The Effect of Turbidity on Functional Responses of European Shore Crab

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Abstract. Understanding the mechanisms of the natural environment that affect the interaction between consumers and resources is the key to understanding the stability and function of ecosystems. Although the effects of many environmental factors on predator-prey interactions have been well studied, turbidity in aquatic ecosystems is not one of them. Turbidity is ubiquitous and can be important because it is related to water pollution and can significantly reduce visibility of both predator and prey. In this study, the effect of turbidity on the interaction between the shore crab *Carcinus maenas* and the gammarid amphipods *Echinogammarus marinus* is studied. The functional response of the predator (crab) under different turbidity levels (consumption rate under different prey (shrimp) densities) was quantified, and it was found that turbidity increased the search speed and handling time. In zero turbidity, that is, completely clear water, the performance of the predator (crab) is not as good as the performance under low turbidity conditions. This may be caused by many reasons, such as the crab is get used to low turbidity conditions because they live at the bottom of intertidal and they will stir up sand at the bottom when they are moving. However, in order to better understand how the interaction between consumers and resources responds to turbidity, more research is needed.

1. Introduction

Function Response in many different areas have played an important role. Basically, it is used to evaluate the community structure, individual behaviour and population dynamics in the food network model [1–3]. At the same time, it can be used as a unified method to understand, evaluate and explain the success and impact of intrusions [4,5]. It can also show the adaptability (physiology) of the organism.

Obviously, mass of participants is a factor in functional response. The resource capture rate usually shows a unimodal dependence in the range of consumer mass (M<sub>C</sub>), resource mass (M<sub>R</sub>), and body mass ratio (M<sub>C</sub>/M<sub>R</sub>). The relatively small predator-prey mass ratios may lead to instability of Type II functional response, which is due to the large amount of resource development under low resource density [3,6]. As the ratio increases, the response exponent (q>0) to the stable type III sigmoid curve is represented by low resource development under low resource density [7]. However, when consumers are extreme (such as very large or very small), their interaction is not optimal [8].

Physical environment may play a central role in determining the type and magnitude of the response function terms. Consumers’ eating rate will be affected by variables such as temperature changes [9]and habitat complexity [8]. In addition, due to changes in the shape and size of the functional response under this environmental dependence, the water chemistry in the water can also be used to predict the impact. Different light regimes also affect the functional response. For example,
lionfish (*Pterois volitans*) consume more prey (*crustacean*) under white and blue light than under red light [10].

For many aquatic predators and prey, visibility in the water is essential to foraging prey or avoiding predation. In the predator-prey dynamics of the white shark - Cape fur seal, the cape seal has good visual acuity on the surface, and then the white shark can be detected visually. But in dim conditions, white sharks may have a visual advantage over cape fur seals [11]. This means that visual acuity and visibility will affect the dynamics of consumer and resources.

After all examples have been shown, the role of turbidity in functional response has actually been studied to some extent, but it has not been studied carefully. If the relationship between turbidity and prey density gradient is not studied, it is impossible to analyse the space usage and encounter case under the maximum feeding speed. Turbidity is the basic indicator of water. Clearly, it plays an important or even more dominant role in functional response, especially for those aquatic species. For them, turbidity is as important as temperature.

Turbidity is a characteristic of water and should have a non-negligible and noticeable impact on aquatic individuals. Since little or no research has focused on how components affect functional response and how to produce mechanical effects through turbidity, it has not been well studied. This study aims to find out the mechanism of turbidity affecting functional response.

2. Material and Methods

2.1. Experimental Materials

In this project, all crabs (*Carcinus maenas*) and amphipods (*Echinogammarus marinus*) used were collected from Swanpool Beach, which is near Plymouth, Cornwall. Rocks were turning over to find crabs and were washed to collect shrimps. There were 60 crabs used in this project in total. The mass of 19 of them were recorded. The average weight of these 19 crabs is 1.841g. Under laboratory conditions (15°C and 12:12 L:D), all the crabs were adapted the new environment in two opaque shallow tanks for 5 days. There were 30 crabs in each tank. Light given illuminated the tank vertically. Before each trial, the predator must be starved for at least 24 hours. The length of amphipods used for experiments were measured and the average total length is 7.767 ± 1.946 mm. All these amphipods were obtained in opaque bucket whose diameter is 15 cm.

2.2. Turbidity Level

6 different turbidity levels were set and used in experiments. To fine the best material which can make a constant turbidity environment, three different materials were tested, including clay, mud and kaolinite. The result showed that kaolinite was the best material to make an anthropogenic turbid environment for crabs and shrimps. Although kaolinite achieves the most constant turbidity level among these three materials, the turbidity still slightly decreases due to the sedimentation of kaolin over time. The concentration of kaolinite to make different turbidity level was listed as follows (Table 1). A turbidimeter was used to test the turbidity level from 0 NTU to 200 NTU. Distilled water were used to set 0 NTU as standard. All the water used in the experiment was in the form of 35g/L sea salt in dechlorinated tap water. Experimental waters with different turbidity levels were prepared in six different water tanks (585 x 383 x 400 mm).

2.3. Experimental Set-up

Arenas were used transparent buckets whose diameter is 17 cm. The bucket contains 700 ml of water, which can provide a foraging environment. There are no obstacles in the arena. The temperature of a 1-hour trial is 15°C. In each arena, the number of preys, which is amphipods in this experiment, was recorded twice: before and after each trail. All recorded data were shown below: date, trail number, temperature, arena area, turbidity, resource species, consumer species, prey density (per arena), preys which are eaten by consumer and preys survived. Due to the accidental death of amphipods, the number of preys eaten, and number of preys survived were recorded, respectively. For all turbidity levels, 188 experiments were performed. Under each condition of turbidity level and resource density, there were at least three repetitions. All experimental details were listed in Table 1.
Functional responses show the relationship between per capita consumer feeding rates and resource availability [12,13]. The equation of functional responses is defined as [14]:

$$N_e = \frac{bN^{q+1}}{1+bhN^{q+1}}$$  
(Eqn. 1)

$N_e$ is the per capita consumption rate (individuals s-1), $N$ represents the resource availability which is resource density here (individuals m$^2$ or m$^3$). $b$ is the search coefficient of the consumer which can also substitute for the capture rate (m$^2$/s or m$^3$/s); $h$ (s) is consumer handling time and $q$ is the scaling exponent which determines the functional response type. Where $q$ is 0, $b$ is constant with $N$ which is type II, functional response is a decelerating hyperbola; where $q > 0$, $b$ follow a power-law with $N$ which is type III, often suggesting that consumers is learning during their foraging process, functional response is a sigmoidal form [14,15].

### Table 1. Prey density used in each turbidity level

| Turbidity Level (g/L) | Prey Density (Individuals/arena) |
|-----------------------|----------------------------------|
| 0.00                  | 1, 2, 3, 5, 8, 10, 15, 20, 25, 1(control), 20(control) |
| 0.04                  | 1, 2, 3, 5, 8, 10, 15, 25, 30, 40 |
| 0.08                  | 1, 2, 3, 5, 8, 10, 15, 25, 30, 40 |
| 0.15                  | 1, 2, 3, 5, 8, 10, 15, 25 |
| 0.20                  | 1, 2, 5, 10, 15, 1 (control), 15(control) |
| 0.30                  | 1, 2, 3, 5, 8, 10, 15, 25, 25 (control) |

Control: No consumer in the arena.

### 2.4. Statistical Analysis

All the data analysis is performed by the statistical software R (3.6.1) [16]. There are three models that can be used to determine the type of functional response: Type II model, Type III model and flexible model. Under each condition, the best fitted model will be selected by R$^2$. In each model, the search rate $b$ and the processing time $h$, which are the only two coefficients in the Holling’s model, will be fitted. Then the models of turbidity level and the search rate $b$ and the processing time $h$ will be constructed, respectively. Based on these models, the mechanism of how the turbidity level affect the consumption rate can be understood initially.
3. Results

![Figure 1](image1.png)

**Figure 1.** Functional response model comparison. The three lines in different colour shows the fitting curve under three different models: Type II model, Type III model and flexible model.

As can be seen from Fig.1, except for the turbidity of 0.2 g/L, the best fitting model across turbidity levels is Type II model. When the turbidity level is 0.2 g/L, the best fitting model is flexible model and the scaling exponent is over 3, and the proportion of preys eaten is negative against prey density. As a result, the model of turbidity under 0.2 g/L was also selected as Type II model.

![Figure 2](image2.png)

**Figure 2.** Type II model component against turbidity level. A) Type II search rate against Turbidity. B) Handling time against Turbidity.

The result was indicated that both search rate and handling time are positively correlated with the turbidity level (Fig.2 A: solid line: adjusted $R^2$: 0.40; B: solid line$R^2$: 0.11). The dotted line represents a model fitted with no data at 0 g/L turbidity (Fig.2 A: dotted line: $R^2$: 0.76; B: dotted line: adjusted $R^2$: 0.79). All models are weighted. Weight is used as $1/(s.e.)^2$.)
4. Discussion and Conclusion

In Fig.1, the Type II model is the best fitted model for each turbidity condition. This implies that the foraging interaction between crabs and amphipods is a Type II functional response which can help the prey population remain stable.

It can be seen from Fig.2 that as the turbidity level rises, the handling time increases. According to the Equation 1, the maximum $N_c$ equals to $1/h$. As a result, as the turbidity increases, the maximum number of preys consumed by the predator decreases. There are several possibilities for this phenomenon. On the one hand, it may be more difficult for predators to catch prey due to the reduced vision and limited reaction distance. This may increase processing time. On the other hand, in a turbid environment, consumers may need to walk around and check the danger in the environment. This may also lead to increased handling time.

The capture rate of functional response also has an upward trend with increased turbidity level. The effect of environmental change is two-way. At higher turbidity levels, predation becomes more difficult due to low response distance. More time will be requested for the consumer to detect resource. At the same time, prey may not notice predators as easily as clear water. This can increase the capture rate.

New models were built because higher $R^2$ were gotten when the data under clear water were deleted. This shows that the behaviour of both consumer and resource are not fitted the model when the water is totally clear. Most crabs used in this experiment were living at the bottom layer of seashore. They need rocks and turbid environment to hide themselves when they are foraging. They behaved much careful under this condition. This could be the reason that why they have lower capture rate when the turbid level is 0. Furthermore, crabs may be accustomed to the turbid waters at the bottom of the intertidal zone because they always stir up the sand at the bottom when they are moving. Completely clear water is not the optimal foraging condition for those crabs.

As a result, the capture rate is rising as water turbidity level increases. The handling time and search rate will also increase. This implies that turbidity of water will affect the foraging behaviour of consumer. To further understand how exactly these components work, future study is needed. More data should be extracted, and computer learning should be used to obtain more data from videos of predation. In this way, more detailed and accurate data of factors in the Holling’s model can be obtained. On this basis, the existing model can be refined. If more about the mechanism of turbidity’s effect is needed to be understood, further research is required to gain more details.

5. Acknowledgements

This project is supervised by Samraat Pawar and Daniel Barrios-O’Neill. Samraat offered lots help on coding and modelling meanwhile it is Daniel that help me to collect crabs and amphipods and offer me equipment to do experiments. Both of them made great contributions to this project.

6. Reference

[1] Neutel, A. M. & Thorne, M. A. S. Linking saturation, stability and sustainability in food webs with observed equilibrium structure. Theor. Ecol. (2016) doi:10.1007/s12080-015-0270-z.
[2] Baek, H., Do, Y., Lim, Y. & Lim, D. A three-species food chain system with two types of functional responses. Abstr. Appl. Anal. (2011) doi:10.1155/2011/934569.
[3] Barrios-O’Neill, D. et al. On the context-dependent scaling of consumer feeding rates. Ecol. Lett. 19, 668–678 (2016).
[4] Laverty, C. et al. Assessing the ecological impacts of invasive species based on their functional responses and abundances. Biol. Invasions 19, 1653–1665 (2017).
[5] Dick, J. T. A. et al. Functional responses can unify invasion ecology. Biol. Invasions 19, 1667–1672 (2017).
[6] Pawar, S., Dell, A. I. & Savage, V. M. Dimensionality of consumer search space drives trophic interaction strengths. Nature 486, 485–489 (2012).
[7] Kalinkat, G. et al. Body masses, functional responses and predator-prey stability. Ecol. Lett. 16, 1126–1134 (2013).
Barrios-O’Neill, D., Dick, J. T. A., Emmerson, M. C., Ricciardi, A. & Macisaac, H. J. Predator-free space, functional responses and biological invasions. Funct. Ecol. 29, 377–384 (2015).

Englund, G., Öhlund, G., Hein, C. L. & Diehl, S. Temperature dependence of the functional response. Ecol. Lett. 14, 914–921 (2011).

South, J., Dick, J. T. A., McCard, M., Barrios-O’Neill, D. & Anton, A. Predicting predatory impact of juvenile invasive lionfish (Pterois volitans) on a crustacean prey using functional response analysis: effects of temperature, habitat complexity and light regimes. Environ. Biol. Fishes 100, 1155–1165 (2017).

Martin, R. A., Hammerschlag, N., Collier, R. S. & Fallows, C. Predatory behaviour of white sharks (Carcharodon carcharias) at Seal Island, South Africa. J. Mar. Biol. Assoc. United Kingdom 85, 1121–1135 (2005).

Holling, C. S. Some Characteristics of Simple Types of Predation and Parasitism. Can. Entomol. 19, 385–398 (1959).

Holling, C. S. The Functional Response of Invertebrate Predators to Prey Density. Mem. Entomol. Soc. Canada 98, 5–86 (1966).

Real, L. A. The Kinetics of Functional Response. Am. Nat. 111, 289–300 (1977).

Pritchard, D. W., Paterson, R. A., Bovy, H. C. & Barrios-O’Neill, D. frair: an R package for fitting and comparing consumer functional responses. Methods Ecol. Evol. 8, 1528–1534 (2017).

Team, R. D. C. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing vol. 2 https://www.R-project.org (2018).