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BEHAVIOURAL NOTE

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First field evidence for alloparental egg care in cooperatively breeding fish

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Abstract

Helping behaviour in cooperative breeders has been intensively studied in many animal taxa, including arthropods, birds and mammals. In these highly social systems, helpers typically engage in brood care and the protection of dependent young. Such helping systems also exist in cooperatively breeding cichlid species of Lake Tanganyika. However, breeding in these species happens in clefts, narrow holes or shelters underneath stones. Therefore, direct brood care by breeders and helpers has thus far only been observed under artificial laboratory conditions. Under natural conditions, brood care behaviour has been estimated indirectly by determining the time spent in the breeding chamber, or by the number of visits to the breeding chamber. The reliability of such substitutes needs to be validated, for instance, by demonstrating alloparental egg care of helpers through direct observations in nature. Here, we describe direct egg care by a male helper of the cooperatively breeding cichlid *Neolamprologus savoryi* in the field. The helper inspected and cleaned the eggs and defended them against predators. By reconstructing the genetic relatedness using microsatellite markers, we show that the helper was the son of the breeding male, but unrelated to the breeding female. The genetic mother of the helper was defending a different territory next to the one where the helper showed alloparental egg care. This indicates that the helper had dispersed inside the male territory to assist another female to care for his half-siblings. These results demonstrate alloparental egg care without reproductive share in a fish species under natural conditions, underlining that helping behaviour in cooperatively breeding fish has a strong non-self-serving component.

1 | INTRODUCTION

Cooperative breeding, where a dominant breeding pair is assisted by subordinate individuals to rear their offspring, represents one of the most complex forms of sociality (Field & Leadbeater, 2016; Skutch, 1935; Solomon & French, 1997; Taborsky, 1987). It evolved in a range of animal species, including arthropods, mammals, birds and fishes (reviewed in: Koenig & Dickinson, 2016; Rubenstein & Abbot, 2017). Helping duties in cooperative breeders are highly variable between species, including vigilance behaviour and food provisioning in birds and mammals (Clutton-Brock, 2016) and egg cleaning and fanning, shelter digging, and antipredator defence in fishes (Taborsky, 1994, 2016). Some of these behaviours, like food provisioning and care of foreign eggs or young, can be called altruistic, as they involve immediate fitness costs to the alloparent without immediate fitness benefits (as defined by Taborsky, Frommen, & Riehl, 2016). Other behaviours, such as antipredator defence and territory maintenance (e.g., shelter digging) might additionally have an immediately self-serving component, especially when they are also shown in the absence of dependent young (Brouwer, Heg, & Taborsky, 2005). To understand the evolution of cooperative breeding systems it is important to clarify whether

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other individuals than the breeders engage in non-immediately self-serving helping behaviours, which are expected to increase the survival of dependent young and the fitness of breeders. Care for eggs or young can be observed rather easily under natural conditions in birds and mammals. It is, however, difficult to show direct brood care in nature in cooperatively breeding fishes, because these species typically excavate breeding shelters underneath rocks or breed in narrow clefts or holes, where direct brood care by breeders and helpers cannot be observed. Therefore, researchers often use proxies of presumed brood care, like the time spent in the breeding chamber (cf. Balshine et al., 2001; Tanaka, Frommen, Engqvist, & Kohda, 2018) or changes in behaviour depending on the presence of juveniles (Brouwer et al., 2005; Bruintjes, Heg-Bachar, & Heg, 2013). Some cooperatively breeding fishes are known for having only few juveniles, which is probably due either to small clutch sizes (Tanaka, Kohda, & Frommen, 2018), or to high mortality of eggs and juveniles. The latter may be somewhat compensated by parental and alloparental care, for example by removing fungi or bacteria, or by protection from predators (Brouwer et al., 2005; Knouft, Page, & Plewa, 2003). If egg care is provided by helpers, breeders might further benefit from gaining time and energy to invest in other activities. Nevertheless, individuals engaging in egg care accept energetic costs (Taborsky & Grantner, 1998). To the best of our knowledge, removing fungi, bacteria or debris from the eggs have not been shown to provide nutritional benefits in any fish species. Such benefits would accrue when eggs were cannibalised (Gomagano & Kohda, 2008; Mehlis, Bakker, & Frommen, 2009). This behaviour is punished, however, in cooperatively breeding fishes (Taborsky, 1985; Zöttl, Heg, Chervet, & Taborsky, 2013).

Until today, helpers engaging in direct egg care have been observed only in the *Neolamprologus pulcher/brichardi* species complex (Duftner et al., 2007) under laboratory settings (von Siemens, 1990; Taborsky, 1984, 1985; Zöttl et al., 2013). Evidence for such behaviour from the field is hitherto missing for any cooperatively breeding fish species. Here we provide the first evidence of alloparental egg care of a helper in the cooperatively breeding cichlid *Neolamprologus savoryi* (Garvy et al., 2015; Heg, Bachar, & Taborsky, 2005) in nature. We furthermore describe the spawning behaviour of this species and apply genetic methods to elucidate the relatedness between different territory members and the brood caring helper.

2 | METHODS

2.1 | Study species

Neolamprologus savoryi is a cooperatively breeding cichlid fish endemic to Lake Tanganyika, East Africa (Heg et al., 2005). Breeding groups are composed of a dominant male and one to several breeding females (Garvy et al., 2015; Heg et al., 2005). Females defend distinct sub-territories, in which they tolerate subordinate individuals of varying age, size and sex. Breeding groups cluster into colonies, and each group defends the territory against conspecific and heterospecific intruders and neighbours (Heg, Heg-Bachar, Brouwer, & Taborsky, 2008; Heg, Jutzeler, Bonfils, & Mitchell, 2008). Subordinates help in territory maintenance and defence (Heg et al., 2005). Furthermore, they have been assumed to help in guarding and cleaning the eggs.

2.2 | Study site and observation period

Data were collected on 24 September 2016 at Kasakalawe point at the southern tip of Lake Tanganyika, Zambia. The study site was a sandy area at a depth of 10.2 m. Small groups of rocks of sizes between 10 and 40 cm in diameter served as shelter for the fishes. We established a 10 × 10 m grid subdivided into 1 m^2 squares covering the whole focal colony. This grid allowed us to draw a detailed map of the habitat inside the colony. The territory borders of the focal groups were determined by 20 min observations a few days prior to the occurrence of the spawning and egg laying and plotted on the map. Based on these territory borders and behavioural observations we marked all potential male and female territories with numbered stones. Our focal group of *N. savoryi* was part of a colony containing 22 dominant males, each defending a territory containing 0–5 females (median = 3) and tolerating between 0 and 3 large subordinate males (N = 13) in their territory (median = 0). The breeding females' groups (N = 59) contained 0 to 3 helpers larger than 1.5 cm standard length (median = 1).

2.3 | Observations and data acquisition

While conducting an experiment in the colony (D. Josi et al., in preparation), we haphazardly witnessed intense courtship behaviour in one of our focal territories. Spawning took place in this territory at an easily observable position, allowing us to record courtship, spawning and egg care. In total, we recorded 30 min and 16 s of spawning behaviour. Recordings of egg care started directly after the spawning and lasted for ~2 hr. Within this timeframe, we produced three video recordings (1: 13 min 13 s; 2: 22 min 29 s; 3: 35 min 30 s). Video material was afterwards processed with Adobe premiere pro CC and analysed for behavioural frequencies of the breeder male and female, and the helper.

Subsequently we caught all fish of the focal male's territory (i.e., one male, 4 females, 1 helper; see Figure 1). Standard length (SL) was measured from the tip of the mouth to the posterior end of the vertebral column with an accuracy of ±1 mm using a 1 mm measuring board. Further, the sex was confirmed by external examination of the genital papillae. Finally, we removed a small piece of tissue from the fin for genetic analyses. Afterwards, all individuals were released back to their shelter. They recovered within a few minutes.

2.4 | Genetic relatedness analysis

To scrutinize the genetic relatedness of the group members, total DNA was extracted from the ethanol preserved fin-clip samples using a magnetic separation protocol (MagneSil™ Paramagnetic Particles,

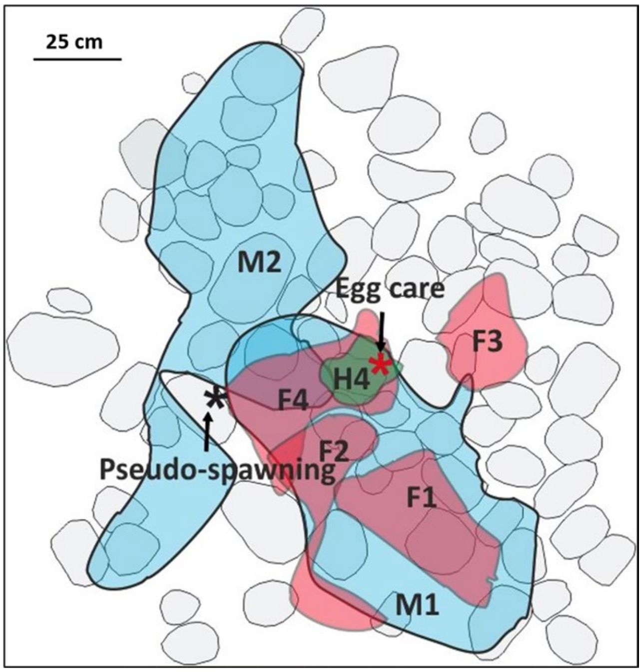

FIGURE 1 Home ranges of the fish observed in this study. Shown are territories of two neighbouring males (M1, M2). M1 guarded four breeding females (F1–F4) in his territory, and M2 monopolized three breeding females (not indicated in the map). Female F4 had 1 male helper (H4). The location of the egg deposition site (red star) and the pseudo-spawning site (black star) are indicated. Grey structures indicate individual rocks [Colour figure can be viewed at wileyonlinelibrary.com]

Promega; Kotrschal, Heckel, Bonfils, & Taborsky, 2012). Fourteen polymorphic microsatellite loci were used to determine relatedness (loci UNH154, UNH106 (Lee & Kocher, 1996); NP007, NP773, ULI2 (Schliewen et al., 2001); Pzeb3, Pzeb4 (Van Oppen, Rico, Deutsch, Turner, & Hewitt, 1997); TmoM11, TmoM13, TmoM25, TmoM27 (Zardoya et al., 1996); UME003 (Parker & Kornfield, 1996); UNH1009 (Carleton et al., 2002), and Ppun21 (Taylor et al., 2002). Some of these sequences were already optimized for the closely related species *N. pulcher*. DNA was amplified using the QIAGEN® Multiplex PCR Kit (Qiagen), allowing co-amplification of several locus-specific, fluorescently labelled primer pairs in one single PCR reaction. We used two different primer sets containing seven primer pairs each to amplify the 14 microsatellite markers. PCR reactions were attained in a 10 μl volume containing 1 μl of the genomic DNA, 5 μl 2× QIAGEN Multiplex PCR Master Mix, 3 μl H20dd and 1 μl of 10× primer mix consisting of fluorescently labelled forward and non-labelled reverse primer pairs with end concentrations of 0.4–0.6 μM each, according to the intensity of the respective amplification products. The fluorescent dyes were the following: 6-FAM (blue), HEX (green), Yakima Yellow (green), ATTO550 (yellow), ATTO565 (red) (Microsynth), VIC (green) and PET (red) (Thermo Fisher). Amplification was performed in a GeneAmp® 9700 PCR System (Applied Biosystems) using the following cycling parameters: 15 min at 95°C, 35 cycles at 95°C for 30 s, 57°C for 3 min and 72°C for 60 s followed by a final elongation step of 72°C for 15 min. Fluorescent PCR fragments were visualized by capillary electrophoresis on an ABI3100® Genetic Analyser (Applied Biosystems). GeneScan 500 LIZ (Thermo Fisher) was used as an internal size standard and the fragments were analysed using the GeneMarker® Analysis software version 2.4.0 (SoftGenetics). We reconstructed relatedness within the focal group using the Simpson-assisted descending ratio algorithm in KINGROUP v2.1 (Konovalov, 2006), compared against the null hypothesis of no relatedness.

3 | RESULTS

3.1 | Group structure

The breeding male (M1) of the focal group measured 60 mm SL. His territory contained 4 females defending sub-territories (F1: 44 mm; F2: 45 mm; F3: 46 mm; F4: 48 mm; all measures in SL; for home ranges see Figure 1). Female F4 had a single male helper (H4; 27 mm SL) in her territory. The relatedness analysis revealed that the breeding male was the genetic father of helper H4, while female F2 was its genetic mother ($p < 0.01$, type II error = 0%). Furthermore, female F3 was either the daughter or sister of the breeding male, while the other females were unrelated to him ($p < 0.01$, type II error = 0%).

3.2 | Spawning behaviour

While female F4 showed spawning behaviour with the territory owner, she also showed 32 times pseudo-spawning (behaviourally identical to spawning but without eggs being laid) with a neighbouring male (M2 (61 mm SL); see Video supplement material 1). Thus, she switched several times between the pseudo-spawning site and the egg deposition site (see Figure 1 and Video supplement material 1). During pseudo-spawning, female F4 received aggression from the breeding male M1 as well as from female F2 (see Video supplement material 1). The male M2 never showed any aggression towards female F4, but observed or inspected her rather closely during pseudo-spawning. Based on the typical male posture and behaviour during the release of sperm, we counted that male M2 released 9 times sperm during pseudo-spawning, while the female did not lay any eggs. At the egg deposition site, she laid eggs that were fertilized directly afterwards by the dominant breeding male M1. During spawning, no other individual beside the breeding male M1 and female F4 approached the egg deposition site. In total, six eggs were deposited, which does not seem to be an exceptional small clutch size for *N. savoryi*, as during a second observation in another territory a clutch of 10 eggs was recorded (DJ, personal observation). After the spawning, M1 shortly inspected the eggs (0.8 s) while M2 never inspected them. However, the breeding female F4 and her helper H4 inspected, cleaned, and defended the eggs (see Figure 2; Video supplement material 2). During the 71 min of recordings after spawning had ended, the female showed egg cleaning behaviour six times, defended the spawning site against conspecific and heterospecific intruders 20 times, and inspected the eggs for a total period of 106 s. In the same time period, the helper cleaned the eggs 28 times, defended once against a heterospecific egg predator (*Telmatochromis vittatus*), and

FIGURE 2 Four out of six eggs (two eggs per black circle) laid by the breeding female and inspected by the helper (H4; 27 mm SL). The egg deposition site was on one of the stones used for marking the different territories [Colour figure can be viewed at wileyonlinelibrary.com]

inspected the eggs for a total period of 339 s. Most defence behaviour was shown by the breeding female against the facultative egg predator *Telmatochromis vittatus* (twice during the spawning and 7 times afterwards), the piscivorous eel *Mastacembelus moorii* (8 times during spawning and once after the spawning) and against conspecifics (5 times during spawning and 12 times afterwards; see video recordings in Supplement material 1, 2). The breeding male M1 defended the eggs only against conspecific intruders after spawning (6 times in total), but did not engage in cleaning the eggs.

4 | DISCUSSION

To fully comprehend the occurrence of altruistic behaviour in cooperative breeders it is important to show alloparental care under natural conditions. Here we provide results from the first field observations of egg care behaviour by a helper in a cooperatively breeding fish. The caring helper was the genetic son of the breeding male, whereas it was unrelated to the female laying the eggs. The genetic mother of the helper defended the neighbouring subterritory (F2) of the egg-laying female (F4; see Figure 1). This indicates that helpers are tolerated not only in their mothers' territory, but also in other female subgroups of the breeding male. Helpers might hence be recruited from neighbouring subgroups, depending on the need for help. The helper carefully inspected and cleaned the eggs and showed vigilance behaviour close by. This is in accordance with the helping behaviour of *N. pulcher* described from the laboratory (von Siemens, 1990; Taborsky, 1984, 1985; Zöttl et al., 2013). The helper's effort cannot be explained by a share in reproduction, as it was too small to be sexually mature (D. Heg, personal communication) and as it was not close to the egg-laying site while spawning took place. Hence, the helper might have gained indirect fitness benefits by caring for his half-siblings (Bruintjes & Taborsky, 2011) and delayed direct benefits through group augmentation (Kokko, Johnstone, & Clutton-Brock, 2001) by increased egg survival, and/or by being allowed to stay in the female's territory, where it enjoys protection from predation ("pay-to-stay": Taborsky, 1985; Bergmüller & Taborsky, 2005; Zöttl et al., 2013; Fischer, Zöttl, Groenewoud, & Taborsky, 2014). Compared to the breeding female, the helper cleaned the eggs 4.6 times more often and spent 3.2 times more time with inspecting the eggs, whereas the female spent seven times more effort in defence against egg predators. These results indicate that breeding females and helpers may specialize in different duties during egg care, suggesting division of labour as demonstrated in the cooperatively breeding congener *N. pulcher* (Bruintjes & Taborsky, 2011).

The clutch had disappeared by the next morning, probably because the egg deposition site was quite exposed to predators. Especially during the night, eggs may be vulnerable to predation by nocturnal predators. Indeed, already during daytime the eel *Mastacembelus moorii* and the facultative egg predator *Telmatochromis vittatus* tried repeatedly to approach the egg deposition site, but were chased away by the breeding female (see Supplement materials 1, 2). After the eggs disappeared, the helper was no longer observed at the egg deposition site, indicating that he had no other interests in this particular part of the female's territory.

The spawning was frequently interrupted by pseudo-spawning events. Such pseudo-spawning behaviour has been shown in other cooperatively breeding cichlids as well (Taborsky, 1985). While the function of this behaviour is not fully understood (Heg, Heg-Bachar et al., 2008; Heg, Jutzeler et al., 2008; Kohda, 1995), it has been interpreted as evidence of mate choice (Egger, Obermüller, Eigner, Sturmbauer, & Sefc, 2008). Alternatively, it might serve to coordinate the behaviour of the spawning partners. Our observation might indicate that pseudo-spawning of the female can also serve to reduce reproductive conflict through paternity insurance between breeding males and the female. The female showed pseudo-spawning behaviour with the neighbouring male at a different location than the egg deposition site. Additionally, the neighbouring male released sperm at the pseudo-spawning site and afterwards never visited or inspected the egg deposition site. However, whether such behaviour leads to a reduction of disturbances during the actual spawning needs to be experimentally tested in future studies.

In summary, we observed for the first time direct alloparental egg care behaviour in a cooperatively breeding fish in the field. These observations may enhance our appreciation of the evolutionary mechanisms underlying cooperative breeding in fishes and in general.

ETHICAL NOTE

Data collection caused minimal disturbance to the animals and followed the regulations of the Zambian Prevention of Cruelty to Animals act.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

DJ, MT and JGF conceived the study; MT and JGF organized funding; DJ conducted fieldwork, prepared the video material and conducted the genetic analyses; DJ wrote the first draft of the manuscript, which was edited by MT and JGF; all authors approved the final version of the manuscript.

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REFERENCES

Balshine, S., Leach, B., Francis, N., Hannah, R., Taborsky, M., & Werner, N. (2001). Correlates of group size in a cooperatively breeding cichlid fish (*Neolamprologus pulcher*). *Behavioral Ecology and Sociobiology*, *50*, 134–140. https://doi.org/10.1007/s002650100343

Bergmüller, R., & Taborsky, M. (2005). Experimental manipulation of helping in a cooperative breeder: Helpers 'pay to stay' by pre-emptive appeasement. *Animal Behaviour*, *69*, 19–28. https://doi.org/10.1016/j.anbehav.2004.05.009

Brouwer, L., Heg, D., & Taborsky, M. (2005). Experimental evidence for helper effects in a cooperatively breeding cichlid. *Behavioral Ecology*, *16*, 667–673. https://doi.org/10.1093/beheco/ari042

Bruintjes, R., Heg-Bachar, Z., & Heg, D. (2013). Subordinate removal affects parental investment, but not offspring survival in a cooperative cichlid. *Functional Ecology*, *27*, 730–738. https://doi.org/10.1111/1365-2435.12088

Bruintjes, R., & Taborsky, M. (2011). Size-dependent task specialization in a cooperative cichlid in response to experimental variation of demand. *Animal Behaviour*, *81*, 387–394. https://doi.org/10.1016/j.anbehav.2010.10.004

Carleton, K. L., Streelman, J. T., Lee, B. Y., Garnhart, N., Kidd, M., & Kocher, T. D. (2002). Rapid isolation of CA microsatellites from the tilapia genome. *Animal Genetics*, *33*, 140–144. https://doi.org/10.1046/j.1365-2052.2002.00817.x

Clutton-Brock, T. (2016). *Mammal societies*. Chichester: Wiley Blackwell.

Duftner, N., Sefc, K. M., Koblmüller, S., Salzburger, W., Taborsky, M., & Sturmbauer, C. (2007). Parallel evolution of facial stripe patterns in the *Neolamprologus brichardi/pulcher* species complex endemic to Lake Tanganyika. *Molecular Phylogenetics and Evolution*, *45*, 706–715. https://doi.org/10.1016/j.ympev.2007.08.001

Egger, B., Obermüller, B., Eigner, E., Sturmbauer, C., & Sefc, K. M. (2008). Assortative mating preferences between colour morphs of the endemic Lake Tanganyika cichlid genus *Tropheus*. *Hydrobiologia*, *615*, 37–48. https://doi.org/10.1007/978-1-4020-9582-5_3

Field, J., & Leadbeater, E. (2016). Cooperation between non-relatives in a primitively eusocial paper wasp, *Polistes dominula*. *Philosophical Transactions of the Royal Society B*, *371*, 20150093. https://doi.org/10.1098/rstb.2015.0093

Fischer, S., Zöttl, M., Groenewoud, F., & Taborsky, B. (2014). Group-size-dependent punishment of idle subordinates in a cooperative breeder where helpers pay to stay. *Proceedings of the Royal Society B*, *281*, 20140184. https://doi.org/10.1098/rspb.2014.0184

Garvy, K. A., Hellmann, J. K., Ligocki, I. Y., Reddon, A. R., Marsh-Rollo, S. E., Hamilton, I. M., … O'Connor, C. M. (2015). Sex and social status affect territorial defence in a cooperatively breeding cichlid fish, *Neolamprologus savoryi*. *Hydrobiologia*, *748*, 75–85. https://doi.org/10.1007/s10750-014-1899-0

Gomagano, D., & Kohda, M. (2008). Partial filial cannibalism enhances initial body condition and size in paternal care fish with strong male—male competition. *Annales Zoologici Fennici*, *45*, 55–65. https://doi.org/10.5735/086.045.0105

Heg, D., Bachar, Z., & Taborsky, M. (2005). Cooperative breeding and group structure in the Lake Tanganyika cichlid *Neolamprologus savoryi*. *Ethology*, *111*, 1017–1043. https://doi.org/10.1111/j.1439-0310.2005.01135.x

Heg, D., Heg-Bachar, Z., Brouwer, L., & Taborsky, M. (2008). Experimentally induced helper dispersal in colonially breeding cooperative cichlids. *Environmental Biology of Fishes*, *83*, 191–206. https://doi.org/10.1007/s10641-007-9317-3

Heg, D., Jutzeler, E., Bonfils, D., & Mitchell, J. S. (2008). Group composition affects male reproductive partitioning in a cooperatively breeding cichlid. *Molecular Ecology*, *17*, 4359–4370. https://doi.org/10.1111/j.1365-294X.2008.03920.x

Knouft, J. H., Page, L. M., & Plewa, M. J. (2003). Antimicrobial egg cleaning by the fringed darter (Perciformes: Percidae: *Etheostoma crossopterum*): Implications of a novel component of parental care in fishes. *Proceedings of the Royal Society B*, *270*, 2405–2411. https://doi.org/10.1098/rspb.2003.2501

Koenig, W. D., & Dickinson, J. L. (2016). *Cooperative breeding in vertebrates*. Cambridge, UK: Cambridge University Press.

Kohda, M. (1995). Territoriality of male cichlid fishes in Lake Tanganyika. *Ecology of Freshwater Fish*, *4*, 180–184. https://doi.org/10.1111/j.1600-0633.1995.tb00031.x

Kokko, H., Johnstone, R. A., & Clutton-Brock, T. H. (2001). The evolution of cooperative breeding through group augmentation. *Proceedings of the Royal Society B*, *268*, 187–196. https://doi.org/10.1098/rspb.2000.1349

Konovalov, D. A. (2006). Accuracy of four heuristics for the full sibship reconstruction problem in the presence of genotype errors. *Proceedings of the 4th Asia-Pacific Bioinformatics Conference*, 7–16. https://doi.org/10.1142/9781860947292_0004

Kotrschal, A., Heckel, G., Bonfils, D., & Taborsky, B. (2012). Life-stage specific environments in a cichlid fish: Implications for inducible maternal effects. *Evolutionary Ecology*, *26*, 123–137. https://doi.org/10.1007/s10682-011-9495-5

Lee, W. J., & Kocher, T. D. (1996). Microsatellite DNA markers for genetic mapping in *Oreochromis niloticus*. *Journal of Fish Biology*, *49*, 169–171. https://doi.org/10.1111/j.1095-8649.1996.tb00014.x

Mehlis, M., Bakker, T. C. M., & Frommen, J. G. (2009). Nutritional benefits of filial cannibalism in three-spined sticklebacks (*Gasterosteus aculeatus*). *Naturwissenschaften*, *96*, 399–403. https://doi.org/10.1007/s00114-008-0485-6

Parker, A., & Kornfield, I. (1996). Polygynandry in *Pseudotropheus zebra*, a cichlid fish from Lake Malawi. *Environmental Biology of Fishes*, *47*, 345–352. https://doi.org/10.1007/BF00005049

Rubenstein, D. R., & Abbot, P. (2017). *Comparative social evolution*. Cambridge, UK: Cambridge University Press.

Schliewen, U., Rassmann, K., Markmann, M., Markert, J., Kocher, T., & Tautz, D. (2001). Genetic and ecological divergence of a monophyletic cichlid species pair under fully sympatric conditions in Lake Ejagham, Cameroon. *Molecular Ecology*, *10*, 1471–1488. https://doi.org/10.1046/j.1365-294X.2001.01276.x

Skutch, A. F. (1935). Helpers at the nest. *The Auk*, *52*, 257–273. https://doi.org/10.2307/4077738

Solomon, N. G., & French, J. A. (1997). *Cooperative breeding in mammals*. Cambridge, UK: Cambridge University Press.

Taborsky, M. (1984). Broodcare helpers in the cichlid fish *Lamprologus brichardi*: Their costs and benefits. *Animal Behaviour*, *32*, 1236–1252. https://doi.org/10.1016/S0003-3472(84)80241-9

Taborsky, M. (1985). Breeder-helper conflict in a cichlid fish with broodcare helpers: An experimental analysis. *Behaviour*, *95*, 45–75. https://doi.org/10.1163/156853985X00046

Taborsky, M. (1987). Cooperative behaviour in fish: Coalitions, kin groups and reciprocity. In Y. Ito, J. L. Brown, & J. Kikkawa (Eds.), *Animal societies: Theories and facts* (pp. 229–237). Tokyo, Japan: Japan Scientific Societies Press.

Taborsky, M. (1994). Sneakers, satellites, and helpers: Parasitic and cooperative behavior in fish reproduction. *Advances in the Study of Behavior*, *23*, 1–100. https://doi.org/10.1016/S0065-3454(08)60351-4

Taborsky, M. (2016). Cichlid fishes: A model for the integrative study of social behavior. In W. D. Koenig, & J. L. Dickinson (Eds.), *Cooperative breeding* (pp. 272–293). Cambridge, UK: Cambridge University Press.

Taborsky, M., Frommen, J. G., & Riehl, C. (2016). Correlated pay-offs are key to cooperation. *Philosophical Transactions of the Royal Society B*, *371*, 20150084. https://doi.org/10.1098/rstb.2015.0084

Taborsky, M., & Grantner, A. (1998). Behavioural time–energy budgets of cooperatively breeding *Neolamprologus pulcher* (Pisces: Cichlidae). *Animal Behaviour*, *56*, 1375–1382. https://doi.org/10.1006/anbe.1998.0918

Tanaka, H., Frommen, J. G., Engqvist, L., & Kohda, M. (2018). Task-dependent workload adjustment of female breeders in a cooperatively breeding fish. *Behavioral Ecology*, *29*, 221–229. https://doi.org/10.1093/beheco/arx149

Tanaka, H., Kohda, M., & Frommen, J. G. (2018). Helpers increase the reproductive success of breeders in the cooperatively breeding cichlid *Neolamprologus obscurus*. *Behavioral Ecology and Sociobiology*, *72*, 152. https://doi.org/10.1007/s00265-018-2566-7

Taylor, M. I., Meardon, F., Turner, G., Seehausen, O., Mrosso, H. D. J., & Rico, C. (2002). Characterization of tetranucleotide microsatellite loci in a Lake Victorian, haplochromine cichlid fish: A *Pundamilia pundamilia* × *Pundamilia nyererei* hybrid. *Molecular Ecology Notes*, *2*, 443–445. https://doi.org/10.1046/j.1471-8286.2002.00272.x

Van Oppen, M. H., Rico, C., Deutsch, J. C., Turner, G. F., & Hewitt, G. M. (1997). Isolation and characterization of microsatellite loci in the cichlid fish *Pseudotropheus zebra*. *Molecular Ecology*, *6*, 387–388. https://doi.org/10.1046/j.1365-294X.1997.00188.x

von Siemens, M. (1990). Broodcare or egg cannibalism by parents and helpers in *Neolamprologus brichardi* (Poll 1986) (Pisces: Cichlidae): A study on behavioural mechanisms. *Ethology*, *84*, 60–80. https://doi.org/10.1111/j.1439-0310.1990.tb00785.x

Zardoya, R., Vollmer, D. M., Craddock, C., Streelman, J. T., Karl, S., & Meyer, A. (1996). Evolutionary conservation of microsatellite flanking regions and their use in resolving the phylogeny of cichlid fishes (Pisces: Perciformes). *Proceedings of the Royal Society B*, *263*, 1589–1598. https://doi.org/10.1098/rspb.1996.0233

Zöttl, M., Heg, D., Chervet, N., & Taborsky, M. (2013). Kinship reduces alloparental care in cooperative cichlids where helpers pay-to-stay. *Nature Communications*, *4*, 1341. https://doi.org/10.1038/ncomms2344

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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