Lability of sex differentiation in fish

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The processes of sex determination and differentiation are labile in teleosts and are amenable for manipulations by ploidy during fertilization, hormone during hatching, temperature during the juvenile stage and other environmental or surgical factors during the adult stage.

In oviparous teleosts early embryonic events, namely insemination, second polar body extrusion and first mitotic cleavage are manipulable and render 37 different types of ploidy induction possible; such ploidy inductions during early embryonic stages result in the production of all-male, all-female or all-sterile population. However, the scope for ploidy alterations to regulate sex determination is restricted to early embryonic stages alone. A large number of previous publications have attempted to precisely delineate the optimum (labile) period, during which it is possible to successfully induce ploidy. The process of sex differentiation in teleosts is also labile, rendering hormonal induction of sex reversal possible in 37 gonochoristic species and 13 hermaphroditic species; hormonal manipulations during the labile period result in the production of monosex population; again, the labile period is restricted mostly to just before and after hatching stages. Thus sex determination and differentiation in fish are labile and can be reversed by manipulating ploidy, and hormone during fertilization and hatching stages, respectively.

A series of publications by Strussmann et al.6 and others7 have recently documented thermal lability of sex determination in a number of teleosts; for instance, fish exposed to colder or warmer temperature from hatching to juvenile stage lead to the production of all-female or all-male progenies8,9; hence, thermal induction may serve as a third technique to regulate the sex of teleosts. A number of others, such as social and surgical factors may also induce sex reversal in adults. In many coral fish and in the freshwater Chinese paradise fish Macro-podus opercularis, hierarchy and aggressive behaviour have led to the formation of a definite social organization and any manipulation to alter the social structure lead to sex reversal.10-12 Besides, it has long been known that gonadectomy induces sex reversal in a few teleosts. For instance, female Betta splendens developed testes after ovariectomy and became functional male. Therefore, the processes of sex determination and differentiation are labile in teleosts, rendering manipulations of ploidy during fertilization, hormone during hatching, temperature during juvenile, and surgical and social during adult stages. This communication reports the amenability of teleosts to sex regulation almost throughout life by manipulating ploidy, hormone, temperature and other selected environmental factors.

Table 1 lists selected representative species, in which sex reversal has been successfully accomplished by manipulating one or more of the following: ploidy, hormone, temperature and environmental factors. The scope for ploidy manipulation is indeed very strictly restricted to a limited period of few seconds and minutes during fertilization; likewise, the duration of the labile period is also very much restricted to a few minutes just before and after hatching, when the immersion technique is chosen for hormonal induction, or a few days immediately following hatching in ornamental fish, or a few months in foodfish like carps and salmon, when dietary administration is chosen for hormonal induction of sex reversal; rarely, Poecilia reticulata has been shown to be amenable for hormonal induction of sex reversal during embryogenesis, just before and after hatching and post-maturity stage; yet, the optimum period for hormonal induction of sex reversal is mostly restricted to the hatching stage. Likewise, the optimum stage for successful sex reversal by manipulating thermal, or any other environmental factor is now shown to be restricted to the juvenile or adult stage. In more than 60% of the selected representatives species, successful sex reversal has been induced by ploidy and/or hormonal manipulation(s) by different authors. In hermaphroditic species like Monopterus albus, sex is spontaneously reversed in adults; such spontaneous sex reversal during adult stage is recorded in hermaphrodites characterized by polyandrous or polygynous social system; a manipula-
Table 1. Lability of sex differentiation of selected fish; the lability provides scope for (1) ploidy (during and after fertilization), (2) hormonal (during and after hatching), (3) thermal (during juvenile stage) or (4) environmental (4a: spontaneous; 4b: density dependent or 4c: surgical – during adult stage) manipulations. +* = all ♀ brood; +** = all ♂ brood

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td></td>
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<td></td>
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<td></td>
<td><em>Trichogaster trichopterus</em></td>
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<td></td>
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<td></td>
<td><em>O. aureus</em></td>
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<td><em>Brachydanio rerio</em></td>
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<td><em>Oryzias latipes</em></td>
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<td><em>Misgurnus anguillicaudatus</em></td>
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<td>Paralichthyidae</td>
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![Figure 1](image_url)  
Figure 1. Suggested pathways through which thermal treatment generates all male/female progenies in fish.  
(AP = Activator proteins; SP = suppressor proteins; ⋄→ Feminizing pathway; → Masculinizing pathway.)

Discussion

In the model system of Clarias lazera, the interplay of genetic sex and thermal treatment predicts two outcomes: male or female sex. This is consistent with the theory of temperature-dependent sex determination (TDS) as proposed by Parrish et al. [2000]. The key to this sex determination lies in the expression of aromatase, which converts androgens to estrogens. The transition from masculinization to feminization is induced by a temperature change, mediated by the expression of aromatase. This mechanism is supported by the findings of Chen et al. [2012], who observed that aromatase activity is highest at 25°C, intermediate at 15°C, and lowest at 35°C in the Clarias lazera ovary.

The ability of the Clarias lazera to switch sex under varying thermal conditions highlights the importance of environmental factors in sex determination. This is a significant finding, as it suggests that the sex of future generations can be influenced by environmental conditions, such as temperature. This has implications for conservation efforts, as it may allow for the manipulation of the sex ratio in populations to achieve desired ecological outcomes.

In summary, the interplay of genetics and environment in sex determination in Clarias lazera provides a powerful example of how such systems can be manipulated for conservation purposes. Further research is needed to understand the full extent of this phenomenon and its implications for other species. The results of this study contribute to our understanding of the complex interplay between genetics and environment in sex determination and provide a valuable tool for conservation biologists.
of aromatase, which is a ‘turn-key’ enzyme in sex differentiation; its full expression may reduce normal androgenic profile in genetic males, resulting in 100% female progeny; alternatively the reduction of its activity maintains normal endogenous androgen profile in genetic females resulting in 100% male progeny (Figure 1).

Although ploidy and hormonal induction of sex reversal have been widely practised now for over 20 years in many commercially important species, it has increasingly become apparent that these techniques used for sex reversal result in stunted growth (e.g. *Oryzias latipes*), sterility (e.g. *Poeclia reticulata*), intersexuality (e.g. *P. reticulata*) and/or low fecundity (e.g. *P. reticulata*), when the reversed individual is fertile (see also Pandian and Sheela); incidentally, these techniques also require skilled labour, costly chemicals and may involve consumer resistance, when the residual level of the administered hormone is high. Thermal manipulation to reverse the sex may prove to be the cheapest and easiest technique and can easily be practised for mass production by unskilled farmers or by using the equipment for industrial level production of monosex population.

It is known that the primordial germ cells of teleosts are of extra gonadal origin, and retain their bipotentiality to differentiate into male or female germ cells until sexual maturation. A large number of teleosts are known to retain this bipotentiality, even after sexual maturity. Thus the ability to retain bipotentiality, a unique characteristic of many teleosts may ultimately be responsible for the observed lability of sex differentiation throughout the life of the teleost species.

It must, however, be mentioned that not a single teleost species has thus far been subjected to all the 4 methods of manipulations to reverse the sex from fertilization to adult stage, although such a possibility is suggested by the present communication.


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