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Advancements in Research on Cichlid: Reproductive Biology, Social Structure, and Communication

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Abstract: The social behavior of cichlid fish emerged as a captivating subject within the realm of ichthyological research. The sociality of these aquatic organisms often encompasses a wealth of intricate elements. Within this complexity, the reproductive biology of cichlids was observed to mirror the characteristics pivotal for progeny propagation and population development. Their social structures were characterized by stringent hierarchies and occupational specialization among individuals. Communication mechanisms were found to be instrumental in ensuring the timely exchange of information across members of the species. Furthermore, population behaviors served as vital conduits, maintaining the cohesion of the aforementioned elements and securing the seamless operation of this organic system. Given these aspects, this study chose these topics as entry points for inquiry, synthesizing recent scholarly work on cichlid sociality to retrace the trajectory of research in this field. This retrospective analysis was conducted to distill clear future directions based on the examined data. The research undertaken provided a scientific reference poised to enhance further inquiry into the enigmatic subject of cichlid sociality, laying a robust foundation for both advancing the study of these fishes and fostering their conservation.

Keywords: Cichlids; Social structure; Population behavior; Communication; Reproductive biology

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1. Introduction

Group living is defined as the phenomenon where individuals of the same species maintain spatial proximity through social attraction mechanisms. This mode of existence enables species to survive in harsh and changing environments. It is undeniable that social behaviors, indicative of interactions among individuals, are exceedingly common among animals that exhibit group living. Ecologists and ethologists have taken note of this aspect, carving out a distinct niche for research within their fields.

In particular, such social behaviors are notably pronounced in a specific type of fish known as cichlids. Cichlids are distributed across the Americas, Africa, Asia, the Middle East, and India and

represent a diverse group of teleost fishes. In the wild, many cichlids form groups and collectively respond to external stimuli. Moreover, they are dubbed "cichlids." The Cichlidae, commonly referred to as cichlids, exemplify a classic taxonomic classification at the familial level, encompassing a diverse array of species within its ranks. As such, they have garnered significant attention from scholars in the field as critical subjects for scientific inquiry. The following discussion on research advancements will thus revolve around the existing scholarly reports about the family Cichlidae. Previous research indicates that cichlids exhibit a degree of complex sociality and display an array of social behaviors. Among the diverse range of social behaviors, key areas of interest in the study of cichlid sociality include reproductive biology, social structure formation and its underlying mechanisms, intraspecific behavioral interactions, and intraspecific communication. Reproductive biology encompasses a vast array of topics such as reproductive strategies, cooperative breeding, and mate selection, reflecting how individuals within a cichlid population engage in communication to perform these crucial life-sustaining activities, demonstrating the intrinsic drive for species development. Cichlids are renowned for their strict hierarchical systems; the establishment of individual ranks facilitates clear delineation of social roles, which is vital for population maintenance. A variety of communication methods have been discovered in cichlid research, showcasing the flexibility of their multimodal communication and highlighting different roles and operational mechanisms through in-depth studies. The rich tapestry of population behaviors, such as schooling and subordination, change alongside social structure and are outcomes of social organization and intraspecific communication. The underlying mechanisms of these behaviors and their association with the cichlid population biology have been hot topics in recent years.

Building on past research, this study has reviewed cichlid research literature from the last two decades, focusing on the aforementioned aspects, and organizing and analyzing research content related to cichlid sociality. This research not only aids in a better understanding of the social behaviors of cichlids in group living but also serves as an important exemplar in the fields of ecology and ethology, enhancing our familiarity with the social structures and group behaviors of other animal collectives.

2. Reproductive interactions of cichlids

The study of reproductive biology in the cichlids holds a crucial position, as it is closely related to their social behavior. The reproduction and sociality of fish provide an insight into their behavioral evolution. By studying the reproductive strategies and parenting behavior of cichlids, the interrelationships between individuals, cooperative behavior, and factors that influence population reproductive success can be understood, which is significant for maintaining population structure stability. Current studies on cichlid reproduction mainly concentrate on reproductive strategy analysis (reflecting the roles and sociality of different individuals within the population), physiological changes, parental care, and exploration of factors affecting reproductive success.

The selection of reproductive strategies by the cichlids largely reflects its group evolution and environmental adaptability, relying to some extent on the social relationships within the population to assist successful reproduction and parenting. In a study on *Neolamprologus savoryi*, reproductive individuals and assisting breeders to participate in maintaining the breeding shelter, and the existence of assisting breeders significantly reduces the work energy investment of female individuals. The

benefits obtained by the group increase with the number and size of assisting breeders. If there is fry present, the reproductive female and assistant will visit the breeding chambers more frequently, and the presence of assistants improves the reproductive success rate of the breeders. During reproduction, participants in reproductive activity exhibit pro-social and anti-social behaviors based on social relationships with individuals of the same species and overall social background. Moreover, they also change their behavioral strategies according to changes in the number of offspring [1–2]. From the perspective of reproductive outcomes, compared with other animal species, cichlids usually engage in inbreeding with a high degree of consanguinity, resulting in decreased allelic diversity, reduced heterozygosity, and inbreeding depression consequences, which leads to negative effects such as reduced activity and potential damage to foraging success of inbred individuals [3–4]. In addition, sibling groups that are inbred recover faster after interference, indicating improved coordination. This research reveals that higher correlations in inbred populations may have a positive impact in the form of decreased significance. While reduced activity can damage foraging success, it can be compensated by quickly recovering from interference. Research also suggests that this may be greatly related to the environment and mate selections [5].

The mating system also reflects the social relationships within the cichlid population. It has been reported that cichlids usually have three types of mating systems, including monogamy, monogamy with helpers, and polygyny with helpers [6]. Each of these mating systems has its advantages and disadvantages and varies among different species of cichlids. Socially, monogamy does not necessarily lead to genetic monogamy. In the study of *Variabilichromis moorii* (monogamous), many extra-pair paternity relationships were found, which were attributed to extrapair copulations by male individuals. Compared with the rainy season, in dry season breeding and parenting, the paternity share of male parents was consistently higher, and the number of male parents per brood was lower. Seasonal fluctuations in environmental conditions, such as water turbidity, are considered to be the underlying mechanism behind changes in mating patterns [7]. *Herichthys minckleyi* (polygynous) males appear less frequently in nesting sites, exhibiting lower levels of offspring aggression defense rate, while females exhibit high levels of offspring defense [8]. The one-female, multiple-male *Julidochromis transcriptus* uses “step nests” to restrict larger and smaller males to wide and narrow nesting areas, respectively (limiting larger male attacks on smaller males), and then manipulates parent-child relationships by controlling the location of egg laying to obtain more benefits [9].

3. Characteristics of population social structure and behavior, and their influencing mechanisms

The social structure and behaviors within populations, particularly territorial behaviors, are key areas of research in the study of sociality in cichlids. Exploring the formation characteristics and mechanisms of social structure within species contributes to the understanding of the adaptive traits of these species. The richness, plasticity, and dynamic changes in population behavior help us understand the mechanisms that maintain their social structure.

Division of labor within the cichlid population forms the foundation of social structure formation. Individuals may coordinate different tasks based on differences in gender, size, and age. For example, some individuals may excel at predation, while others may excel at patrolling and defending territories. This division of labor enhances the overall efficiency and survival success rate of the group.

Research on *Laetacara araguaiae* suggests that during the initial stages of mating, both males and females participate in nest-building and territory defense. Females spend more time on nest-building, while males dedicate more time to territory defense. After spawning, males and females take turns in nest-building and guarding the territory. Females invest more time in nurturing the fry during the egg/larval stage [10]. However, this phenomenon may differ among other species. *Herichthys minckleyi*, a polygynous species, exhibits low levels of aggressive defense with males showing less presence in the nest cavities, while females display high levels of offspring defense [11]. Nonetheless, cichlids still share commonalities in terms of hatching division of labor. Research findings indicate that during the hatching defense process, males defend the territory from conspecific adults, while females protect the nest from predators [12].

In addition to adult males and females, some species demonstrate division of labor during early development. In *Neolamprologus pulcher*, juveniles delay dispersal and assist the mother in offspring care. Subordinate females grow larger and disperse into other groups, while subordinate males leave the mother's territory and remain in the father's territory [13]. Furthermore, a series of role differentiations occur after cooperative breeding. Previous studies have shown that individuals who remain in their birthplace exhibit extended reproductive time and lifetime reproductive success for both sexes, whereas dispersed individuals eventually establish dominance within smaller groups [14]. Not only during the breeding process, but cichlids also exhibit division of labor in group defense. Research indicates that dominant and subordinate female cichlids show higher defensive behaviors towards invaders matching their size and status, while male defensive levels are lower and less variable [15]. Additionally, gender and species are important factors influencing the defensive behavior of different group members. When facing invasion threats, both dominant males and females display high aggression towards heterospecific predators and intrasexual competitors, but lower aggression towards individuals of the opposite sex. The decrease in aggression of dominant males is most significant towards conspecific females. Subordinate members exhibit lower defensive levels against all types of invaders [16]. These roles contribute to enhancing the efficiency and survival success rate of the entire group.

Cluster behavior is one of the representative social behaviors in populations of *Neolamprologus pulcher*, commonly known as the cichlid fish. These fish form groups of various sizes in the wild, typically consisting of dozens or even hundreds of individuals. This aggregative behavior is vital for the survival and reproduction of cichlids as it allows them to resist predators, engage in reproductive activities, and cooperate in hunting. According to studies on cooperative defense behavior in *Neolamprologus pulcher*, male cichlids rely on perceiving threats from intruders to defend their territories. In contrast, territorial males depend on the size and behavior of their neighbors for defense [17]. This makes territory protection in cichlids more convenient because they can predict different response outcomes to different invaders and neighbors, thereby reducing unnecessary harm. Members within the group, especially helpers, also contribute to increasing reproductive success by caring for eggs and defending against predators. Helpers participate not only in the reproduction of the group but also in locating food resources, playing a significant role in this activity. For example, hatching helpers can increase food abundance within the territory by assisting in maintaining and excavating burrows [18]. These are some fundamental benefits of cluster behavior.

Furthermore, the characteristics and underlying mechanisms of cluster behavior are an area of research interest. They are influenced by many factors, such as population-specific factors and environmental factors, including food availability and habitat characteristics. Previous studies

have shown that kin aggregation preference decreases with increased perceived competition levels. Gender composition, familiarity among group members, and adaptive responses to the environment influence clustering behavior in *Pelvicachromis taeniatus*. The results indicate that a higher proportion of females increases clustering behavior, while increased familiarity among group members and individual adaptability to the environment decreases the magnitude of behavioral changes in *Pelvicachromis taeniatus* following disturbances (such as sudden noise and water fluctuations) [19]. Individuals facing food scarcity avoid smaller fry, implying that living together with relatives under intense competition may reduce an individual's indirect fitness [19]. In locations with high predation risk, groups consist of more helpers, which are typically larger, less likely to disperse and exhibit shorter dispersal distances. Additionally, helpers tend to spend more time in their birthplace compared to low predation risk conditions [20]. Therefore, in areas with high activity of other large predatory fish, helpers in the group prioritize protecting the young individuals as a primary task and gradually develop larger body sizes for more effective defense. Moreover, helpers visit other groups more frequently than subordinate assistants. When the family group size is larger, assistants tend to visit other groups more frequently [21]. This more frequent patrolling behavior also offers protection against uncertain factors to some extent. The composition of workers is reflected not only in the number of assistants but also in the gender ratio. In cooperative breeding groups, there are more male helpers than female helpers. Individuals of different social statuses (dominant males > breeders > helpers) have different body sizes, and both dominant males and helpers exhibit brood care behavior [22]. On the other hand, cichlids can make choices by adapting to uncertain group sizes. Studies have shown that individuals living in larger groups usually exhibit higher resistance to instability but take longer to recover from disturbances. Members of smaller groups are more susceptible to instability but recover faster [23]. Furthermore, at lower densities, larger population sizes increase productivity, whereas at higher densities, smaller populations are more productive. However, neither population size nor density affects individual-level survival [24]. Therefore, small populations with high densities may be more productive than typical large populations, indicating a greater probability of offspring success. Hence, both large and small groups have their advantages depending on their circumstances and the influence of uncertain factors.

In addition to the aforementioned social behaviors, aggressive behavior, and submissive behavior reflect the territorial defense and social hierarchy characteristics of individual *Neolamprologus pulcher* fish, which are also important social traits of this species. Individuals of *Neolamprologus pulcher* that attain higher levels of dominance exhibit distinct behavioral features. Similarly, individuals belonging to subordinate positions also display unique characteristics. For instance, research has indicated that males have a higher propensity for aggression towards same-sex intruders. The social hierarchy and winner-loser effect in *Neolamprologus pulcher* may have complementary roles in conflict resolution. Winners are more likely to win subsequent encounters and demonstrate higher levels of aggression. In groups, subordinate individuals exhibit lower aggression (social rank influences threat behavior) [25]. When faced with invasive threats, dominant males and females of *Neolamprologus savoryi* display high levels of aggression towards predators and same-sex conspecific competitors, while their aggression towards opposite-sex conspecifics is relatively low. Dominant males show the most significant decrease in aggression towards females of the same species. Subordinate members exhibit lower defense levels against all types of invaders [16]. Gender differences are also observed at the behavioral level. For instance, in *Neolamprologus multifasciatus*, there are variations in the investment

costs of defense between males and females, with males exhibiting higher levels of aggression less frequently than females [26]. *Neolamprologus pulcher* displays behavioral response differences when encountering foreign intruders. Foreign invaders are perceived as potential group members, bringing different costs and benefits to the current group. When individuals with a similar body size to the intruder are removed from the group, dominant males reduce their aggression towards the intruder, while lower-ranking subordinate males exhibit increased aggression. In groups where individuals with similar body size to the intruder are not removed, dominant females and individuals of the same sex and similar body size as the intruder show heightened aggression [27]. Interesting phenotypic traits can also be observed in terms of morphological features. In the study of *Neolamprologus pulcher*, there is no evidence to suggest that the size of facial patches is related to social rank or body size, but dominant males tend to have larger patches compared to dominant females. The size of patches has a rank-specific relationship with the number of subordinate behaviors displayed by individuals, where dominant males with larger patches engage in fewer submissive behaviors within the group. However, subordinate males with larger patches acquire more subordinate behaviors from similar individuals [28]. Molecular biology research on *Neolamprologus pulcher* has revealed that subordinate males, who share genetic relatedness with breeding males, resembling the body size of breeding females, are allowed to remain within the territory of breeding males but not within the territory of breeding females. Additionally, offspring delay dispersal and assist the mother in parental care. Subordinate females disperse to other groups once they reach maturity, while subordinate males leave the mother's territory and remain in the father's territory.

The behavior and reciprocal responses between dominant individuals and subordinate individuals in the field and subordinate behavior are regulated by environmental and micro-level factors. For example, the presence of neighbors in a population of *Neolamprologus pulcher* can mediate behavioral responses between the two groups. Results show that neighbors weaken conflicts between mates and increase conflicts between dominant and subordinate individuals. Neighbors also trigger attacks and submissive behaviors among similarly-sized group members without altering behaviors related to promoting group cohesion [29]. At the micro-level, dominant and subordinate individuals exhibit differences in various aspects, revealing inherent driving forces. Research on *Cichlasoma dimerus* found that plasma levels of testosterone and 11-ketotestosterone, which are hormones associated with dominance, were higher in dominant males than in non-dominant ones, while non-dominant males had higher levels of 17β-estradiol and testosterone metabolic index. There were no observed differences in cortisol levels. The plasma index for converting 11-ketotestosterone and testosterone into 11-ketotestosterone was positively correlated with the frequency of attacks, while E2 showed the opposite pattern. The gonadal indices of dominant males were higher than those of non-dominant males. Quantitative assessment of testicular cell types revealed that non-dominant males had a higher percentage of spermatogonia and sperm cells, while dominant males had a higher percentage of sperm [30].

In the study of dominant and subordinate males of *Astatotilapia burtoni*, individuals with moderate cortisol levels exhibited more direct behavior, while those with high and low cortisol levels exhibited more replacement behavior, suggesting that an optimal level of cortisol may help subordinate males improve their social rank [31]. Sexual selection, as an important research topic, also reveals differences in social rank in cichlids. For example, dominant male *Cichlasoma dimerus* individuals are larger and have brighter colors than subordinate males. These sexually-selected characteristics can be further reinforced through inter-sexual selection. Moreover, the pituitary levels of β-follicle-stimulating

hormone and somatolactin in breeding males were higher than those in non-breeding males, while there were no differences between females [23]. Interestingly, if a subordinate individual can replace a dominant individual, significant changes will be found in the subordinate individual. A study evaluated the effects of social status elevation on the stress axis of *Neolamprologus pulcher*. The results showed that the status-elevated individuals exhibited high aggressiveness, activity, and workload within 72 hours, and received a high proportion of submissive behavior from group members. However, their cortisol levels remained higher than those of dominant individuals after three days. Compared with subordinate individuals, the stress axis activation of status-elevated individuals was increased (star and p450scc in the head kidney), and those who showed low aggression had the lowest cortisol levels, which may reflect the reconstruction of social stability in these groups. Compared with dominant individuals, the transcript abundances of two glucocorticoid receptors (gr1 and gr2) in the preoptic area of the brain were increased in status-elevated individuals, indicating enhanced regulation of cortisol through negative feedback [32].

The above content shows that cichlid fish have a structured social hierarchy for research, and this strict social hierarchy also affects the relationship between dominant and subordinate individuals. Various factors influence these relationships, and their dynamic changes become the intrinsic mechanism for maintaining the population of the cichlids.

4. Communication to maintain the social structure of cichlids

For social hierarchy-obvious cichlids, maintaining relationships between individuals within the population to minimize conflicts and reduce individual casualties is an intriguing topic in animal sociality. With the long process of biological evolution, this group of fish has developed unique mechanisms for maintaining their social groups. Among these complex mechanisms, communication behavior undoubtedly serves as a powerful means to facilitate communication and cooperation among individuals. Visual, auditory, tactile, and olfactory communication are the primary modes of sensory communication in animal communication. Similarly, these communication modes have been found in the individual communication of cichlids and play important roles in various aspects such as the formation of social hierarchy, mate choice, and reproduction.

Among the existing studies on cichlid fish communication behavior, reproduction is undoubtedly a hot topic. Researchers have not only analyzed the effects of cichlid fish chemical secretions on the behavioral responses between individuals during reproduction but also delved into the underlying molecular and neurobiological changes at a deeper level. For example, recent studies have explored the impact of unimodal and multimodal sensory signals on subordinative behavior and neural activation patterns in gravid females of the *Astatotilapia burtoni*. Specifically, investigations have been conducted to compare how reproductive females respond behaviorally and neurologically when exposed to male visual cues alone, auditory cues alone, or a combination of both visual and auditory stimuli. The findings indicate that the absence of visual signals from males leads to a reduction in subordinative behaviors among the gravid females. This suggests that male visual cues play a significant role in influencing the submissive behaviors of reproductive females within this species. In addition, specific social-related brain nuclei were found to exhibit differential activation under unimodal and multimodal conditions, as well as different neural coactivation networks associated with each environmental perception [33]. By injecting pregnant *Astatotilapia burtoni* females with blue dye

and observing urinary pulses, it was found that the urination behavior of pregnant females is correlated with environmental factors. They exhibited a higher urination rate when dominant males (reproductive environment) and nurturing females (aggressive environment) were present. Moreover, pregnant females displayed stronger aggression towards nurturing females [34]. In studies on pheromones in cichlid fish, it has been confirmed that pheromones have species specificity, and the effects and roles of the same pheromone vary greatly among species. For example, *Astatotilapia burtoni* males are insensitive to Prostaglandin F2α (PGF2α), which acts as a female reproductive and sex hormone in some species, but they show a strong preference for females injected with PGF2α. This indicates that female attraction to males does not depend on the PGF2α receptor but rather on a yet undiscovered metabolite of PGF2α acting as a pheromone [35]. The other two modes of communication, auditory and tactile, also contribute to reproductive success to varying degrees. By describing the sounds and behaviors produced by dominant males during courtship and comparing the differences in auditory ability of females at different reproductive stages and male social status (the hearing threshold of females is negatively correlated with cyclic steroids levels, but positively correlated in males), it has been revealed that dominant males emit sound frequencies similar to those most sensitive to females during their current stage. Furthermore, behavioral experiments have shown that females prefer to mate with males producing courtship sounds [36]. Contact with visual cues from males also promotes oviposition in *Sarotherodon mossambicus* females [37].

Various communication methods play important roles in maintaining social hierarchy and individual relationships. Research has shown that the olfactory potency of intestinal fluid and bile from dominant male *Australoheros facetus* is greater than that from subordinate males, indicating that odorants released in intestinal fluid may transmit signals of dominant status. Further analysis revealed that bile acids may contribute significantly to this phenomenon [38]. Studying the neurons and local field potentials in dominant and subordinate males of the cichlids provided insights into the olfactory neuronal response characteristics of individuals in different social ranks. The results demonstrated that dominant males exhibit responses to multiple odor types, with a larger proportion of neurons responding to sex and food-related odors. On the other hand, subordinate males have a higher proportion of neurons responding to complex odors emitted by dominant males. This allows dominant males to occupy high-quality resources while subordinate individuals can survive more safely within the population [39].

Chemical signals are released during conflicts in the life processes of the cichlids, serving multiple purposes such as intimidation and regulation to avoid significant losses. A study investigated the impact of chemical signals on social groups of *Cichlasoma paranaense* by replacing the water in the aquarium. The results indicated that water replacement (removing chemical information) reduced their aggression [40]. Research on *Oreochromis mossambicus* revealed that, during conflicts between individuals, dominant males actively release odorants through urine when engaging in aggressive behavior. The olfactory potency of urine is positively correlated with the male's social status. For competitors in a subordinate position, this serves as an important signal to indirectly mitigate risks [41]. By exposing *Neolamprologus pulcher* territorial competitors to chemical and visual cues separately, the study explored the role of chemical signals in their competitive process. The results showed that only fish exposed to visual cues increased their urine output and exhibited greater aggression. Additionally, appropriate agonistic responses may depend on available chemical signals [42]. In addition to being the main source of information, chemical signals play a vital role in enhancing species' adaptive survival through tactile

communication. The characteristics of the lateral line system in *Astatotilapia burtoni* demonstrate the role of mechanoreception in competition. It suggests that the lateral line system helps resolve conflicts during territorial disputes and reduces self-inflicted injuries [43].

Visual signals can transmit predator signals as well. Studies have shown that under visual pressure from predators, *Neolamprologus pulcher* reduces activity and exploratory behavior, spending more time seeking refuge and staying closer to conspecifics. Compared to isolated visual stimuli from predators, their response is weakened when combined with visual predator stimuli and the odor of injured conspecifics [44]. Visual signals also convey signals of intraspecies competition. *Neolamprologus pulcher* individuals with reduced facial bars exhibit less submissive behavior and use facial bar intensity as a measure of intraspecies threat [45].

Summarizing the above content in detail, various signals play important roles in maintaining the social structure and regulating individual relationships in cichlid fish. Overall, cichlids primarily communicate individual identity, status, and reproductive state through chemical signals, while visual, auditory, and tactile modes of communication assist in accomplishing these functional tasks. These communication modes are interconnected and work collaboratively.

5. Research prospects

The study of the social behavior of cichlids has always been a particularly fascinating subject. Historically, the concept of "sociality" has been predominantly focused on terrestrial mammals such as primates; however, with advancements in research, aquatic species like cichlids have gradually been reported to exhibit various social characteristics. In the preceding sections of this paper, this study has thoroughly discussed three typical aspects of social behavior research, highlighting the progress made under each thematic area. Overall, the trend in research development concerning the sociality of cichlid fish appears promising. Building on the summaries, compilations, and analyses presented herein, this study proposes several research prospects aimed at providing scientific references that may catalyze further in-depth investigations into the related studies. Reproduction represents the cornerstone of biological propagation and the maintenance and evolution of populations. The strategies, behaviors, and environmental responses among individual cichlid fish during reproductive activities have all been addressed in past studies. However, upon reviewing these works, certain aspects warrant additional attention and deeper examination. First, regarding reproductive strategies, current studies tended to focus on individual species. Given that species within the same family are likely to share similar reproductive strategies, future research could investigate universally characteristic reproductive strategies, which would enhance our understanding of the overall social traits of cichlid fish. Second, cooperative breeding, an important manifestation of interactions within a population and a means of maintaining population stability, is extensively documented in avian studies, but less so in cichlids. Future efforts could strengthen this line of inquiry by delving into the external and internal drivers behind cooperative breeding strategies and behaviors, as well as the resultant benefits, thereby clarifying the features of this unique form of social behavior. Third, mate selection is a crucial aspect of reproductive biology, determining the success of reproductive activities. This process is influenced by various factors including social hierarchies, personality, and behavior. However, the specific modes and mechanisms by which these factors exert their effects are not well-documented and remain unclear, making them worthy of continued exploration. Fourth,

there is considerable variation in the mating systems among cichlid species, and while current studies predominantly report on the types of mating systems observed, there is a significant gap in studies addressing the advantages, disadvantages, driving forces, and response mechanisms associated with these different mating types. Fifth, studies have commonly reported incidences of inbreeding among cichlids. Although inbreeding is generally believed to produce severe consequences since this mode of reproduction is widely selected within cichlid breeding activities, its outcomes, whether beneficial or detrimental, remain uncertain. Most existing work has explored the drawbacks, overlooking potential advantages, an oversight that merits attention.

The second aspect pertains to the social structure and population behavior of the Cichlids, which represents a significant manifestation of their sociality. The rigid hierarchy, role differentiation, dominance, and subordination within their communities are indicative of these characteristics. Furthermore, these aspects promise a broader scope for future exploration. Formation of social structure and its link with kinship: The relationships among kin directly influence the outcomes of hierarchical formations within the populations. Future research should employ modern molecular markers such as microsatellite DNA or Single Nucleotide Polymorphisms (SNPs) to intricately delineate kinship relations within the population. This will aid in understanding their complex social networks and hierarchical systems. Research should focus on the interactions among individuals within the populations and integrate ecological data to examine how different social structures affect resource acquisition, risk aversion, and survival strategies. Particularly under environmental stresses such as habitat loss and intensified food competition, the impact of these social structures on population stability warrants in-depth investigation. Mechanisms underlying group behaviors, aggression, and subordination: The selection and execution of behaviors reflect individuals' survival adaptations and responses to interactions among them, which is crucial for delving into the formation and maintenance of cichlids' sociability.

Communication behavior in cichlids is fundamental to their social interaction. Information transfer is also essential for maintaining inter-individual relationships. However, there are significant gaps in available studies, suggesting that future efforts could focus more on the following.

While existing studies predominantly reflect on the role and function of chemical cues in cichlid communication, there remains an acute shortage of research on other modes of communication. Hence, future research should pay greater attention to the mechanisms behind the production, transmission, and reception of visual, auditory, and tactile signals. Advanced recording and imaging techniques could provide more precise descriptions of the types and complexities of signals used by cichlids, offering new insights into intraspecific communication. From a conservation biology perspective, future work could consider the potential disturbances to cichlids' communication from human activities, such as marine noise pollution. Research should evaluate the potential impacts of these factors on their natural expression and information transmission capabilities.

6. Conclusion

Reproduction, communication, social organization, and group behavior are essential aspects of the communal life of the Cichlidae species. These key elements not only significantly enhance the survival rates of cichlids in the wild but also secure the continuation of their lineage. To elucidate the benefits of group formation, factors influencing the composition and size of groups, the interactions

between different groups, and the diverse characteristics exhibited by cichlids within these groups, it is evident that cichlids display a variety of social structures and collective behaviors. With the growth of ecological and ethological sciences, these relatively new research directions have steadily increased in prominence within scholarly studies and have become focal points in contemporary research topics. Concurrently, cichlids, as research subjects, have become increasingly familiar to researchers, and their social behaviors have been systematically categorized, although this systematization remains complex and somewhat obscure. However, with the advancement of more forward-looking studies and the substantiation of additional hypotheses, clarity in this area is expected to improve. These studies not only facilitate a better understanding of the sociality of cichlids but also provide invaluable paradigms for the fields of ecology and ethology, contributing to a more profound exploration of the social structures and behaviors of other animal groups.

Disclosure statement

The authors declare no conflict of interest.

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