

## Dynamics of social interactions during group formation in males of the cichlid fish *Oreochromis mossambicus*

Rui F. Oliveira\* & Vitor C. Almada

*Unidade de Investigação em Eco-Etologia, Instituto Superior de Psicologia Aplicada  
Rua Jardim do Tabaco, 44, P-1100 Lisboa (ruiol@ispa.pt).*

After a period of social isolation all-male groups of *O. mossambicus* were observed for 5 days after which ovulated females were added. The frequency of different types of social interactions and behavioural activities along the observation period were recorded, and their patterns of temporal variation were studied. The relationships among the different variables were analysed using PCA. During the process of group formation the following regular temporal sequence of predominant activities was detected: (a) mutual assessment and hierarchy formation; (b) territorial establishment and nest digging; (c) courtship. We suggest that these results reflect the probable sequence of events during the process of lek formation in nature at the onset of each breeding period.

Key words: Social behaviour, cichlids, behavioural systems, group-formation

### Introduction

*Oreochromis mossambicus* (Peters, 1852) (Teleostei: Cichlidae) is a maternal mouthbrooding cichlid in which the males form dense nest aggregations in sand substrates (Bruton & Bolt, 1975; De Silva & Sirisena, 1988). The territorial males defend pits that are visited by ripe females, and where spawning takes place (Baerends

---

\* Author to whom correspondence should be addressed.

The authors would like to express their gratitude to the staff of Laboratório Marítimo da Universidade de Lisboa) where part of this study was carried on, specially to its late Director Prof. Saldanha and to Dr. Pedro Ré. We would also like to thank Hunter Halder who revised the English manuscript. This work was part of the Ph.D. research project of R.F.O. granted by Junta Nacional de Investigação Científica e Tecnológica (JNICT-BD/1032/90-IG).

Baerends van Roon, 1950; Neil, 1964). The social behaviour of this species has received considerable attention. Not only the basic social behaviour patterns are well described (Seitz, 1949; Baerends & Baerends van Roon, 1950; Neil, 1964; N'Gokaka, 1984), but also the causal processes underlying different aspects of social behaviour and coloration patterns have been explored (Lanzing, 1974; Lanzing & Bower, 1974; Silverman, 1978a, 1978b; Wendelaar-Bonga et al., 1984; Billy & Liley, 1985; Turner, 1986; Turner & Huntingford, 1986; Smith & Haley, 1988; Robinson & Doyle, 1990; Turner, 1994; Oliveira et al., 1996).

In other arena breeding cichlids dominance relationships have been described and were shown to affect the ability of the fish to secure a territory and even the quality, in terms of attractiveness to females, of these territories (Fishelson, 1983; Chan, 1987; McKaye et al., 1990; McKaye, 1991; Falter & Foucart, 1991; Rossiter, personal communication).

Most studies have focused on the behaviour of groups of fishes that were together for periods of weeks or months and there is a lack of information on the short-term processes that operate immediately after group formation.

These short-term processes may play an important role in the subsequent dynamics of group formation, because early assessments by each fish of the competitive abilities [i.e. resource holding power (RHP) *sensu* Parker 1974] of other group members may constrain the subsequent patterns of social interactions that occur in later stages, and ultimately the success of the fishes in establishing territories. In a previous study it was demonstrated that in *O. mossambicus* the dominance structure that emerges in the first day after group formation is a good predictor of the dominance structure measured on the subsequent days of the experiment (Oliveira et al., 1996). In a similar vein Nelissen (1986) showed that in another cichlid (*Melanochromis auratus*) the crucial events that determine the social status of the individual occur in the first hours after group formation.

In this paper we describe the temporal dynamics of social interactions, namely agonistic, sexual, and nesting activities of males, and their inter-relationships in the first days after group formation.

## Methods

### *Subjects and maintenance*

The individuals used in the present study were obtained from a captive stock of *O. mossambicus*, founded in the early seventies at Aquário Vasco da Gama (Lisbon) from fishes captured at Incomati River, Mozambique. The size of the fishes used in the present study ranged from 7.9 cm to 10.4 cm standard length for males, and 6.0 cm to 7.0 cm standard length for females. Fishes were kept at  $24 \pm 2$  °C on a 12D:12L light regime. They were fed daily with commercial fish food commonly used for tropical aquarium fish.

In the present experiment we have tried to assess the sequence of behavioural events that occur at the beginning of each breeding episode, namely the establishment of dominance hierarchies among males and the subsequent displaying behaviour of males towards females after the arrival of females. Outside breeding periods male *O. mossambicus* move around in schools. At the beginning of a breeding period males establish territories in clusters (arenas) to which females are attracted when ready to spawn. Contrary to intermittent lekking, the males of this species practice continuous lekking (*sensu* Loiselle & Barlow, 1978), not leaving their territories for foraging during

an entire breeding period. Neil (1964) found that in a laboratory population of *C. mossambicus* an individual male would keep its territory for on average one week. In our captive population male territoriality is synchronised, and the duration of each territorial bout ranges from 8 to 24 days (R. F. Oliveira, unpublished data).

### *Experimental procedure*

Sixteen males were individually isolated in standard aquaria (46×36×40 cm) for eight days in order to minimise possible effects of prior social experience, which has been demonstrated to be a short-lived process in fishes, lasting for some hours (winner effect) to a few days (loser effect) (Chase et al., 1994).

At the end of the isolation period four groups of four individuals each were formed and placed in standard aquaria (93×36×40 cm). To avoid any residency effect the four fishes of each group were placed simultaneously in the tanks. Care was taken to minimise the within-group variance of size (the standard length coefficients of variation for each group were as follows: CV1= 0.07; CV2= 0.04; CV3= 0.01; CV4=0.10). These all-male groups were maintained for 6 days (day zero to day five).

On the seventh day two ovulated females were introduced in each group. Ovulation was induced artificially by an intraperitoneal injection of 200µl saline containing 5µg des-Gly 10, [D-Ala &]-LHRH ethylamide (Sigma) 48 hours prior to their introduction in the all-male groups. The mixed sex groups were maintained for two days (day six and day seven).

### *Behavioural Observations*

Daily behavioural observations were conducted between 11 am and 6 pm for each group. The fishes were individually recognised by a small clip in the dorsal fin membrane. Following Martin and Bateson (1993) two types of sampling procedures were used:

(a) Behaviour continuous sampling - During four periods of 5 min each, every social interaction that occurred in each group was recorded and its behavioural elements and the identity of the actor and the receiver of the acts were noted. The social interactions were identified based on the occurrence of the behaviour patterns described by Baerends and Baerends van Roon (1950) and Neil (1964). The following behavioural elements were considered:

Agonistic interactions - those that involved one or more of the following behavioural patterns: approach, charge, butting, biting, chasing, frontal and lateral display, circling, mouthfighting, pendelling, fleeing, submission posture. An agonistic interaction was considered terminated when one of the opponents moved away from the other and no further agonistic acts were observed in the next 3 sec or more. The agonistic interactions were classified as: Symmetrical (SIM), when a receiver of an agonistic act retaliated with another aggressive act (e.g. mouthfighting, circling, pendelling, mutual display); Asymmetrical interactions, when the actor of the aggressive act supplanted the receiver without retaliation, i.e. the receiver did not perform any aggressive act. The asymmetrical interactions were further classified according to the degree of overt aggression involved: high-intensity (AHI), involving attack-flee, chase-flee, bite-flee, display-flee; and low-intensity (ALI) involving approach-withdrawal only.

Sexual interactions - when one or more of the following acts were detected: tilting, jerking, leading, quivering, pit circling.

Colour patterns and Nests - At the beginning of each sampling period the colours of the fishes were recorded according to the patterns described by Neil (1964). We counted as black males those in the Dark 3 and Black patterns on the coloration scale proposed by Neil (1964). The number of nests present in each aquarium was also noted at the beginning of each observation.

(b) Focal instantaneous sampling - At intervals of 30 sec the behaviour of the focal individual was noted for a period of 5 min per fish. The following behavioural categories were considered: Swimming; Hovering (in the water column); Agonistic interaction (either giving or receiving an agonistic act); Sexual behaviour; Hovering in the Nest (when a territorial male hovers in its pit); Nest digging (when a territorial male actively mouth digs its pit); Others, which include other behavioural activities that occurred to seldom to be considered individually, that is, chafing, nipping at the surface, digging, feeding.

### *Data Analysis*

In the present paper we considered the data for all the 16 fishes together. So the behavioural frequencies of a given category for all the fishes in each day were pooled. In order to uncover potential patterns of variation in the behavioural frequencies over the days, we have compared the observed data for each day against the expected frequencies that would result if the total number of observed frequencies was equally divided by the number of days. Thus our goal was to detect potential cases in which for a given day the frequencies were exceptionally higher or lower than the average. The comparison between observed and expected values was based on a  $\chi^2$  goodness-of-fit test using a simulation method. The rationale of this method was inspired by the Estabrook and Estabrook (1989) program ACTUS, developed to analyse contingency tables by simulation methods. In our case this rationale was modified to yield a goodness-of-fit test (Almada & Oliveira, 1997). One thousand simulations were run in a computer that generated  $n$  random numbers,  $n$  being equal to the total sum of the observed cases. These random numbers range from 0 to  $n-1$ , and according to their value are distributed by each of the classes of expected frequencies. The number of times out of 1000 that for a given class the observed count for that class was equal to or greater than the simulation count for that class was noted, the same being applied to the number of times in which the observation count for that class was equal to or lower than the simulation count. Using a significance level of 5%, cases in which the simulation count was lower than or equal to 50 out of 1000 were considered significantly lower than expected. The reverse was applied to find significantly higher than expected values (i.e. when 50 out of 1000 times the observed count was lower than or equal to the simulated count for that class).

The significance of the  $\chi^2$  value was tested by this procedure without any reference to the specific properties of the  $\chi^2$  distribution. For each simulation a  $\chi^2$  was computed for simulated vs. expected values, and the number of times out of 1000 that the  $\chi^2$  for the simulations was equal or exceeded the  $\chi^2$  obtained with the observation values was noted. If in 1000 simulations the  $\chi^2$  for the observed vs. expected values was equalled or exceeded less than 50 times it was considered significant. This computer program was developed by one of us (V. C. Almada) and is available upon request to interested colleagues.

## GROUP FORMATION IN A CICHLID FISH

In order to uncover basic inter-relationships among the temporal patterns of variation of the different behavioural categories a Principal Components Analysis (PCA) was performed based on a correlation matrix, followed by a normalised varimax rotation. The PCA computation was performed on the software package STATISTICA for Windows version 4.0 [copyright Statsoft Inc., 1993]. To determine the number of factors extracted we used the scree test (Cattell, 1966) together with the condition that we retained only factors with eigenvalues greater than 1 (Kaiser criterion, Kaiser 1960) that is when a factor extracts at least as much as the equivalent of one original variable (Comrey & Lee, 1992).

### Results

#### *Qualitative observations*

The qualitative behavioural observations suggest that the dynamics of group formation can be summarised considering five phases.

Phase 1 - Immediately after being introduced into the tanks the fishes remained motionless in the water column often in the corners of the aquaria. No social interactions were detectable during this phase that could last from a few seconds (ca 20 sec) to a few minutes, varying among individuals.

Phase 2 - Some individuals began to darken (reaching Dark 3 in the coloration scale of Neil, 1964), and engaged in symmetrical fights involving mainly circle fighting, mouth fighting, and mutual displays. Possibly because not all individuals entered this phase simultaneously, in three out of four tanks, a pair of fishes engaged in symmetrical agonistic interactions while the other two fishes remained motionless near the surface or in the corners of the aquarium. In one tank, interactions involving three fishes were observed. This phase started soon after the introduction of the fishes into the tanks (from a few seconds to a few minutes) and lasted for 1 to 2 hrs.

Phase 3 - The symmetrical agonistic interactions gradually decreased while asymmetrical high intensity interactions involving attack, chase and biting emerged. This phase started a few hours (ca 2-3 hrs) after group formation and extended for the first day of observation (day zero).

Phase 4 - The asymmetrical agonistic interactions decreased but remained at relatively high levels, the few symmetrical interactions observed changed in nature. Pendelling, a behavioural pattern typical of encounters between territorial males, was now the main element of these interactions. During this phase the males began to court and defend territories centred on these nests, and despite the absence of female courtship behaviour occurred (being directed by territorial males towards subordinate males). At this phase, territorial males often adopt the black coloration (in the scale of Neil, 1964). This phase extended from day one to day five.

Phase 5 - After the introduction of the females in the groups (days six and seven) a marked decrease of agonistic interactions was observed with a concomitant increase in courtship behaviour, that was mainly directed towards females.

#### *Temporal patterns of variation in the behavioural frequencies*

The temporal patterns of variation of the different behavioural categories recorded are shown in Fig. 1 and Fig. 2, and the variation in the number of nests and dark males during the observation period is presented in Fig. 3.

## GROUP FORMATION IN A CICHLID FISH

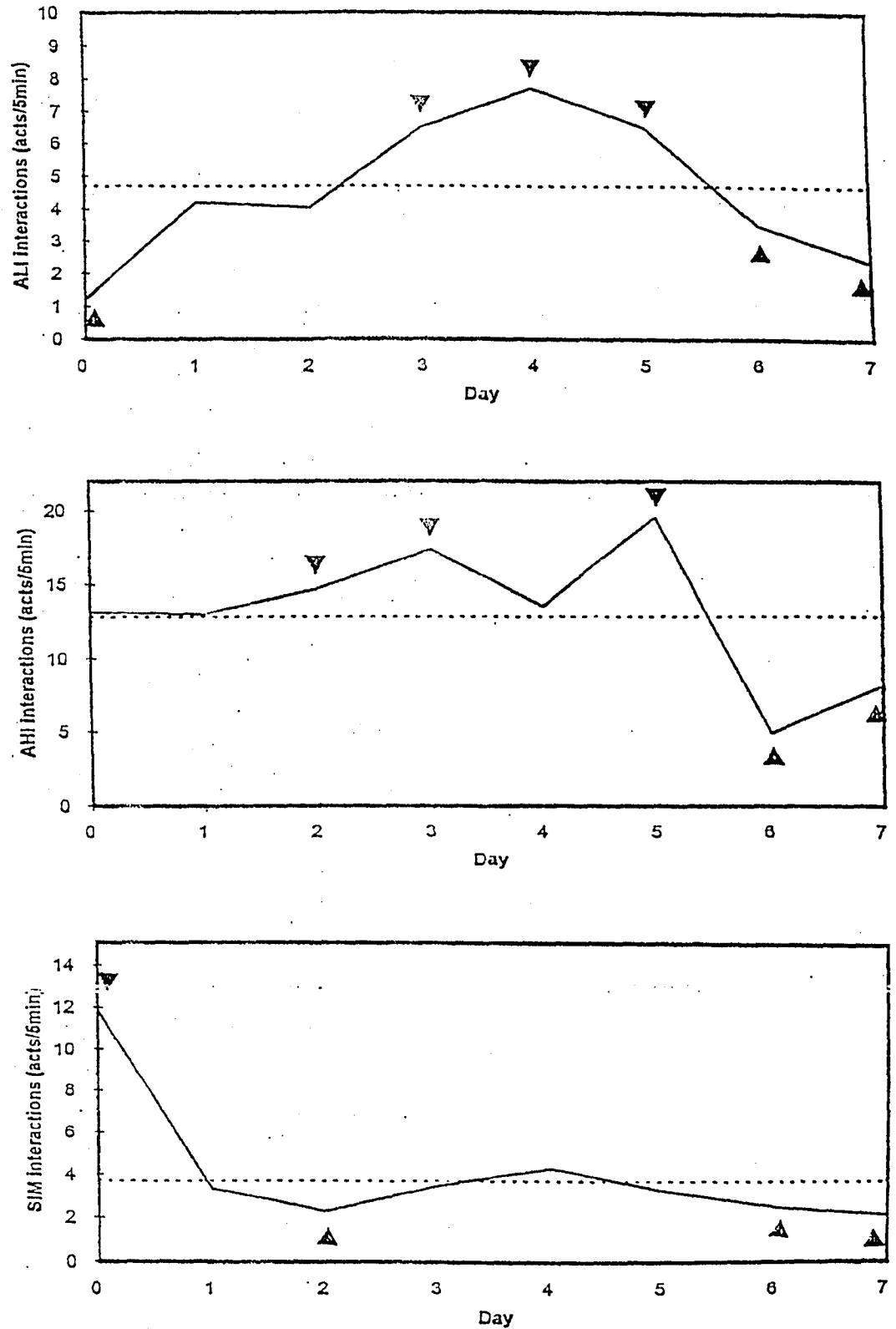


Figure 2. Temporal variation of the different types of agonistic interactions considered during the days of the experiment: (a) Asymmetric low intensity interactions; (b) Asymmetric high intensity interactions; (c) Symmetrical interactions. The observed (continuous line) and expected (dotted line) values are presented as mean number of acts per observation period (5/min). Significant lower or higher values ( $p < 0.05$ ) are marked with an arrow.

## GROUP FORMATION IN A CICHLID FISH

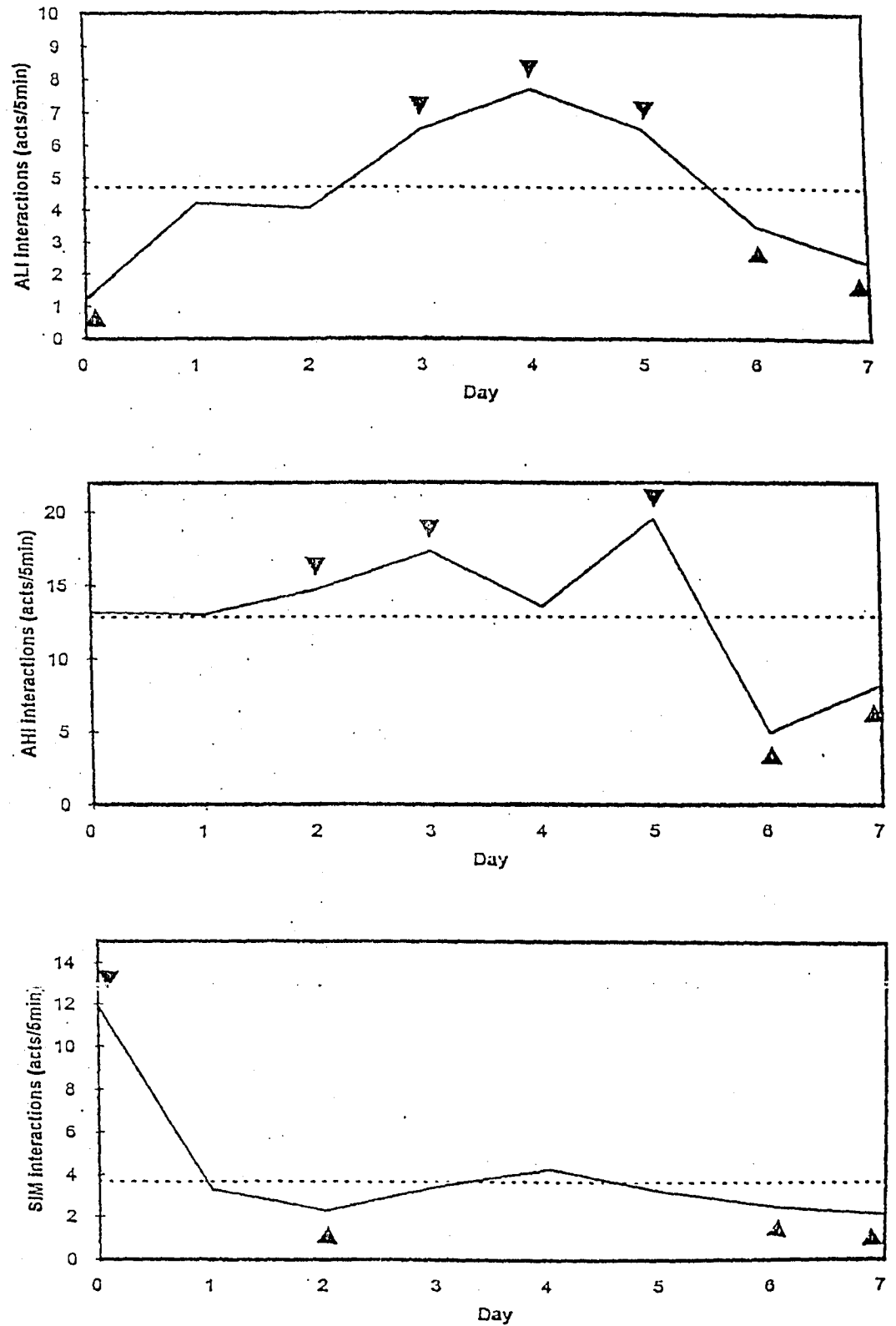


Figure 2. Temporal variation of the different types of agonistic interactions considered during the days of the experiment: (a) Asymmetric low intensity interactions; (b) Asymmetric high intensity interactions; (c) Symmetrical interactions. The observed (continue line) and expected (dotted line) values are presented mean number of acts per observation period (5/min). Significant lower or higher values ( $p < 0.05$ ) are marked with an arrow.

## GROUP FORMATION IN A CICHLID FISH

Table 2. Factor loadings of the behavioural variables after a varimax normalized rotation.

Variable	Factor 1	Factor 2	Factor 3
Swimming	-0.654*	0.445	0.323
Hovering	-0.364	0.071	-0.814*
Nest digging	0.636*	0.205	0.081
Sexual behaviour	0.052	0.657*	0.381
Agonistic Interactions	0.144	-0.896*	0.291
Hovering in the Nest	0.791*	0.284	0.239
ALI interactions	0.140	0.090	-0.767*
AHI interactions	0.859*	-0.218	-0.050
SIM interactions	-0.292	-0.708*	0.355

Three factors were extracted that explain ca 70 % of the total variance. In Fig. 4 and Table 2 the factor loadings of each behavioural variable, after a varimax normalized rotation, are presented. We suggest that these 3 factors may be interpreted as representing 3 vectors in the temporal organisation of male social behaviour in this species. Using a cut-off value of 0.63, considered by Aspey and Blankenship (1977) as very good (variable and factor sharing approximately 40% of the variance in common), one can interpret these factors as follows.

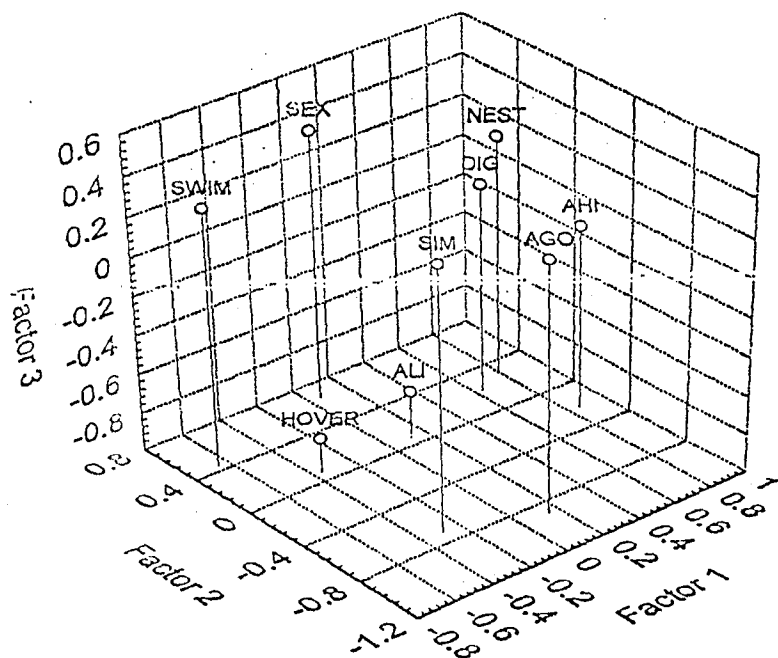


Figure 4. Associations among the different behavioural variables considered as expressed by the PCA factor loadings on the 3 factors extracted.

Four behavioural variables were associated with Factor 1: Hovering in the nest, Nest digging, and Attack, with positive loadings and Swimming with a negative value. We suggest that this factor expresses a territorial vector with activities related to territory

## GROUP FORMATION IN A CICHLID FISH

Table 2. Factor loadings of the behavioural variables after a varimax normalized rotation.

Variable	Factor 1	Factor 2	Factor 3
Swimming	-0.654*	0.445	0.323
Hovering	-0.364	0.071	-0.814*
Nest digging	0.636*	0.205	0.081
Sexual behaviour	0.052	0.657*	0.381
Agonistic Interactions	0.144	-0.896*	0.291
Hovering in the Nest	0.791*	0.284	0.239
ALI interactions	0.140	0.090	-0.767*
AHI interactions	0.859*	-0.218	-0.050
SIM interactions	-0.292	-0.708*	0.355

Three factors were extracted that explain ca 70 % of the total variance. In Fig. 4 and Table 2 the factor loadings of each behavioural variable, after a varimax normalise rotation, are presented. We suggest that these 3 factors may be interpreted as representing 3 vectors in the temporal organisation of male social behaviour in this species. Using cut-off value of 0.63, considered by Aspey and Blankenship (1977) as very good (variable and factor sharing approximately 40% of the variance in common), one can interpret these factors as follows.

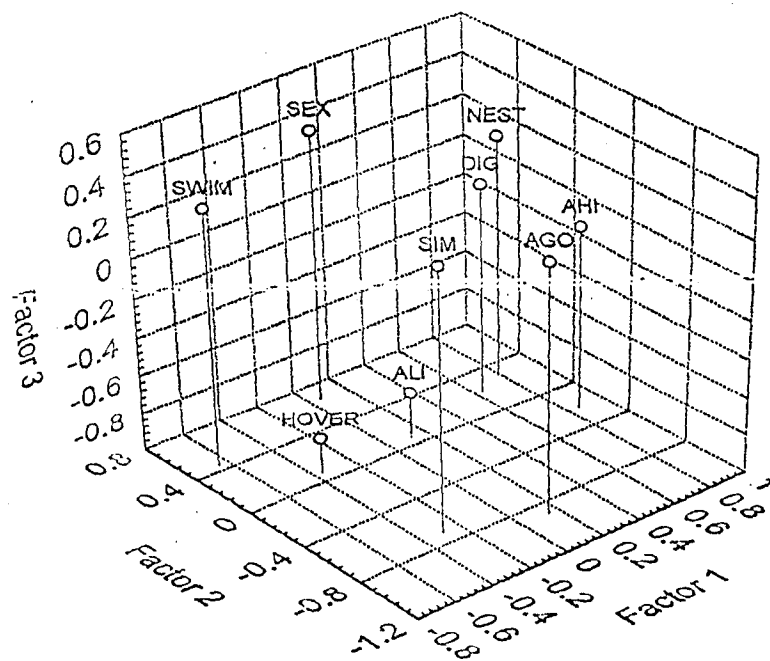


Figure 4. Associations among the different behavioural variables considered as expressed by the PCA factor loadings on the 3 factors extracted.

Four behavioural variables were associated with Factor 1: Hovering in the nest, Nest digging, and Attack, with positive loadings and Swimming with a negative value. We suggest that this factor expresses a territorial vector with activities related to territorial

is again consistent with what was to be expected in lek formation in nature, since in this species courtship is centred on a nest (Baerends & Baerends van Roon, 1950). The occurrence of male-male courtship by fishes that are strongly motivated to breed is not an artefact of our experimental setting since it was documented in the literature (Baerends & Baerends van Roon, 1950; Neil, 1964; Pinheiro, 1980).

The introduction of females, at day six, was immediately followed by a sharp drop in agonistic interactions among the males and a concomitant increase in courtship behaviour. This finding must be interpreted with caution, since we had no adequate control for the possibility of a similar temporal pattern emerging in all-male groups. This point deserves further study since in other lek-breeding species the presence of females promotes an increase of agonistic interactions among lekking males, which is supposed to be important in the females choice of mates (see Wiley, 1991). If our results can be confirmed it indicates that such a mechanism of mate choice does not operate in *O. mossambicus*.

The results of PCA seem to confirm the interpretation of the sequence of predominant activities that was outlined above. Indeed, the first Factor grouped behaviours that correspond to territorial defence and nest digging, the same behaviours that peaked together in the second phase of the observation period.

The analysis also separated the asymmetrical interactions associated with territorial defence from the symmetrical fights involved in mutual assessments and hierarchy formation that was represented in Factor 2. Thus, the temporal difference in the peak of these two types of agonistic interactions was reflected in the PCA results. The position of courtship in Factor 2, with an opposite sign relative to symmetrical fights, suggests an incompatibility between the two types of activities. The association between the decrease of agonistic interactions and the increase of courtship after day five points in the same direction.

The third Factor contains Approach and Hovering. We suggest that this factor may represent a natural distinct group of "gregarious behaviour" probably linked to the schooling activities of this species when not breeding.

PCA and Factor Analysis have often been used in ethological investigations as means to uncover underlying mechanisms involved in the causation of behavioural transitions (Wiepkema, 1961; Balthazart, 1973; Heiligenberg, 1973; Huntingford, 1976; Baerends, 1984). In such studies the raw data on which the analysis is based are typically transitions between behavioural patterns (e.g. Baerends, 1984). In the present study however, the basic data were frequencies of different types of interactions in a given group and not behavioural transitions at the level of the individual. Thus, our results are not directly comparable to the above mentioned studies. Despite this difference it is likely that many properties that emerge in the study of groups are the result of the mechanisms underlying the behaviour of the individuals that constitute that group, as pointed out by Hinde (1976) in a broader context.

Baerends (1984) in a study on the organisation of the pre-spawning behaviour in a substrate-brooding cichlid (*Aequidens portalegrensis*) found 3 causally distinct groups of behaviour: agonistic, transitory, and courtship which includes digging movements associated with nest building. In our study, digging was expressed in the territorial factor together with attack and hovering in the nest. Barlow (1974) also viewed pit building as an expression of territorial behaviour among cichlids including *O. mossambicus*.

## GROUP FORMATION IN A CICHLID FISH

is again consistent with what was to be expected in lek formation in nature, since in this species courtship is centred on a nest (Baerends & Baerends van Roon, 1950). The occurrence of male-male courtship by fishes that are strongly motivated to breed is an artefact of our experimental setting since it was documented in the literature (Baerends & Baerends van Roon, 1950; Neil, 1964; Pinheiro, 1980).

The introduction of females, at day six, was immediately followed by a sharp drop in agonistic interactions among the males and a concomitant increase in courtship behaviour. This finding must be interpreted with caution, since we had no adequate control for the possibility of a similar temporal pattern emerging in all-male groups. This point deserves further study since in other lek-breeding species the presence of females promotes an increase of agonistic interactions among lekking males, which is supposed to be important in the females choice of mates (see Wiley, 1991). If these results can be confirmed it indicates that such a mechanism of mate choice does operate in *O. mossambicus*.

The results of PCA seem to confirm the interpretation of the sequence of predominant activities that was outlined above. Indeed, the first Factor grouped behaviours that correspond to territorial defence and nest digging, the same behaviours that peaked together in the second phase of the observation period.

The analysis also separated the asymmetrical interactions associated with territorial defence from the symmetrical fights involved in mutual assessments and hierarchy formation that was represented in Factor 2. Thus, the temporal difference in the peak of these two types of agonistic interactions was reflected in the PCA results. The position of courtship in Factor 2, with an opposite sign relative to symmetrical fights, suggests an incompatibility between the two types of activities. The association between the decrease of agonistic interactions and the increase of courtship after day five points in the same direction.

The third Factor contains Approach and Hovering. We suggest that this factor may represent a natural distinct group of "gregarious behaviour" probably linked to schooling activities of this species when not breeding.

PCA and Factor Analysis have often been used in ethological investigations as a means to uncover underlying mechanisms involved in the causation of behavioural transitions (Wiepkema, 1961; Balthazart, 1973; Heiligenberg, 1973; Huntingford, 1976; Baerends, 1984). In such studies the raw data on which the analysis is based are typically transitions between behavioural patterns (e.g. Baerends, 1984). In the present study however, the basic data were frequencies of different types of interactions in a given group and behavioural transitions at the level of the individual. Thus, our results are not directly comparable to the above mentioned studies. Despite this difference it is likely that many properties that emerge in the study of groups are the result of the mechanisms underlying the behaviour of the individuals that constitute that group, as pointed out by Hinde (1976) in a broader context.

Baerends (1984) in a study on the organisation of the pre-spawning behaviour of a substrate-brooding cichlid (*Aequidens portalegrensis*) found 3 causally distinct groups of behaviour: agonistic, transitory, and courtship which includes digging movements associated with nest building. In our study, digging was expressed in the territorial factor together with attack and hovering in the nest. Barlow (1974) also viewed pit building as an expression of territorial behaviour among cichlids including *O. mossambicus*.

## GROUP FORMATION IN A CICHLID FISH

- Chan, T. -Y. (1987). The role of male competition and female choice in the mating success of a lek-breeding southern African cichlid fish *Pseudocrenilabrus philander* (Pisces: Cichlidae). M.Sc. Thesis, Grahamstown, South Africa: Rhodes University.
- Chase, I. D.; Bartolomeo, C. & Dugatkin, L. A. (1994). Aggressive interactions and inter-contest intervals: how long do winners keep winning? *Anim. Behav.*, **48**, 393-400.
- Comrey, A. & Lee, H. B. (1992). A first course in factor analysis, 2nd Ed. Hillsdale, N. J.: Lawrence Erlbaum Associates.
- De Silva, S. S. & Sirisena, H. K. G. (1988). Observations on the nesting habits of *Oreochromis mossambicus* (Peters) (Pisces, Cichlidae) in Sri Lankan reservoirs. *J. Fish Biol.*, **33**, 689-696.
- Estabrook, C. B. & Estabrook, G. F. (1989). ACTUS: a solution to the problem of small samples in the analysis of two-way contingency tables. *Hist. Meth.*, **22**, 5-8.
- Falter, U. & Foucart, D. (1991). Territorial competition and sexual selection in the colonial mouthbrooder *Oreochromis mossambicus* (Pisces: Cichlidae). *Ann. Kon. Mus. Mid. Afr., Zool. Wetensch.*, **262**, 1-12.
- Fishelson, L. (1983). Social behaviour of adult tilapia fish in nature and in captivity (Israel). In L. Fishelson & Z. Yaron (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, (pp.4-11). Tel-Aviv: Tel Aviv University.
- Fryer, G. & Iles, T. D. (1972). The cichlid fishes of the Great Lakes of Africa: their biology and evolution. Edinburgh: Oliver & Boyd.
- Heiligenberg, W. (1965). A quantitative analysis of digging movements and their relationship to aggressive behaviour in cichlids. *Anim. Behav.*, **13**, 163-171.
- Heiligenberg, W. (1973). Random processes describing the occurrence of behaviour patterns in cichlids. *Anim. Behav.*, **21**, 169-182.
- Hinde, R. A. (1976). Interactions, relationships and social structure. *Man*, **11**, 1-17.
- Huntingford, F. A. (1976). An investigation of the territorial behaviour of the three-spined stickleback (*Gasterosteus aculeatus*) using principal components analysis. *Anim. Behav.*, **24**, 822-834.
- Lamprecht, J. (1973). Mechanismen des Paarzusammenhaltes beim Cichliden *Tilapia mariae* B. (Pisces: Cichlidae, Teleostei). *Z. Tierpsychol.*, **31**, 10-61.
- Lanzing, W. J. R. (1974). Sound production in the cichlid *Tilapia mossambica* Peters. *J. Fish Biol.*, **6**, 3-12.
- Lanzing, W. J. R., & Bower, C. C. (1974). Development of colour patterns in relation to behaviour in the cichlid *Tilapia mossambica* (Peters). *J. Fish Biol.*, **6**, 29-41.
- Loiselle, P. V., & Barlow, G. W. (1978). Do fishes lek like birds? In E. Reese & F.J. Lighter (Eds.), Courtship in behavior: adaptations in the aquatic and terrestrial environment, (pp.31-75). New York: John Wiley & Sons.
- Mckaye, K. R., Louda, S. M. & Stauffer Jr., J. R. (1990). Bower size and male reproductive success in a lek-breeding fish. *Am. Nat.*, **135**, 597-613.
- Mckaye, K. R. (1991). Sexual selection and the evolution of the cichlid fishes of Lake Malawi, Africa. In H. A. Keenleyside (Ed.), Cichlid fishes: behaviour, ecology and evolution, (pp.241-257). Ithaca: Cornell University Press.
- N'Gokaka, C. (1984). Ethologie et hybridation des Tilapias. *Cahiers d'Ethologie Appliquee*, suppl. 3, 1-12.
- Neil, E. H. (1964). An analysis of color changes and social behavior of *Tilapia mossambica*. *Univ. Zool.*, **75**, 1-58.
- Neil, S. J. (1984). Field studies on the behavioral ecology and agonistic behavior of *Cichlasoma nigrofasciatum* (Pisces: Cichlidae). *Env. Biol. Fish.*, **10**, 59-68.
- Nelissen, M. H. J. (1986). The development of a dominance hierarchy in *Melanochromis auratus* (Pisces: Cichlidae). *Ann. Kon. Mus. Mid. Afr., Zool. Wetensch.*, **251**, 17-20.
- Oliveira, R. F., Almada, V. C. & Canário, A. V. M. (1996). Social modulation of sex steroid concentrations in the urine of male cichlid fish *Oreochromis mossambicus*. *Horm. Behav.*, **30**, 2-12.
- Parker, G. A. (1974). Assessment strategy and the evolution of fighting behaviour. *J. Theor. Biol.*, **47**, 2-18.
- Pinheiro, M. (1980). Observações etológicas em *Sarotherodon mossambicus* (Peters) (Pisces, Cichlidae). *Garcia de Orta, Sér. Zool.*, **9**, 13-50.

## GROUP FORMATION IN A CICHLID FISH

- Chan, T. -Y. (1987). The role of male competition and female choice in the mating success of a lek-bre southern African cichlid fish *Pseudocrenilabrus philander* (Pisces: Cichlidae). M.Sc. T. Grahamstown, South Africa: Rhodes University.
- Chase, I. D.; Bartolomeo, C. & Dugatkin, L. A. (1994). Aggressive interactions and inter-contest int how long do winners keep winning? *Anim. Behav.*, 48, 393-400.
- Comrey, A. & Lee, H. B. (1992). A first course in factor analysis, 2nd Ed. Hillsdale, N. J.: Law Erlbaum Associates.
- De Silva, S. S. & Sirisena, H. K. G. (1988). Observations on the nesting habits of *Oreochromis mossambicus* (Peters) (Pisces, Cichlidae) in Sri Lankan reservoirs. *J. Fish Biol.*, 33, 689-696.
- Estabrook, C. B. & Estabrook, G. F. (1989). ACTUS: a solution to the problem of small samples in the ar of two-way contingency tables. *Hist. Meth.*, 22, 5-8.
- Falter, U. & Foucart, D. (1991). Territorial competition and sexual selection in the colonial mouthbr *Oreochromis mossambicus* (Pisces: Cichlidae). *Ann. Kon. Mus. Mid. Afr., Zool. Wetensch.*, 262,
- Fishelson, L. (1983). Social behaviour of adult tilapia fish in nature and in captivity (Israel). In L. Fis & Z. Yaron (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, (pp.4 Tel-Aviv: Tel Aviv University.
- Fryer, G. & Iles, T. D. (1972). The cichlid fishes of the Great Lakes of Africa: their biology and evo Edinburgh: Oliver & Boyd.
- Heiligenberg, W. (1965). A quantitative analysis of digging movements and their relationship to aggr behaviour in cichlids. *Anim. Behav.*, 13, 163-171.
- Heiligenberg, W. (1973). Random processes describing the occurrence of behaviour patterns in cichlid *Anim. Behav.*, 21, 169-182.
- Hinde, R. A. (1976). Interactions, relationships and social structure. *Man*, 11, 1-17.
- Huntingford, F. A. (1976). An investigation of the territorial behaviour of the three-spined stick (*Gasterosteus aculeatus*) using principal componentes analysis. *Anim. Behav.*, 24, 822-834.
- Lamprecht, J. (1973). Mechanismen des Paarzusammen haltes beim Cichliden *Tilapia mariae* Bourc. 1899 (Cichlidae, Teleostei). *Z. Tierpsychol.*, 31, 10-61.
- Lanzing, W. J. R. (1974). Sound production in the cichlid *Tilapia mossambica* Peters. *J. Fish Biol.*, 6, 34
- Lanzing, W. J. R., & Bower, C. C. (1974). Development of colour patterns in relation to behaviour in *mossambica* (Peters). *J. Fish Biol.*, 6, 29-41.
- Loiselle, P. V., & Barlow, G. W. (1978). Do fishes lek like birds? In E. Reese & F.J. Lighter (Eds.), Co in behavior: adaptations in the aquatic and terrestrial environment, (pp.31-75). New York: John Wiley & Sons.
- Mckaye, K. R., Louda, S. M. & Stauffer Jr., J. R. (1990). Bower size and male reproductive success in a fish lek. *Am. Nat.*, 135, 597-613.
- Mckaye, K. R. (1991). Sexual selection and the evolution of the cichlid fishes of Lake Malawi, Africa. H. A. Kecnleyside (Ed.), Cichlid fishes: behaviour, ecology and evolution, (pp.241-257). L Chapman & Hall.
- N'Gokaka, C. (1984). Ethologie et hybridation des Tilapias. *Cahiers d'Ethologie Appliquee*, suppl. 3, 1
- Neil, E. H. (1964). An analysis of color changes and social behavior of *Tilapia mossambica*. *Univ. Publ. Zool.*, 75, 1-58.
- Neil, S. J. (1984). Field studies on the behavioral ecology and agonistic behavior of *Cichlasoma* (Pisces: Cichlidae). *Env. Biol. Fish.*, 10, 59-68.
- Nelissen, M. H. J. (1986). The development of a dominance hierarchy in *Melanochromis auratus* (Cichlidae). *Ann. Kon. Mus. Mid. Afr., Zool. Wetensch.*, 251, 17-20.
- Oliveira, R. F., Almada, V. C. & Canário, A. V. M. (1996). Social modulation of sex steroid concen in the urine of male cichlid fish *Oreochromis mossambicus*. *Horm. Behav.*, 30,2-12.
- Parker, G. A. (1974). Assessment strategy and the evolution of fighting behaviour. *J. Theor. Biol.*, 47, 2
- Pinheiro, M. (1980). Observações etológicas em *Sarotherodon mossambicus* (Peters) (Pisces, Cichlidae). *Garcia de Orta, Sér. Zool.*, 9, 13-50.