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Short Note

Effect of turbidity on the foraging success of *Glossogobius callidus* (Teleostei: Gobiidae)

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Particles suspended in water attenuate the light that passes through it via absorption or scattering (Utne-Palm 2002). For example, whereas algae absorb specific wavelengths of light necessary for photosynthesis, inorganic suspensoids tend to scatter light (Radke and Gaupisch 2005). This results in lowered ambient light levels and reduces the visual acuity of aquatic organisms. From a fish's perspective, an increase in water turbidity has the potential to alter visually-mediated reproductive behaviours (Järvenpää and Lindström 2004), predator avoidance (Meager et al. 2006) and foraging success negatively (Utne-Palm 2002, Rowe et al. 2003, Sweka and Hartman 2003, Stuart-Smith et al. 2004). The foraging success of various fish species was affected by increased turbidity through decreasing predator-prey encounter rates (Sweka and Hartman 2003) and through decreasing visual acuity whereby the distance at which prey are visually detected is reduced (Utne-Palm 2002).

In highly turbid water, fishes may compensate for the reduced reaction distance and volume searched by increasing their activity and actively searched areas (Sweka and Hartman 2001). Increased activity may be costly in terms of energy expenditure and has been noted to compromise growth, whilst maintaining prey consumption rates (Sweka and Hartman 2001). A flexible foraging strategy may therefore optimise the rate of energy intake within the constraints of the proximal optical environment (Meager and Batty 2009).

Encounters between predators and their prey occur at shorter distances in turbid water, with the probability of escape by the prey being determined by the probability of the prey sensing the predator before the predator detects the prey (Abrahams and Kattenfeld 1997). Therefore, to some extent, turbidity provides an optical refuge for the prey (Granqvist and Mattila 2004, Lehtiniemi et al. 2005). When a prey organism becomes aware of a predator a minor escape response is likely to result in the evasion of the predator, due to the decreased reaction distance making it difficult for the predator to predict the prey's movement (Cyrus and Blaber 1987).

With the current trend of South African rivers and estuaries becoming increasingly degraded and turbid (Bruton 1985,

Cyrus and Blaber 1987), understanding the potential impact of increasing turbidity on fish has important conservation implications. This study aims to elucidate some of the potential effects that increased turbidity could have on the foraging success of the river goby *Glossogobius callidus* (Smith 1937). It was chosen because it is a common species in both fresh and estuarine waters from Swartvlei in South Africa (Whitfield 1998) north-eastwards through Mozambique to Malawi (Tweddle 2007). It is a benthic species that feeds on aquatic macroinvertebrates (Whitfield 1998).

Gobies of 91.8 ± 14.3 mm TL were collected with a beach seine net from Pikoli Dam ($33^{\circ}10' S$, $26^{\circ}55' E$), Eastern Cape, South Africa, and acclimated for several months in a clear, freshwater recirculating system consisting of three 300-litre tanks and fed on commercial flaked food. All experiments were conducted indoors in a constant environment (CE) room with the temperature and pH of the water ranging from 15.6 to 18.3 °C and 6.4 to 7.1, respectively.

Turbid water was constituted by adding approximately 20 ml (wet volume) of kaolin clay to clear untreated water from the holding system. Turbidity was quantified by shining light from a 60 W incandescent bulb through a small 5 cm thick glass tank filled with a sample of the experimental water and measuring the irradiance against the glass on the opposite side of the tank with a light meter. Ambient light was also measured. The irradiance of the clear water was 47 000 lx and that of the turbid water was 32 000 lx. The ambient light in the CE room was 73 lx.

The prey types used in the experiment were divided into (1) benthic prey, consisting of coenagrionid (damselfly) nymphs, and (2) swimming prey, comprising corixids (water boatmen), all collected in scoop nets from several small dams in Grahamstown. The insects used in the experiments were selected because of their relative ease of capture, due to their abundance in the littoral zone of dams, and because they serve as suitable models of prey, i.e. those that tend to remain relatively inactive on the benthos and submerged plants and the more-active swimming prey.

The detrital substrate, consisting of plant matter including small sticks and leaves collected from the littoral zone of

the dams, was used to provide a refuge for the insects that lacked any other protection against predation. Water boatmen were observed to swim down to the detrital matter, clinging onto the particles, where they became inconspicuous.

Four treatments were used for each of the two prey types: (1) clear water with a detrital substrate, (2) clear water without a detrital substrate, (3) turbid water with a detrital substrate, and (4) turbid water without a detrital substrate. Experiments using damselflies and water boatmen were replicated eight and six times, respectively. In each replicate, 10 water boatmen or five damselflies were placed in a 15-litre grey, opaque bucket (30 cm surface diameter, 20 cm high), filled with 13 litres of water of the desired turbidity, with or without detritus, and a single goby, which had been starved for at least 12 h, was introduced. Six hours later the water from each bucket was drained through a fine net to determine how many insects remained. It was necessary to use some individual gobies more than once, but this was only conducted after they had been returned to the holding system for several weeks. In addition, six control replicates, each with 10 water boatmen but no gobies, were run for at least 6 h to determine whether water boatmen escaped from the experimental units, as they are able to fly. No water boatmen escaped from the control units. No controls were undertaken with damselfly nymphs as they were not near metamorphosis and so could not escape. No insects died during the experiments without being consumed.

The proportion of prey, p_{ij} , consumed at the end of each experimental replicate i for species j was $\sin^{-1}(\sqrt{p_{ij}})$ -transformed and the effect of water turbidity and the presence of detritus on mean foraging success was assessed using two-way analysis of variance.

The mean proportion (\pm SD) of swimming prey consumed in treatments without a detrital substrate was 0.33 ± 0.16 and 0.28 ± 0.24 in clear water and turbid water, respectively. With a detrital substrate, the mean proportion consumed decreased to 0.23 ± 0.27 and 0.27 ± 0.28 in clear and turbid water, respectively (Figure 1). Water turbidity, the presence of a detrital substrate and their interaction had no significant effect on foraging success ($F_{1,20} = 0.006$, $p = 0.94$; $F_{1,20} = 0.83$, $p = 0.37$; $F_{1,20} = 0.57$, $p = 0.46$).

With respect to benthic prey, in the absence of a detrital substrate the mean proportion of prey consumed was 0.38 ± 0.33 and 0.78 ± 0.31 in the clear and turbid water treatments, respectively (Figure 1). With a detrital substrate the mean proportion of prey consumed in the clear water treatment increased slightly to 0.43 ± 0.27 , but in the turbid water treatment dropped dramatically to 0.13 ± 0.10 . Water turbidity had no significant effect on foraging success ($F_{1,24} = 1.18$, $p = 0.29$). The presence of a detrital substrate and the interaction effect between turbidity and substrate had significant effects on foraging success ($F_{1,24} = 6.30$, $p = 0.02$; $F_{1,24} = 10.04$, $p = 0.004$), with a lower proportion of prey consumed in the 'turbid with detritus' treatment compared to the 'turbid without detritus' treatment.

Increased turbidity and the presence of a detrital substrate had no effect on the predation rate of gobies foraging on active prey. This may be explained by the possibility that similar encounter rates were maintained, due to the mobility of the prey (Gregory and Levings 1998), in addition to any

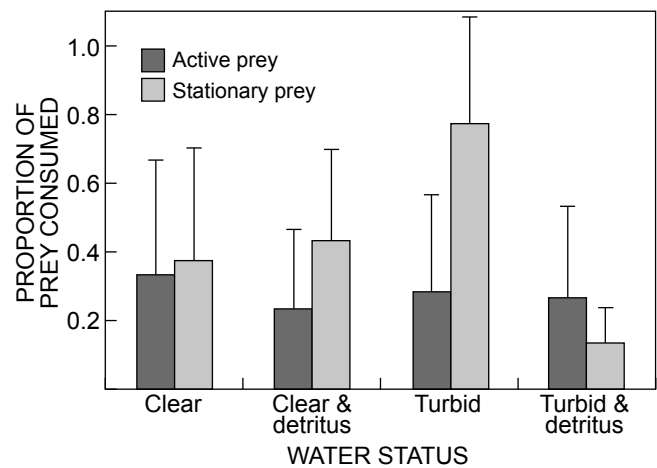


Figure 1: Proportion (\pm SD) of active prey (water boatmen) and stationary prey (damselfly nymphs) consumed by *Glossogobius callidus* in clear and turbid water with and without the addition of detritus as a substrate

searching undertaken by the gobies. These prey organisms respire with a plastron and are obligated to rise periodically to the water surface to respire (Picker et al. 2002). Any potential reduction in encounter rates because of reduced water clarity is mitigated due to the consistency in encounter rates due to prey mobility, regardless of visual cues. The gobies may also rely more on lateral line sensing to detect their prey when visual acuity is impaired.

In the benthic prey experiments, water turbidity alone had no significant effect on foraging success. There was, however, a significant increase in foraging success in the 'turbid' compared to the 'clear' treatment. Certain levels of turbidity may increase the reaction distance and the foraging success of fishes (Utne-Palm 1999). Two hypotheses are offered in explanation of this phenomenon: the physical effect hypothesis, which notes that at certain turbidities there is a greater contrast between a prey organism and their background making them more easily discernible (Hinshaw 1985); and the motivation hypothesis, which predicts higher feeding levels at increased turbidities. The latter is due to an increased feeding motivation because of a perceived lower risk of predation, under cover of the increased turbidity of the water, resulting in an increased frequency of encounter between predator and prey (Utne-Palm 2002). The presence of detrital substrate may have provided benthic prey with a substrate against which they were more camouflaged. Even though there was no reduction in prey consumption rates in clear water with a detrital substrate compared with the clear water without a detrital substrate, when combined with turbid water, the visual prey-detecting abilities of the gobies became impaired.

Previous studies investigating the foraging dynamics of fishes in various turbidities reported mixed results. Rowe and Dean (1998) working with two goby-like species—common bully *Gobiomorphus cotidianus* and redfinned bully *G. huttoni*—noted results similar to those of this study in that the feeding rate of the redfinned bully increased with increases in turbidity up to 40 NTU, above which level their feeding rates

declined. The common bully's feeding rates, however, were reduced by any increase in turbidity. Studies that noted that the predation success of several fish species was reduced with increasing turbidity attributed their findings to the fishes' reliance on visual cues in searching for prey (Gregory and Northcote 1993, Gregory and Levings 1998, Rowe and Dean 1998, Cobcroft et al. 2001, Stuart-Smith et al. 2004). Several studies have found turbidity to have no major impacts on the foraging success of fishes (Vandenbyllaardt et al. 1991, Grecey and Targett 1996, Abrahams and Kattenfeld 1997, Rowe et al. 2003, Granqvist and Mattila 2004) with these authors attributing this to various factors including changes in activity and search patterns of the predator, changes in prey behaviour, altered contrast and the use of alternate senses, including chemoreception and lateral line sensing, when vision is ineffective. At higher turbidities where activity rates of foraging fish are observed to be elevated, the expected increased searching time will result in increased energy costs relative to predatory success (Meager and Batty 2009).

Fishes may have the ability to adopt different foraging modes suited to the prevailing optical environment. Atlantic cod, *Gadus morhua*, for example, are suggested to have different foraging modes, facilitated by senses additional to vision, for different levels of turbidity (Meager and Batty 2009). The reliance on senses other than vision when conditions necessitate have been demonstrated by experimenting in total darkness. Rowe and Deane (1998), for example, found several species of indigenous New Zealand fishes were all still able to capture prey in total darkness. Possessing a flexible foraging strategy may maximise the rate of energy acquisition within the constraints of the optical environment (Meager and Batty 2009).

From the results of this study it may be predicted that an increase in water turbidity is only likely to have impacts on predator–prey relationships involving the river goby where the prey are limited in their mobility, with the turbid water providing added refuge to the prey. If the gobies respond to an increase in turbidity by increasing their searching activity, then the less mobile prey are likely to be encountered with a higher frequency than usual. For mobile prey, the encounter rates are not likely to be reduced to a level which will have any significant impact on predation rate.

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