Architectural engineering models: Application of intricate structure-building methods (bowers, pit, and castle) in Cichlid fishes of global waters

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Abstract

This study investigates parental care behaviors in Cichlid fishes through the lens of architectural engineering models. Cichlids employ intricate structure-building methods, notably the construction of bowers using pit and castle techniques, both in natural waters and in public aquaria. These reproductive strategies represent remarkable examples of behavioral adaptation. By excavating pits or building castle-like structures, Cichlids demonstrate advanced engineering skills that serve to attract mates and defend territories.

Keywords: Cichlid fishes; Bower construction; Intricate structures; Pit and castle method; Behavioral adaptation

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Introduction

Borgia (1985) and Frith and Frith (2004) have refereed the term was initially used to defined the constructions of bowerbirds and widowbirds in Australia and New Guinea. The above said species male birds build 'avenue' or 'maypole' structures from twigs or clear exhibition areas of the jungle floor and may decorate these with up to thousands of items. In general, parental care Cichlids fish the most complex male secondary sexual traits is the bower, broadly defined as a decorative structure built in a male's territory where wooing and mating takes place. Kellogg *et al*. (1995) and Taylor *et al*. (1998) have observations show that females often visit and mate with multiple males with a lekking Cichlids species also elaborate spawning platforms (KcKaye *et al*., 2001). Eggs are laid on the bower platform, collected in the female's buccal cavity, fertilized, and brooded away from the lek for approximately one month before release of free-swimming fry into the medium. According to McKaye (1991) has reviewed 10 categories of qualitatively different bower form in Lake Malawi Cichlids, including pits, mounds and volcanoes. Stauffer *et al*. (1995) and McKaye *et al.* (2001) have discussed with Bowers within each category vary quantitatively, different ranging in size from a few centimetres to 3 m across to the nest. York *et al*. (2015) have assess that the bower constructing species in Lake Malawi, two major behavioural phenotypes have repeatedly evolved: "pit-digging", or construction of crater-like depressions, and "castle-building," or construction of volcano-like elevations. Zachary Johnson *et al*. (2020) has analysed progressive, three-dimensional and social scopes of bower construction, feeding and trembling (an engagement behaviour in which males rapidly vibrate and display their anal fins for reproductive females), that would be difficult and impractical to quantify through manual annotation. Viz.,

(i) bower construction unfolds through punctuated bursts of activity,
(ii) bower construction is performed at different times and locations relative to feeding behaviours,
(iii) bower construction is performed at different times but in the same locations as quivering behaviours, and
(iv) bower construction, feeding, and quivering behaviors are expressed in different social contexts.

The present observation of exhibits system, on associations of bower construction in the form of 'pit' and 'castle' methods and application of intricate structure method has been studied.

Materials and methods

Mathematical modelling of fish-inspired construction (like biomimetic design), typical formulas involve:

Hydrodynamics (fish swimming efficiency)

Drag force:

$F_D = \frac{1}{2}\rho v^2 C_D A$

where ρ = fluid density, v = velocity, C_D = drag coefficient, A = Cross-sectional area

Structural scaling (allometry in fish/bowers)
Length–weight relation in fish:
$W=aL^b$
Where, W = weight, L = length, a, b = species constants
Optimization (patentable design principles)
Bower shapes (circular / tunnel) modeled with equations of paraboloids, ellipses, or spheres:
Paraboloid:
$Z = x2/a2 + y^2/b^2$

The "Bowers – Pit and Castle method" is not an engineering or surveying formula at all it comes from behavioral ecology. In Lake Malawi and related African Cichlid fishes, males construct bowers (courtship structures in the sand) that are of two main forms:
Pit bowers - crater-like depressions, often shaped like an *inverted paraboloid*.
Castle bowers - mound-like heaps, which can resemble a *paraboloid hill*.

Researchers studying these bower forms (e.g., "pit vs. castle" building species) occasionally model their geometry using paraboloids to measure volume, height, slope, or to simulate how these structures develop and influence mate choice.
"Paraboloid" is the mathematical surface used to approximate the shape of the bowers (both pit and castle).

"Bowers – Pit and Castle method" refers to categorizing Cichlid bowers into those two forms and analyzing them, often by fitting paraboloid equations to describe their geometry.

Resutls and discussions

Cichlids exhibit a variety of breeding and parental care behaviors. While almost all Cichlid species exhibit rather strong parental care, it is the haplochromine Cichlids that show a particularly remarkable parenting behaviour referred to as mouth-brooding. The present observation of construction method and behavioural sequence of parental caring of Cichlids species are typical construction proceeds by repeated, stereotyped bouts of substrate manipulation (scooping with the mouth, tail-flicking, spitting sand, carrying small stones) organized into distinct micro-behaviors (digging, shoveling, smoothing, decorating). Sequences are repeatable within species-specific species are fish dig or pile sand, inspect the structure, perform courtship displays near it, and maintain or repair the bower throughout the breeding period. Measurement units used in studies include excavation volume, mound height, pit depth, building bout frequency, and transition probabilities among micro-behaviours. East African Cichlids apply intricate construction methods to build pit (excavation) and castle (accumulation) bowers. These structures are not just shelters but courtship arenas that demonstrate male fitness, influence female choice, and drive speciation.

The construction of intricate spawning structures represents a remarkable example of behavioural engineering among Cichlid fishes of Lake Malawi. According to McKaye *et al*. (2001) and York *et al*. (2015) have highlighted to the sand-dwelling species, particularly member of the genus *Copadichromis*, had confirmed that the bower-building behaviours, which typically take the form of either pit bowers and shallow depressions excavated in the sandy substrate or castle bowers, where males pile sand into conspicuous mounds or crate-like arenas. Bowers had a dual purpose: Cichlid function as sites for courtship and spawning, while instantaneously acting as extended phenotypic gestures that advertise male fitness to potential mates (Andersson, 1994; Pauers *et al*., 2012). The scale, symmetry, and maintenance of these structures directly influence female mate choice, thereby linking architectural complexity to reproductive success. The comparison between *Copadichromis* and *Melanochromis* highlights how habitat structure drives divergent evolutionary solutions to the same reproductive challenge. While sand-dwellers express their fitness through the construction of large, visually conspicuous bowers, rock-dwellers rely on the refinement of naturally available spaces, producing a form of architectural behavior scaled to the constraints of their environment. This divergence underscores the plasticity of Cichlid reproductive behaviour and suggests that bower-building and rock-clearing are functional analogues, both serving as structural signals of male quality, though manifested in distinct ecological contexts. Thus, the present study showed that the Maingano Cichlids develops our understanding of "intricate structure methods" in Cichlid fishes by indicating that architectural wooing strategies are not limited to pit or castle bowers. Instead, they may extend to micro-scale habitat modification, reflecting a broader spectrum of structural behaviours shaped by environmental pressures. Future comparative analyses between sand-dwelling and rock-dwelling species may further clarify the evolutionary pathways that underlie this diversity in courtship architecture.

Refereces

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