Influence of natural silt on the survival of *Oreochromis mossambicus* yolk sac larvae

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This study investigates the tolerance of *Oreochromis mossambicus* yolk sac larvae to natural silt from the Phalaborwa Barrage. Larvae survived silt concentrations lower than 13.2 g silt/l, but were highly active, indicating sublethal stress effects. When silt concentrations exceeded 29 g silt/l, stress reactions such as floating at the surface, gulping air, reduced fin and opercular movements and partial and complete loss of equilibrium were observed. Fish that succumbed exhibited darker pigmentation, and silt and mucus covered bodies. LC_{50} values were derived as 53.4 g silt/l, 31.7 g silt/l and 19.1 g silt/l for 1 hour, 24 hour and 48 hour exposure periods, respectively. Since these concentrations are much lower than the silt released from the Phalaborwa Barrage during flushing, it can be concluded that the release of high silt concentrations can severely impact the larval fish populations in the Olifants River below the Barrage.

Key words: silt, fish, larvae, LC_{50}, Phalaborwa Barrage, Olifants River.

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Introduction

The concentration of suspended sediment to which aquatic species are exposed at any given time is attributable in part to natural processes, and in part to man's activities (Auld & Schubel 1978). Land use for example, plays a major role in accelerating the input of sediment to stream systems (Coats *et al.* 1985). The unnatural increase in suspended sediment loads not only reduces the water transport capacity of rivers and streams, but may have negative impacts on fish and wildlife. Fish in particular may be affected by suspensoids (suspended solid or colloidal particles; Bruton 1985) either directly, by abrading tissues or reducing visibility for feeding, or indirectly by altering components of the environment such as substrate composition (Redding *et al.* 1987). The life stages of warmwater fishes are not equally susceptible to suspended particles (Muncy *et al.* 1979). Early life stages such as eggs and especially the larval stages are usually more susceptible than the adults to the direct effects of suspensoids (Muncy *et al.* 1979; Wilber 1983). Increased suspended solids reduce sight-feeding distances, disrupt normal activity and respiratory patterns, and change orientation responses of some larval warmwater fishes. For visual plankton feeders such as larval fishes, which feed on small particles (Hunter 1981) and have small search volumes, turbidity may reduce search and reaction distances resulting in lowered feeding abilities. In addition to lowered prey availability, larvae may consume suspended particles with food. This could result in blockage of the oesophagus preventing or hindering further feeding (Rosenthal 1971).

Increased suspended and sedimented particles are not only cited as causes of species composition changes (Muncy *et al.* 1979), but may also affect other ecological parameters such as temperature (Ellis 1936) and water quality (Robinson 1971). All these changes combine to exert sufficient stress to reduce or even alter population structure. Nevertheless, several species have successfully circumvented the adverse effects of sustained high levels of suspended solids in their environment through functional and behavioural adaptations conducive to survival in turbid habitats (Muncy *et al.* 1979; Cambray 1983).

This study was conducted to determine the lethal threshold concentration of suspended natural silt from the Phalaborwa Barrage for *Oreochromis mossambicus* yolk sac larvae. *Oreochromis mossambicus* was selected as the test species because it is found in most of the Kruger National Park rivers (Pienaar 1978), and easily propagated in artificial systems. In an attempt to evaluate the possible direct impact of silt releases on the survival of yolk sac larvae (*O. mossambicus*) the derived LC_{50} values were compared with the silt concentrations during the flushing of the Phalaborwa Barrage (Buermann *et al.* 1995).

Materials and Methods

Silt collection

Natural silt was collected at a water depth of 2–4 m from approximately the centre of the Phalaborwa Barrage, Mpumalanga, South Africa. Silt (top 20 cm of silt layer) was retrieved from a boat by means of a Birge-Eckman grab (grab-surface area: 225 cm²) and stored in plastic buckets at 8±2 °C until used in the exposure experiments.

Experimental procedure

Oreochromis mossambicus were obtained commercially. In the laboratory, fish were acclimated in plastic tanks (2000 l which were connected to a filter system and filled with ground (borehole) water. The filter system consisted of a 500 litre sedimentation tank which collected solid wastes, and a biological filter which removed excretory and other waste products from the water. Water was recirculated with a submersible pump. To maintain dissolved oxygen at high levels (>90 % saturation), compressed air was supplied to the water via air stones. During the acclimation period of six months, the water temperature was regulated at 27±1 °C, corresponding to the mean summer water temperature of the Olifants River below the Phalaborwa Barrage (Seymore *et al.* 1994). During this period fish were fed a commercial diet of trout pellets once a day (protein = 39.9 %; lipid = 5.3 %; ash = 9.6 %; carbohydrate = 45.2 %; energy = 22.8 kJ/g).

After the initial acclimation period, breeding pairs (one male and three females) were selected and placed into the four breeding systems filled with ground water (27±1 °C). Each system consisted of a 300 litre glass tank, a sedimentation tank with pump which collected solid wastes, and two biological filters which removed excretory and other waste products from the water. The photoperiod was regulated with a timer to produce 14:10 day:night light regime.

Yolk sac larvae were collected from the mouths of incubating females. This stage is characterised by mixed exogenous and endogenous feeding, a well developed yolk sac, and active swimming (Holden & Bruton 1992). In further references to the larvae of *O. mossambicus* used in this section, the terms yolk sac lavae or larvae are used as synonyms.

Five yolk sac larvae exposure chambers (one control and two duplicate sets) were used with 20 larvae used in each chamber. Each chamber consisted of a glass 600 ml glass beaker with a plastic tube supplying compressed air attached in a circular fashion to the bottom. The circular bottom section of the plastic tube was perforated with small holes to establish a continuous stream of small air bubbles. This was to ensure adequate suspension of the silt in the chamber without causing too much turbulence and disturbance of the yolk sac larvae.

Suspended silt concentrations used in the trails ranged from 1.2±0.9 g silt/l to 79.8±4.6 g silt/l (Table 1). Natural silt was used in all the exposures and the test suspension was calculated from a dry-wet mass ratio. To determine these ratios a sub-sample of silt was weighed (wet), placed in an oven at 60 °C for 48 h and re-weighed (dry) after cooling. The trimmed Spearman-Karber method was used to calculate the LC_{50} values and the associated 95 % confidence interval levels (Hamilton *et al.* 1977).

Table 1

*Summary of data obtained during silt exposure test with yolk sac larvae (*Oreochromis mossambicus*). LC_{50} values were derived for 1 h, 24 h and 48 h exposure periods at 27±1 °C*

	1 h exposure		24 h exposure		48 h exposure	
No of test larvae	Silt concentration (g silt/l)	No of survivals after 1 h	Silt concentration (g silt/l)	No of survivals after 24 h	Silt concentration (g silt/l)	No of survivals after 48 h
20	0	20	0	20	0	20
40	1.2±0.9	40	1.2±0.9	40	1.2±0.9	39
40	4,4±1.3	40	4.4±1.3	40	4.4±1.3	36
40	24.5±1.0	40	26.7±0.1	35	20.7±3	24
40	40.5±6.4	35	28.1±1.9	29	27.4±3.5	22
40	48.7±1.3	38	35.3±0.1	30	37.3±1.3	6
40	50.3±0.9	32	37.5±0.7	24	44.4±2.7	10
40	54.0±1.1	16	41.7±0.4	0	63.6±4.2	0
40	71.8±1.3	0	42.2±0.3	1		
40	79.8±4.6	0	44.6±3.0	0		
40	–	–	47.5±0.6	0		
LC_{50}	53.4 g silt/l		31.7 g silt/l		19.1 g silt/l	
95 % lower confidence	51.1 g silt/l		28.6 g silt/l		15.3 g silt/l	
95 % upper confidence	55.7 g silt/l		35.0 g silt/l		23.8 g silt/l	

Results

The trend during the lower exposure concentrations (<13 g silt/l) where the fish survived was that directly after the addition of silt, the larvae became highly active for a short time after which they returned to normal behaviour after 1 to 2 hours. This increase in activity suggests that silt causes sub-lethal stress to larval fish. When turbidity reached 30 g silt/l, stress reactions such as floating at the surface, gulping air, reduced fin and opercular movements and partial and complete loss of equilibrium were observed. Fish that succumbed to the high silt levels and lower oxygen concentration showed darker pigmentation, opercular cavities became clogged with silt and mucus-covered their bodies. These reactions to suspended sediment were less conspicuous at lower concentrations (<20 g silt/l), but more pronounced in exposure chambers containing the higher silt concentrations (>28.1 g silt/l). At the high silt suspensions (>28.1 g silt/l), dissolved oxygen in the exposure system decreased immediately after the addition of the silt. Dissolved oxygen concentrations of 0.0–0.1 mg/l (0–1 % saturation) were recorded, depended on the silt concentration used. Dissolved oxygen concentration started to increase slowly over a period of 2–24 h, to the initial values (5.8–6.8 mg/l; 85–104 % saturation).

Mortality percentages varied, depending on the concentration of silt added and exposure period (Table 1). No mortalities occurred at concentrations lower than 1.2±0.9 silt/l and exposure of 48 hours. As the silt concentration increased, mortalities occurred at shorter exposure periods (Table 1). At silt concentrations of 71.8±1.3 silt/l and higher, 100 % mortalities occurred during the exposure period of 1 hour. Higher percentage mortalities were usually recorded at lower silt concentrations after 24 and 48 hours of exposure. All of the exposed larvae usually died when exposed to silt concentrations higher than 44.6±3 silt/l and exposed for at least 24 hours. The LC_{50} values were determined as 53.4 g silt/l, 31.7 g silt/l and 19.1 g silt/l for the 1-hour, 24-hour and 48-hour exposure periods (Table 1) respectively.

Discussion

The larval period in most fishes is characterised by rapid changes in morphology which culminate in the establishment of the adult form. The series of development events is frequently associated with functional and behavioural modifications in larvae reflecting their continuously changing role in the ecosystem and varying degrees of sensitivity to different environmental influences (Muncy *et al.* 1979). Futhermore, studies have shown that the early life stages, (eg. embryo, larvae and early juveniles in the life cycle of fish), are the most sensitive to toxicants (McKim 1985). This also appears to be true for suspended sediment since larval stages of various fish species are reported to be less tolerant than adults (Wilber 1983; Muncy *et al.* 1979; Boehlert & Morgan 1985; Buermann *et al.* 1997). From the literature it is evident that suspended particles affect fish in a varied and complex manner. For instance, can be lethal, while sub-lethal levels influence survival indirectly by affecting their food intake. Other impacts from excessive suspended sediment in the environment can include biochemical, physiological, morphological and behavioural effects (O'Connor *et al.* 1977; Muncy *et al.* 1979; Bruton 1985; Redding *et al.* 1987). In this study high suspended sediment concentration also resulted in mortalities and behaviour changes such as gulping for air, coughing, increased activity, swimming at the surface and rapid fin movement.

The oxygen requirements of early larval stages are met by diffusion through the epidermis, which is only a few cells thick (Jones *et al.* 1966; Blaxter 1969; O'Connell 1981). The mucus/silt layer on the gills and bodies thus hinders gaseous exchange (Hunter 1972; Weihs 1980), thereby reducing oxygen availability to tissues and ultimately results in death. Trout (*Salmo trutta*) larvae are able to keep themselves and their respiratory apparatus clear of fine sediment by respiratory currents produced by the pectoral fins, and later in their development when the gills become more important, by a coughing reflex and agglomeration of particles with mucus (Stuart 1953). Similar behaviour was observed when yolk sac larvae (*O. mossambicus*) were exposed to low suspended sediment concentrations (<13 g silt/l). The mobility, pectoral fin action and tail flexions, may prevent silt deposition, enabling the *O. mossambicus* larvae to cope with the low sediment concentrations present both in the exposure system and possibly in nature. During the 24-hour exposure experiments, the mouth and gills of the larvae began functional (Holden & Bruton 1992) and were therefore increasingly affected by suspended sediment particles. During this stage, the addition of suspended sediment could result in serious abrasion and inflammation of the gill membranes which could eventually cause death (Cordone & Kelly 1961).

At high silt concentrations (>28 g silt/l) the larvae were severely stressed and in many cases death was rapid. The addition of silt concentrations, especially those >28 g silt/l, caused rapid decline in oxygen concentrations, particularly during the first 1–2 hours. This decline in dissolved oxygen concentration is a result of the oxygen demand of the silt particles both when in suspension and when settled (O'Connor *et al.* 1977; Buermann *et al.* 1995; Du Preez 1995). The introduction of the silt therefore disrupts the balance that exists between the water body and diffusion of oxygen through the air-water interface. This dramatic decrease in dissolved oxygen concentration was also observed in the Olifants River below the Phalaborwa Barrage during the flushing process (Buermann *et al.* 1995). It appears that larval mortalities are a result of the combined effects of the high silt concentrations (physical damage) and low dissolved oxygen concentrations. However, if the larvae survived the first 24 hours, clogging of opercular cavities and gill filaments as well as mechanical damage to the gills and skin epithelium would be the main cause of death.

Published data shows that suspended silt concentrations >28 g silt/l causes larval mortalities (Rosenthal 1971; Sherk *et al.* 1975; Auld & Schubel 1978). This corresponds well with the presented data for *O. mossambicus* larvae. The first mortalities occurred during the 1 h exposure period at 38 g silt/l (LC_{50}: 53.4 g silt/l) during the 24 h period at 27 g silt/l (LC_{50}: 31.7 g silt/l) and during the 48 h period are higher than 5 g silt/l (LC_{50}: 19.1 g silt/l). It can therefore be assumed that the continuous or frequent exposure of larval populations to the above suspended sediment concentrations is unacceptable as it will reduce the survival of recruits impacting whole fish community. The recorded silt release from the Phalaborwa Barrage (25 to 79 g silt/l (Deacon 1991; Moore *et al.* 1991; Buermann *et al.* 1995) is much higher than both the concentrations where mortalities were first observed, as well as the LC_{50} values. The flushing of the Phalaborwa Barrage and the resultant exposure of larval fish populations of the Olifants River below the Barrage to high suspended sediment concentrations and associated low dissolved levels, and would reduce recruitment. This will have an impact on the fish community below the Phalaborwa Barrage and is therefore a cause of concern for sustaining a healthy fish population in this river inside the Kruger National Park.

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