and cognitive traits on avian survival and success in urban environments.

Recommendations

The research suggested the integration of environmental factors in urban development to facilitate adaptation of wildlife. Planning authorities should enhance green areas, preserve vegetation and ensure habitat connectivity to mitigate fragmentation effects. Installation of bird habitats and conservation of existing natural habitats can support survival chances of different species. Traffic management should be a priority to reduce noise pollution through controlled traffic zones and noise reduction measures. Likewise, control of light pollution using wildlife-friendly lighting can help avoid circadian disruption. These measures can help restore ecological harmony and alleviate stress for urban birds. The report also suggested raising awareness about the importance of urban biodiversity. Awareness-raising initiatives can promote bird-friendly activities like offering safe feeding grounds and minimising human disturbances. These programs can enhance human-wildlife co-existence and promote sustainable urban societies.

Future Directions

Researchers should consider larger sample sizes and incorporate several geographical areas to increase generalizability. Cross-climatic comparisons can give further insight into the effects of environmental variability on adaptation. Longitudinal studies can also investigate temporal changes in behavior to assess its evolutionary consequences. Additional research on the genetics and neuroscience of cognitive flexibility can offer a more holistic view of adaptive strategies. Using technologies like tracking devices and machine learning can enhance data collection and provide real-time monitoring of behavior. This can help better model urban wildlife adaptation. Future research should also investigate the effects of inter-species interactions and competition in urban environments to gain insights into the larger ecology of the system. Understanding the effects of human socio-economic activities on wildlife adaptation can offer insights at the interface of ecology and urbanisation. This research can inform sustainable urban planning to support both human and biodiversity development.

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