The effects of social interaction on sex determination in Midas cichlids

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Abstract. Juvenile Midas cichlids, *Amphilophus citrinellus*, have been reported to have sex determined by social factors. I observed behavior in, and histologically analyzed gonads of, specimens from nature and laboratory to determine the effects of behavioral interaction and relative body size on sex determination. Social conditions were found not to influence whether an individual differentiated as a female or a male.

INTRODUCTION

Adult sex change in fishes is thought to evolve when the critical period of gonad differentiation extends into adulthood, when development can be influenced by social interactions (Oldfield 2005). Sexual lability at an intermediate life stage has been reported in the Midas cichlid, *Amphilophus citrinellus*, and was considered to represent a mid-point on a developmental continuum, lying between fish that have sex controlled genetically and fish that change sex as adults. At the juvenile stage, individuals were reported to differentiate as males if they were larger than most of their group-mates, and females if they were smaller than most (Francis and Barlow 1993). This finding has been cited frequently, but never experimentally confirmed by additional investigators.

My hypotheses:
(which would be consistent with social control of sex determination)

(1) In nature, individuals will be socially assorted by body size
(2) Social interaction will be common at the juvenile stage
(3) Males will be larger than females within social groups
(4) Bisexual gonads may be present
(5) Aggressive fish will develop as males, subordinate fish as females

Alternative hypothesis:

(6) Sex is not determined socially; adult males are larger than females because they grow faster

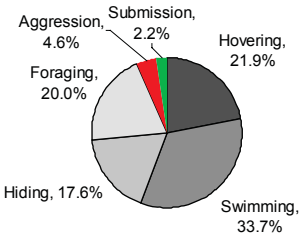
LAKE APOYO SOCIAL BEHAVIOR

In Lake Apoyo, Nicaragua, underwater observations revealed Midas cichlids socially assorted by body size. Social interaction was common in small juveniles in shallow water (Oldfield et al. 2006).

104 total quadrat observations
Midas cichlids in 68 of these 104
2 or more fish in close proximity (<20 cm) in 22 of these 68

Followed each of 33 Midas cichlids for up to 5 minutes
Recorded # of social interactions and observed:
0.76 aggressive acts / min.
0.37 submissive acts / min.

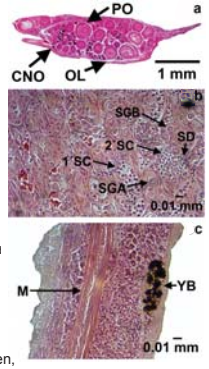
Recorded behavior at specific time intervals and calculated the time budget to be:



LAKE APOYO SEX DISTRIBUTIONS

Two shoals of larger juveniles were captured in deep water. Histological analysis revealed that they were at the onset of sexual differentiation, but sex was not associated with body size in either group ($p > 0.50$). No bisexual gonads were observed.

Group 1 SL (mm)	Sex	Group 2 SL (mm)	Sex
63	F	60	M
64	F	61	undifferentiated
65	F	61	M
65.5	M	61	M
67	M	64	undifferentiated
67	M	65	undifferentiated
70	F	66	F
70	M	66	M
71	F	66	M
72	F	66.5	M
72.5	M	69	F
73	M	69	M
77	F	70	F
77	F	70	F
		72.5	poorly preserved
Mean SL:	69.6	65.8	
Std. Dev.:	4.5	3.9	

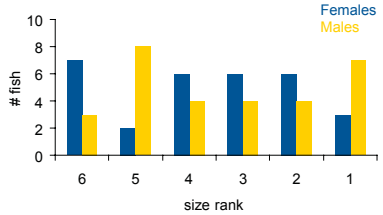


Typical female (a), male (b), and (c) undifferentiated gonads. CNO = chromatin nucleolus phase oocyte, OL = ovarian lumen, PO = perinucleolar phase oocyte, 1°SC = primary spermatocyte, 2°SC = secondary spermatocyte, SD = sperm duct containing spermatids and spermatozoa, SGA = spermatogonia A, SGB = spermatogonia B, M = mesentery, YB = yellow body

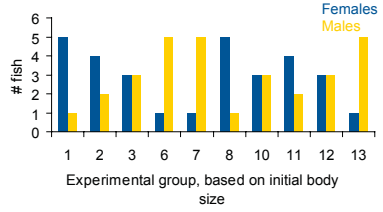
BEHAVIOR EXPERIMENT

One brood of juveniles was divided into 13 groups each containing 6 similarly-sized fish and raised in the laboratory to early maturity. I analyzed behavior and relative body size in 10 intact groups (Oldfield 2007).

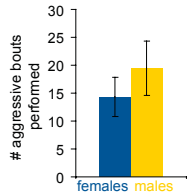
Relative body size in experimental groups was not related to sex (n = 30 females, 30 males, Kolmogorov-Smirnov: $k = 6$, $p > 0.50$).



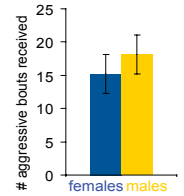
Relative body size in original brood not related to sex (Kolmogorov-Smirnov: $k = 10$, $p > 0.50$).



There was no difference in aggression performed or received between females (n = 29) and males (n = 24). (Means ± SE)

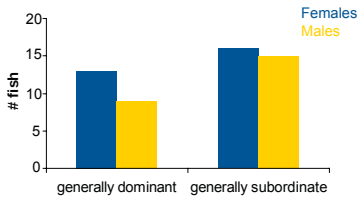


Mann-Whitney U = 285.5, two-tailed p = 0.262



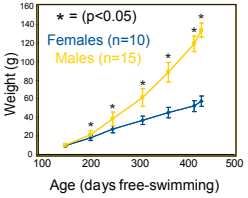
Mann-Whitney U = 310.5, two-tailed p = 0.501

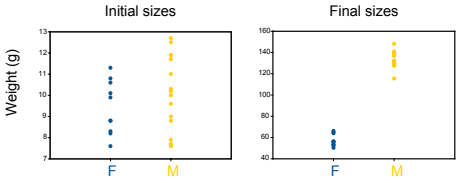
Fish that usually won encounters did not develop as males more often than fish that usually lost (Chi-square test: $\chi 2 = 0.289$, $p > 0.50$).



GROWTH EXPERIMENTS

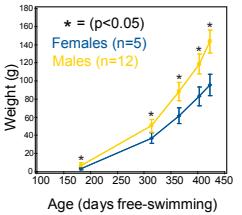
Juveniles from four lineages were marked, divided into large groups (n = 8), grown to adulthood and sex identified. Initially there was no difference in body size between females and males within each group. Larger size of males at adulthood was due to faster growth than in females. (Data shown are from one group of Lake Nicaragua-lineage Midas cichlids, means ± SD).





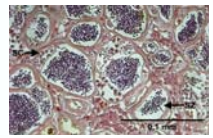
FISH RAISED IN ISOLATION

15 of 30 isolated fish differentiated as females. The resulting 1:1 sex ratio was the same as in group-housed fish (n = 60), and wild populations. Isolation did not affect sex determination. Interestingly, growth in isolated females was faster than in group-held females.



LAKE MASAYA SPECIMENS

Of 25 individuals of various ages from Lake Masaya, Nicaragua (the source of fish in the original reports), none had bisexual gonads, although these are often present in sexually labile species. There was no significant difference in SL between immature females and immature males ($t = 1.95$, $p = 0.09$). In adults, males were much larger than females ($t = 6.36$, $p < 0.0001$). Typical (a) female and (b) male. LA = lamella, OL = ovarian lumen, SC = spermatocyte, SZ = spermatozoa.



a 1.0 mm b

CONCLUSIONS

Field observations and laboratory experiments consistently indicate that social conditions do not affect sex in Midas cichlids and that differences in relative body size in adults are due to greater post-maturational growth in males than in females.

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