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Dynamics of Predator-prey Interactions in Sharp Tooth Catfish (*Clarias gariepinus*; Burchell, 1822) and Carp Fingerlings (*Labeo bata*; Hamilton, 1822) with Special Reference to the Development of Anti-Predatory Strategies

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

This study explores the dynamics of predator-prey interactions and functional response of *Clarias gariepinus* (African Magur/Sharptooth Catfish - predator) and of *Labeo bata* **(**Carp fingerlings - prey). Author investigated the behavioral patterns of both species in isolation and during

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encounters, exploring the impacts of predator size, prey-predator ratio, encounter duration and placement of separators on anti-predatory strategies. Results indicated that prey behavior is influenced by predator presence, with crowding, hiding, and inspection emerging as key anti-predatory strategies. The development and intensity of these strategies are intricately linked to prey-predator ratio, size difference, and encounter duration. Notably, larger predators trigger more pronounced anti-predatory responses in preys, while high prey composition motivates individuals to inspect predators, conveying fearlessness and fitness. Findings provide valuable insights into the evolution of predator-avoidance behaviors in prey species, sheds light on the complex dynamics governing predator-prey interactions in aquatic ecosystems.

Keywords: Predator-prey interactions; anti-predatory strategies; Clarias gariepinus; Labeo bata.

1. INTRODUCTION

The functional response of a predator provides important insight on mechanisms underlying predator–prey dynamics. Predator's strategy causes strong selection pressure on behavior of prey (Lima and Dill, 1990). The result often appears to be expression of facultative predator avoidance behaviors (e.g., reduced feeding, reduced activity, and refuge use, longer hiding, forming defensive groups) when prey encounters the predator (e.g., Boersma et al., 1998; Wisenden et al., 1999). Facultative changes in behavior are often taken as evidence for evolution of prey behavior in response to selection by predation (Watkins, 1996; Blumstein et al., 2000) because behavioral patterns induced by the presence of a predator are often associated with lower vulnerability to predation (e.g., McPeek, 1990; Skelly and Werner, 1990; Grill and Juliano, 1996). Group living in animals is essentially to increase their foraging success and to avoid predators (Pollard and Blumstein 2008). For example, they reduce their probability of being predated by belonging to a group (dilution effect: Cresswell and Quinn 2011); this mechanism is attributed with increased accuracy in predator detection through improved surveillance (many eyes effect: Roberts 1996), or by making the capture of an individual more difficult (confusion effect: Ioannou et al. 2007). Some individuals in groups are privileged, such as those in the physical centre, who can hide behind others to avoid predators (Parrish and Edelstein-Keshet 1999).

The Sharptooth Catfish *(Clarias gariepinus; family: Clariidae)* locally called African Magur; is an indigenous species in Africa where it is widely distributed. It naturally inhabits tropical swamps, lakes, rivers and floodplains some of which are subject to seasonal drying. In recent years the species has been introduced in Europe, Asia and South America. The species easily adapts to environments, where the water temperature is higher than 20 °C. *Clarias gariepinus* (Burchell 1822) was recognized as one of the most suitable species for aquaculture around the world. The suitability of this species for culture is based on its capacity to reproduce relatively easy in captivity, grow fast and efficiently, supports high stocking densities, hardiness and tolerate adverse water quality conditions (Hogendoorn, 1979). The fish turn lighter in color when exposed to high and prolonged light. During stress they show a mosaic-like pattern of dark and light spots. The head is flattened, highly ossified, the skull bones (above and on the sides) forming a casque. The length of head is 30–35 % of body length. Around the mouth, 4 pairs of barbels are distinguishable (nasal, maxillary, the longest and most mobile, outer mandibular and inner mandibular). The Magur can move the maxillary barbels independently of its mouth. The barbels serve as tentacles. Magur recognizes its prey mainly by touch and smell which has relevance during feeding at night and in highly turbid or muddy waters where visibility is less. African Magurs with their wide mouth are able to feed on a variety of food items ranging from minute zooplankton to large fish. They are able to suck benthos from the bottom, tear pieces of cadavers with the small teeth on its jaws and to swallow prey such as a whole fish. A number of studies have been made on the natural food of *C. gariepinus* in Africa. Micha, (1973) considered African Magur as an omnivorous fish with a high tendency for predation. Different kinds of food items were found by different authors in the stomach of the African Magur captured from natural waters.

The food items reported are: aquatic and terrestrial insects, fish, molluscs, fruits, diatoms, arachnids, plant debris, seeds, detritus, bird eggs, young birds, droppings of poultry and zooplankton. The mouth circumference is about 25 % of its total length and it determines the maximum size of its prey. A Magur of 30 cm (approx. 200 g) has a mouth circumference of about 7.5 cm. When a suitable food item is found, Magur grasps it often by suction. A strong negative pressure (suction) is created by increasing the volume of the buccopharyngeal chamber. However, predation needs much more energy than swallowing food items. Thus, where abundant food items, other than fish, are available, the Magur feeds almost entirely on these items. However, in juvenile stages, cannibalism does occur, mainly in high density pond culture. After reaching a certain size (50–100 g), in properly fed fish ponds, cannibalism practically stops.

The present study tried to define following behavioral aspects relevant to explain predatory and anti-predatory strategies in the selected prey-predator pair.

- To find out the natural behavior of prey species *Labeo bata* (Hamilton, 1822) and predator species *C. gariepinus* (Burchell, 1822) in isolated mono-species condition.
- To identify behavioral patterns associated with prey and predator at different size and population ratio.
- To learn what are the anti-predator strategies in *L. bata* prey in presence of predator.
- To determine the roles of size difference and population ratio in the development of anti-predator strategy.

2. METHODOLOGY

2.1 Fish Tank Preparation

The functional response studies were conducted in a glass aquaria or water tank (height 1.2 ft., bottom area 3 sq. ft.; 15 gallon capacity) with 3 cm high semi-fine gravels as substratum. The aquaria were supplied with freshwater from overhead tank, treated with anti-chloride rid-all solution to reduce chloride levels to nominal with temperature of 28 °C ± 0.7 °C. The *C. gariepinus* predators and *L. bata* (prey) were procured from Naihati fish seed market and acclimatized in a temperature regulated maintenance tank for 7 days within normal 12 hr. light-dark cycle with *ad libiitum* conditions.

2.2 The Fish Species Selected as Behavioral Models

2.2.1 The Predator - *C. gariepinus*

In predators *(N = 10)* each of identical length 2.5 inches as well as of 4.5 inches were placed in separate aquarium (Total Length from the tip of the snout to the end of longer lobe of the caudal fin). All through the experimental session, the predators from two size classes were not mixed together (Agwu et al., 2022). During acclimatization the predators were fed regularly with High protein dried fish flexes available in market before the start of each experiment (Fig. 1).

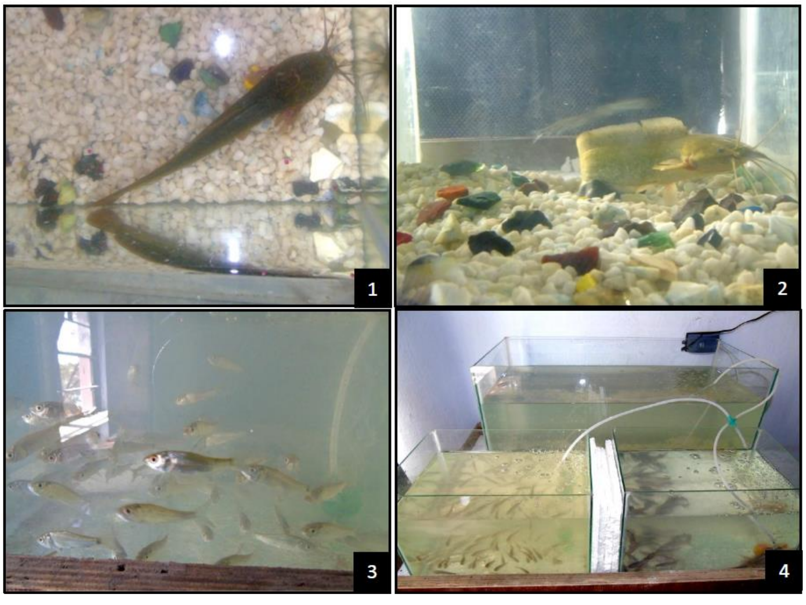

Fig. 1. The Predator (C. *gariepinus; Sharptooth Catfish) inside water tank, 1 & 2 preys (L. bata) maintained within fish tank and 4. Aquaria set up*

Table 1. Dynamics parameters of prey-predator used in the study

Predator size	Prey-predator ratio
2.5 inch	Equal prey-predator ratio (7:7) Low Prey-High Predator (4:10) Low Predator-High Prey (10:4)
4.5 inch	Equal prey-predator ratio (7:7) Low Prey-High Predator (4:10) Low Predator-High Prey (10:4)

2.2.2 The Prey - *L. bata*

A stock of 50 fingerling of *L. bata* were brought from the market and housed in fish tank for acclimatization and observation (Fig. 1). From the stock population a group of 10 fingerlings were transferred into another tank of similar dimension that of predators. *L. bata* as a bottom feeder and herbivore where the plant-food forming almost 80 % of diet (Sehgal and Kaur, 1969). They were maintained with phytoplankton collected from nearby ponds during the acclimatization period.

2.2.3 Experimental design

i. **Isolation study:** Both prey and predators were kept in separate tanks for observation. This observation was done by 30 min (5-1-5-1-5-1-5-1-5) cycles with 5 min of observation and 1 min of rest. Each and every move were recorded in Logitech webcam as well as noted in the datasheets. The aim was to identify major behavioral patterns in these species in absence of the other. Implication of this is also to compare those patterns during the phases of encounter. The 30 min cycle was repeated for few times for consistency of result. We have also employed hiding spaces for preference of the species.

ii. **Encounter study:** This study is a follow up of isolation study. We had performed this observation at multiple combinations.

iii. **Predator size and prey behavior:** Two different predator sizes (2.5 inches and 4.5 inches) were used for this study. It helps us to know whether predator size has any significant role in shaping of prey-predator interaction anti-predator behavior in particular.

iv. **Prey-predator ratio and prey behavior:** We had performed this analysis with multiple combinations (Table 1) such as low prey (4:10), low predator (10:4) and equal ratio (7:7).

v. **Assessment of signaling between prey and predator:** The prey and predator were kept isolated yet inside one tank by 1 ft. x 1.2 ft. glass separator and a nylon mesh. The glass separator had served as chemical signal blocker as it allows visual communication between prey and predator but not allow the chemical substances from their bodies. Nylon mesh on the other hand serves as visual signal blocker but easily allow chemical signal molecules to travel through. Employment of these structures when followed by behavioral study – helps us to identify importance of the two signal form in development of prey-predator relationship.

vi. **Assessment of agility in prey and predator:** Agility in participating individuals is key indicator of prey-predator interaction. Encounter leads to rise in sequential behavioral activities. During encounter study, agility in both the species were visually scored and compared at five observation phases separated by brief intervals.

2.2.4 Ethical NOTE

C. gariepinus and *L. bata* is a commercially available common marketable species of India commonly used as live food for other fish species. No specific license was required to maintain this species in fish tanks.

3. RESULTS

3.1 Ethogram Preparation

The prey and the predator when observed alone in separate tank and when allowed to interact either through glass separator or nylon mess or just freely mingle inside a fish tank, demonstrates following behavioural repertoire. The stocking density, predator size, exposure duration etc. were experimentally varied to study the dynamics of prey-predator interaction.

3.2 Behaviors in Isolation

Both prey and predators were observed thoroughly in isolation (with regular feeding, constant water parameter) for long periods in order to identify their common behaviors. At this point both the species had no experience of each other and therefore no prey induced or predator induced behaviors can be recorded. For recording behavior, we had employed 30 min cycles with 5 min of observation and 1 min of rest. During this observation phase, activities were recorded in a Logitech webcam for further analysis. Prior to analysis, an ethogram was prepared with frequent behavioural repertoire - agility, crowding or schooling, rest, hiding and chasing (for the predator) and again agility, crowding or schooling, rest, hiding, chasing and inspection (for the prey) for evaluation. The observations from this study were documented in the Table 2.

3.3 Behaviors During Encounter

To observe the interaction between the prey and predator we have devised encounter arena comprising of larger water tank with similar water parameter (water temperature and pH value was measured before releasing fishes) with hiding structures. Prey-predator encounter were recorded for different time length (multiple 30 min cycles), size ratio (prey size kept constant where predator of 2.5 inch and 4.5 inch total length) and count ratio (high predator, low predator and equal ratio).

3.3.1 Attacking / chasing

Low predator (Table 2c) and equal prey-predator ratio (Table 2a) demonstrate low to medium level of attacking and chasing in predator which goes high in low prey condition (Table 2b). The observation in different combinations shows attacking and chasing the counterpart is absolutely a predatory strategy and its intensity grows with the numerical abundance of the predator. On the other hand, *L. bata* never opt attacking or chasing as responsive strategy against its predator even when it is in greater numerical strength (Table 2a, b, c).

3.3.2 Crowding / schooling

Crowding and schooling are common interspecies activity in fishes. They also use this as an anti-predator strategy in presence of some predator. In the encounter analysis we had observed crowding and schooling in our model species. We had noticed crowding in prey increase over exposure time and with the increase in predator number. Predators on contrary not prefer clumping or crowding rather choose to disperse in the tank. Such observations clearly show prey chooses to crowd regularly irrespective to the presence of a predator but they have a greater tendency to crowd or form school in response of predator. By crowding they reduce predatory attacks – an observation in low predator

3.3.3 Territoriality

Territoriality often develops in predators to manipulate the prey population in order to access maximum resource. In our case, we have expected territoriality to occur in the *C. gariepinus* in response of prey. Territoriality is associated with intraspecies aggression and resource manipulation. However, the observation of prey-predator encounter demonstrates no such behavioral features, thus no record of territoriality. Territoriality is absent even in larger predators (Table 2d, e, f) as well as in preys as discussed earlier. Thus we can consider, territoriality is absent in this species may be due to its natural adaptation in large stock sizes and lesser exposure to environment where they have to look for prey (mostly supplied with food supplement).

3.3.4 Resting

Predators are aggressive in nature thus they often tend to get tired and take rest to regain energy. *C. gariepinus* take rest both in presence or absence of prey species but resting appear as frequent behavioral pattern. They often hang near the water surface in angular or vertical posture for as long as 5 min, at that time they even seize movement of pectoral fins. Larger predators are more sluggish than smaller ones. They regularly take rest during the observation sessions (Table 2d, e, f). Though, in preys such resting found missing altogether. Therefore, we cannot consider resting as an anti-predator behavior as it has no functional significance in escaping predator; rather it allows the predator to manage its energy levels during the predation process.

3.3.5 Hiding

Hiding is an efficient strategy for both species as it works as ambush for predator and hide out for prey. When the preys are exposed to the predator of larger size, they tend to hide more in number compared to low predator conditions. Therefore, one can conclude that prey choose to hide in order to avoid the predator raids as it is one of the low-cost anti-predatory strategy than others.

3.3.6 Inspection

Another common anti-predatory behavior demonstrated by prey population is the inspection into the predator zones or territories. This behavioral type allows preys to collect vital information on predators and such strategy is found to be carried from generations to next and considered to be the part of their evolution. Here, we have looked into the movements of preys particularly on individual journeys close to predators. As we have set three different levels of interactions between *L. bata* preys and *C. gariepinus* predators we noticed inspection behavior comes up in high prey composition whereas in other compositions it is lacking. This may suggest that high prey number motivates some of the members to inspect predators in order to convey their fearlessness and fitness to the predator. Surprisingly, with larger predator inspection strategy abolished altogether as it suggests they have assessed the consequence and readjusted their approach towards predator.

4. DISCUSSION

Development of anti-predatory strategies is related with prey-predator ratio: To summarize the observations we can come into inference that development and disappearance of anti-predatory strategies is connected with the ratio of prey and predators. High prey condition is associated with frequent inspection, crowding or clumping in prey group and lesser attacking and chasing in predators (Fig. 3). Inspection behavior is a proven predator avoidance strategy in many small fishes including tetras, mollies, guppies etc. where some member of the group explore out into predator's zone (*Grant and Victoria 2002)*. In contrary low prey condition triggers attacking and chasing in predators as well as lower rest as they pursue for prey more in this condition. Preys almost never take rest or demarcate territory in any of the ratios, considered.

Development of anti-predatory strategies is related with prey-predator size ratio: With the introduction of larger predators, preys tries to readjust some of their existing anti-predatory strategies to increase survivorship. They stopped inspection behavior altogether, tends to clump or crowd together more than before and hide more in order to stay away from predators.

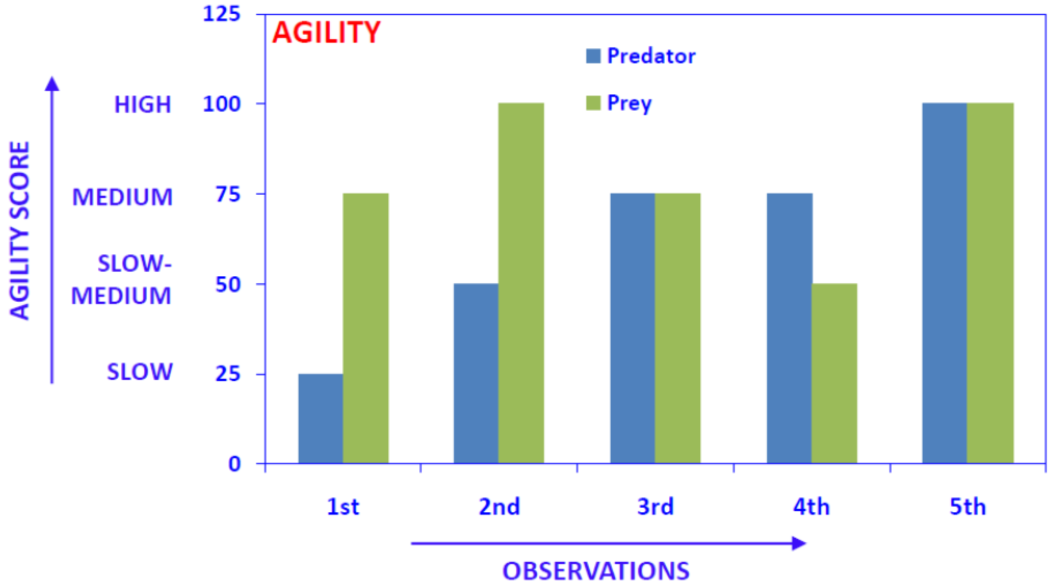

Fig. 2. Comparison between levels of Agility in observation phases (each for 5 min followed by 1 min interval) in predator (*C. gariepinus*; Blue bar) and in prey (*L. bata* – Green bar). Slow, Slow-medium, Medium and High were assigned with 25, 50, 75 and 75 respectively for graphical plotting

Table 2. Dynamics of prey-predator interaction (X = absence/non-occurrence; Y = presence/occurrence)

(I) ENCOUNTER STUDY- SMALLER PREDATOR (2.5 INCHES)

a. Equal prey-predator ratio (7:7)

Study phases	Predator (*C. gariepinus*)				Prey (*L. bata*)					
	Attacking / Chasing	*Crowding / Schooling*	*Territoriality*	*Resting*	*Attacking & Chasing*	*Crowding / Schooling*	*Territoriality*	*Resting*	*Hiding*	*Inspection*
1st	low	X	X	long	X	low	X	X	X	X
2nd	low	X	X	long	X	low	X	X	X	X
3rd	low	X	X	short	X	high	X	X	X	X
4th	medium	X	X	short	X	high	X	X	X	X
5th	medium	X	X	short	X	high	X	X	X	X
b. Low Prey-High Predator (4:10)										
1st	high	X	X	short	X	medium	X	X	X	X
2nd	high	X	X	X	X	high	X	X	Y	X
3rd	medium	X	X	X	X	high	X	X	Y	X
4th	high	X	X	X	X	high	X	X	Y	X
5th	high	X	X	X	X	high	X	X	Y	X
c. Low Predator-High Prey (10:4)										
1st	low	X	X	long	X	low	X	X	X	X
2nd	low	Y	X	long	X	high	X	X	X	X
3rd	medium	Y	X	long	X	high	X	X	X	X
4th	medium	Y	X	Short	X	high	X	X	X	X
5th	medium	Y	X	short	X	high	X	X	X	X

(II) ENCOUNTER STUDY - LARGER PREDATOR (4.5 INCHES)

d. Equal prey-predator ratio (7:7)

Study phases	Predator (*C. gariepinus*)				Prey (*L. bata*)					
	Attacking / Chasing	*Crowding / Schooling*	*Territoriality*	*Resting*	*Attacking & Chasing*	*Crowding / Schooling*	*Territoriality*	*Resting*	*Hiding*	*Inspection*
1st	low	X	X	long	X	low	X	X	X	X
2nd	low	Y	X	long	X	high	X	X	X	X
3rd	medium	Y	X	long	X	high	X	X	X	X
4th	medium	Y	X	short	X	high	X	X	X	X
5th	medium	Y	X	short	X	high	X	X	X	X
e. Low Prey-High Predator (4:10)										
1st	high	Y	X	short	X	medium	X	X	X	X
2nd	high	Y	X	short	X	high	X	X	Y	X
3rd	medium	Y	X	short	X	medium	X	X	Y	X
4th	high	Y	X	X	X	high	X	X	Y	X
5th	high	Y	X	X	X	high	X	X	Y	X
f. Low Predator-High Prey (10:4)										
1st	low	X	X	short	X	high	X	X	X	X
2nd	low	X	X	short	X	high	X	X	Y	X
3rd	low	Y	X	short	X	high	X	X	Y	X
4th	low	Y	X	short	X	high	X	X	Y	X
5th	medium	Y	X	short	X	high	X	X	Y	X

Study phases	Predator (*C. gariepinus*)				Prey (*L. bata*)					
	Attacking / Chasing	***Crowding / Schooling***	***Territoriality***	***Resting***	***Attacking & Chasing***	***Crowding / Schooling***	***Territoriality***	***Resting***	***Hiding***	***Inspection***
(II) ENCOUNTER THROUGH SEPERATOR										
g. Separator Study: Glass										
1st	low	X	X	X	X	x	X	X	Y	Y
2nd	low	X	X	X	X	x	X	X	Y	Y
3rd	low	X	X	X	X	x	Y	X	Y	Y
4th	X	X	X	X	X	x	X	X	Y	Y
5th	X	X	X	X	X	x	X	X	Y	Y
h. Separator Study: Nylon mesh										
1st	X	X	X	X	X	medium	X	X	Y	Y
2nd	X	X	X	X	X	medium	Y	X	Y	Y
3rd	X	X	X	X	X	high	X	X	Y	Y
4th	X	X	X	X	X	high	X	X	Y	Y
5th	X	X	X	X	X	high	X	X	Y	Y

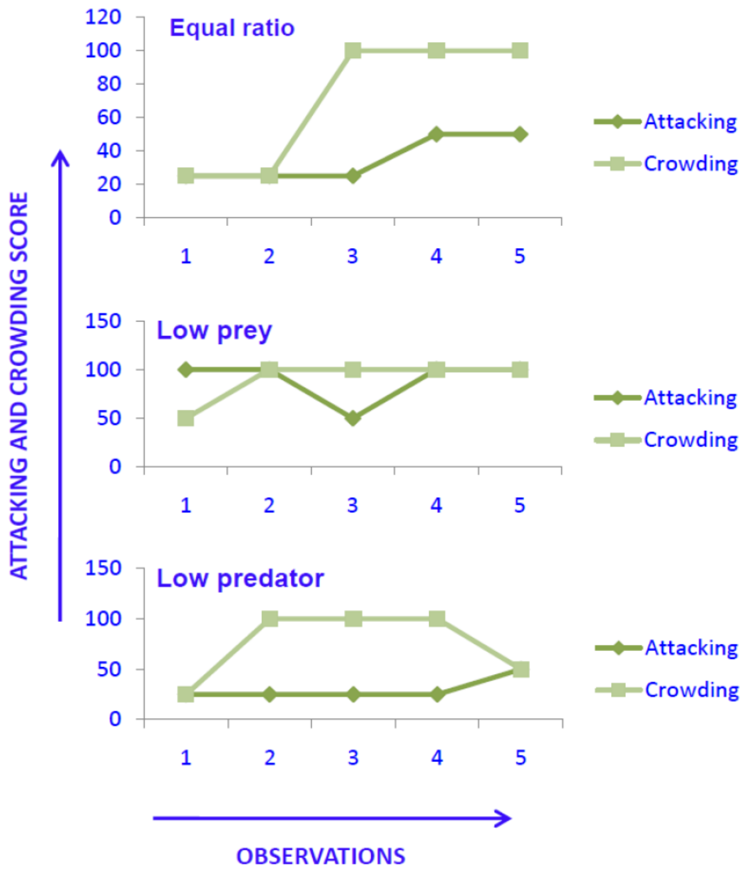

Fig. 3. Comparison between levels of Attacking (Dark Green line) and Crowding (Light Green line) in observation phases in equal ratio, Low prey and Low predator conditions. (Low, Medium and High values were assigned as 25, 50 and 100 respectively for graphical plotting)

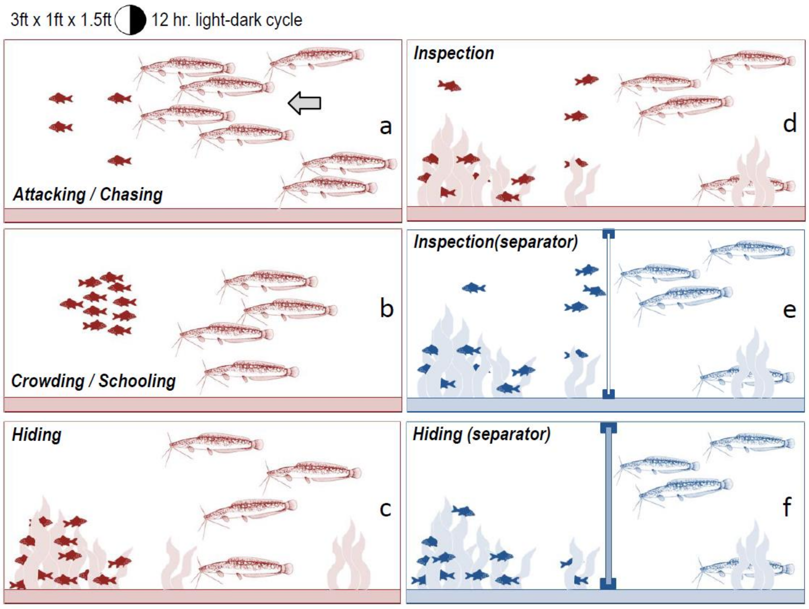

Fig. 4. Schematic representation of the experimental design and various behavioral repertoires of prey-predator dynamics. Illustration of the outcomes of encounter study (a-d) and encounter through separators (e – see through glass separator, f- nylon mesh separator)

Development of anti-predatory strategies is related with the duration of encounter: We have noticed most anti-predatory strategies in preys appear slowly after the encounter or can be said that prey take time to decide their action towards the predator as from our observation sets most of the behaviors had started or become prominent only after a short threshold period. This suggests, the prey initially consider any environment as enemy/predator free but with the course of time they habituate and develop suitable responses. More and more time it spent with predator the perfection and intensity of the behavior get increased (Fig. 4).

Polysensory ability alters prey-predator interaction: Glass separator was expected to restrict chemical signals coming from the either species while dense nylon mesh restricts the visual signals (Table 2 g, h). Installation of such structures within the arena impacts the behavioral interaction results differently compared to free mingling encounter. Free mingling allows occasional active predation – devouring of *L. bata* prey. Polysensory basis of feeding in *C. gariepinus* (Fatollahi and Kasumyan 2006) has been suggested elsewhere Glass separators make both the participating species aware about the ultimate non-contact, thus significantly alter the behavioral pattern (absence territoriality, crowding, hiding etc.), while increase the time budget for inspection and resting. Nylon separators too alter the interaction. Absence of visual detection results into increased inspection and crowding time.

5. CONCLUSION

Dynamics of anti-predatory strategies in relation to varying prey-predator ratios, sizes, and encounter durations has been an interesting model behavioral study, since this allows biologists to assess the co-culture of different species. Energy expenditure plays conclusive role during selection of various anti-predator strategies, while they also evolve over time, with diminished behavioral responses in prey with prolonged exposure to predators. Moreover it showed polysensory ability in both prey and predator significantly alter the complex interplay of prey-predator interaction.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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