Fish Association With Different Aquaculture Gear Types

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Lucas Wong

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Lucas Wong

We, the thesis committee for the above candidate for

the

Master of Science degree, hereby recommend

acceptance of this thesis.

Dr. Bradley Peterson – Thesis Advisor
Professor, SoMAS

Dr. Joseph Warren – Second Reader
Professor, SoMAS

Dr. Aaren Freeman – Third Reader
Professor of Biology, College of Arts and Sciences, Adelphi

This thesis is accepted by the Graduate School

Celia Marshik
Dean of the Graduate School

Abstract of the Thesis

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Oyster aquaculture has become more prominent in Long Island, New York, with the help of the Suffolk County Aquaculture Lease Program. Farmers on Long Island use benthic or floating gear to raise seed oysters to market size in 2 years. This aquaculture gear can act as an artificial reef, providing organisms with shelter and a source of food. However, we do not know which species of fish are around the oyster gear on Long Island. For this study, we used time-lapse cameras, the KiloCam and the Brinno Camera TLC 300, to capture images of the fish around the benthic and floating gear and measure their abundance. We observed many juvenile fish and a lack of larger fish around the gear, suggesting that the oyster gear may act as artificial reefs, providing shelter for juvenile fish. We used a binomial generalized linear model to test for presence and absence around the gear and found that fish were more associated with the benthic gear than the floating gear ($p < 0.001$). We also found that the fish community around the benthic gear is more species rich than the floating gear, using the Shannon-Weiner Index equation. This study can help the Long Island Suffolk County Aquaculture Lease Program with management

decisions on what gear types farmers can use, knowing what fish species are around the oyster gear.

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Introduction

Global Aquaculture

Aquaculture has been growing in recent decades to meet the demand for seafood, making up approximately 50% of the world's seafood supply (Botta et al. 2020). Aquaculture is regarded as the breeding, rearing, and harvesting of seafood in aquatic environments where livestock are raised in open or closed aquaculture systems. Open aquaculture systems are net pens or cages open to the surrounding water, allowing water to freely flow through the system, typically in coastal marine waters (NY Aquaculture Report 2022). Oyster bags made from thick polyethylene mesh are placed within cages and then anchored to the sea floor by one or multiple points. In Long Island, oysters are grown in open aquaculture systems, filter-feeding on algae and particulate organic matter from the water flowing through the cages (NY Aquaculture Report 2022).

Long Island Aquaculture

Historically, oysters have been one of the most commercially important shellfish in New York State since the 1800s. Early oyster aquaculture started as transplanting natural seed (spat) oysters to planting areas, where they are raised for optimum growth and fattening before market. The natural seed came from beds in the mouths of rivers in Connecticut and the Hudson River, and areas around Staten Island and New York City (NY Aquaculture Report 2022, Timmons et al. 2004). The New York oyster industry declined in production after its peak in 1911, due to a lack of supply of seed oysters, effects of pollution, diseases, predation, changing hydrographic patterns, and overfishing.

Today, much of New York's oyster aquaculture is through shellfish from on-bottom and off-bottom methods. The on-bottom culture is where the crop is raised on the seafloor without bags or cages, inherently more susceptible to predation and sedimentation. Off-bottom culture is the use of cages, bags, trays, or racks on the sea floor or suspended in the water column, and surface cages are referred to as surface culture (NY Aquaculture Report 2022).

Figure 1. The left image shows the benthic gear and the right image shows the floating gear used for this study.

Benthic cages are coated metal structures with multiple levels to hold shellfish mesh bags. These cages are weighted to prevent them from floating away and raised to avoid touching the bottom and getting covered in sediment. Similar to the benthic cages, floating cages are a series of shelves but with two floats on each side that hold up bags with shellfish. The empty floating gear gets flipped regularly to prevent fouling. Oyster farmers receive their oysters as spat, larvae oysters that settle out on small shell fragments. The spat is then raised in the cages until they are suitable for table fare, about 18-24 months of growth (Parker et al. 2020).

Currently, there are only 1,694 acres of underwater land held by franchises, and approximately 3,400 acres are individual oyster production NY Aquaculture Report 2022). In 2010, Suffolk County started the Suffolk County Aquaculture Lease Program (ALP) for the

Peconic Estuary, on the East End of Long Island. Suffolk County granted 5- or 10-acre plots with 60 acres leased each year, during the initial 10-year period, 2010-2020 (NY Aquaculture Report 2022). Between 2012-2014, New York's oyster harvest increased more than three-fold compared to 2001, because of the ALP program. Since 2017 aquaculture oysters have accounted for over 50% of the state's harvested oysters and in 2020 it accounted for 79% of the state's oyster harvest (NY Aquaculture Report 2022). Implementation of the lease program has created jobs that stimulate economic growth. However, there remain questions about the potential impacts, harmful or beneficial, that shellfish aquaculture farms have on the health of the Peconic Estuary ecosystem. With the collaboration of shellfish growers, assessing the effects of aquaculture operations on wild fish communities will help inform the management of ALP. The results may help justify the sustainable growth of the ALP and other shellfish aquaculture programs in New England. If continued, the expansion of the ALP will increase marine-based jobs and provide opportunities for baymen to participate in sustainable seafood production on the East End of Long Island.

Fish community composition can indicate habitat degradation, ecosystem productivity, and environmental change (Holbrook et al., 1994). Counting and identifying fish can be difficult due to their high mobility. Capturing organisms is an effective, and common, method to sample abundance and identify fish. This method can be harmful to the environment and the organisms through the direct removal of them. Time-lapse cameras have been proven important for surveying fish and invertebrates through minimal interaction with the species (Philips et al. 2022). This method allows for more studies in areas that may be hard to physically sample and avoid biased results. Studies using time-lapse images have been highly successful in counting and identifying fish species and are a very repeatable and cost-effective method (Cappo et al.

2006, Philips et al. 2022). To understand the community structure around oyster cages, both time-lapse and acoustic cameras were deployed to observe the fish community around oyster cages during both day and night. Lastly, the acoustic camera is a new technology that provides information about the individual's size, movement, and behavior of fish. It allows for data to be collected in turbid water at any time of the day removing many of the constraints of visible camera or video (Hightower et al. 2013). The role of oyster aquaculture cages as aggregation fish sites in the Peconic Estuary is unknown. While it is thought that oyster cages attract and concentrate fish, there is currently no data on which species are attracted to and at what density. Nor is there an understanding of why fish utilize these structures. Fish may utilize oyster cages as a food source, for shelter from predation, or as a refuge from current flow. Oyster aquaculture cages may act as artificial reefs, thus attracting greater numbers of fish than usually found on bare bottom. How this expected utilization of the aquaculture gear changes diurnally or across the seasons is unknown. This research enables management agencies to substantially advance their understanding of the suspected utilization of oyster aquaculture gear in the Peconic Estuary.

We hypothesized that the fish would be more associated with the benthic gear than the floating gear. Species like Black sea bass (*Centropristis striata*), Scup (*Stenotomus chrysops*), and Blackfish (*Tautoga onitis*) are most likely to be found around the benthic cages as they are structure-loving, local species to Long Island. The null hypothesis is that fish would be equally associated with the benthic and floating gear, and there would be no difference in day and night activity.

Methods

Site Description

Figure 2. The Hampton Oyster Company uses the floating cages on their farm (green square), and North Fork Big Oyster uses benthic cages (red square). The pin represents the control site.

The study was conducted in Little Peconic Bay off the North Fork of Long Island, New York. Little Peconic Bay is mostly a shallow, flat, muddy bottom bay with very few boulders and large structures. Hampton Oyster Company uses floating aquaculture gear exclusively while North Fork Big Oyster uses only benthic gear (Figure 2). Both farms are approximately 40,469 m^2 (5 acres) plots characterized by soft, muddy sediments with an average visibility of about 1 m at the surface and 0.6 m at the bottom during the summer months. Both gear types are organized in rows and anchored to the bottom with enough slack rope to adjust for the change in tides. The benthic and floating sites have an average depth of 6 m, with up to 1 m of change between low and high tide. Southern and eastern winds prove to be a challenge on the farm due to the large fetch. The farms are sheltered by the north fork of the Island from north to northwest winds. These sites were chosen to minimize the different variables that could affect the study. Both sites have similar depth, water flow, and sediment characteristics. The study compares floating cages and benthic cages and a control site away from the farm with no cage present to represent the typical Peconic Bay.

KiloCams

Figure 3. GoPro housing with KiloCam hardware, zip-tied to a 3/4'' thick PVC sheet.

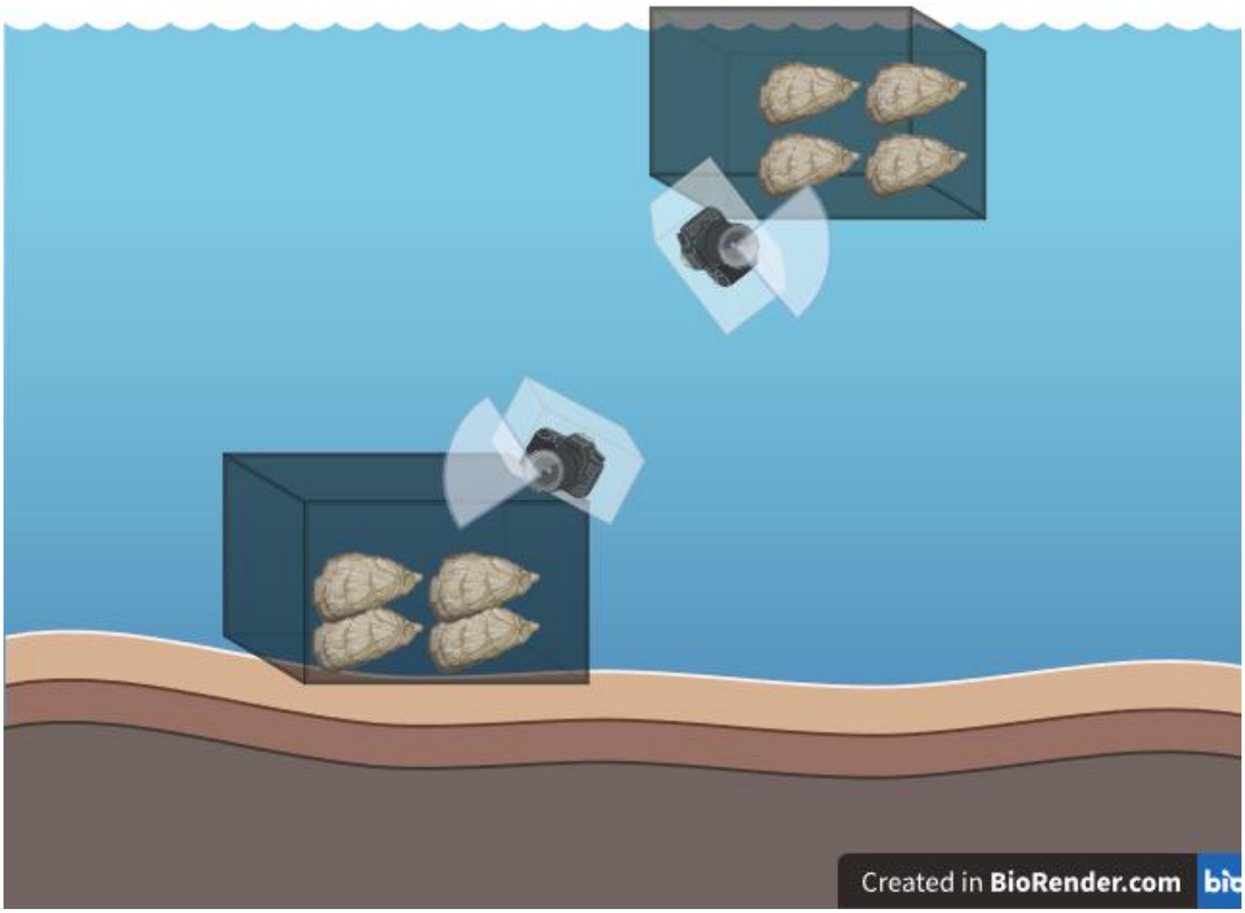

Figure 4. KiloCams are zip-tied to the top of the benthic gear and the underside of the floating gear.

To monitor what species of fish were associated with the two types of oyster cages through a full diel cycle, a low-cost ($18) time-lapse camera (KiloCams) was first utilized. The KiloCams can be programmed to take photos at any desired period, greater than or equal to 20 seconds. The KiloCams are built from two Arduino boards, a mini camera, a rechargeable 3.3v battery, and a CR2016 battery. The Arduino boards, batteries, desiccant, and paper towel are then placed within a Hero 3 GoPro housing. Each GoPro housing was zip-tied to a 15 x 10 x 2.5 cm PVC sheet with 0.6 cm holes drilled on each corner for mounting onto the cages (Figure 4). In the Summer of 2023, the cameras were programmed to capture 1 photo every 5 mins from 7 am to 8 pm (13 hours during the day) over a 14-day deployment. Initially, three cameras were deployed at the benthic and floating sites, each on randomly selected floating or benthic cages. Cameras were mounted on the top of the benthic and the underside of the floating cages, and the GoPro housing was tilted towards the cage to capture part of the cage in the frame of the image (Figure 5).

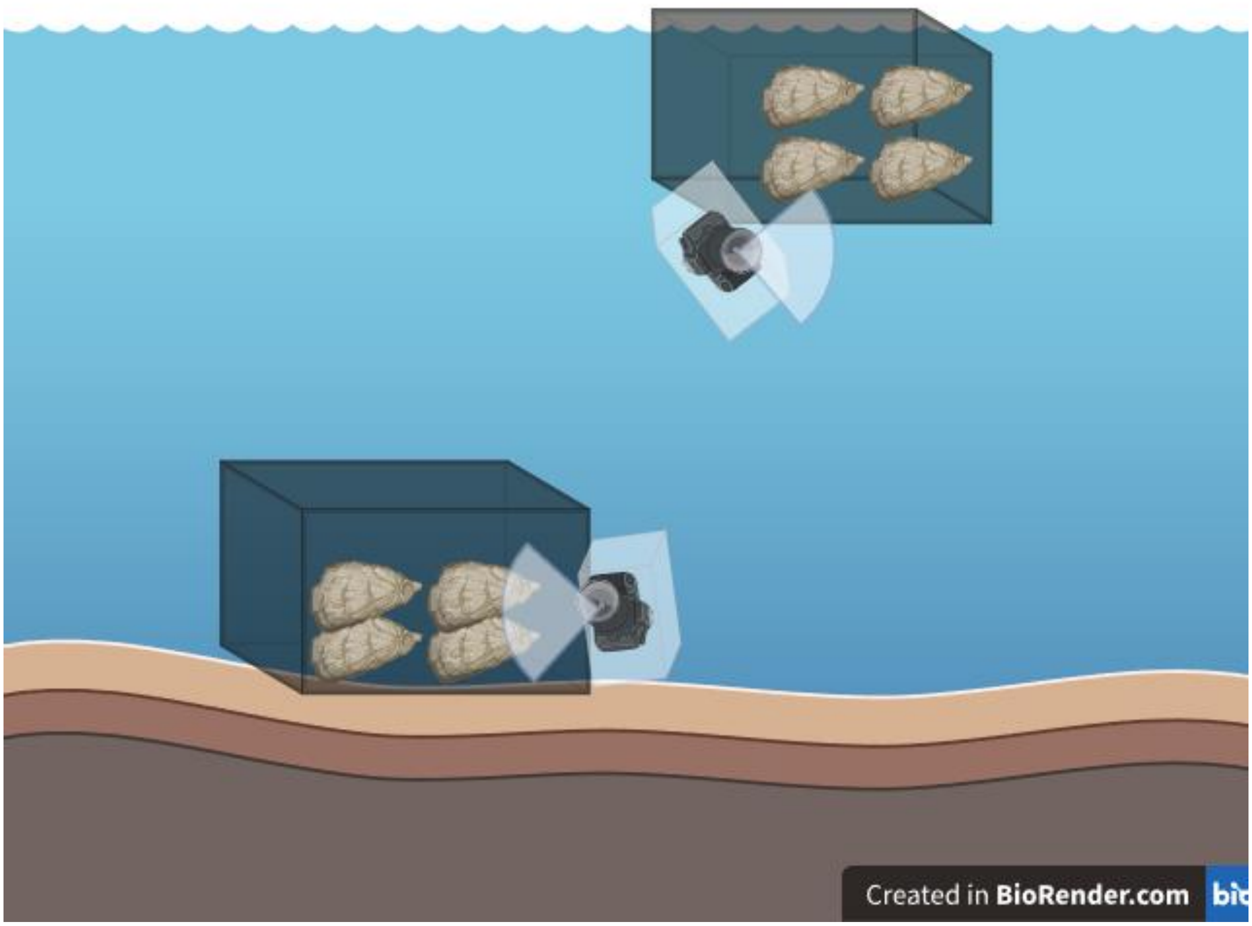

Figure 5. KiloCam set up zip-tied to the side of the benthic gear and to the underside of the floating gear in 2024.

After assessing the images from the year, there were several changes made, including programming the cameras to capture one photo every 20 secs from 7 am to 8 pm instead of every 5 mins and shortening the deployment time from 14 days to 1 day. This was done to increase the usable images from both oyster gear types; another KiloCam camera was added to each deployment, totaling four cameras for each benthic and floating cage site and the cameras on the benthic cages were repositioned to the side of the cage rather than the top to improve image clarity and to capture more fish in the images (Figure 5). One camera was attached to a screw anchor at the control site and was tilted down to capture part of the bottom in the frame. While the KiloCams allow a long deployment, their image quality was challenging, and ultimately, it was decided to supplement these cameras with a more costly but higher-quality time-lapse option.

Brinno Time Lapse Camera

The Brinno Time Lapse Cameras 300 (Brinno TLC300) can capture higher-quality images at a faster capture rate. The Brinno TLC300 is programmable to capture a photo every 1 – 30 seconds and can be scheduled to start and end any day of the week. For this study, we programmed the Brinno Cams to record the images in a video format at 30 frames per second. The cameras were all set to capture an image every five seconds during the day and night and stored images in a video format. Two Brinno Cams are zip-tied to random cages at each site, the side of the benthic gear, and the underside of the floating gear for the 24-hour deployment.

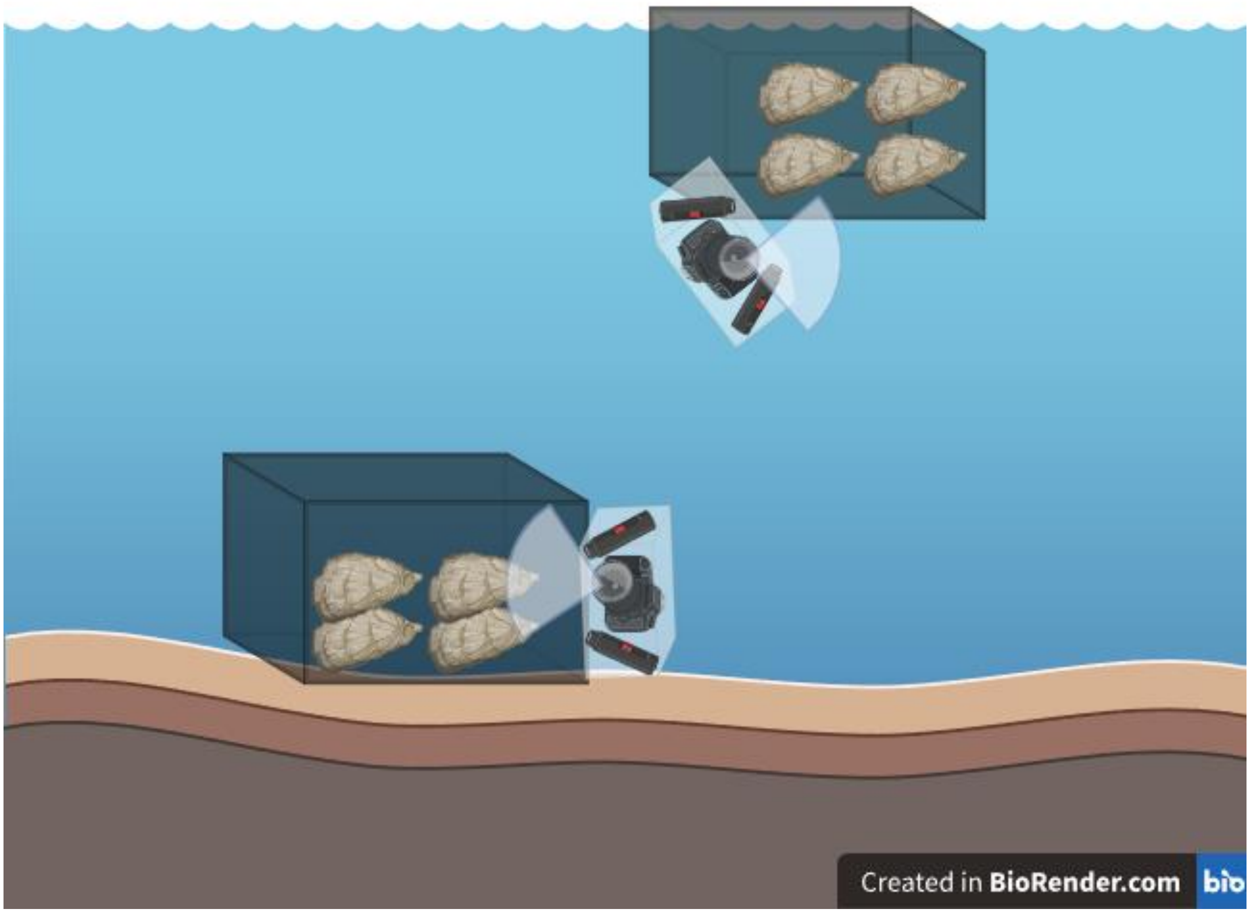

Figure 6. Brinno Cam set up zip-tied to the side of the benthic gear and the underside of the floating gear.

We converted the video recording to images using FFMpeg (https://www.ffmpeg.org/) program. These cameras proved very valuable as they provided nighttime photography with the use of external light and a timestamp for each photo, information that was not available from the KiloCams. With this additional information, the cost of each camera was significantly higher ($250) than the KiloCams but provided critically important information.

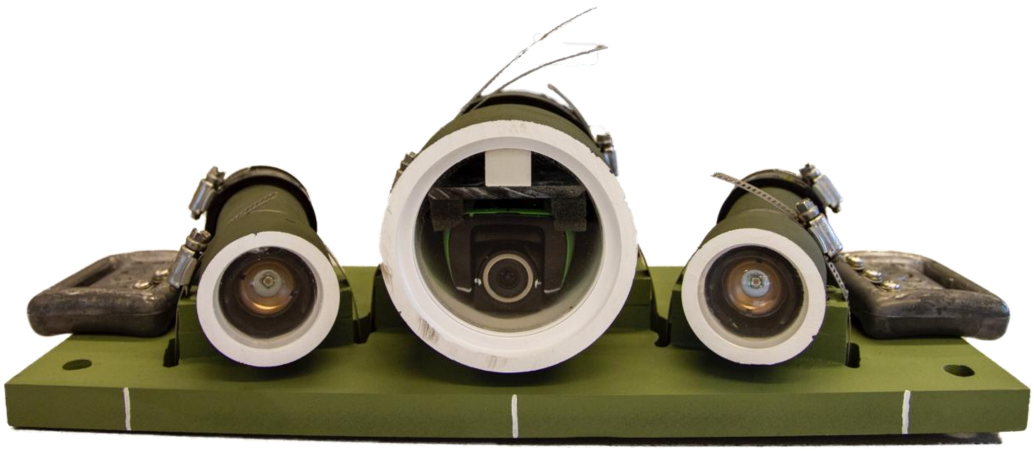

Figure 7. Time-lapse camera set up that was used in this study. Underwater housings for the Brinno TLC300 time-lapse camera and red LED flashlights, as well as the mount, were designed and built for this study.

The Brinno Cam setups were constructed from a water-tight housing containing a time-lapse camera (Brinno, TLC300) and two red LED flashlights (AuKvi Brand) (Figure 7). This setup was adapted from a design by Edmundson (Edmundson et al. 2016, Heck et al., 2021) who used PVC housings for the cameras. The underwater housings for the time-lapse cameras were constructed from PVC pipe with an internal diameter of 7.6 cm with a clear 0.64 cm thick acrylic glass disc secured to one end of the pipe with acrylic plastic cement (SCIGRIP Brand). A PVC coupling (internal diameter of 7.6 cm) was then affixed over the acrylic glass to further secure it and cut down to eliminate any potential visual obstruction of the camera. Housings for the flashlights were made in a similar way, however the PVC pipe used had an internal diameter of 3.8 cm. The housing for each time-lapse camera was secured in the center of a 1.9 cm thick PVC plate (42 cm x 18.5 cm) on a bracket using stainless steel hose clamps (Figure 8). Housings for flashlights were secured on either side of the housing for the time-lapse camera, angled to illuminate the view of the camera. An additional piece of PVC sheet (1.9 cm. thick x 5.5 cm x 32 cm) was secured underneath the main plate to angle the entire assembly down to ensure that the camera and lights could capture fish passing through the cages. The back end of all the housings was sealed with a rubber cap and a hose clamp (Fenco Inc. Qwik Cap Brand).

Imaging SONAR Camera

SONAR cameras are a recent technological adaptation to convert sound into video images through acoustic sensors and therefore, are not dependent on water clarity or light level as the KiloCam and Brinno Cams are. The Kongsberg Flexview Multibeam SONAR (Acoustic Camera) was used for this project to assess fish association with the benthic gear. The Kongsberg Flexview Multibeam SONAR is a high-frequency multibeam sonar up to a 70 m range over a 140º sector at 500-1400 kHz frequency. With this wide range, a series of trials were conducted with a varying distance and frequency. An extra-large tote (Project Source Commander X-large 64-Gallons Black Heavy Duty Rolling Tote with Latching Lid) was used as the outer housing to protect from wave splashes and sunlight. The transducer battery, Toughbook computer, external SSD, and wiring were protected in a clear 27-gallon tote to further prevent water from damaging the electronics. Both totes and plywood sheet were screwed down onto a life raft which was tied with two 10 m long (6.35mm thick) rope tied to screw anchors behind the transducer (Figure 8).

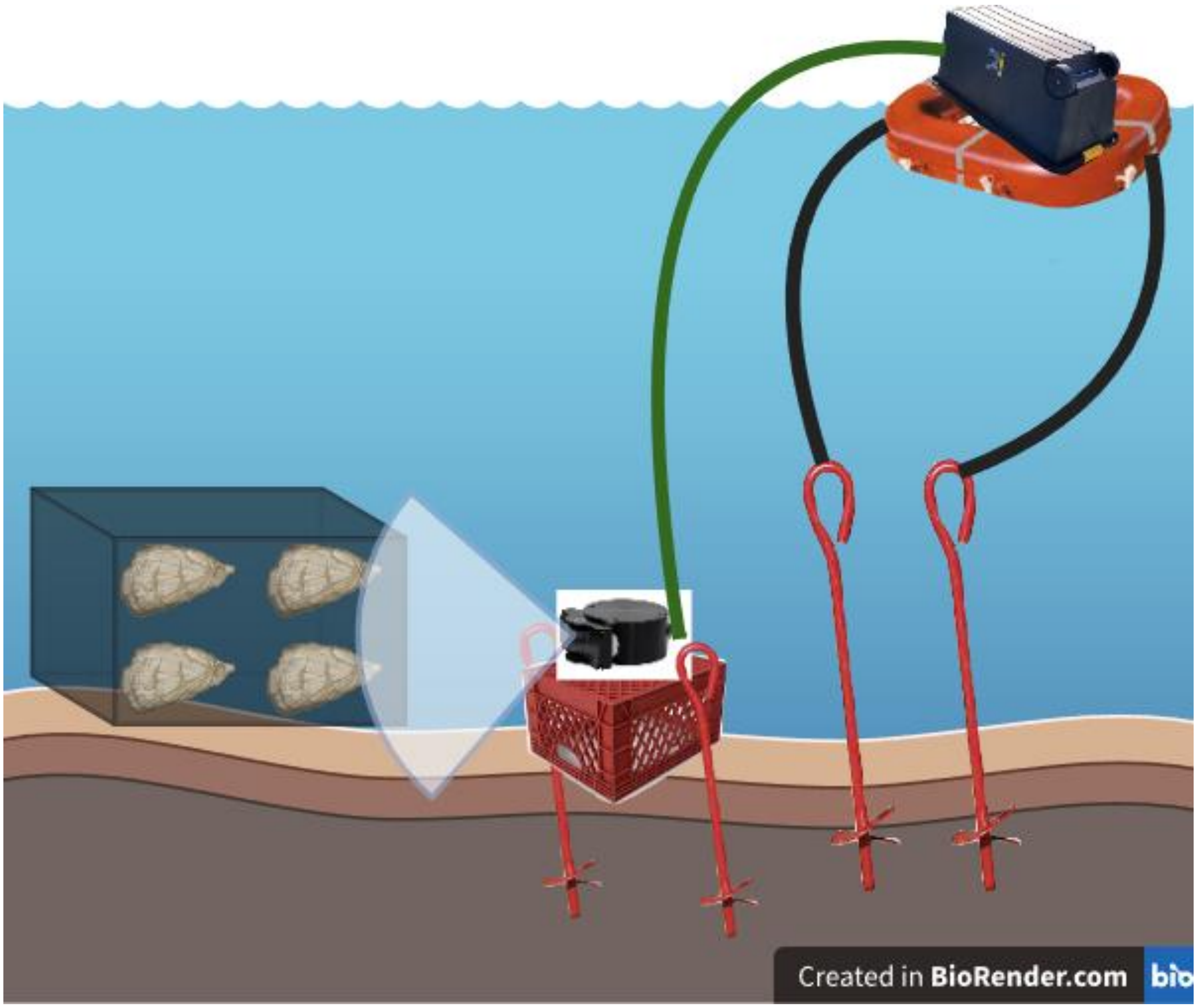

Figure 8. The hardware for the Acoustic Camera is housed within the black tote, secured to a life raft. The life raft is secured to two screw anchors away from the transducer head. The transducer is secured to a PVC sheet, then secured to a weighted milk crate.

An external hard drive was used to store the Acoustic Camera data because the transducer cannot store data directly on it, and the Toughbook laptop did not have enough storage available. Additionally, the transducer was mounted to the bottom of a milk crate and screw-anchored to the benthos to provide extra stability underwater. The Flexview camera was deployed for 24 hours and analyzed for the time spent in the frame by each fish. The Acoustic Camera recording was sub-sampled for 10 mins every hour and compared fish utilization with a section of daytime (12 pm - 3 pm) to a section of nighttime (8 pm – 10 pm). The Flexview was not deployed when wind speeds were above 15 knots to ensure that the camera would not be damaged.

Field Work

2023 Cameras

From July to October of 2023, with the assistance of Cornell Cooperative Extension at Southold, 3 KiloCams were deployed each on the benthic and floating oyster gear. Every 14 days, the KiloCams would be swapped out to download the data as well as clean the GoPro housings of any epiphytic growth and sediment buildup. Cameras were deployed from 11 July to 16 October 2023. January through April was spent assessing the 2023 imagery, and concluded that the dataset was not sufficient to effectively analyze. Few images had fish present in them where most of the images had only one fish present, despite taking approximately 91,000 photos.

2024 Cameras

For the 2024 field season, we decided to add the higher-resolution Brinno cameras, increase the image sampling rate, and increase the number of cameras deployed at each site. The number of KiloCams deployed increased from three to four due to the lack of fish seen from the 2023 data. The sampling rate was changed from 1 photo every 5 mins to 1 photo every 20 secs, which was the frequency limit of these cameras. Any smaller and the KiloCams would not be able to take the photo due to the delay in booting and saving the photo written in the code. Deployments were reduced to 24 hours since the batteries would need to be recharged because of the increased sampling rate. April through May was spent testing different sampling rates as well as debugging each camera to avoid any of the malfunctions from the previous summer.

With the help of Cornell Cooperative Extension, four KiloCams were deployed at each site, benthic and floating, on random cages on 3 June, 11 June, 18 June, and 27 June. One camera at the control site was deployed on 11 June and 18 June. The control KiloCams were mounted on screw anchors away from the cages to look at the typical bottom of Little Peconic Bay. In addition to the KiloCams, 2 replicate Brinno cameras were deployed on both gear types during the last week of June for 24 hours. After testing the Brinno camera's settings, a sampling rate of 1 photo every 5 secs was decided on to conserve battery life so that the Brinno Cam would record for the full 24 hours. Just like the KiloCams, the Brinno cameras were attached to the side of the benthic cage (Figure 6).

Flexview Acoustic Camera

On October 24, 2023, the Flexview SONAR was deployed for 24 hours. Some adjustments were made following the first deployment, as the Acoustic Camera did not record for the full 24 hours. The transducer was mounted on a milk crate to provide more stability underwater and ease of adjusting the position. The lid for the clear tote was removed to prevent the Toughbook laptop from closing on itself and to provide easy access to setting up the laptop and wiring. In 2024, the Acoustic Camera was deployed for 24 hours on 3 June and 11 June. We subsampled 10 minutes of every hour in the data due to the amount of data recorded from the Acoustic Camera. A "fish" was determined as spending time around the benthic gear through a 2 m radius from the edges of the cage.

Table 1. KiloCam deployment dates in the 2023 and 2024 field seasons.

2023 Deployments (14 days = 13,104 images)	2024 Deployments (1 day = 18,720 images)
07/11/2023	06/03/2024
07/25/2023	06/11/2024
08/08/2023	06/18/2024
08/21/2023	06/27/2024
09/4/2023	
09/19/2023	
10/02/2023	

Table 2. Brinno Cam deployment date in the 2024 field season.

2023 Deployments	2024 Deployments (1 day = 138,240 images)
N/A	06/27/2024

Table 3. Acoustic Cam (SONAR) deployment dates in 2023 and 2024 field seasons.

2023 Deployments (24 hours)	2024 Deployments (24 hours)
10/22/2023	06/03/2024
	06/11/2024

Statistical Analysis

We use the Binomial General Linear Model (GLM) to determine whether fish were associated with the benthic or floating gear type or control, no gear type. The Shannon-Weiner index, using the equation: $H' = -\Sigma[(n_i/N)*\ln(n_i/N)]$, is a measure of diversity that measures the number of species present and the relative abundance. The Shannon-Weiner index ranges from 0 – 5 but a normal value falls between 1.5 – 3.5 and a value of 0 means there is only 1 species present. We use MaxN, the maximum number of individuals present in an image to determine if there is a preference for type of gear. We define the variable "Time Spent" from when the fish enters the frame to when the leaves the frame in the Acoustic Camera data. If there is a school of fish, we use the time when the fish enters the frame to when the last fish leaves the frame. Then we look at the "Time Spent" data with the benthic gear type to look for preference for the time of day. All analysis were done in R version 4.4.1 and values in the results are mean $\pm$ standard deviation.

Results

2023 KiloCam Data Collection

In 2023, the first KiloCam deployment started on 11 July, and the last deployment was picked up on 16 October. These cameras were left out for 14 days, taking images for 13 hours per day, and took 13,104 images per camera during each deployment. In 2023, the KiloCams captured a total of 270 images with a fish in frame from 11 different species from the floating and the benthic gear. Of the 270 images with a fish, 77 images with a fish of 4 different species were from the benthic gear and 193 images with a fish of 11 different species were identified from the floating gear (Figure 10A and Figure 11A). Several species identified from the benthic cage images were also seen in the floating cages images.

The average MaxN was calculated by averaging the maximum number of individuals of each species from each camera. The Blackfish (*Tautoga onitis*) had an average MaxN at 0.275 $\pm$ 0.499 fish in the benthic gear and the Scup (*Stenotomus Chrysops*) had an average MaxN of 0.181 $\pm$ 0.386 in the floating gear (Figure 12). We divided the images with a fish in frame over the total images taken to get a proportion of how often there is a fish in frame per gear type. The benthic gear KiloCam had the proportion of images with fish at 0.003 $\pm$ 0.001 and the floating gear KiloCam had the proportion of images with fish at 0.005 $\pm$ 0.002 (Figure 14).

2024 KiloCam Data Collection

In 2024, the first KiloCams deployment was on June 6, and the last deployment was retrieved on June 28. These cameras took images for 13 hours, one day each week, and took 18,720 images between 8 cameras. After changing the KiloCam mounting position to the side of the cages for all deployments in June, the cameras captured 529 images with a fish in the frame

(Figure 10B and Figure 11). Of the 529 images, 499 fish images of 5 different species were from benthic gear, and 30 fish images of 1 species were taken from floating gear. The species found on the floating cages were Blackfish (*Tautoga onitis*), which was also seen on the benthic cages. The control KiloCam was deployed away from any cage, looking at the typical bottom of Little Peconic Bay on 11 June and 18 June. The control KiloCam also captured a sum of 3 Scup (*Stenotomus chrysops*) in the frame (Figure 9B). The benthic gear also had the proportion of images with a fish in the frame at 0.022 $\pm$ 0.008, and the floating gear with a proportion of 0.002 $\pm$ 0.002 (Figure 14).

2024 Brinno Cam Data Collection

In 2024, the Brinno Cams were deployed on June 27 and were retrieved on June 28. These cameras took a total of 138,240 images between the 4 cameras deployed. The benthic Brinno Cams captured a total of 6,096 images with a fish in frame between 8 different species of fish (Figure 10A and Figure 12B). The floating Brinno Cams captured a total of 119 images with a fish in frame of 1 species (Figure 9A and Figure 11B). No Brinno camera was used in the control area because of the limited number of cameras that we had. Black sea bass (*Centropristis striata*) had an average MaxN of 5.5 $\pm$ 3.5 individuals in the benthic Brinno Cam data (Figure 13). The Blackfish (*Tautoga onitis*) had an average MaxN of 0.5 $\pm$ 0.5 from the floating Brinno camera (Figure 13). The benthic Brinno cage cameras had the proportion of images with a fish in the frame at 0.211 $\pm$ 0.093, and the floating Brinno Cams cages had the proportion of images at 0.005 $\pm$ 0.005 (Figure 14).

We also used the Brinno Cams to answer the next question about the time of day the fish may prefer. The nighttime hours were defined as 10 pm to 4 am, and daytime hours were defined as 6 am to 8 pm. The hours from 8 pm – 10 pm and 4 am – 6 am are considered the crepuscular hours. During the night, the highest MaxN was 2 fish between the two benthic Brinno Cams, whereas the highest MaxN during the day was 9 fish (Figure 16). During the night, the highest MaxN for the floating Brinno Cams was 0, and the highest MaxN during the day was 1 between the two cameras (Figure 17).

KiloCam and Brinno Cam

Through the 2023 and 2024 field season, the KiloCam took a total of 166,608 images. The Brinno Cams were deployed on 27 June 2024, and took 138,240 images in 1 day, totaling 304,848 images taken between the KiloCam and Brinno Cam. The benthic gear KiloCams captured a total of 576 fish in the frame, and the floating gear KiloCams captured a total of 223 fish in the frame during both the 2023 and 2024 deployments (Figure 9A). Sixteen species were identified from the cameras however, several photos had partial fins and body parts that were not discernible and were categorized as “Unknown” (Table 4). Summaries of the data collected from both the KiloCams and the Brinno cameras over the whole experiment are provided (Table 4). Between both cameras, the floating gear had the most species associated with it but fewer total number of fish whereas the benthic gear had fewer species, but a higher total number of fish associated with it.

Flexview Multibeam SONAR

The acoustic cam was deployed at the benthic gear for 24 hours, recording 12-14 hours for each of the 2023 and 2024 deployments. In the subsampled data, the MaxN was plotted over time to look at how long a fish spent at the cage. It is not known what the fish may be doing or who they may be, but we get a sense of how long they are spending at the cage and at what time of day they have the most activity near the oyster gear. In 1 subsample of 10 mins, the MaxN was 12 fish during the day, and at night, the MaxN was 3 fish (Figure 19). There is uncertainty in the Acoustic Camera data, as fish would move through the camera's field of view very quickly

We summed the number of fish in a 10-min sample during the day and night. During the day, there were a total of 755 fish that moved across the Flexview's field of view, whereas during the night, there were 141 fish that crossed the camera's view (Figure 19). The average number of fish was calculated from three – 10 min subsamples. During the day, there was an average of 21 $\pm$ 14 fish, whereas the average number of fish at night is approximately 1 with no error (Figure 19). The maximum number of fish across all subsamples during the day is 178 fish, and during the night, the maximum number of fish was 6. However, this doesn't represent how long a fish spends at the cage. Next, we used the equation p = (sum of time spent by a fish (sec)/ 10-minute subsample (600 sec)) to assess the proportion of time spent at the cage. During the day, 27-63% of the 10-minute subsample had a fish in the field of view whereas during the night, 12 – 71% of the 10-minute subsample had a fish in the field of view of the benthic cage. (Figure 24). More fish spend a shorter amount of time around the cages during the day, whereas fewer fish may spend more time at night around the cage.

Binomial General Linear Model

We used a binomial generalized linear model to determine whether fish are associated with the benthic or floating gear. Presence and absence at each gear type were defined as every image with a fish = 1 and every image without a fish = 0. We pooled all the photos from the KiloCams and Brinno cameras to find which cage fish are more associated with. Fish are significantly associated with the benthic cage than the floating cage ($p < 0.001$, 190855 degrees of freedom). In the 2023 KiloCams, fish are significantly associated with the floating cage than the benthic cage ($p < 0.001$, 37312 degrees of freedom). From the 2024 KiloCams, fish are significantly associated with the benthic cage than the floating cage ($p < 0.001$). In the Brinno cameras, fish are significantly more associated with the benthic gear than the floating gear ($p < 0.001$, 83214 degrees of freedom).

Shannon-Wiener Index

The fish community around the benthic gear had a Shannon-Wiener Index value of 0.892 and the fish community around the floating gear had an index value of 1.47 from the KiloCams images indicating that the fish community around the floating gear is more diverse than the benthic gear in 2023. In 2024, the fish community around the benthic gear from the KiloCams images had an index value of 0.774 and the fish community around the floating gear from the KiloCams images had an index value of 0, indicating that the fish community around the benthic gear is more diverse than the floating gear. The fish community around the benthic gear had an index value of 1.22 and the fish community around the floating gear had an index value of 0 from the Brinno cam images, indicating that the fish community around the benthic gear is more diverse than the floating gear.

Discussion

Our hypothesis is supported by the study data, which shows that fish are significantly more associated with the benthic gear than the floating gear. We use the binomial generalized linear model to compare the two cameras, KiloCam and Brinno Cam, to see if the different cameras impacted the study. Both the KiloCam and Brinno Cam showed a significantly higher association with the benthic cage than the floating camera in 2024. The change in the mounting position likely contributed to the higher number of fish in the frame captured versus the 2023 cameras. The cameras on the side of the benthic cages allowed us to see more of what was happening around the side rather than what was above the cages. The images captured showed many of the Black sea bass (*Centropristis striata*) and Blackfish (*Tautoga onitis*) around the side or moving through the holes of the cage rather than moving above it. Many images had 1 fish, whereas fewer images had more than 1 fish in the frame (Figure 18). Many of the images with multiple fish in the frame were taken after sunrise between the hours of 7 am and 9 am. The post-sunrise time is typically when fish are actively feeding. Local species to Long Island were expected to be found such as Black sea bass (*Centropristis striata*), Blackfish (*Tautoga onitis*), Scup (*Stenotomus chrysops*), and Cunner (*Tautogolabrus adspersus*) (Figure 11). These are species that are expected to be found on the benthic gear as they are typically associated with structure. Many of the fish captured in the images are juveniles, supporting the idea that benthic aquaculture gear can act as an artificial reef, providing shelter for the juvenile species (Kawai et al, 2021). Unexpectedly, there was a lack of larger predatory species such as Striped bass, Bluefish, Weakfish, and Summer Flounder. The larger predatory fish may be present, but the KiloCam and Brinno Cam could not capture them due to the limited visibility.

Using the Shannon-Wiener Index, we found that the floating gear had a higher species diversity than the benthic gear in June 2024. However, we saw a higher Shannon-Weiner index in the KiloCam floating gear data in 2023 than in the floating gear data in 2024. In July 2023, we were able to identify local species of Long Island captured in the images from both the benthic and floating gear. That changes in August and September, when we can identify tropical drifters such as the Gray snapper (*Lutjanus griseus*) and Blue runner (*Caranx crysos*), predominantly in the floating gear. These months are typically when tropical drifters are large enough to be seen and sought after by recreational divers and aquarists. Towards the end of the field season in October, we see the local species again and none of the tropical drifters. In June 2024, the tropical drifters are not here or large enough to be seen in the camera images at the time. It would have been interesting to see whether the same tropical species would be seen in August and September. Unexpectedly, we also saw numerous images of juvenile Blackfish (*Tautoga onitis*) on the floating cages (Figure 11). This could be due to a few reasons, possibly avoiding predation or seeking other food sources.

A greater number of fish were seen during the day associated with the gear rather than during the night. Diel movement of fish varies with species where light may stimulate them to feed during the day rather than the night. For example, Cod has shown an increased activity during the morning which gradually decreases through noon (Løkkeborg and Fernö, 1999). Both the Brinno Cams and the Acoustic Camera captured more fish in the frame during the day than the night (Figure 16A and Figure 20). It was difficult to identify each individual that moved across the field of view of the Acoustic Camera, but we can see small schooling baitfish, small fish, and large fish around the benthic cage. Fish that have a laterally compressed or torpedo-shaped body, like Scup (*Stenotomus chrysops*) and Black sea bass (*Centropristis striata*), are more difficult to see than fish that are dorsally compressed, like skates and flatfish. Furthermore, the Acoustic Camera captured very few fish in the frame during the night; however, they spent more time around the benthic gear (Figure 23). During the day, there are more fish, but they spend less time around the gear (Figure 23). This may also support the idea that benthic aquaculture gear can act as an artificial reef, as fish are spending more time around the cages in both the day and night.

This study only looks at the aquaculture cages in the Little Peconic Bay. Other estuaries may have different densities of fish or environmental factors that could change the fish communities or the diel movement of fish. We acknowledge that there are limitations to the equipment and study implications. The KiloCams will only work during the day and in clear conditions with high light. For this study, with less light at the benthos and high turbidity, it was hard to capture and identify fish from the KiloCams. The placement of the cameras on the cages proved important as it changed the number of fish seen in the images between the 2023 and 2024 fieldwork. The Brinno TLC300 are powerful cameras that can produce better quality images than the KiloCams. Due to large file sizes, the Acoustic Camera data has to be downloaded after every 24-hour deployment, which limits the amount of deployments we can conduct. Future work could look at the size distribution of each species around the cages and compare the benthos of the benthic to the floating gear. Based on this study, there is a clear preference for the benthic gear over the floating gear, however, we saw juvenile Blackfish (*Tautoga onitis*) at the floating cages, indicating that there must be some fish below the floating cages. Lastly, it would be more beneficial to use the Brinno Cams over the KiloCams due to the high-quality photos, nighttime images, and time stamps to see what time of day they are moving past.

Figures

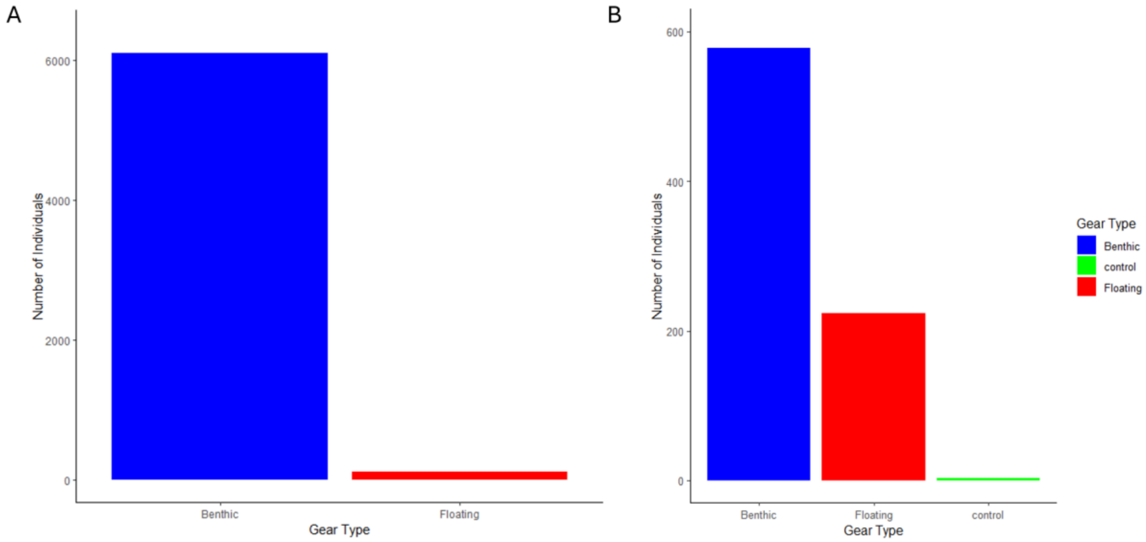

Figure 9. A) Sum of individuals in the Brinno cameras for the benthic and floating site in 2024. B) Sum of individuals in the KiloCams for the benthic and floating sites over the 2023-2024 data.

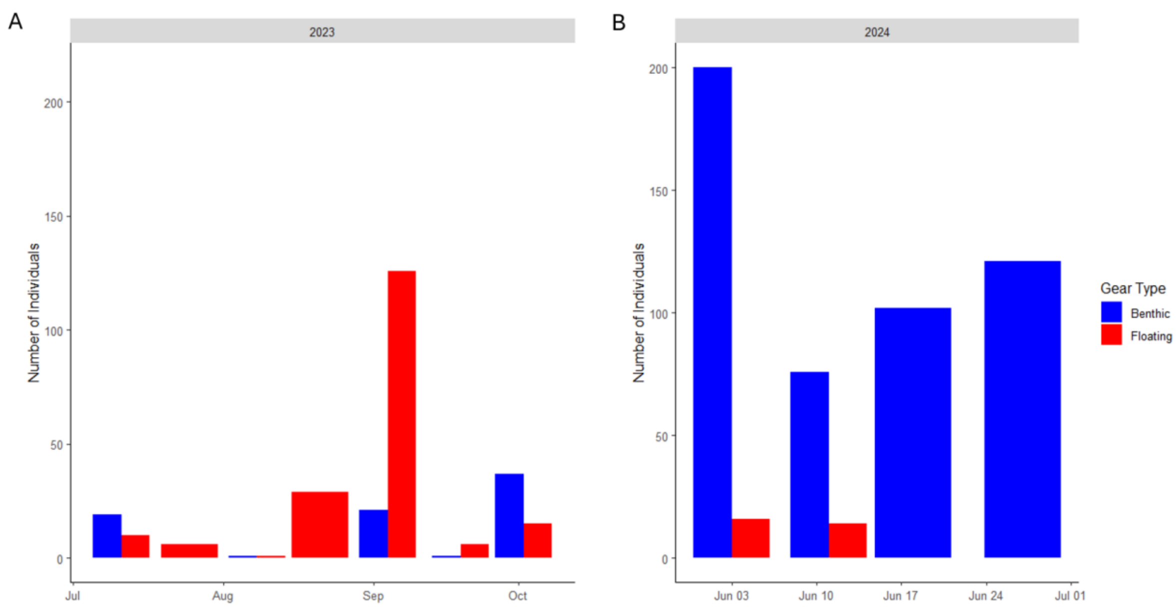

Figure 10. A) Sum of individuals in the KiloCams in 2023 for the benthic and floating site. Each cluster bar represents one 14-day deployment. B) Sum of individuals in the KiloCams in 2024. Each cluster bar represents one 24-hour deployment.

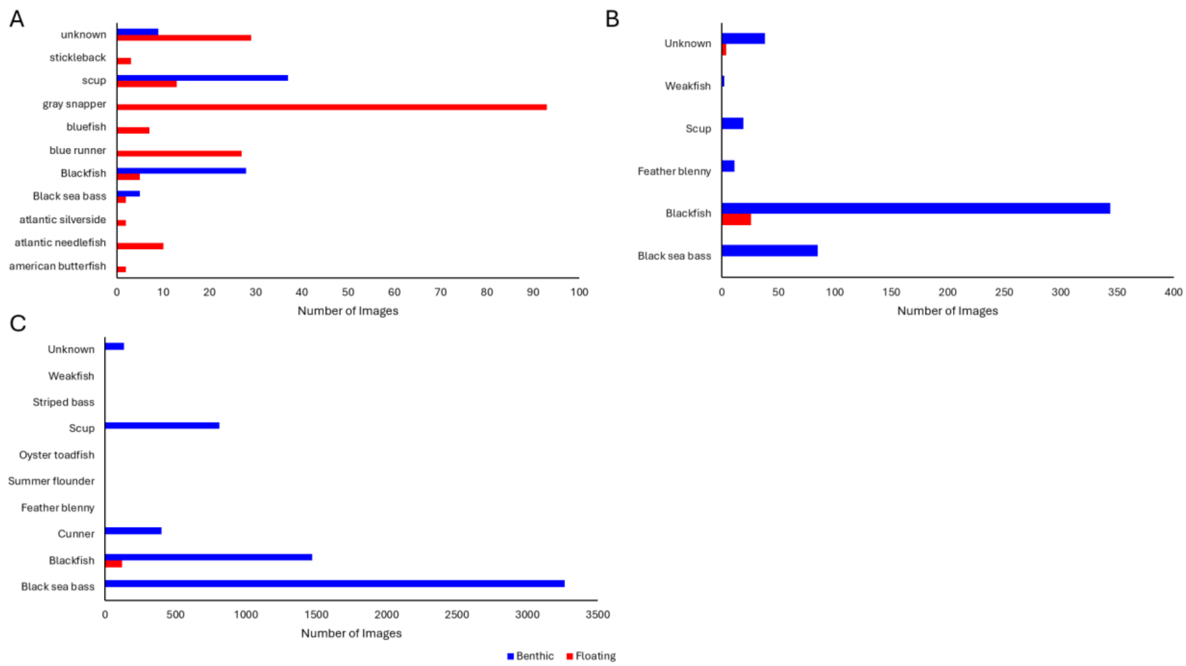

Figure 11. A) The total number of fish per species identified in the KiloCam 2023 images for both the benthic can floating site. B) The total number of fish per species identified in the KiloCam 2024 images for the benthic and floating site. C) The total number of fish per species identified in the Brinno Cam 2024 images for the benthic and floating site.

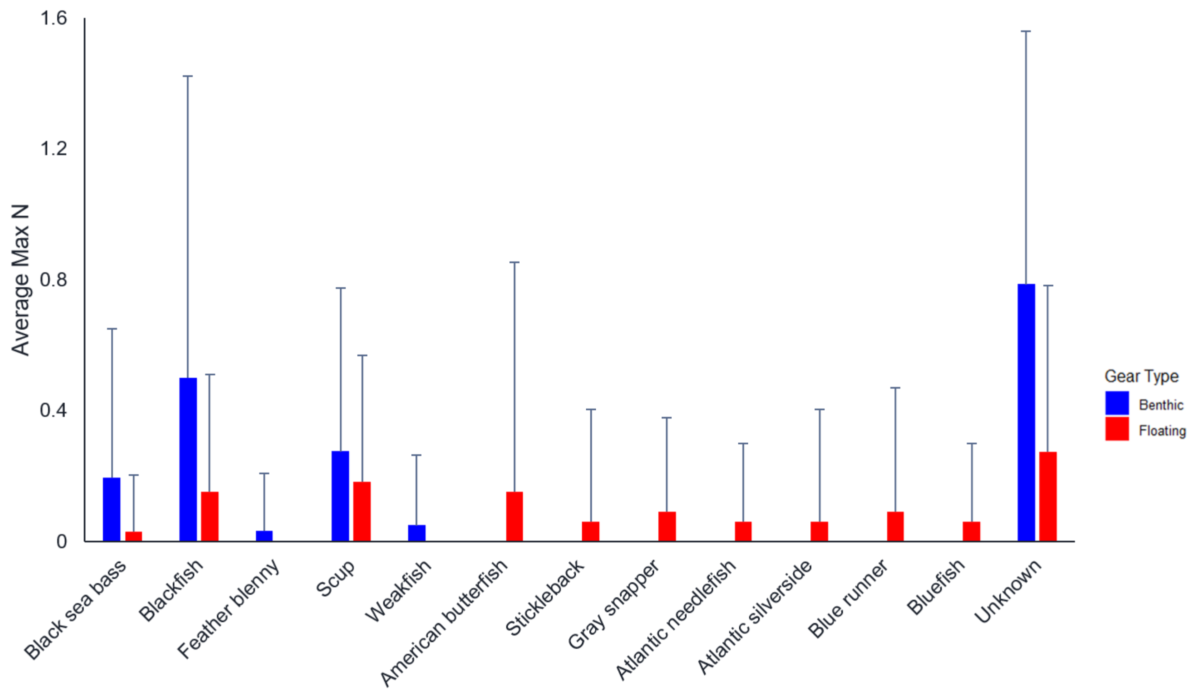

Figure 12. The average MaxN per species found in the KiloCams over the 2023-2024 data for the benthic and floating site. The error bars measure standard deviation.

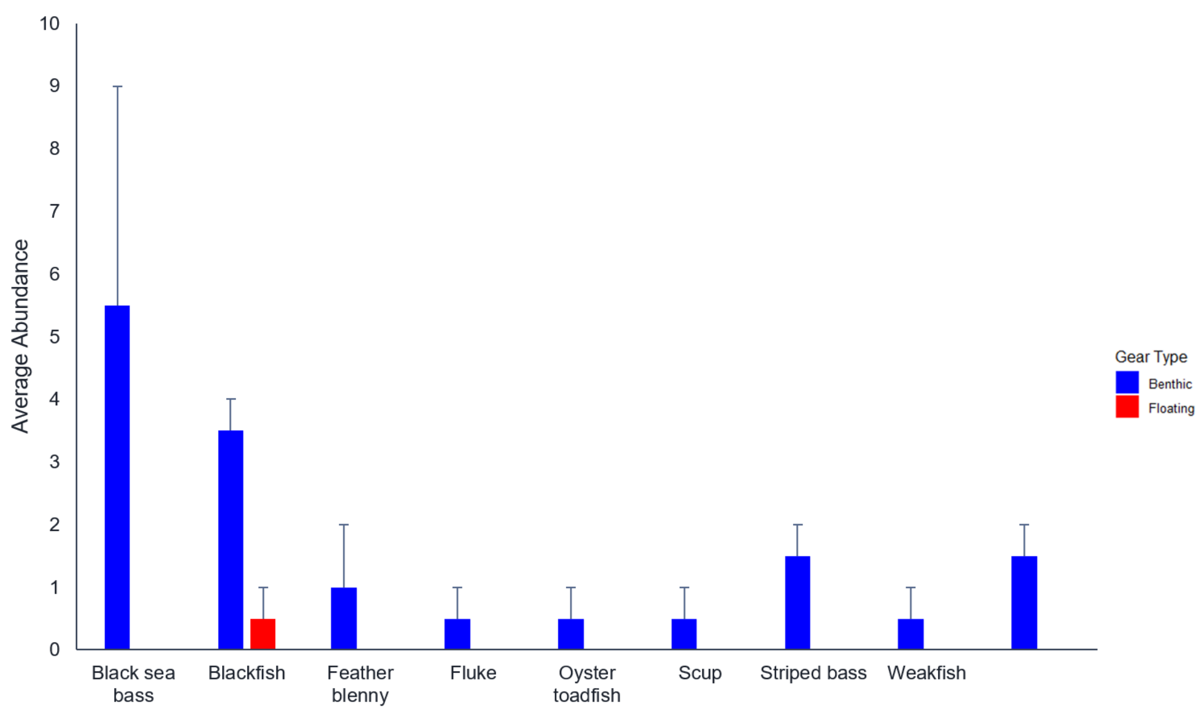

Figure 13. The average MaxN per species found from benthic and floating site in the Brinno Cam images, with standard deviation error bars.

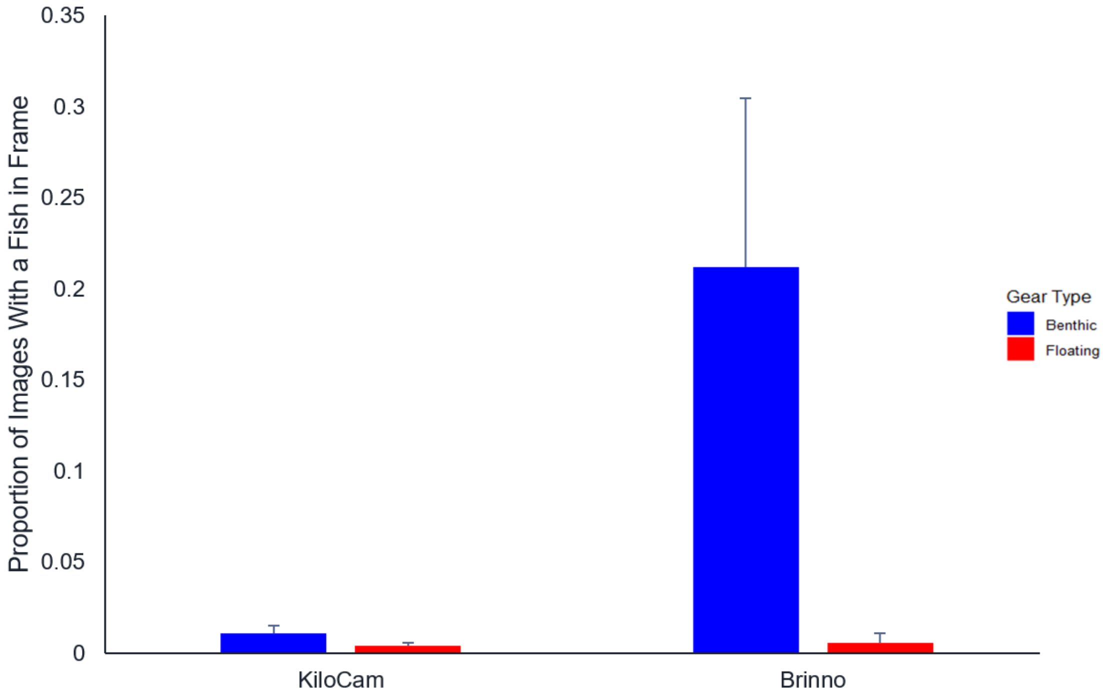

Figure 14. The proportion of images with fish present in the frame of the Brinno cam and 2023 - 2024 KiloCam data for the benthic and floating site.

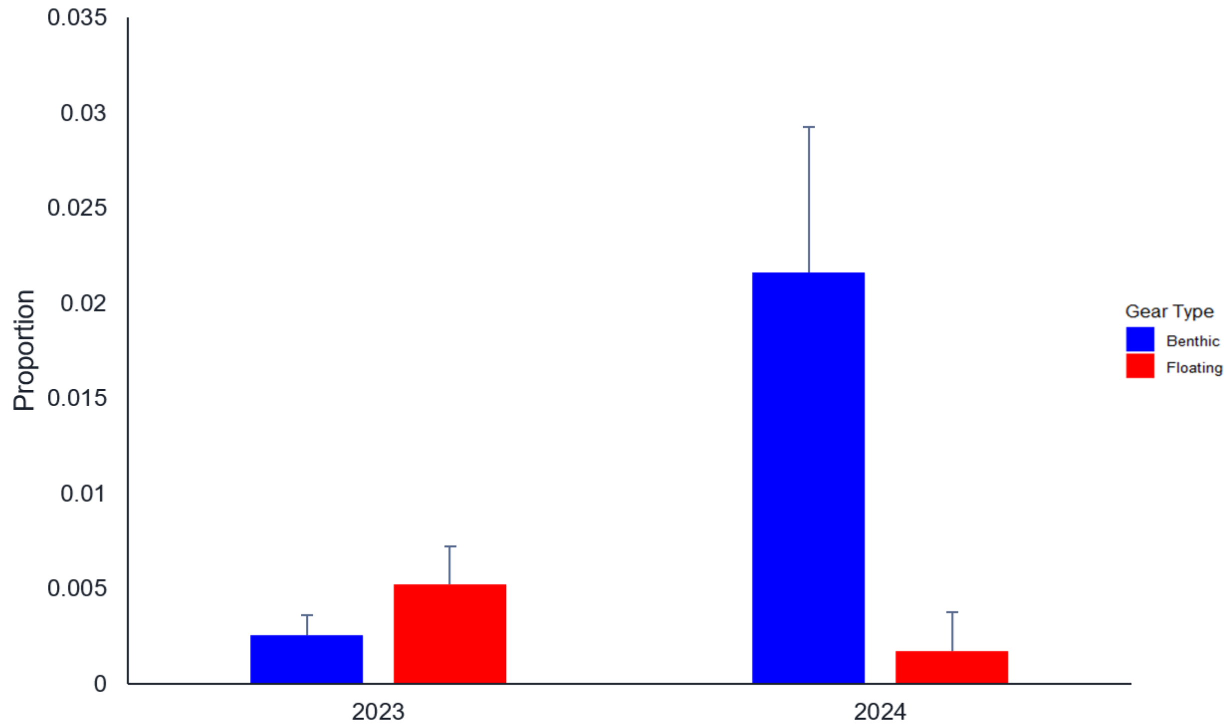

Figure 15. The proportion of images with a fish present in the frame of the KiloCam 2023-2024 data for the benthic and floating sites. A higher proportion of images had a fish in the frame from the floating site in 2023, whereas a higher proportion of images had a fish in the frame from the benthic site in 2024. The error bars are the standard error bars.

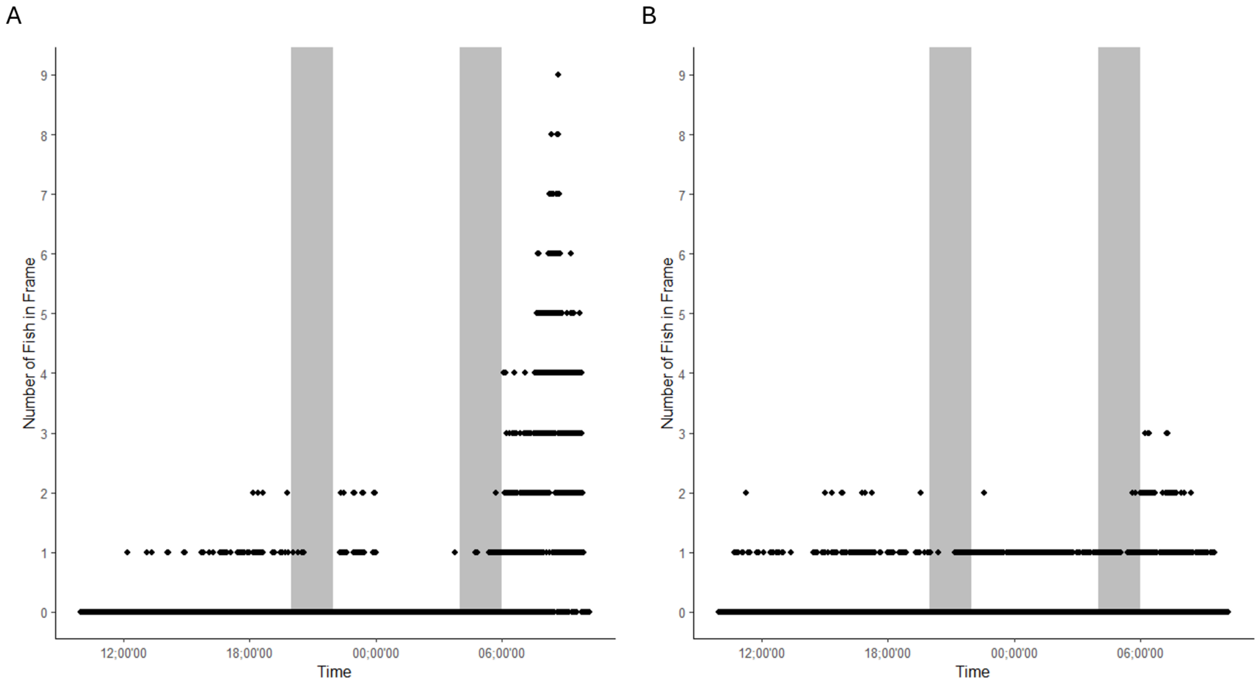

Figure 16. The number of fish in the frame over a 24-hour deployment in the benthic Brinno camera 1 (A) and 2 (B). The maximum number of fish seen within a photo and the grayed-out area represent sunrise (4 am – 6 am) and sunset (8 pm - 10 pm). More fish were seen after sunrise in both cameras.

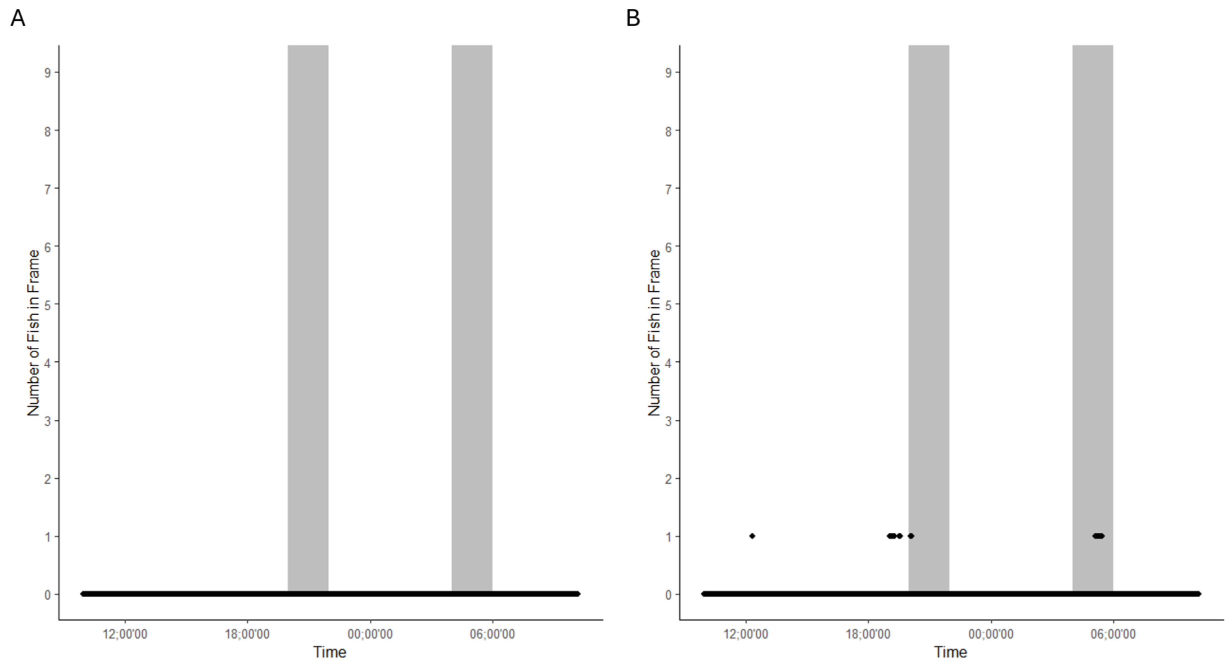

Figure 17. A) Number of fish in the frame over a 24-hour deployment in the floating Brinno camera 1 (A) and 2 (B). The maximum number of fish seen within a photo and the grayed-out area represent sunrise (4 am – 6 am) and sunset (8 pm - 10 pm).

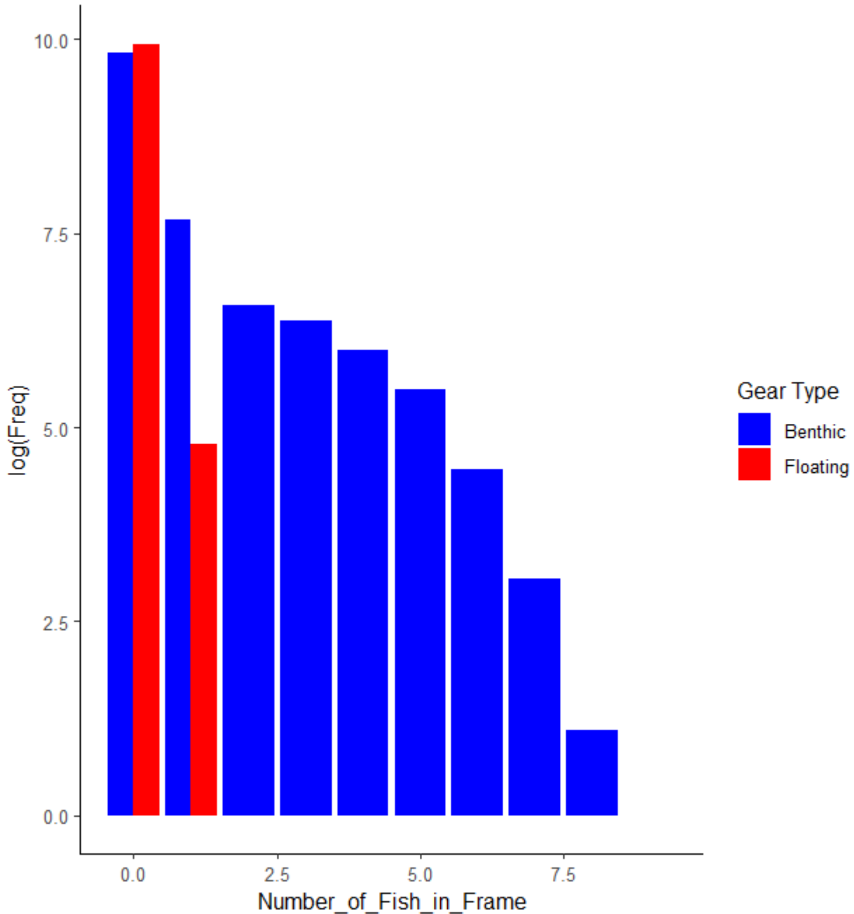

Figure 18. The log10 of the frequency of MaxN of each image, 0 – 9, from both the KiloCams and Brinno Cams for the benthic and floating site. Most of the images with a fish had 1 fish in the frame.

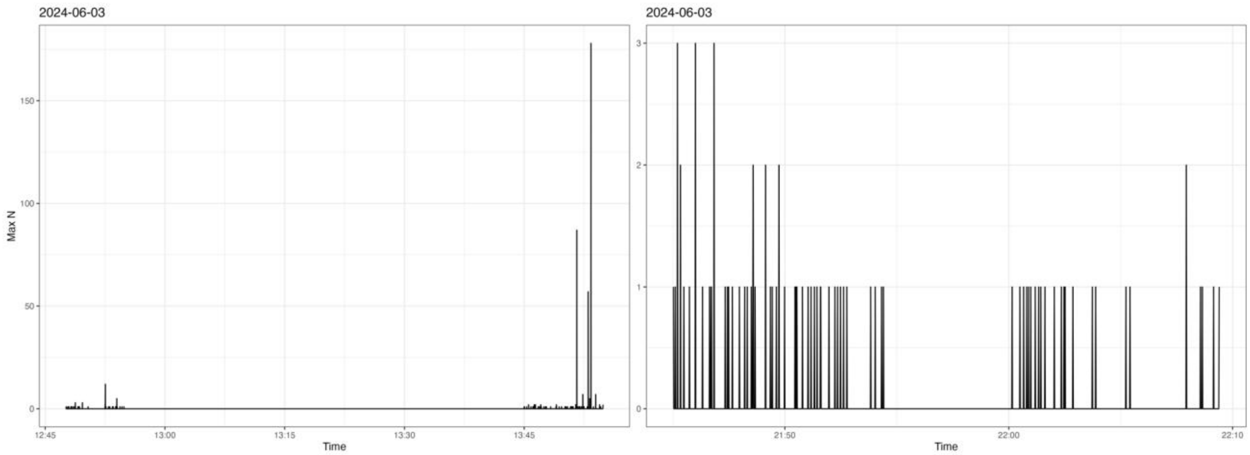

Figure 19. The MaxN of fish in a 10-min Flexview subsample during the day and night from June 3, 2024.

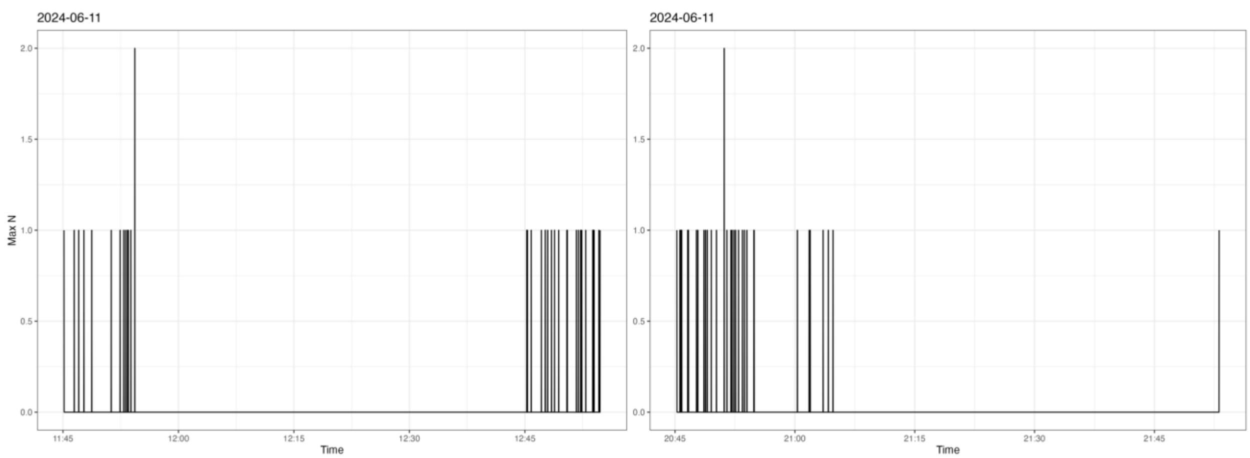

Figure 20. The MaxN of fish in a 10-min Flexview subsample during the day and night from June 11, 2024.

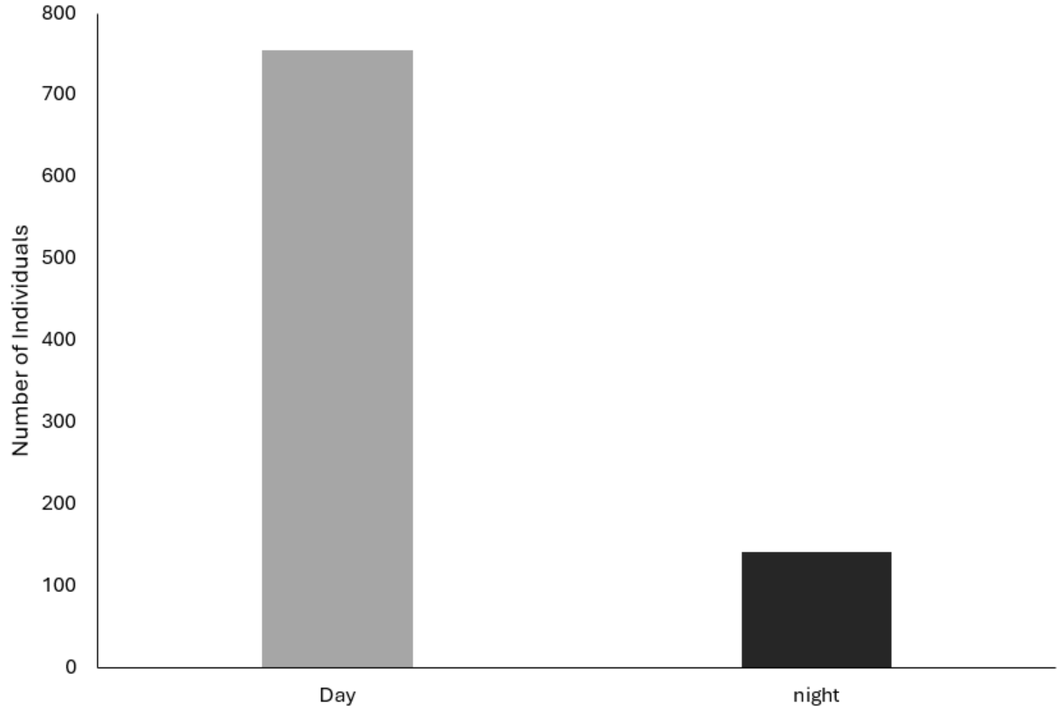

Figure 21. The total number of fish associated with the benthic cage during the day and night of the four subsampled day and four subsampled night data.

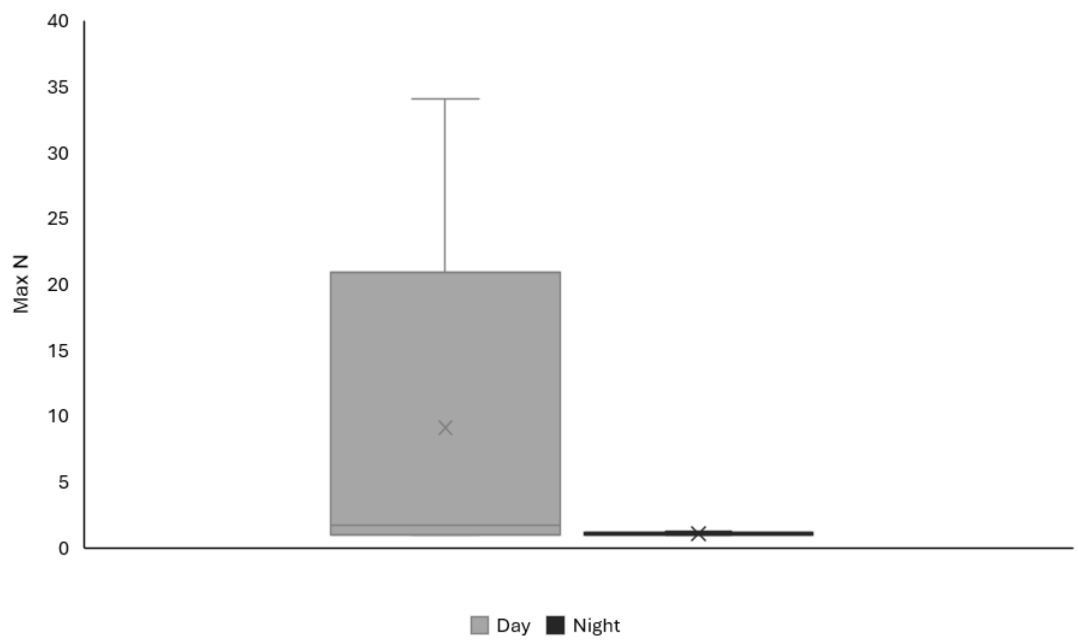

Figure 22. The average MaxN of fish during the day and night of the subsamples. The error are standard error bars.

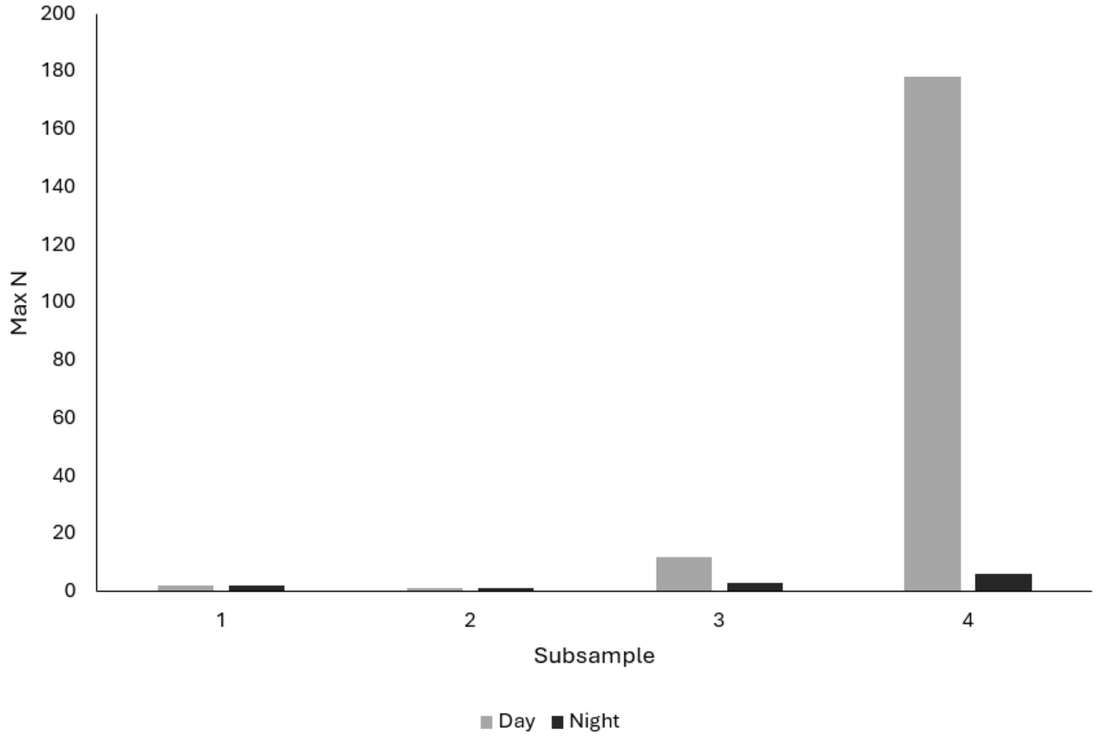

Figure 23. The maximum number of individuals in four of the Acoustic Camera subsamples during the day and night.

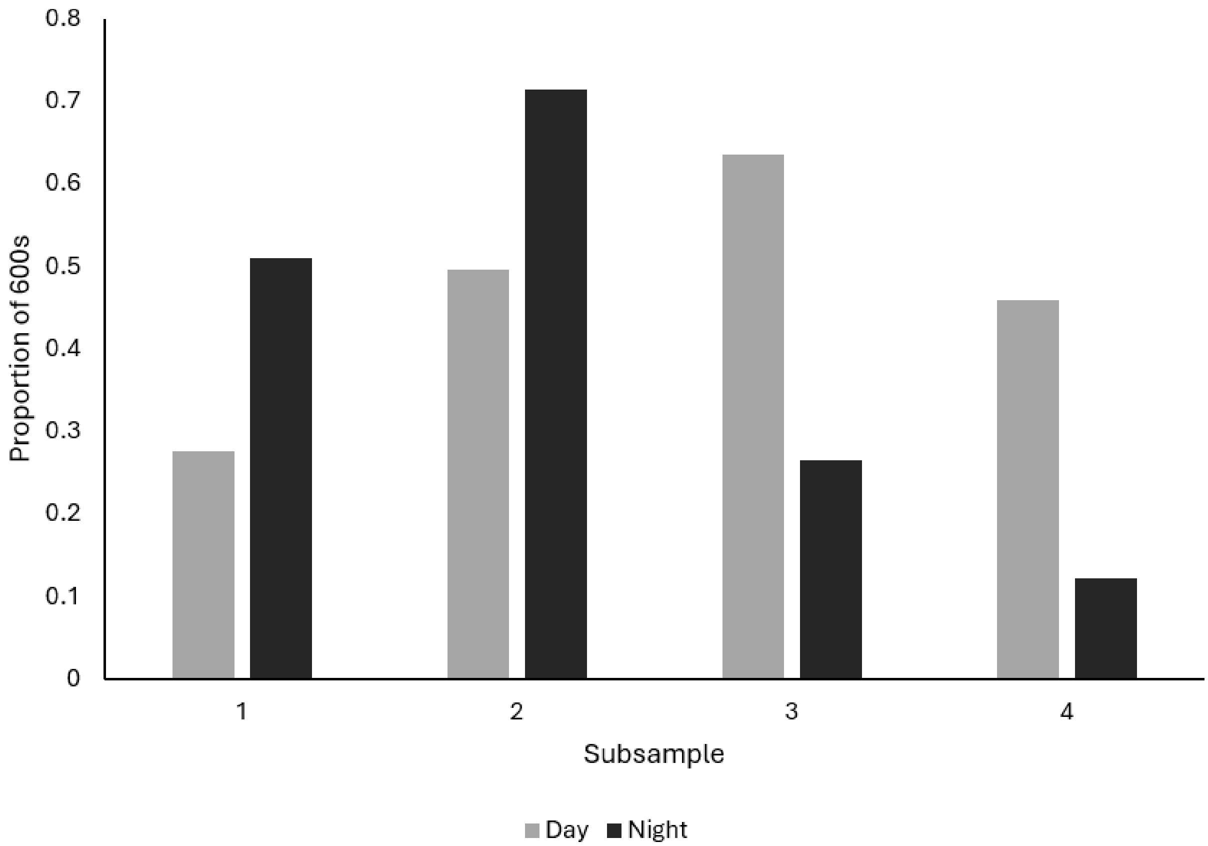

Figure 24. The proportion of time spent in four of the 10-minute subsamples from the Acoustic Camera.

Table 4. The sum of the individuals in each treatment (benthic, floating, and control) cages from the KiloCams and Brinno cam data.

Species	Scientific Name	Benthic	Floating	Control
American butterfish	*Peprilus triacanthus*	5	0	0
Atlantic needlefish	*Strongylura marina*	0	2	0
Atlantic silverside	*Menidia menidia*	0	7	0
Black sea bass	*Centropristis striata*	7876	2	0
Blackfish	*Tautoga onitis*	2102	155	0
Blue runner	*Caranx crysos*	0	29	0
Bluefish	*Pomatomus saltatrix*	0	7	0
Cunner	*Tautogolabrus adspersus*	405	0	0
Feather blenny	*Hypsoblennius hentz*	12	0	0
Summer Flounder	*Paralichthys dentatus*	2	0	0
Gray snapper	*Lutjanus griseus*	0	93	0
Oyster toadfish	*Opsanus tau*	1	0	0
Scup	*Stenotomus chrysops*	878	13	3
Stickleback	*Gasterosteidae sp.*	0	4	0
Striped bass	*Morone saxatilis*	1	0	0
Weakfish	*Cynoscion regalis*	4	0	0
unknown		184	32	0
		Grand Total	**11817**	

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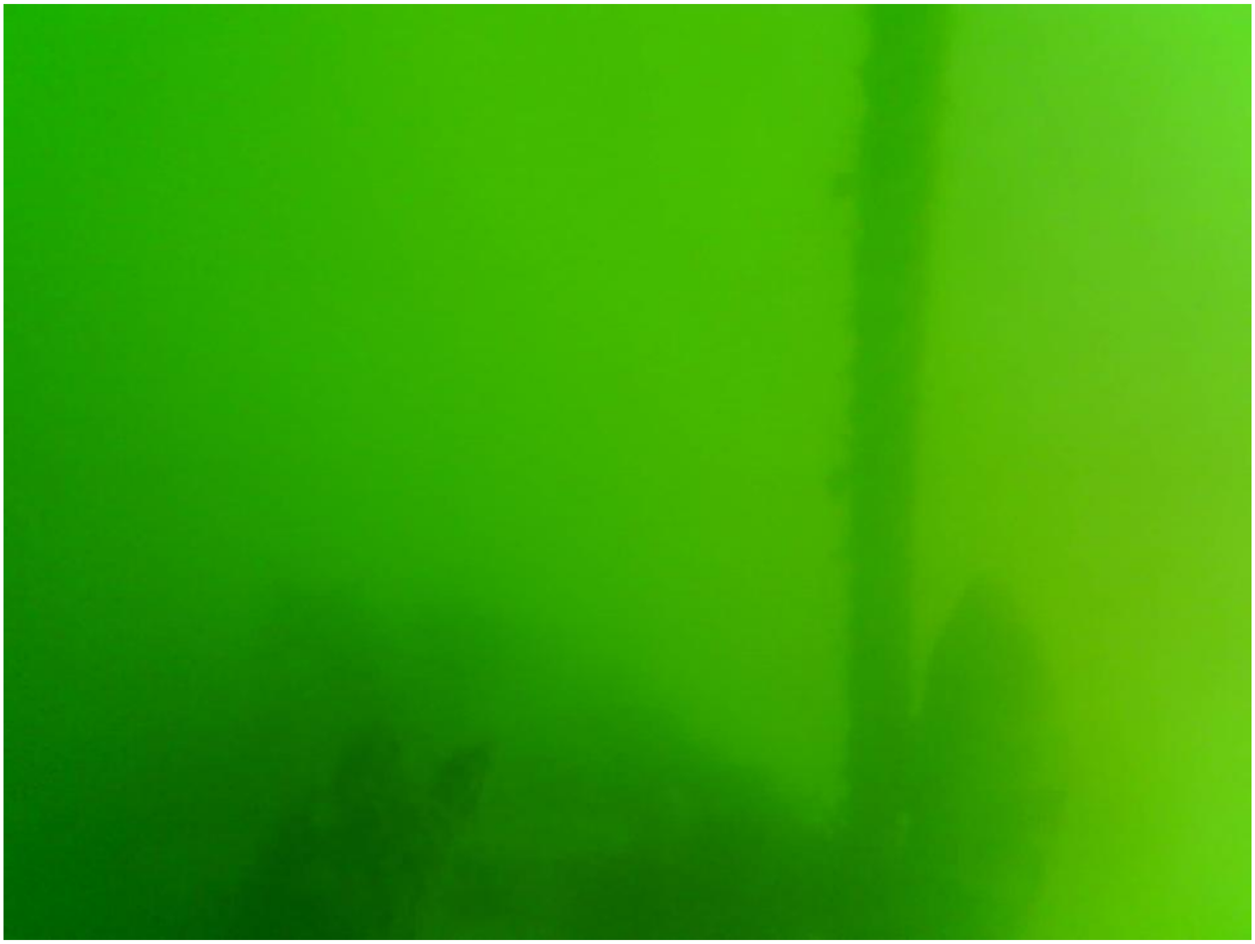
Supplemental Images

Supplemental Figures 1. Floating cages at the floating site. Cages are turned upside down to dry out biofouling.



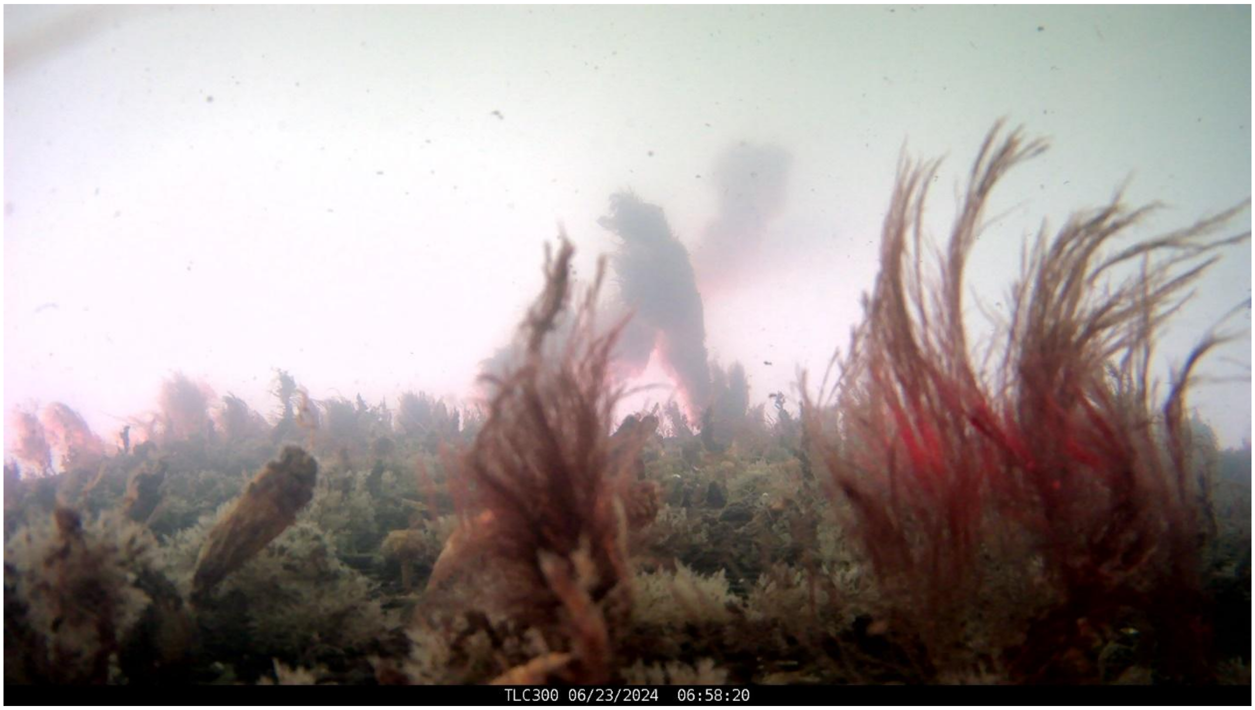
Supplemental Figures 2. Image from the KiloCam of a Black sea bass from the benthic cage.

Supplemental Figures 3. Image from the KiloCam of a Tautog on the floating cage.

Supplemental Figures 4. Image from the KiloCam of grey snapper under the floating cage.

Supplemental Figures 5. Daytime image of three black sea bass and one tautog from the Brinno Cam on the benthic gear.

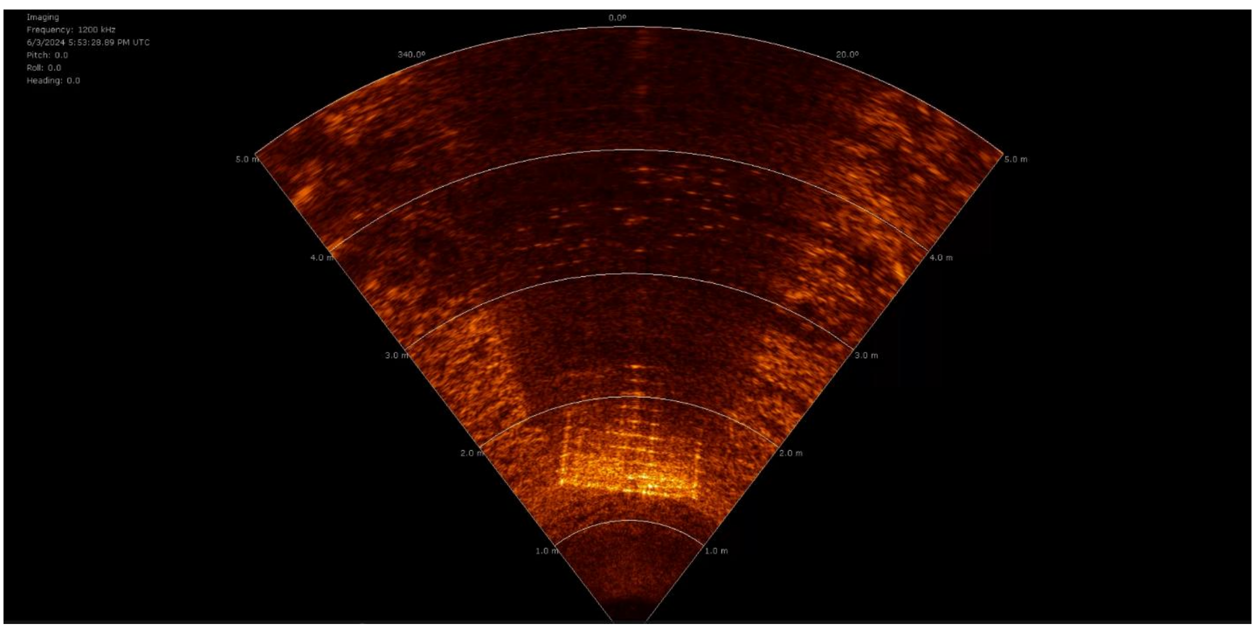
Supplemental Figures 6. Night image of a scup from a Brinno cam on the benthic cage.



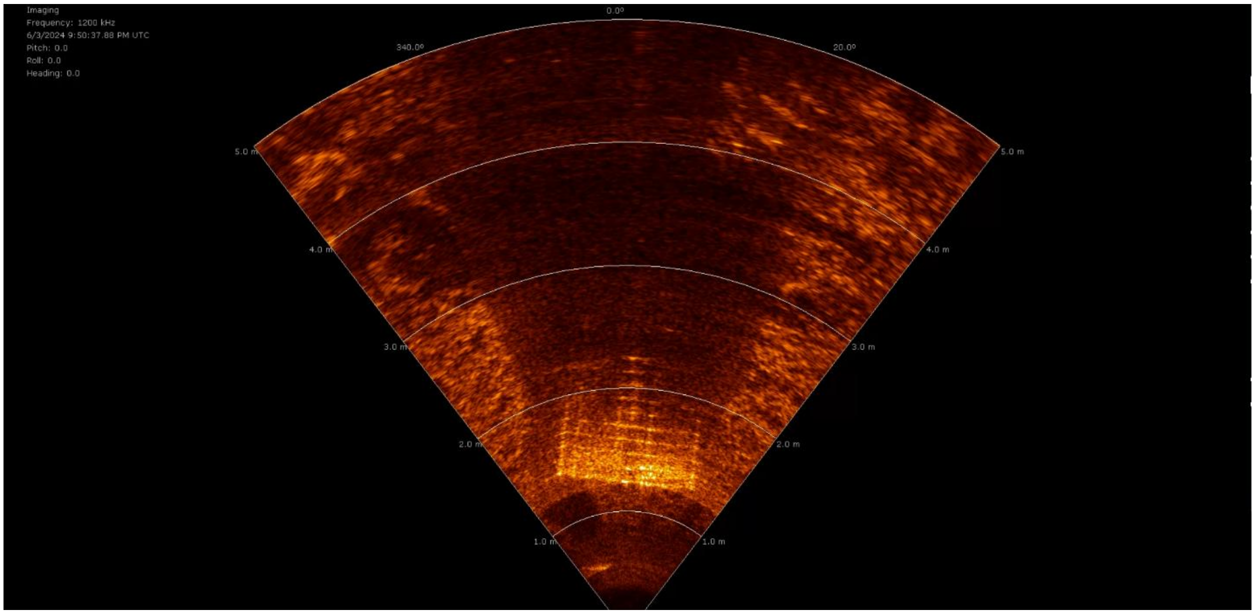
Supplemental Figures 7. Daytime images from the Brinno Cam on the floating gear.

Supplemental Figures 8. Flexview Multibeam SONAR hardware set up on top of a life raft. Hardware includes 2 – 12v batteries, Toughbook laptop, inverter, positive and negative cables, external SSD, and SONAR power supply.

Supplemental Figures 9. Flexview set up before the transducer is secured to screw anchors.



Supplemental Figures 10. School of small fish above the cage.



Supplemental Figures 11. School of large fish above the cage and an individual fish in front of the cage.