The correlation between environmental factors and the reproduction of *Oreochromis mossambicus*

Daryl A Cornish* and George L Smit
Department of Physiology, University of the North, Private Bag X1106, Sovenga 0727, South Africa

Abstract

Syferkuil Dam is situated 8 km NW of the University of the North and comprises a series of eight interconnected rectangular dams, having cement sides and mud bottoms. Aspects of the reproductive physiology of *O. mossambicus* that were investigated included the role of environmental factors such as rainfall, photoperiod, dam-water temperature and dam water pH. The environment plays an important role in at least initiating the commencement of the reproductive cycle in *O. mossambicus*. An increase in photoperiod, rainfall and water temperature together with a decrease in water pH are the cues for gonadal maturity to occur. These changes seem to have a greater impact on female gonad development than male development. Male development seems to be dependent on female development in that it "lags" behind the female by two months.The results imply a close interaction between environmental cues and endocrine control of reproduction. Endocrine control cannot continue without the appropriate environmental cues required to stimulate reproduction.

Introduction

The environment has long been considered to play an important role in the reproductive cycles of freshwater fish. The influence of environmental factors has been reviewed within several fish species (Crim, 1982; Wootton, 1984; Zohar and Billard, 1984; Munro et al., 1990). Amongst those factors considered to be of importance are photoperiod, temperature, salinity, rainfall and lunar cycle. It is thought that the external factors act on exteroceptors of the fish and through them on the hypothalamus - pituitary - gonad axis. Photoperiodic effects on reproduction have been reported for numerous cyprinids (Bromage, 1987; Hontela and Stacey, 1990). A decreasing photoperiod generally inhibits spawning of both male and female fish. Lam (1983) in Hoar et al. (1983) states that photoperiod does not affect the timing of first sexual maturity in *Sarotherodon* (now *Oreochromis*) *mossambicus*. Puberty may occur in either continual darkness or continual light, thereby implying an endogenous rhythm.

In subtropical or subtemperate regions (as is this study area - close to the Tropic of Capricorn), seasonal variations in photoperiod are relatively small. In those species that spawn in spring or early summer, gonadal recrudescence may often be stimulated as a result of increasing photoperiod (Lam, 1983). Fish are, however, usually exposed to a gradual rather than an abrupt increase in photoperiod.

In tropical and subtropical species, peak spawning activity is often associated with rainfall, floods or the lunar cycle (Schwassmann, 1971, 1978, 1980; De Vlaming, 1974; Lowe-McConnell, 1975; Billard and Breton, 1978; Gibson, 1978; Liley, 1980).

It is not clear which of the terminal reproductive events (oocyte maturation or ovulation) is triggered or enhanced by rainfall, or whether spermiation and/or sperm release is involved. Further, it is not clear what specific factor or factors associated with rainfall may be involved in spawning stimulation. Bruton (1979) has suggested numerous related factors, like lowering of water temperature, dilution of electrolytes (e.g. decrease in conductivity), increase in oxygen content and a change in pH. It is most likely that a variety of factors is involved.

It is thought that temperature may exert its effects on fish reproduction by a direct action on gametogenesis (Lofts et al., 1968); an action on pituitary gonadotropin secretion (Breton and Billard, 1977; Peter, 1981); an action on metabolic clearance of hormones (Peter, 1981); an action on the responsiveness of the liver to estrogen in the production of vitellogenins (Yaron et al., 1980) or an action on the responsiveness of the gonad to hormonal stimulation (Jalabert et al., 1977; Bieniarz et al., 1978).

Rana (1990) has shown that low temperatures adversely affect the development of larvae whereas higher temperatures accelerate development in the tilapia, *O. niloticus* (L.). According to Okuzawa et al. (1989), an increase in water temperature induces vitellogenesis and spawning in cyprinid fishes. Their results for the cyprinid, *Gnathopogon caerulescens* indicate that the response to changes in photoperiod is most pronounced at higher water temperatures.

Water pH is an important environmental factor to be considered due to the role it plays in terms of water pollution. Acidification of surface waters is one of the most serious problems of environmental pollution in North America (Fromm, 1980). Acid stress may impair vitellogenesis and even lead to spawning failure. These effects may be related to an upset in calcium metabolism and to a faulty deposition of yolk proteins in developing oocytes. High pH may also pose a problem to the reproductive activity of the fish living in such an environment. Due to the nature of the sampling site, similar problems could be encountered at Syferkuil Dam.

With the foregoing in mind, the role played by the environmental factors of rainfall, photoperiod, dam-water temperature and dam-water pH was examined and related to a possible effect on the reproductive cycle of *O. mossambicus*, using the gonadosomatic index (GSI) as an indicator of reproductive maturity.

Materials and methods

Each Monday morning, over a 12-month period, 10 adult male and 10 adult female *O. mossambicus* specimens were collected at Syferkuil Dam, 8 km NW of the University of the North using a seine net. Before the experimental animals were transported back

* To whom all correspondence should be addressed.
☎(0152)268-2268; Fax (0152)268-2209; e-mail cornish_da@unin1.unorth.ac.za
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to the laboratory at the university campus for further analysis, standard fish length and fish mass were recorded. The environmental parameters recorded included water temperature (°C) and water pH at 08:00 which were carried out using a portable immersible thermometer and pH meter respectively. For both of these parameters, the same three sites in the dam were used each Monday morning throughout the experimental period. The meters used were obtained from Hanna Instruments. The Weather Bureau provided the rainfall (mm) and photoperiod data used in this study.

The environmental factors were related to the GSI as calculated according to the formula of Roff (1983).

Results

Figure 1 shows the relationship of the total monthly rainfall (mm) as measured in the morning at Syferkuil Dam and male and female GSI. No rain was recorded during the winter months but during the hotter summer a maximum of 120.0 mm of rain fell during December. During August an initial surge in rainfall of 32.0 mm was recorded and this coincided with the slight increase in male GSI. Rainfall did not seem to affect female GSI. However, during November when male GSI reaches its maximum value, the total rainfall for the month was also considerably higher with 109.6 mm being recorded.

Figure 2 shows the relationship between male and female *O. mossambicus* GSI and photoperiod as observed at Syferkuil Dam. During the month of August, with the onset of spring, the length of daylight hours begins to increase substantially. This coincides with the change in female GSI. The significance of this change in photoperiod is observed in September during the equinox when female GSI reaches its first peak. However, the maximum daylength of 13.58 ± 0.04 h recorded during December appears to be more closely associated with the maximal male GSI of 0.78 ± 0.12 which is observed in November.

Figure 3 depicts the relationship between water temperature (°C) and pH at Syferkuil Dam. It may be seen that dam-water temperature reaches a minimum of 13.50 ± 0.60°C during June, which is winter in the Northern Province of South Africa. Thereafter, as spring approaches in September, there is a sharp increase in temperature until a maximum of 25.70 ± 1.30°C is reached in November. Dam-water temperature remains fairly high throughout

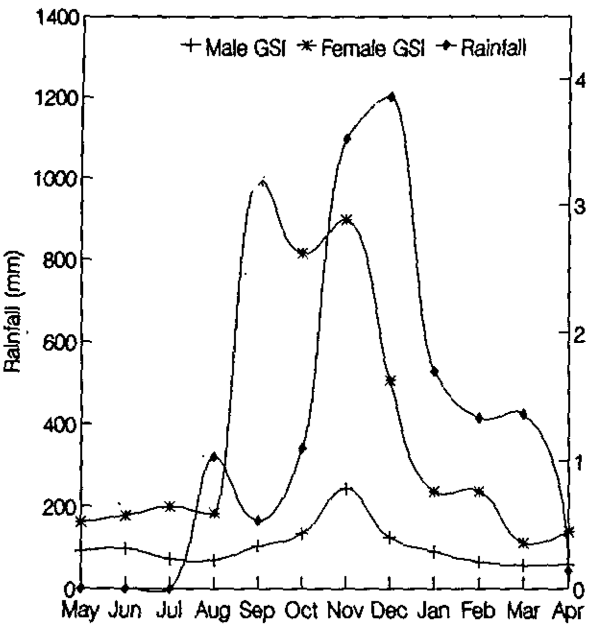

Figure 1
Mean monthly rainfall (mm) recorded at Syferkuil Dam and GSI for male and female O. mossambicus

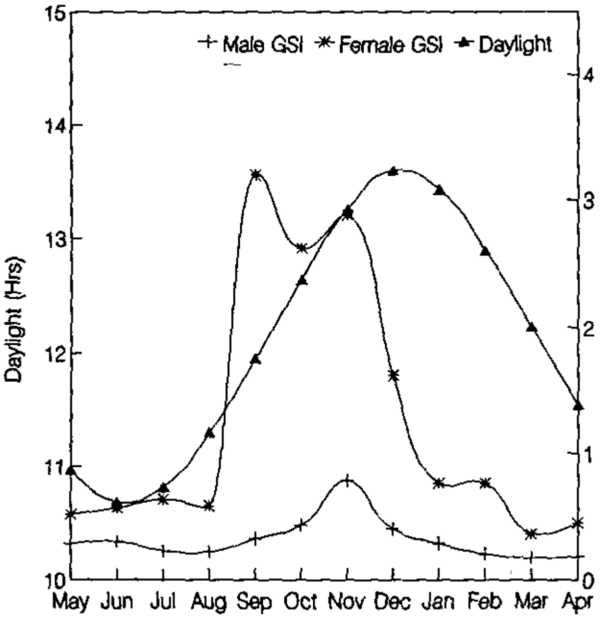

Figure 2
Mean monthly daylight hours recorded at Syferkuil Dam and GSI for male and female O. mossambicus

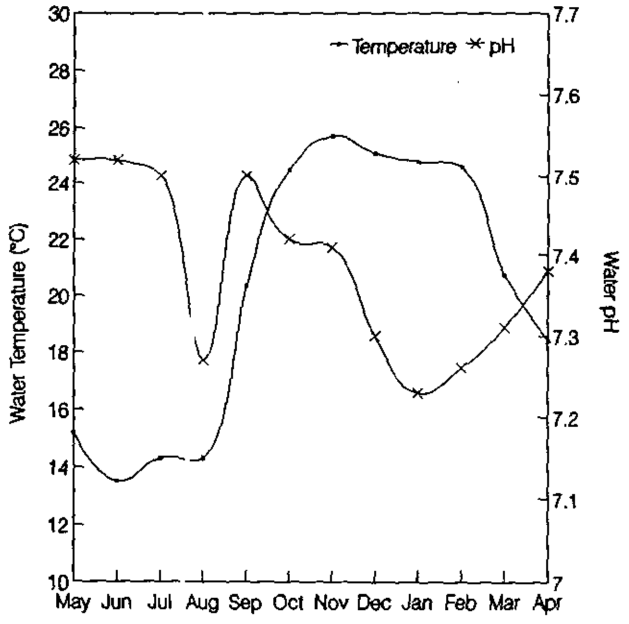

Figure 3
Mean monthly water temperature (°C) and pH recorded at Syferkuil Dam

summer and only falls again during April, which would represent the commencement of autumn. Dam-water pH shows an inverse relationship to the temperature of the water except at the onset of spring when, immediately prior to the sharp increase in water temperature, there is a marked decline in dam- water pH to 7.27 ± 0.12.

Figure 4 shows the relationship of Syferkuil Dam water

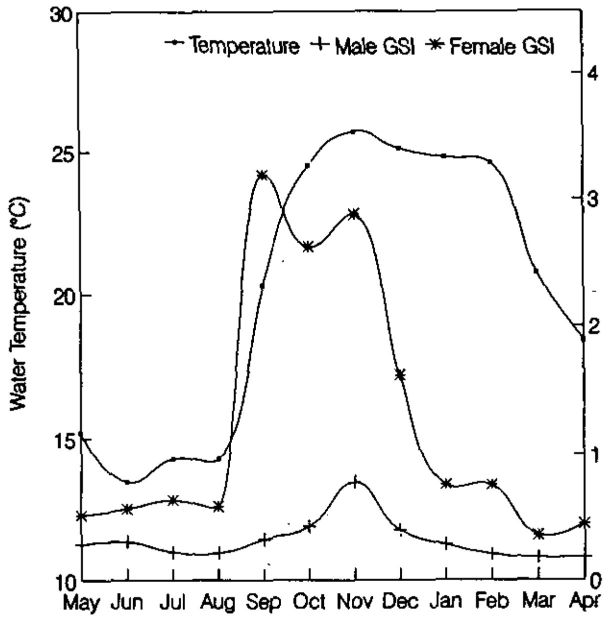

Figure 4

Mean monthly water temperarture (°C) recorded at Syferkuil Dam and GSI for male and female O. mossambicus

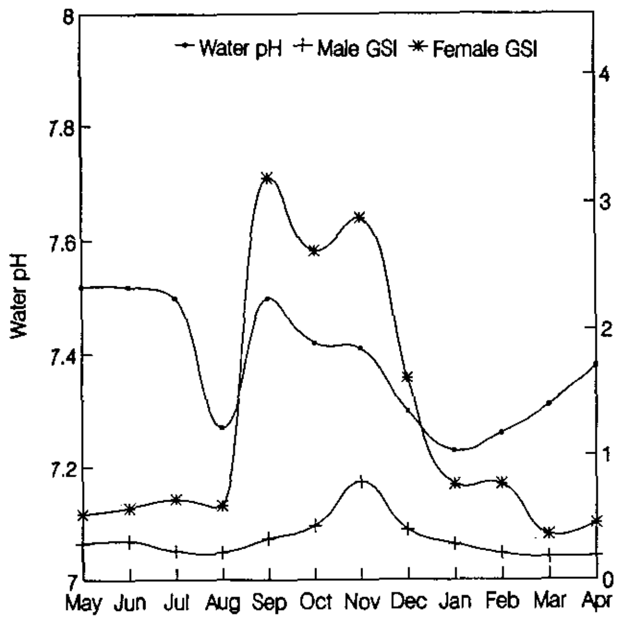

Figure 5

Mean monthly water pH recorded at Syferkuil Dam and GSI for male and female O. mossambicus

temperature (°C) and both male and female *O. mossambicus* GSI values. It may be noted that with increasing water temperatures, female GSI increases markedly to reach its maximum of 3.11 ± 0.72 during September. This is indicative of a "heavier" gonad which represents a higher degree of gonadal maturity. The female *O. mossambicus* GSI remains high until November which is when the male GSI reaches its maximum of 0.78 ± 0.12, indicating that the male is now also reproductively mature.

Figure 5 represents the relationship between water pH at Syferkuil Dam and the GSI in male and female *O. mossambicus*. As water pH increases to a high value of 7.50 ± 0.16 during September, the female GSI reaches its peak of 3.11 ± 0.72. Once water pH starts to decline in November, the male GSI reaches its maximum value of 0.78 ± 0.12.

Discussion

Most teleosts require appropriate aquatic conditions to ensure survival. Reproduction and its control are the only means of ensuring survival of any particular species. It is well known that in nature, most indigenous freshwater fish species' annual breeding season is limited to a few months.

The experimental area (Northern Transvaal) has been gripped by a severe drought for some time, and yet the onset of the rainy season still appears to have played a role in the reproductive cycle of *O. mossambicus*. Figure 1 shows that the first rains of the new season fell in August which seems to have been the initial environmental cue for the female gonad to commence development toward maturity. Although the female reached and maintained a high level of gonadal maturity through the months of September, October and November, male development appears to be linked to the heavy rains recorded in November and December. This is speculative as due to the small changes noted in male cichlid GSI over a reproductive season, it is not considered to be a reliable indicator of male sexual activity.

It has been suggested that photoperiod is a more important regulator of reproduction than is temperature, with the latter acting only as a rate modifier (reviewed by Bye, 1987). Figure 2 indicates that, as is the case with rainfall, there appears to be a relationship between the onset of a longer day length and the initiation of female gonadal development. This fact seems to be indicated by the increase in female gonadosomatic index during September (Fig. 2). This coincided with the equinox. Thus, the change reflected during August may be an important environmental cue to stimulate female GSI to reach a maximum in September. The maximal male GSI is noted during November which is when daylength has virtually reached a peak for the summer months. However, an increase in male GSI also started during September.

Tilapia species, in general, are tropical zone fishes whose breeding is confined to a brief period during a definite season of the year (Fryer and Iles, 1972). The highveld area in the Gauteng province (South Africa) experiences cold winter temperatures and hot summers. It is therefore expected that tropical fish, such as *O. mossambicus*, will commence their breeding cycle as soon as temperatures increase in the spring.

Male GSI shows far less variation than the results obtained for females. This is possibly related to the size and mass of male gonads which are generally smaller than those of females. Thus a small change in male GSI seems to be more significant than that for females.The first significant increase in male GSI, based on this observation, only occurs during September at the peak of female GSI. This suggests that male GSI changes are significantly related to direct aquatic environmental factors rather than indirect factors.

This is demonstrated when comparing daylight hours with male GSI values. It is only when daylight hours have reached 75% of summer values in October, that a significant increase in male GSI is observed. This indicates that male gonad development requires a different triggering mechanism than females. These observations explain why male gonad development is much slower than those of females and that it lags behind female values by a period of approximately two months when comparing peak GSI values for both sexes.

An increase in daylight hours plays a contributing role toward the onset of the female reproductive cycle. It may be concluded that the indirect factors may be used as indicators for forthcoming environmental changes after the winter period. It also appears that these factors are crucial to initiate the onset of the reproductive cycle in *O. mossambicus*. It is for these reasons that a clear distinction be drawn between those environmental factors that are indirectly responsible for the initiation of the onset of the reproductive cycle in females and the direct aquatic changes that are essential for triggering the immediate progress in female gonad development. It thus appears that the onset of the reproductive cycle in females require a "conditioning" process before triggering the onset of the reproductive cycle when compared with male *O. mossambicus*.

In general, Figs. 4 and 5 show that male GSI values started to increase during September and increased significantly from the end of October to show a peak value in November whereafter a sharp decline was observed. This is in total contrast to female GSI values (Fig. 2). These observations suggest that males either require different reproductive triggering mechanisms or that other factors, such as size, mask the initial changes in GSI. The reasons for this are not known, but may be related to different interpretations of environmental changes by the pineal gland.

It may be concluded that the initial change in male GSI during September appears to be linked to rainfall, photoperiod, change in air temperature and relative humidity (Cornish, 1993). Exactly how these factors interrelate with each other is not known. It is, however, possibly associated with the algal blooms coinciding with low water pH. Algal blooms may be responsible for greater turbidity and less visibility which may also impact on the intensity of daylight hours. The number of dark hours and lunar cycles was not positively associated with male GSI values, but rather the change in photoperiod. In contrast to females, the findings suggest that males have a greater significant association with indirect environmental factors as opposed to females where water quality parameters determine gonad development. Rainfall may be responsible for the onset of algal blooms. On the other hand, continued rainfall may cancel algal bloom effects over a longer period, with resultant greater penetration of daylight into the water. This may explain why male GSI is retarded when compared to female GSI. Thus, males require a greater intensity and perhaps also different environmental trigger actions than females.

A significant contributor to the increase in female GSI, is linked to rainfall. It appears that the rainfall recorded during July/August preceded a change in water temperature. It is not known in what manner this contributed to increased GSI levels, but it may be postulated that the rainfall during this period diluted the water to reduce water conductivity. This in turn may act, in conjunction with an increased water temperature, as a triggering mechanism to increase female GSI. The sharp increase in female GSI correlated significantly with the first rainfall of the season. In addition, the two peaks in female GSI coincided with the two peak rainfall sessions during the breeding cycle.

Photoperiod also seemed to be connected to the sharp increase in female GSI. The only significant observations made, were that after the cold winter months, a slow change in photoperiod followed by a sharp percentage increase in daylight hours occurred in September which continued right into December. Maximum female GSI coincided with a day length of 12 h. During December, a significant decline in female GSI was also observed. It is therefore suggested that the breeding cycle starts in August and ends during December. A plateau was reached at this time which continued into February. This suggests some "last minute" breeding activity, possibly associated with a second round of spawning. However, the above observations do not point to multiple spawning for *O. mossambicus* in the Syferkuil Dam system during the breeding season when considering the fact that this species is a mouth brooder.

Figure 3 shows an inverse relationship between the dam water temperature and the pH of the same dam water. Figure 4 shows that the increase in dam water during August appears to be the stimulus for female gonadal maturation to commence. Figure 3 seems to indicate that, during August, the increase in water temperature at the same time as the water pH decreases, plays an important role in terms of female gonadal development. In the case of the male, it would seem that the male requires a period of "conditioning" and it only reaches maximal maturity once the pH of the water has started to decline and the water temperature has reached its summer maximum during November and December. Gonad development in *O. mossambicus* appears to be more directly related to changes in water temperature and water pH. Furthermore, such changes have a greater impact on female gonad development when compared to males.

Water temperature levels appeared to be the single most significant factor to act as a triggering mechanism for the onset of reproduction in females at the end of August and the beginning of spring. GSI increases may have been preceded by the slight increase in water temperature observed during July (Figs. 3 and 4). Significant relationships in female GSI were found with the two-way increase in water temperature during this period. During this investigation, it was established that low water temperatures inhibits the reproductive cycle in females. Such findings were also supported by Jalabert et al. (1977). This confirms that the most significant environmental cue for the onset of reproduction in this species, is linked to water temperature.

The change in the water temperature coincided with a sharp decline in water pH (Fig. 3). This change cannot be explained in terms of GSI values, but may be associated with relative air humidity. The latter increase coincided with the drop in water pH. This change may be ascribed to an algal bloom in the dam at this particular time, since it is well-known that algae consume oxygen and produce large quantities of CO_2 (Schoonbee, 1988). This may explain the sudden drop in water pH that has an inverse relationship with CO_2. However, it is not known in what way this drop in water pH may act as a contributing triggering mechanism for the increase in female GSI. Most information related to this parameter, suggests that acid waters inhibit gonad development. It is possible that long-term acid stress may have an inhibitory effect, but results recorded during this study suggest that short-term exposure to a declining aquatic pH may actually stimulate the onset of female gonad development.

Finally, the results of this investigation support most observations made for this species. However, supportive evidence of the pineal gland and the hypothalamo-pituitary axis is essential to describe the complete reproductive cycle in *O. mossambicus*.

The relative ease with which this species is bred in captivity, under controlled aquatic conditions, may necessitate investigations into their hormonal reproductive cycle under laboratory conditions.

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