THE PENNSYLVANIA STATE UNIVERSITY
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DISCOVERING DIFFERENCES OF EYESPOT SIZE AND COLOR IN INVASIVE *NEOGOBIUS MELANOSTOMUS* USING LOCAL ERIE POPULATIONS

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ABSTRACT

The round goby (*Neogobius melanostomus*) is an invasive fish first discovered in Lake Erie in the 1990s. Since its introduction, round goby populations have exploded, spreading into Lake Erie's tributaries, negatively impacting other aquatic species and augmenting concerns for biodiversity in the region. One trait that might enhance round goby success in its invasive range is the presence of a prominent eyespot on the dorsal and pectoral fins, a color pattern that mimics the eye of a larger vertebrate to intimidate predators. To determine how the eyespot contributes to round goby's invasion success, we first must document variation in round goby eyespot size and color between populations in the Pennsylvania Lake Erie watershed. Round gobies were collected from Lake Erie and its tributaries, and the eyespot on each round goby's dorsal and pectoral fins were photographed. Photographs were then calibrated and quantified for red, green, and blue color values within five regions on the dorsal fin. A principal components analysis (PCA) was used to consolidate all the values into one color axis. The size of the dorsal eyespot, as well as goby length and sex, were also recorded. Our results show that eyespots are abundant in all the sampled locations, but the eyespots vary in size and color depending on the Lake Erie environment. On average, round goby from tributaries had smaller, lighter-colored eyespots than Lake Erie goby, but tributary goby were more likely to exhibit pectoral eyespots. This study helps us to study the variation between round goby populations, to distinguish round gobies from native look-alikes, and to learn about the importance of an eyespot as an anti-predator defense.

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All research was conducted in accordance with IACUC protocols and PA Fish and Boat Commission regulations permit number 2022-01-0271.

Chapter 1

Introduction

Non-native, invasive species quickly spread through environments of all types, resulting in ecological and economic damage (Simberloff 2013, Crystal-Ornela et al. 2021). The resulting decrease in biodiversity decreases ecosystem stability and resilience and harms those who depend on these diverse resources (Rafferty, 2024). Indeed, areas with more resources are more likely to be vulnerable to invasion by species with a high competitive ability (Perkins & Nowak, 2013). How and why certain non-native species become invasive, however, is unknown.

Various hypotheses explain invasive species' success. One of the most widely proposed hypotheses is the Enemy Release Hypothesis. This hypothesis states that invasive species do well where they have been introduced because they do not have the natural enemies that controlled them in their native range. One specific prediction is that the invasive species co-evolved with the pathogens they were introduced to, spreading pathogens rampantly in native species (Liu & Stiling, 2006). Another proposed hypothesis is the Resource Hypothesis, which states that the new environment the species has been introduced to is better suited to their life history than their native range. The invasive species would, therefore, adapt well to the new environment and have a competitive advantage. Invasive species also improve one aspect of their niche over time the longer they are in the habitats they have invaded—their anti-predator defenses, contributing to their success.

Anti-Predator Defenses

Many prey species have strategies to avoid being seen, captured, or killed by predators. Some of these anti-predator defense strategies include crypsis, i.e., the ability of an organism to disguise its appearance to blend in with its surroundings (Arbuckle & Speed, 2015), and warning coloration, i.e., bright colors and patterns that startle predators or warn predators of a defense (Vallin et al., 2011). Another form of defense is mimicry, which is when prey use color patterns or behavior to mimic something dangerous, like another predator or unpalatable organism. Through mimicry, potential predators can become discouraged or threatened by the presence of an enemy and avoid attacking the prey (Stevens et al., 2008). This trait is widespread in the environment, but not well studied to understand its importance as a type of mimicry.

Eyespots

Eyespots, a specific type of anti-predator mimicry, consist of concentric rings of differing colors that resemble the eye of a larger vertebrate. Eyespots increase prey survival by deflecting attacks to nonessential body regions, allowing the prey to escape, or by intimidating potential predators and preventing them from attacking in the first place (Kjernsmo and Merilaita, 2013). These eyespots vary in size, position, and style according to the organism and its environment. For example, the eyespot on a butterfly is larger and varies in color compared to a round goby fish. How the variation in eyespot characteristics influences their effectiveness is unknown. Still, some hypotheses suggest that a larger eyespot is more beneficial for prey so they can better replicate the appearance of the predator's enemy.

The location of the eyespot plays an important role in where predators attack. Eyespots are often strategically placed to protect the prey in case of a predator strike. With the eyespot, the attention of the predator is diverted to attack another part of the prey's body, which allows the prey to experience less damage from the strike. For example, many species of fish have an eyespot in the dorsal region of their bodies that is larger than their actual eye. Having two sets of eyes makes it difficult for the predator to decide where to focus. Some say that the posterior position of the eyespot creates the appearance of the head as being at the end of the organism's body (Kjernsmo and Merilaita, 2013), yet the adaptive value of the location of the eyespot is unknown for many species.

Study Subject

The round goby (*Neogobius melanostomus*), a small fish native to central Eurasia that has been introduced into North America, possesses prominent dorsal and pectoral eyespots (Figure 1). During the 1990s, gobies were discovered in North America in the St. Clair River, which connects Lake Huron and Lake Erie. Since this discovery, gobies have invaded and spread throughout the Laurentian Great Lakes at a very fast rate (Kornis et al., 2012). Gobies are a very successful invasive species because they can expand their range by going upstream and downstream in flowing water bodies, using secondary transport to enter new habitats, migrating between connected water bodies, and expanding their range as larvae drift downstream after hatching (Mikl et al., 2017). It has been found that round goby feed on a wide range of different resident species, such as mollusks and crustaceans, which impacts other species and their food sources (Oesterwind et al., 2017). Goby are also predators of lake trout (*Salvelinus namaycush*) eggs, threatening efforts to restore Lake Erie's lake trout population (Marsden et al., 1996). The abundance of goby has created competition between native species to find resources required to survive (Oesterwind et al., 2017). However, with the introduction of a new fish species, some piscivorous fish and bird species shifted their attention to this abundant food source. How much native species predate on round goby is unknown. Despite some predation by native species, goby populations have continued to increase. It is possible that investigating the round goby's eyespot can yield insights into how predation impacts invasive goby.

Invasive round goby populations have been documented to vary in their eyespot's presence, size, and color. Historic estimates of round goby in Lake Erie documented 80% of goby with eyespots present on the dorsal fin (Cavender et al. 1996). This variation between individuals could be due to differences in predation pressure. Without the eyespot, gobies could be more susceptible to predation. Alternatively, the eyespot may become less prevalent if it is not an effective defense. To determine the eyespot's role in the success of round goby, studies must first systematically document variation in goby eyespots and determine how eyespot characteristics vary between individuals in their invasive range.

Eyespots are an anti-predator mechanism that changes with the amount of predation pressure in the environment. As with all traits that require energy investment from organisms to create and maintain, there is the assumption that if the pressures driving a trait decrease, the trait should be reduced or lost. Thus, if there is less predation pressure, we should see less investment in anti-predator defenses. It is currently unknown why all round goby do not exhibit dorsal eyespots.

In addition to these unknowns, we observed that round goby have a secondary eyespot on their pectoral fins (hereafter referred to as pectoral eyespots). To date, the pectoral eyespot of round gobies has been largely ignored; the variation in this trait is undocumented and poorly understood.

Using populations of round goby in the Pennsylvania waters of Lake Erie, this research aimed to document the variation in size and color of round goby dorsal eyespots and the proportion of goby with pectoral eyespots present. We aimed to determine if this variation differs between local populations, especially Lake Erie and tributary sampling locations, and to further investigate local variation in the pectoral eyespots. To do this, we collected goby from several Lake Erie and tributary locations and used image processing software to quantify variation in eyespot size and color. We then analyzed size and color data to determine if there were differences in eyespot characteristics between locations.

Chapter 2

Materials and Methods

To accomplish our objective, we collected round goby from Raccoon Creek, Elk Creek, Trout Run, Walnut Creek, Presque Isle Bay locations, Fourmile Creek, and Sixteenmile Creek from May 16, 2022, to July 22, 2022 and from June 19th, 2023 to August 18th, 2023 (Figure 2). Collection methods incorporated the use of hook-and-line, minnow traps, and kick seines. Upon collection, round goby were euthanized and separated into four distinct age classes based on size (0-40mm, 40-60mm, 60-90mm, and 90+mm; Thompson and Simon, 2015). We aimed to collect 20 individuals per age class per location. We used these four age classes to distinguish between fish that are zero, one, two, and three years old and older, respectively. We anticipated that our desired sample size will not be collected in a single bout of sampling, therefore we planned for three instances of round goby collections to occur throughout the summers. All research was conducted under IACUC protocols and PA Fish and Boat Commission regulations permit number 2022-01-0271.

Photographing Round Goby

After returning to laboratory facilities on Penn State Behrend's campus, all collected goby were photographed. To capture the difference in the appearance of each eyespot, the round gobies were positioned with the dorsal fins at the top, the ventral fins at the bottom, the head or anterior part of the body to the left, and the tail or the posterior end of the body to the right of the photograph. The dorsal fin was completely extended using a pin, and the fin was splayed out on a foam board so that the eyespot was visible. Photos were taken using a digital single-lens reflex (DSLR) camera, and an X-Rite ColorChecker Passport was opened to incorporate the full color palette and white balance features. It was properly placed at an adequate height next to the round goby in each photo, along with a dry-erase rectangle with the site identification and the goby number. One to three photos were taken of each goby depending on the picture quality with the lighting.

Eyespot Size Quantification

To quantify the size of round goby eyespots, ImageJ software was used to edit, analyze, and process images. ImageJ bundled with 64-bit Java 8 is a public Java image processing program that can calculate pixel and area value statistics as well as measure angles and distances (Rasband, 2012). Each picture was opened as a .jpg file and calibrated using the software. After measuring one millimeter on the ruler included in the photo, the 'Analyze' tab was used to set the scale for each picture by changing the known distance to 1.0 and the unit of length to millimeters. This setting was saved and utilized for each photo from a specific location. After a photo location was calibrated, the settings were changed to match the next set of photos. The zoom and polygon icons were used to isolate each eyespot in the photo and measure the area of the black/gray portions of the eyespot from the images of the goby (Figure 3).

The length and weight of each round goby were measured to account for goby size. Goby length was quantified using ImageJ. The ImageJ software has a straight-edge tool that allows for an exact measurement from the tip of the nose to the posterior edge of the tail. This gives an exact measurement based on the pixels calibrated with each photo. A digital balance weighed each fish to the nearest 0.01 g. The sex of each goby was determined by looking at the shape of the urogenital papilla. Males tend to have a more elongated papilla that protrudes downward while females have a shorter and rounder papilla.

Eyespot Color Quantification

Studying variation in round goby eyespot color is important as the darkness of the black/gray portion of the eyespot might play a role in the effectiveness of this trait for defense. Using methods similar to Mack and Beaty (2021), we quantified the average red, green, and blue (RGB) values within the black/gray regions of the eyespots using Adobe Photoshop 2023. A principal component analysis was used to summarize the RGB values into one that summarizes each eyespot region's color.

Organization of the photographs was completed along with the processing of each picture in R version 3.6.1 using a Shiny app (Cheng et al. 2019). This software calibrated the colors in every photo with the colors on the ColorChecker Passport. This would facilitate color comparisons between photos and allow for better data. Once the photos were calibrated, each photo was individually white-balanced in Adobe Lightroom Classic.

The red, green, and blue values were quantified using Adobe Photoshop by importing each white-balanced photo into the program. The marquee tool was set to rectangular with fixed dimensions of 10 x 10 pixels for sampling colors with the dorsal eyespot. Five points on each eyespot were sampled for color: the top left, top right, bottom left, bottom right, and one in the center (Figure 4). A histogram opened on the software and the red, green, and blue values for the selected sample regions were recorded.

Statistical Analysis

We used ANOVAs to determine if there were differences in eyespot size and color between local populations of round goby in Lake Erie. Analysis of variance is a widely used statistical technique that a range of professions utilize for results. It tests the significance of mean differences amidst differing groups of data (Tabachnick & Fidell, 2007).

Although the weight and length of each goby were measured, these two metrics were highly correlated ($r=0.86$ [0.84, 0.88] 95% CI). So, only the results of the length are discussed in more detail. To determine if the length of male and female round goby differed between lake and tributary locations, we fit a linear mixed model containing the fixed effects of sex, location, and the interaction between the two. Collection site was nested within sampling year as a random effect.

We calculated body condition by dividing goby weight (g) by goby length (mm). The resulting body condition data were right-skewed and log-transformed prior to analysis. To determine if male and female round goby body condition differed between lake and tributary locations, we fit a linear mixed model containing the fixed effects of sex, location, and the interaction between the two. Site was nested within sampling year as the random effect.

The difference in population sex ratio between lake and tributary locations was assessed using a generalized (binomial) linear mixed model with a logit link function. Location was treated as a fixed effect, and collection site was considered a random effect. Preliminary analyses suggested that year was not a significant contributor to the random effects ($\Delta AIC > 2$) and was, therefore, not included in the analysis.

The factors influencing the proportion of goby with an eyespot present on their dorsal or pectoral fins were assessed using generalized (binomial) linear mixed models with a logit link function. Location, sex, and the interaction between the two were treated as fixed effects and site was nested within sampling year as a random effect. For pectoral eyespots, preliminary analyses suggested that variation between sites did not play a significant role in random variation ($\Delta AIC > 2$), so it was not included in the analysis.

Goby dorsal eyespot size was significantly and positively correlated with goby length ($r=0.88$ [0.87, 0.90] 94% CI). So, we conducted our analyses on size-corrected measures of dorsal eyespot size (i.e., dorsal eyespot area/length). Not all collected goby had their dorsal eyespot size measured from photos ($N=747$ vs. complete data $N=860$) due to inadequate photo quality or the eyespot being shredded to where an accurate area could not be obtained. Preliminary analyses indicated that collection year and site had negligible effects on size-corrected eyespot areas ($\Delta AIC >2$). So, we ran a linear model containing location and sex as fixed effects on size-corrected dorsal eyespot area values to determine the factors that influenced dorsal eyespot size.

We assessed variation in dorsal eyespot color using goby collected in 2022 and only assessed 30 goby per site (N=260). For each goby, we averaged their five RGB values to result in one R, G, and B value per individual. These three values were then collapsed into one color axis using a principal components analysis (PCA). The first principal component (PC1) explained 97.5% of the variation in the data, so the values of this component were used to assess the factors influencing goby eyespot color. Each average R, G, and B value was positively associated with PC1 (loadings: R = 0.985, G = 0.997, B = 0.980). Thus, smaller values along the PC1 axis represent darker colors.

We then performed model selection analysis with PC1 as the response variable and alternative model combinations containing body length, sex, site, and location as fixed factors. Models were then assessed by comparing Akaike's Information Criterion corrected for small sample sizes (AICc) such that the model with the lowest AICc score was considered to be the most supported.

All analyses were conducted in R version 4.4.1 (R Core Team 2024). Linear mixed-effects models were fit using the "nlme" package (Pinheiro & Bates 2000, Pinheiro et al. 2023) and generalized linear-mixed effects models were fit using the "lme4" package (Bates et al. 2015). The PCA was run using the "FactoMineR" package in R (Le et al. 2008), and visualizations of the variation in dorsal eyespot color were created using the "scatterplot3d" (Ligges and Mächler 2003) package. Model selection analysis was accomplished using the "AICcmodavg" package (Mazerolle 2023).

Chapter 3

Results

In 2022, we collected round goby from twelve different locations around the Pennsylvania shore of Lake Erie and its tributaries. In 2023, we collected round goby from ten different locations in Lake Erie and its tributaries. A total of 1,011 round goby were collected and analyzed from all locations to acquire a large data set for determining differences in eyespot size and color (Table 1). Eyespots were abundant in all the sampled locations, but the eyespots vary in size and color depending on the Lake Erie environment.

Round goby length differed by location and sex and had a significant interaction between location and sex (conditional R^2 = 0.69, marginal R^2 = 0.68; Figure 5). Tributary goby were shorter, on average, than lake goby (β= -25.99, 95% CI[-31.19, -20.79], t(18) = -10.50, $p < .001$). Male goby were longer than female goby (β = 10.47, 95% CI [7.54, 13.41], t(837) = 7.01, $p < .001$). Male goby from tributaries, however, were shorter than female gobies from tributaries (β = -13.83, 95% CI [-17.66, -9.99], t(837) = -7.08, $p < .001$).

Like round goby length, goby body condition differed by location and sex and had a significant interaction between the two (conditional R^2 = 0.82, marginal R^2 = 0.41; Figure 6). Tributary goby had lower body condition, on average, than lake goby (β= -0.90, 95% CI [-1.10, -0.69], t(18) = -9.24, $p < .001$), and male goby had higher body condition than female goby (β= 0.23, 95% CI [0.14,0.33], t(837) = 4.72, $p < .001$). Male goby from tributaries, however, had lower body condition than female gobies from tributaries (β = -0.45, 95% CI [-0.58, -0.32], t(837) = -6.96, $p < .001$).

Population sex ratio did not differ between lake and tributary locations (conditional R^2 = 0.06, marginal R^2 = 0.01; Figure 7). Although there were slightly more females found in tributary locations, the proportion was not significantly different from lake populations (β = 0.37, 95% CI [-0.15, 0.90], p = 0.164).

The proportion of captured goby possessing a dorsal eyespot did not differ between locations or sexes, nor was there a significant interaction between location and sex (Location: β = -0.55, 95% CI [-1.55, 0.44], p = 0.275; Sex: β = 0.14, 95% CI [-0.68, 0.97], p = 0.731; Location*Sex: β = -0.40, 95% CI [-1.39, 0.59], p = 0.431; conditional R^2 = 0.14, marginal R^2 = 0.05). In contrast, location significantly impacted the proportion of captured goby with a pectoral eyespot (conditional R^2 = 0.24, marginal R^2 =

0.04; Figure 8). Goby from tributary populations were more likely to possess a pectoral eyespot than goby from lake populations (β= 0.65, 95% CI [0.04, 1.26], p = 0.036). The impacts of goby sex and the interaction between sex and location were not significant (Sex: β = -0.14, 95% CI [-0.67, 0.39], p = 0.599; Location*Sex: β = 0.20, 95% CI [-0.51, 0.92], p = 0.583).

Location, sex, and the interaction between the two explain a statistically significant and substantial proportion of variance in size-corrected dorsal eyespot area ($R^2 = 0.48$, F(3, 743) = 229.36, p < .001; Figure 9). Goby from tributaries had smaller dorsal eyespots than lake goby (β = -0.06, 95% CI [-0.07, -0.04], t(743) = -9.22, p < .001), and males had larger dorsal eyespots than females (β = 0.02, 95% CI [0.01, 0.03], t(743) = 4.21, p < .001). However, male goby from tributaries had smaller dorsal eyespots than female goby from tributaries (β = -0.03, 95% CI [-0.05, -0.02], t(743) = -4.90, p < .001).

The most supported model to explain variation in eyespot color contained only collection site (Table 2; F(7,252)=28.89, p<0.0001, R^2=0.43; Figure 10). While many sites did not differ from each other in eyespot color, individuals collected from South Pier (p=0.0009) and Elk Creek (p<0.00001) were darker, and individuals collected from Walnut Creek were lighter than individuals collected elsewhere (p=0.04).

Chapter 4

Discussion

Though we found variation in round goby size between Lake Erie and tributary locations, dorsal eyespots were ubiquitous. Dorsal eyespots varied in size and color depending on their environment; however, they occurred less frequently and were smaller in tributary populations than the Lake Erie populations. Pectoral eyespots were observed more frequently in tributary goby than in Lake Erie goby.

There was a notable difference in round goby length by location and sex. The tributary goby, on average, were shorter than Lake Erie goby. Regarding sex, the males were longer than the females in the

Lake Erie populations but shorter than the females in the tributary locations. Body condition was also lower in the tributary goby than in the Lake Erie goby. Together, our length and body condition results suggest that tributaries provide fewer resources for round goby. Thus, the Resource Hypothesis cannot explain their success in these novel habitats. It is possible that competition among goby in the main Lake drove goby to live in these, apparently, suboptimal habitats. Future studies should examine competition-related behaviors and outcomes in round goby to better understand round goby tributary use.

The area of the dorsal eyespot was larger in Lake Erie round goby than in the tributary populations, and Lake Erie male goby had larger dorsal eyespots than females. In tributary locations, the males had smaller dorsal eyespots than females. The dorsal eyespots of Lake Erie goby may be larger to more accurately mimic the eyes of the larger predators found in the Lake compared to the smaller predators inhabiting tributary ecosystems. Furthermore, male goby collected at Lake locations may have had larger eyespots than females to aid in their defense of nest sites. Male round goby found in Lake Erie defend nests where multiple females have deposited eggs and larger eyespots may dissuade other males or potential predators from attacking while the male is defending a nest. It is currently unknown if male round goby from tributary locations also participate in similar reproductive behaviors. Future studies should examine behavioral differences between Lake Erie and tributary male round goby to elucidate the mechanism underlying these observed sex differences in dorsal eyespot size.

While the presence of a dorsal eyespot was not different between Lake Erie and tributary round goby populations, but more pectoral eyespots were present in the tributary populations than the lake populations. This suggests different predation pressures in the tributaries than in the Lake Erie waters. Alternatively, this could be due to differences in the abiotic conditions that the fish experience. For example, in the shallower waters of the tributaries, where predators are more likely to be encountered head-on and at the same depth as the goby, pectoral eyespots may confer a stronger survival benefit than dorsal eyespots.

The only previous record detailing round goby eyespot defenses is from 1996, shortly after round gobies were introduced into Lake Erie. At this time, 80% of round goby collected from Lake Erie possessed a dorsal eyespot (Cavender et al., 1996). We found that over 80% of the round goby sampled in comparable areas have a dorsal eyespot. This could be due to increased pressures from native predators and the continued need for a trait to help survival rates. Future studies should examine differences in predator attention between goby with differing eyespot sizes and arrangements.

Dorsal eyespot color differed between locations. While color varied substantially between locations, a few tributary locations had goby whose dorsal eyespots were lighter or darker in color than the Lake Erie goby dorsal eyespots. Location differences in dorsal eyespot color may be attributed to local habitat differences, resource availability, or a founder effect. Given that light differentially penetrates water based on depth and turbidity, it is possible that the benthic lighting conditions varied greatly between sampling locations. This difference in lighting condition would aid in selecting differences in eyespot color to make them more or less obvious, depending on the predator regime. Furthermore, given that the dark portion of eyespots is melanin-based, which is a costly pigment to produce and maintain, it could be that the variable resource quality of tributary locations influenced goby ability to produce and maintain darkly pigmented eyespots. Lastly, it is possible that differences in eyespot color occur between locations because the invasive individuals founding that local population exhibited different eyespot colors. For example, the round goby population in Walnut Creek could have been initiated by individuals with lighter-pigmented eyespots. If there were little movement between round goby populations, then the subsequent round goby population at that location would also have lighter dorsal eyespots.

This research determined the abundance and population variation in eyespot characteristics of invasive round goby in Lake Erie. Although round gobies have only been in Erie, Pennsylvania since 1990, they have had dramatic negative effects on the native ecosystem. Goby are eating prey in large quantities which makes it very difficult for populations of native species to survive. Specifically, round goby target invasive zebra mussels (*Dreissena polymorpha*) as a food source. The consumption rate has increased dramatically, making the mussels alter their size due to heavy predation and increasing round goby population growth rates. Therefore, round goby may become more widespread and cause additional issues for other species (Cavender et al., 1996).

Round goby eyespots can also help distinguish round goby and native species that look similar, like the sculpins (Cottoidae). Many native fish species do not possess an eyespot and information regarding proper identification of round goby disseminated to the general public often uses the presence of the eyespot as a key characteristic when identifying goby. If the round goby resembles the appearance of native species, humans will have more difficulty telling the difference between an invasive species and a native species, possibly resulting in the removal of native species or the introduction of non-native species. Our results show that the eyespot is prominent in these invasive populations and can still be used as an important distinguishing feature to identify this species.

From this information, it is possible to speculate that the eyespot of the round goby has contributed to their success as an invasive species. As such, future research should more accurately determine variation in native predation pressure on round gobies. In addition, future studies on the effectiveness of eyespots as an anti-predator defense in goby would also be helpful in determining their importance for fish survival.

FIGURES

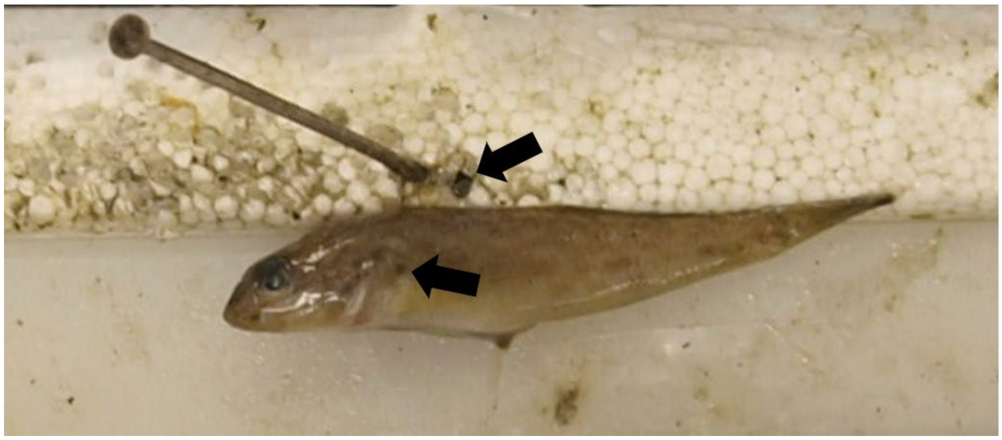

Figure 1. Eyespots present on the dorsal and pectoral fins of a round goby. The eyespots are used for mimicry to intimidate their predators. (Photo by M. Causer)

Figure 2. A map detailing the sampling locations throughout Erie County where round goby were collected.

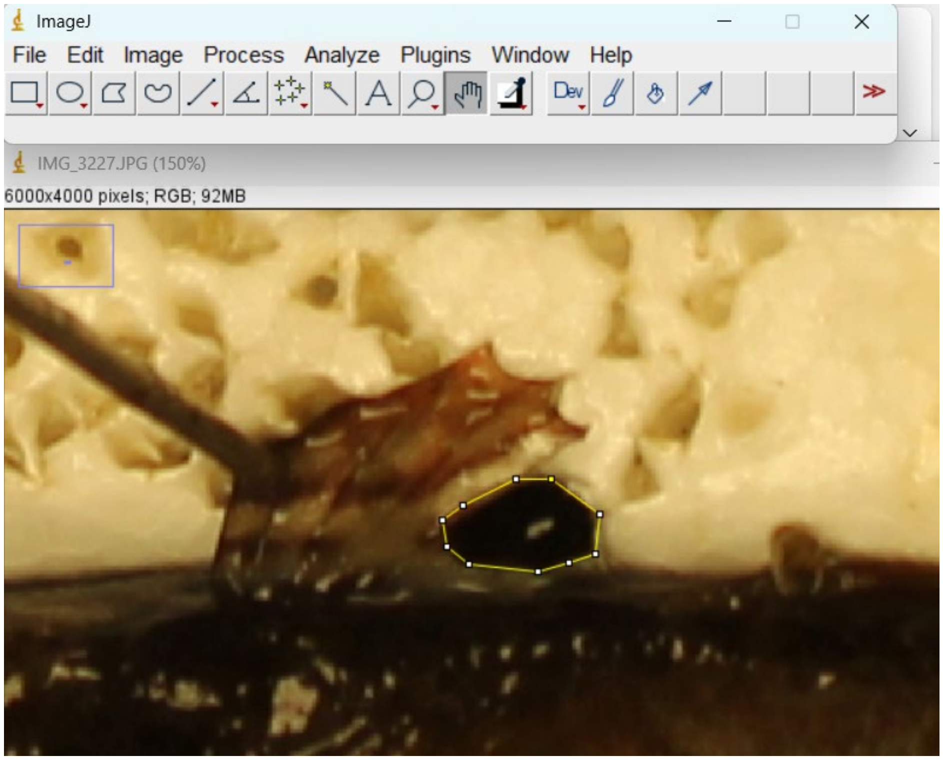

Figure 3. An image showing the use of the polygon tool in ImageJ to get the dorsal eyespot area measurement (Photo by M. Causer).

Figure 4. The five locations on the round goby dorsal fin eyespot sampled for red (R), green (G), and blue (B) values to assess dorsal eyespot color.

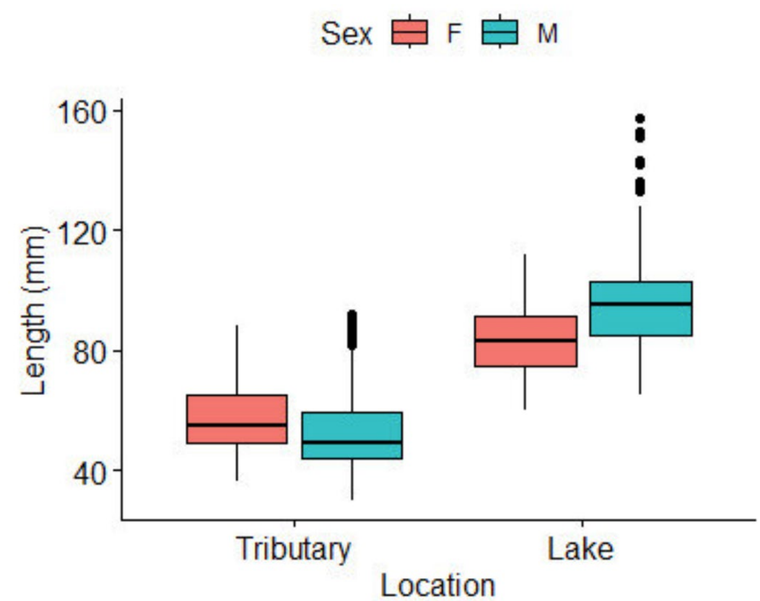

Figure 5. Length of male (M) and female (F) round goby collected from Lake Erie and tributary locations in 2022 and 2023.

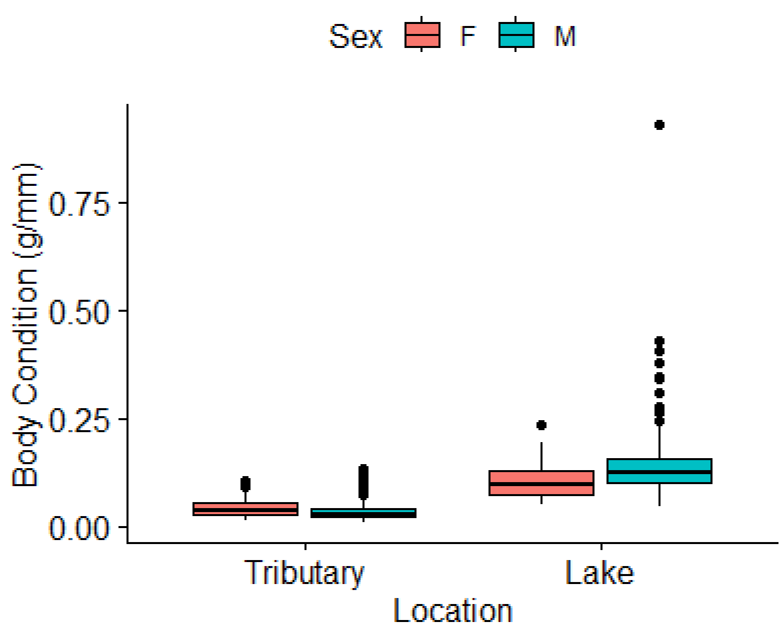

Figure 6. The body condition of male (M) and female (F) round goby collected from Lake Erie and tributary locations in 2022 and 2023.

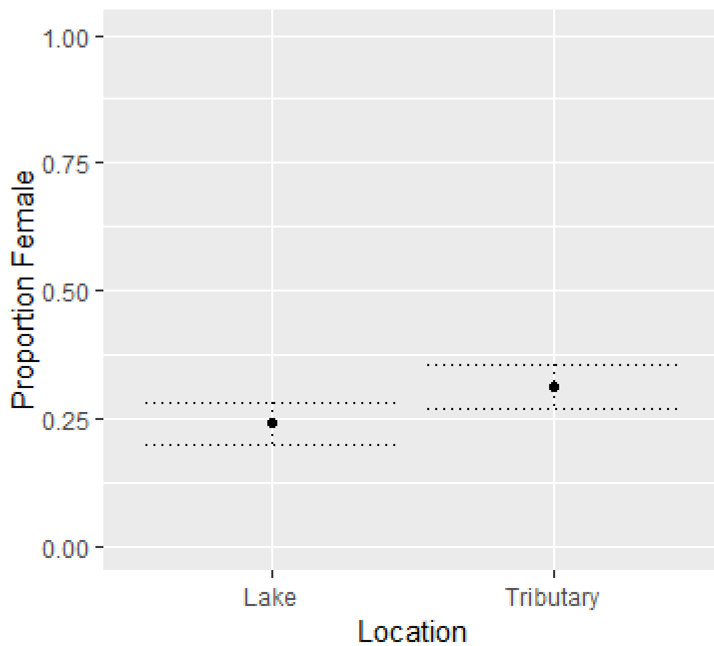

Figure 7. Round goby sex ratios in Lake Erie and tributary locations. Points indicate means and error bars indicate standard error of the mean.

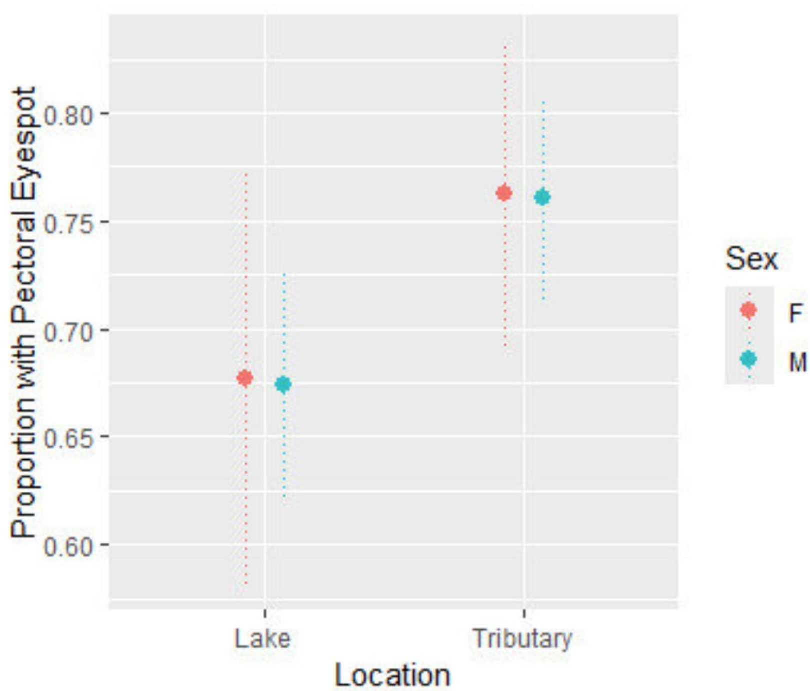

Figure 8. Proportion of male (M) or female (F) round goby that possessed a pectoral eyespot from Lake Erie or tributary populations. Points indicate means and lines indicate 95% confidence intervals.

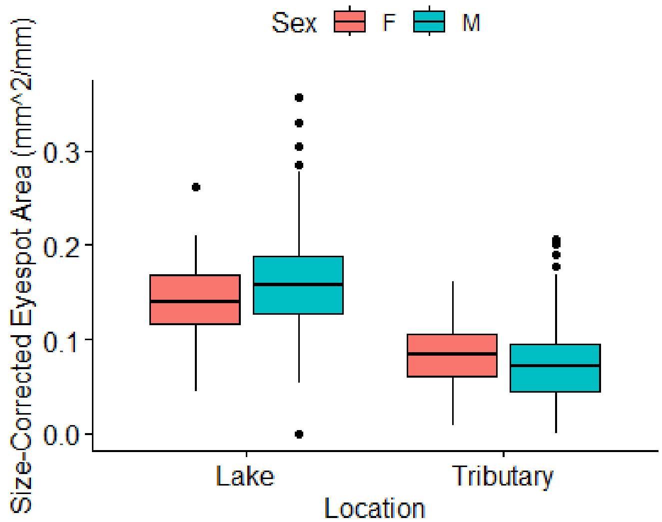

Figure 9. Size-corrected dorsal eyespot size of male (M) and female (F) round goby collected from Lake Erie and tributary locations in 2022 and 2023.

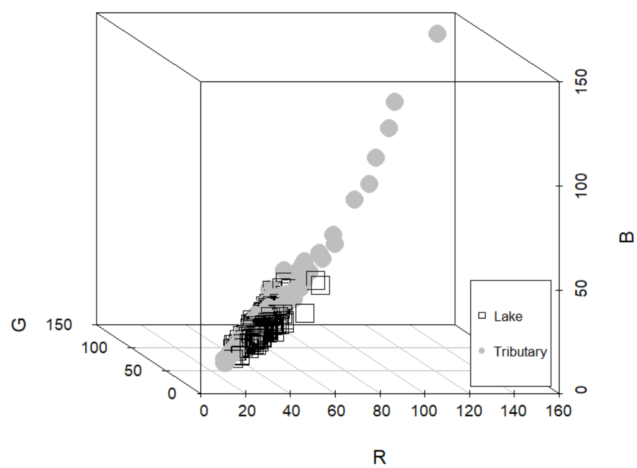

Figure 10. Red (R), blue (B), and green (G) color axes for round goby dorsal eyespots from Lake Erie (open square) and tributary (filled gray circle) sampling locations.

TABLES

Table 1. Round goby sample sizes from 2022 and 2023. Round goby were collected from Lake Erie or tributary locations to observe the difference in size and color of the eyespots.

Location	Lake Erie or Tributary	Year	
		2022	2023
South Pier	Lake Erie	42	36
State Street	Lake Erie	30	30
East Avenue	Lake Erie	43	31
Holland Street	Lake Erie	37	30
Chestnut Pier	Lake Erie	32	31
North Pier	Lake Erie	-	30
Poop hole	Lake Erie	31	-
Elk Creek	Tributary	115	52
Walnut	Tributary	110	69
Four Mile	Tributary	36	58
Sixteen Mile	Tributary	44	88
Trout Run	Tributary	33	-
Raccoon Creek	Tributary	3	-

Table 2. Model selection results examining the factors that influence dorsal eyespot color in invasive round goby found in Lake Erie and its Pennsylvania tributaries. "Site" refers to the specific pier or tributary site that the goby were collected while "Location" refers to whether the goby were collected at a Lake Erie or tributary location. K= number of parameters, AICc = Akaike's Information Criterion corrected for small sample sizes, ΔAICc = change in AICc value relative to the model with the lowest AICc score, Wt = model weight, R^2 = adjusted R^2 value.

Model	K	AICc	ΔAICc	Wt	R^2
Site	9	882.49	0.00	1	0.43
Length	3	1010.96	128.47	0	0.04
Location	3	1014.82	132.33	0	0.03
Null	2	1021.00	138.51	0	0
Sex	3	1022.34	139.84	0	0

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EDUCATION

The Pennsylvania State University, Erie, PA 12/2024

Bachelor of Science in Biology | Health Professions Option

Minor of Science in Chemistry

Penn State Schreyer Honors College Scholar

Dean's List Fall 2021, Spring 2022, and Fall 2022

RESEARCH EXPERIENCE 5/2022 - Present

Research Assistant, Penn State Behrend School of Science, Erie, PA

Thesis Advisor: Dr. Lynne Beaty, PhD.

- Assisted in conducting research on Round Goby, an invasive species in local waters, and discovering differences in eyespot size and color from various populations
- Gained exposure to field and laboratory work as well as working to collect and analyze specimens
- Presented research at the 18th and 19th Annual Research Symposiums in Erie, PA on November 2nd, 2022, and November 8th, 2023. Presented research at the Penn State Behrend Sigma Xi Undergraduate Research Conference on April 22nd, 2023 and April 20th, 2024

ACTIVITIES AND COMMUNITY INVOLVEMENT

Behrend Honors Student Association Club, President 9/2021 - Present

- My role is to run general meetings and coordinate events for the academic year
- The organization aims to develop the existing Behrend Honors College community by providing leadership, academic, social, civic, and community engagement opportunities to members

Scrubs Club, Vice President, President 9/2021 - Present

- Plan and organize events to educate students on healthcare positions that they may potentially be interested in pursuing as a future career
- Provides Behrend students with the resources and instruments necessary for preparation in healthcare professions

Science Ambassadors, Member, Vice President 5/2022 - Present

- Work with active members to create outreach opportunities and promote involvement with the Penn State Behrend science students
- To promote science learning within Penn State Behrend and within the local region through volunteer work, STEM fairs, outreach, and providing tours to prospective students

Beta Beta Beta, Member, Treasurer 9/2021 – Present

- Submit funding forms for the organization to be able to hold events on campus for recruitment or campus involvement
- An honor society recognizing students interested in biology and giving students the opportunity to discuss undergraduate research findings and generally come together as a biological community

Lion Ambassadors, Member, Founder's Day Chair, Treasurer 9/2021 - Present

- The mission and goal of the Lion Ambassadors is to help students, alumni, and friends of the University realize that their involvement with Penn State can and should be a lifetime

experience by sharing their pride, enthusiasm, and commitment to Penn State and to the Behrend College
- Create events celebrating the founding of Penn State Behrend and educating students about the history of the college
- Managed the funding account for the organization and approved any expenses

Alternative Spring Break Program 11/2022 – Present
- Providing service during Spring Break to communities in need all around the country
- The service trip aims for participants to make a positive, lasting impact on the communities they serve
- I participated in a serve trip to Fort Myers, Florida to provide relief from Hurricane Ian damage and I participated in a trip to Puerto Rico

Welcome Week Program 8/2022 – Present
- Create a welcoming atmosphere for the incoming students at Penn State Behrend by promoting student involvement and boosting morale
- I held the position of Welcome Week Leader and my duties consisted of leading a team of guides, getting more experience with logistics and problem solving, having a higher level of responsibility, and assisting the guides with the move-in process

OTHER EXPERIENCES

Patient Care Technician at UPMC Hamot in Erie, PA 5/2023 – 5/2024
- Provides routine patient care including assisting with patient procedures and activities of daily living
- Assists with physical, respiratory and cardiopulmonary therapies as well as providing feedback to the RN regarding patient care and reports changes in patient status
- I perform the UPMC nursing core nursing assistant responsibilities which include blood glucose measurement, weights, vital signs, input and output, telemetry monitor application, specimen collections, Foley care, bladder scanning, simple dressings and IV removal
- Additionally, this position includes bathing, feeding, transporting, toileting, ambulating, turning and repositioning patients
- Being a PCT has given me the opportunity to be exposed to patient care and make connections with colleagues and the patients that I care for

Medical Assistant at Bradford Family Practice in Bradford, PA 5/2024 – 8/2024
- Assist the providers in obtaining vital signs for each patient, documenting important details, completing necessary paperwork, and calling patients regarding test results
- Aid in procedures completed in the office, provide wound care information, and help with scheduling follow-ups

Peer Tutor for the Penn State Behrend LRC in Erie, PA 2/2022 – 8/2023
- Assist students with difficult material in the areas of mathematics, biology, and chemistry
- From this position, I have developed strong communication and interpersonal skills