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A narrative review of reproduction in freshwater fishes of semiarid Northeastern Brazil

Abstract

Stressors of various nature impact fish reproduction from the physiological to the behavioural levels. Seasonal changes such as drought and pluvial (rainfall) variations have a profound effect on reproduction of semiarid tropical fishes. In the semiarid tropical region of Brazil the factors that influence fish reproduction are changes in rainfall regimes and drought. These environmental changes can either stimulate or inhibit reproduction in fishes. Information on these fundamental variables on reproduction can help management and conservation of tropical fishes. Information on fish reproduction also is an important factor for understanding the freshwater ecosystems of the semiarid region. This paper is a narrative review on the effects caused by rainfall and drought on reproduction of some cichlids and an annual fish from the semiarid region of Brazil. During the breeding period cichlid fishes demonstrate aggressive behavior and dominant fishes often get priority of access to territories and mates. On the other hand, the annual fishes have rapid growth and gonadal development to complete their life cycle within a short span of time. Fishes which are subjected to varying pluvial pressures have characteristic life history patterns.

Keywords: neotropical cichlids, angel fish, annual fish, mating system, conservation

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Sathyabama Chellappa,[1] Thiago Chellappa,[2] Wallace S Nascimento[1]

[1]Department of Oceanography and Limnology, Universidade Federal do Rio Grande do Norte (UFRN), Praia de Mãe Luiza, CEP: 59.014-100, Natal, Rio Grande do Norte, Brazil

[2]Humanities Institute, Universidade Federal do Rio Grande do Norte (UFRN), Lagoa Nova, CEP: 59.078-970, Natal, Rio Grande do Norte, Brazil

Correspondence: Sathyabama Chellappa, Department of Oceanography and Limnology, Universidade Federal do Rio Grande do Norte (UFRN), Praia de Mãe Luiza, CEP: 59.014-100, Natal, Rio Grande do Norte, Brazil,
Email chellappa.sathyabama63@gmail.com

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Introduction

Environmental factors play an essential role in the growth and physiology of fishes. Fish has a stress response to adverse external environmental factors, such as, long periods of drought and rainfall variations. During the reproductive phase of cichlid fishes, alternative strategies for resource acquisition, dominance hierarchies, territoriality and mate guarding are commonly encountered. Aggressive competitions are common among male fishes during their reproductive phase in order to maximize their genetic contribution for future generations. They often adapt their forms and intensities of agonistic responses to the context in which an encounter occurs. Dominance is one form of behavior employed during conflict resolutions of fishes. Individual attributes associated with body length, weight and level of aggressiveness determines dominance in fishes. Aggression allows some social fishes like the Amazonian Cichlid, *Pterophyllum scalare* to sort out their relative ranks within a dominance hierarchy.[1–3]

Mild stress situations can have beneficial or positive effects. On the other hand, higher stress levels induce adaptive responses, which could have negative consequences. The stress response is initiated and controlled by two hormonal systems, those leading to the production of corticosteroids (mainly cortisol) and catecholamine's (such as adrenaline, noradrenaline and their precursor dopamine). Together these regulate the secondary stress response factors that alter the distribution of necessary resources such as energy sources and oxygen to vital areas of the body.[4] Different taxa of fish have different tolerances to stress. Tilapia, *Oreochromis niloticus* respond by acceleration or complete inhibition of reproduction, depending on the maturational stage when the stressor was experienced. The physiology associated with maturation and spawning appears to be coupled with stress physiology.[5]

Understanding the reproductive biology of fishes can provide insight into their mating system and reproductive success. This paper reviews the effects caused by rainfall and drought on reproduction of some cichlids and an annual fish from the semiarid region of Brazil. Literature search strategy was based on databases, research papers and reference lists for studies pertaining to reproduction of tropical fishes. Information was gathered for the neotropical cichlid, *Cichla monoculus,* the Amazonian angel fish, *Pterophyllum scalare,* Amazonian red discus, *Symphysodon discus,* red hybrid tilapia, *Oreochromis niloticus* (Osteichthyes; Cichlidae) and the neotropical annual fish *Hypsolebias antenori* (Rivulidae). Details obtained from reproductive analyses of gonad maturation, fecundity and spawning seasonality are important for understanding the population dynamics of freshwater fishes. A literature search was done on reproduction of freshwater fishes from semiarid tropical region of Brazil. There are no new data associated with this narrative review article. The following objective has been narratively reviewed: how do drought and rainfall variations interfere with the reproduction in Cichlids and in a tropical annual fish.

Environmental factors interfering with fish reproduction

Fishes are increasingly exposed to multiple stressors with cascading effects affecting the wild fish populations through selective processes. The main direct and indirect factors resulting from global climatic changes that are likely to influence fish reproduction are temperature, photoperiod, acidification, hypoxia, change in pluviosity regimes (reduced rainfall, altered rainfall patterns and especially long dry spells) and food availability. Reproduction can be stimulated in fishes or inhibited by these environmental factors. They can switch from a "compensation" to a "conservation" metabolic strategy, which can lead to synergistic or antagonistic effects of multiple stressors.[6,7]

The semiarid biome of Brazil plays an important role in the maintenance of regional macro-ecological process, and indirectly supports regions with diversity and endemism. Scrub vegetation referred to as "Caatinga", consists of xerophytic low thorny bushes adapted to the semiarid climate, which covers over 10% of the Brazilian territory, located between 3°S 45°W and 17°S 35°W. This region receives almost 750 mm of annual rainfall and has an average annual temperature of 26°C throughout most of the region. This biome is characterized by short spells of rain interspersed with frequent droughts. The seasonality of the semiarid freshwater ecosystems is due to recurrent extended drought, irregular rainfall, high temperatures

and an elevated rate of water evaporation.[8,9] The fishes that occur in the freshwater ecosystems of semiarid Northeastern Brazil are the result of evolutionary processes modulated by climatic factors and hydrological cycles of the region. Environmental changes caused by human influence and introduction of Amazonian fish species have modified the composition of the original ictiofauna of this region.[10]

Increase in temperature and changes in rainfall, with the incidence of prolonged drought and reduced rainfall are predicted due to the effects of global warming on climatic conditions and their impacts on the Brazilian semiarid region.[11] The climate models show a 20% reduction in rainfall in the semiarid region for every decade. This factor will directly influence fishes, by diminishing wetlands and preventing the continuation of their life cycle. For the conservation of fishes, management should focus primarily on the integrity of the habitats where they are found, such as, small temporary pools, which in most cases are not considered as a priority for conservation. Several actions should be taken in order to preserve the fish stocks. Among these are banning deforestation and occupation of wetlands adjacent to watercourses of hydrographic basins; control of indiscriminate use of pesticides and agrochemicals, as well as the release of industrial effluents, domestic waste into water courses; insist on the compliance with the laws protecting the environment, land use and construction of reservoirs on rivers.

Seasonality of reproduction in fishes

The Neotropical cichlid, *Cichla monoculus* and Amazon Cichlid fishes, such as, the Amazonian angel fish, *Pterophyllum scalare,* Amazonian red discus, *Symphysodon discus*, along with and the red hybrid tilapia (*Oreochromis niloticus* x *O. mossambicus*), have developed marked degrees of physiological plasticity that allows them to adapt to a highly variable natural environment.[10] During the reproductive season the large male cichlids in general are more aggressive and establish their territorial dominance. In territorial fishes dominance is usually identified by analyzing agonistic profiles, where the dominant fish attacks and the subordinate retreats.[12] The gonadosomatic index (GSI) of male cichlid fishes show significant correlations with dominance level, where the dominant fishes have higher GSI than those of the subdominants and submissives. Gonad development may precede hierarchy establishment and some fish become dominant with higher GSI. Male fishes with developed gonads have elevated plasma testosterone levels. This hormone is associated both to reproductive functions and to increased aggressiveness in teleost fish. Thus the higher GSI in the dominant fish may be associated to the greater aggressiveness and may affect their hierarchical relation in the group.[13]

Males of the Neotropical cichlid, *Cichla monoculus* with 180 mm TL (Total Length) and females with 200 mm TL are usually sexually mature. The GSI of these fishes indicate multiple spawning's throughout the year. Microscopic examinations of the ovaries show that females spawn three to four times during the year. Eggs are released on submerged tree trunks or on rocky substratum. This is followed by a period of parental care. In both males and females, the Condition Factor (CF) has an inverse relationship with increasing gonadal maturation. After reproduction the spent fishes were observed to be in poor body condition. The sexual maturity in mature males of *C. monoculus* is marked by the appearance of a bright yellowish-orange post-occipital cephalic protuberance. The cephalic protuberance of this fish has a mean height of about 1 cm. Histological examinations of the post-occipital cephalic protuberance shows the presence of large quantities of oil droplets. Males spawn within three weeks from the appearance of the cephalic hump. The lipid stores are mobilised during breeding and parental care. The lipid stores are depleted in spent males.[8,9] *C. monoculus* shows phenotypic plasticity in allocation of resources to growth or reproduction according to the environmental conditions of drought and rainfall. This fish increases reproductive effort before the onset of drought. Red tilapia hybrids (*Oreochromis* sp.) respond to decreasing water levels by spawning at a smaller size and producing more batches of eggs, and resume allocation of energy to growth when conditions improve.[14]

The graceful angelfish, *Pterophyllum scalare* originates from the Amazonian basin, prefers shallow and calm waters with aquatic vegetation and forms small schools. This is a valuable ornamental fish, very popular all over the world. Aggressiveness and territoriality are expressed with great ferocity by male fishes during the reproductive phase, when they guard their nests and young. Throughout the breeding period these fish demonstrate aggressive behaviors such as threats, attacks and bites. Dominant fishes often get priority of access to limiting resources, shelters, food and mates. Social dominance is a function of body size in angelfish, which gives the dominant male fish priority to spawning sites and females. Moreover, the preferred type of spawning site is related to the size of the leaves of aquatic vegetation, where the eggs are laid. Space use was also related to body size and aggression resulting in differential occupation among males during reproductive competitions. In the Amazonian angelfish aggression is a mean to assure mating success wherein large body size of the males influenced aggression, dominance, proximity to preferred egg laying sites and mating success.[3,15,16]

The family Rivulidae is one of the largest families of freshwater fishes of the Neotropical region. It is a diverse group, most popularly known as "killifish". Annual fishes with a short life span are among the most remarkable species that thrive in extreme environments (extremophile species). They inhabit ephemeral ponds and during rainy season reach sexual maturity in few weeks and breed continuously. As the breeding season progresses, and the pond dries out, future mating opportunities decrease together with the impoverished drought conditions. Stress promotes reproduction in the annual fish *Hypsolebias antenori.*[17] The canonical effect of stress on reproduction is reverted in annual fish, *Austrolebias reicherti.* As mating opportunities run out, cortisol levels and reproductive effort increase. Annual fish arise as ideal models to test the link between stress and life history.[18]

H. antenori does not have a large ecological plasticity of adaptation to climate change despite its extreme life strategy. These fishes complete their life cycle in temporary pools and when the pools dry out, the entire population dies from desiccation. These temporary pools are environments that have large fluctuations in temperature, dissolved oxygen concentration and volume of water.[19] To survive in these extreme conditions, the fish eggs that are deposited in the sediment of the water pools go through diapause stages, during which time the embryonic development becomes temporarily arrested. With the onset of the next rainy season, the eggs hatch out and a new generation is formed.[20] These temporary environments have suffered major human impacts such as siltation, deforestation, pollution and drainage. *H. antenori* spawns during the rainy season (r reproductive strategy). This species has a simple digestive tract which probably is related to the necessity of rapid growth and gonad development to complete its life cycle within a short span of time.[21]

Fish reproductive strategies result from selection pressures on a species to produce the maximum number of young fish to survive under the prevailing environmental conditions, thereby maximizing fitness. With the onset of rainy season, under favourable environmental

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conditions, Cichlid fishes allocate resources to growth. However, under stressful conditions, they reproduce.(Figure 1) Natural selection would be expected to favor changes in allocation of a species resource from reproductive to competitive activities only where this enhances the survival of future offspring. Fishes which are subjected to different selection pressures would have characteristic life history patterns. In annual fishes, stress due to drought promotes reproduction, which likely guarantees its survival and reproduction in tropical temporary pools. (Figure 2).

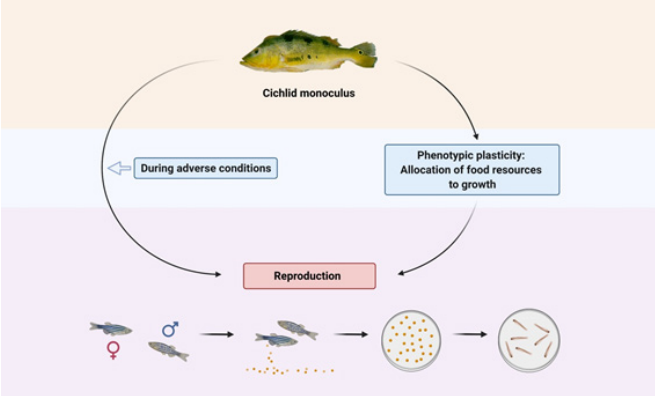

Figure 1 Stress caused by seasonality in rainfall and drought leads either to growth or reproduction in cichlid fish *Cichla monoculus*.

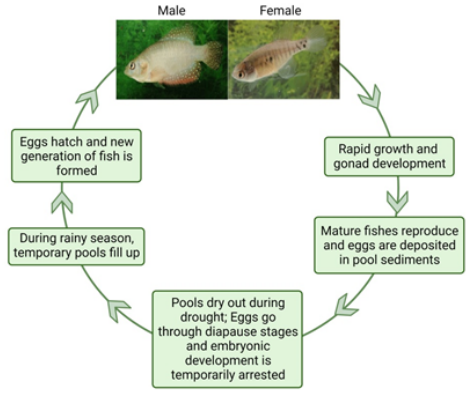

Figure 2 Stress caused by drought promotes reproduction in the annual fish *Hypsolebias antenori*.

Conclusions and future directions

Reduced rainfall, altered rainfall patterns and especially long dry spells affects reproductive and early life history events of semiarid fishes. Drought is considered a natural disturbance of aquatic ecosystems and has a major influence in structuring aquatic communities. Such eenvironmental factors may stimulate or inhibit reproduction in fishes. A specific factor may be either inhibitory or stimulatory depending on the time of the year or the stage of sexual development of fishes. A drastic environmental change or aggressive interactions are followed by an elevation of levels of plasma corticosteroids and catecholamine's, as a primary stress response.[6] In cichlids, competition among male's fishes is evident as sexual selection process influences the reproductive success of individuals.[16] During the breeding season, male fishes establish a territory and compete for females directly through mate defense or indirectly by defending the territory to which the females are attracted by their courtship behavior. During courtship females select their mates based on various physical attributes, such as body size and coloration, and dominant males are generally chosen by females.[22] Social interactions affect several processes, such as growth,[23] stress[24] and reproduction.[15] During parental care of the young, which lasts for about three weeks, the offspring is protected by one or both parents. The evolution of mating systems in cichlid fishes has proceeded from monogamy with bi parental care to polygamy with maternal care, with a number of variations on these two themes.[25] In substrate brooders the parents maintain their brood on or close to the substrate until the young become independent. On the other hand, in mouth brooders the parents carry their offspring in their mouth until the young become independent. The protective role begins as soon as the eggs are shed and ends when the link between parents and offspring is broken as the fish larvae becomes independent. High variance may be caused by agonistic variability occurring during social interactions.

Limited research and available literature hinders the development of conservation strategies of semiarid annual fishes. There are knowledge gaps for the data that are currently available for semiarid fishes. There is a need for conservation measures to protect annual fish populations, especially creation of protected areas in the Brazilian semiarid region. This narrative review synthesizes the current state of information available, highlighting the need for greater focus in this area. Future studies could be carried out on the reproductive patterns of many freshwater fish species of the semiarid region of Brazil. These include estimates of fecundity by fish species, age at first maturity, spawning type and the relationship between environmental parameters and spawning season. It is important that these studies should be carried out in a standardised manner with similar methodologies to facilitate comparisons between fish species.

Conflicts of interest

There are no conflicts of interests declared on by authors.

Acknowledgements

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