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Final Report

Artificial light as a tool to reduce bycatch in the sea scallop, *Placopecten*, *magellanicus*, dredge fishery

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Project Summary

In the U.S. Sea scallop fishery, the status of a number of stocks that interact with the fishery are currently of concern and represent choke species for the fishery (O'Keefe and DeCelles, 2013). While roughly 20 stocks have been identified as interacting with the fishery, the scallop fishery has been allocated sub-allocations for a subset of these stocks (NEFMC, 2020). This includes the Georges Bank (GB) and Southern New England/Massachusetts (SNE/MA) yellowtail flounder stocks, and the Southern and Northern windowpane flounder stocks. Bycatch mitigation in the fishery has leveraged off an understanding of the spatio-temporal interactions between bycatch species and the fishery, as well as efforts to engineer the scallop dredge to facilitate the reduction of bycatch. Uncertainty surrounds the future status of the stocks that interact with the fishery and given this, continuing avenues of research that serve to mitigate bycatch become important for the future sustainability of sea scallop landings and the stocks of fish that represent bycatch.

The Virginia Institute of Marine Science (VIMS) conducted a field study that focused on a scallop dredge conservation engineering approach to mitigate the impact of the fishery on a suite of bycatch species, with special emphasis on windowpane and yellowtail flounder. To accomplish this, we tested the efficacy of SafetyNet Technology Pisces LED lights strategically affixed to the dredge and twine top in an effort to reduce bycatch relative to an identically rigged control dredge tested in a paired experimental design. We evaluated relative scallop and other bycatch species catch over three cruises on GB, targeting areas and times that provided an increased opportunity to encounter a range of bycatch species, especially yellowtail and windowpane flounder.

Results indicated trying to have fish avoid the oncoming dredge, through the use of Pisces lights attached to the balebar facing out from the dredge, was ineffective at reducing the bycatch of yellowtail or windowpane flounder. This approach also did not decrease the catch of other bycatch species such as monkfish or skates. This can be attributed to the commercial tow speed and species-specific behaviors to towed fishing gear. The installation of a square mesh escape panel in the twine top showed promise in reducing the catch of both flatfish. The square mesh escape panel was tested in the center of the twine top and at one end of the twine top, so when the twine top was installed in the dredge the escape panel was directly above the apron. Pisces lights were attached to the twine top to illuminate the escape panel in both configurations. The use of the Pisces lights aided in decreasing flatfish captured in the dredge with the square mesh escape panel located in the center of the dredge. The color of the light, flash rate or brightness did not impact catch rates. The Pisces lights located on the escape panel above the apron did not have an impact of flatfish catch. There was a greater reduction in the catch of windowpane and yellowtail flounder when the escape panel was located above the apron of the dredge. Neither escape panel configuration nor the use of the Pisces lights affected the catch of harvestable size scallops. Fewer small scallops were caught when testing the escape panel placed above the apron twine top configuration.

Project Background

The sea scallop, *Placopecten magellanicus*, supports a fishery that, in the 2022 fishing year (FY), landed 14.4 mt. of meats with an ex-vessel value of approximately US $479 million (NOAA, 2024). These landings have contributed to the sea scallop fishery being one of the most valuable single species fisheries along the East Coast of the United States. The fishery has benefited from management measures intended to bring stability and sustainability. These measures include limited entry, total effort (days-at-sea), gear and crew restrictions, and a strategy to improve yield by protecting scallops through rotational area closures.

While scallop landings have been generally high over the last decade, non-scallop resource issues confronting the fishery present a risk to the long-term trajectory of landings. Central to these issues of concern is the bycatch of vulnerable finfish species. Roughly 20 fish stocks are known to be vulnerable to capture by scallop dredge gear (NEFMC, 2020). These stocks are demersal and consist of numerous flatfishes, monkfish, and skates. While the status of many of the impacted stocks are not in an overfished/overfishing occurring state, that is not the case for all stocks. Several stocks of greatest concern to the fishery are yellowtail flounder (*Pleuronectes ferruginea*) and windowpane flounder (*Scophthalmus aquosus*), and for these stocks a portion of the annual allocation of the overall allowable catch is allocated to the sea scallop fishery, referred to as a sub-Annual Catch Limit (sub-ACL). Exceeding the sub-ACL for these stocks can trigger accountability measures (AM), that have traditionally consisted of closures (both spatial and temporal) as well as the use of gear modifications that have been shown to reduce the bycatch of the species of concern. AMs typically fall in to two categories, one is a reactive measure that attempts to "pay back" at a future time the overages that have occurred. The second type of AM is a proactive approach enacted to anticipate potential situations (e.g. scallop resource conditions that that seem likely to concentrate fishing effort) where catch in excess of the allocation is likely. Irrespective of the type of AM, there exist two broad categories of measures: spatio-temporal closures and gear modifications.

There has been a long history of conservation engineering with respect to scallop dredges and reducing the catch of flatfish and small scallops (DuPaul et al., 2001; Wright et al., 2012; Davis et al; 2013; Davis et al., 2019). Much of the early scallop dredge gear work focused on the mechanical nature of the sorting done by various components of the scallop dredge. Ultimately, in this context, there are limited options for modifications with the dredge frame, ring dimensions (ring diameter and inter-ring spaces), and twine top (mesh size and orientation) being leading candidates (DuPaul et al., 2001; Wright et al., 2012; Davis et al., 2013). These avenues of investigation were typically based on the ability of scallops or finfish to passively escape through the dimensions of the modified component. In the case of scallops, mechanical sorting is a reasonable process to manipulate the length-based efficiency of the gear; however, in the case of finfish, additional elements can be explored to facilitate escapement.

One additional factor is the behavioral response of finfish species to stimulus. The options for stimulus are generally categorized as auditory, mechanical or optical. For this work, we explored the use of optical stimulation to facilitate the reduction of finfish bycatch upon interaction with the sea scallop dredge. Light represents the most likely stimuli to elicit a behavioral response in fish with respect to fishing gear (Nguyen and Winger, 2019). The application of lights has been explored in numerous fisheries (Ryer and Barnett, 2006; Hannah et al., 2015; Lomeli et al., 2018). Prior work, highlights the variability in species specific response to light, as some applications have been used to increase catch rates (e.g. squid jigging, some pot fisheries), while other applications have used artificial lights to reduce bycatch (Nguyen and Winger, 2019). Notable examples of studies that attempted to reduce bycatch include an attempt to reduce finfish bycatch in Nephrops trawls (Melli et.al., 2018), juvenile finfish in groundfish trawls (Grimaldo et. al., 2018), and Pacific halibut from groundfish trawls (Lomeli et. al., 2018). Specific to scallops, Southworth et al. (2020) tested the use of LED lights to exclude multiple taxa of finfish bycatch in queen scallop trawl fishery. The use of the Pisces devices in the Queen scallop trawl fishery reduced flatfish bycatch by 25 percent without reducing the catch of Queen scallops (Southworth et al., 2020).

While there have been limited attempts to transfer LED light technology to dredges, this project builds off of the experiences in other fisheries and gear types to test the application of lights to scallop dredge gear. Nguyen and Winger (2019) stressed the importance of light placement in combination with an understanding of the likely behavioral responses of the species of interest to achieve the desired response. Acknowledging the likely species-specific responses, we assessed the impact of LED light technology to reduce the catch of yellowtail and windowpane flounder in the sea scallop dredge fishery, as well as understand the impact of LED lights on a suite of other bycatch species encountered in the fishery.

Methods

Experimental Gears

Behavioral responses of fishes to LED lights have been shown to be both species and environment specific (Ryer and Barnett, 2006; Lomeli et al., 2018). Given that some species may be either attracted or repelled by the lights, we tested the Pisces lights in two different locations on the dredge (Figure 1). Pisces lights are engineered with a remote control that allows the user to turn the lights on or off, as well as change light color, brightness level, and flash rate. To test the response of species to a deterrent configuration, Pisces lights were secured to the balebar facing out from the dredge (Figure 2). The hypothesis behind this placement is that the light shining forward would elicit a flight response from fish in the dredge path, thus fish would move out of the dredge path. Three lights were placed in stainless steel housings welded to the balebar on each side of the dredge. The lights were angled down toward the sediment at 10°. The second option was to secure the Pisces lights to the twine top of the dredge in an attraction configuration. Lights were attached to a standard twine top with a 10-inch diamond mesh, as well as to two versions of an experimental twine top. The hypothesis for this light placement was that the Pisces lights would illuminate either the escape panel or traditional twine top and attract fish to escape out of the twine top and/or escape panel. The experimental twine top had two rows of 6-inch square mesh that were used as escape panels. The remainder of the twine top was a 10-inch diamond mesh. Five Pisces lights were hung in the middle of the square mesh escape panel across the length of the twine top to illuminate the panel (Figure 3). Two versions of the square mesh escape panel twine top were tested. The first version, referred to as SMPV1, had the square mesh escape panel in the middle of the twine top (Figure 3).

The second version, referred to as SMPV2, had the square mesh escape panel located at one end of the twine top, and when the twine top was installed in the dredge the escape panel was directly above the apron (Figure 4). The lights were placed in the same locations on the traditional twine top. The lights were placed in mesh bags and stainless-steel quick links were used to attach the bag to the twine top at each corner.

Several light colors, flash rates, and brightness levels were tested during the project (Table 1). Aqua blue, green, and white light colors were tested for either the deterrent or attraction light placements. Green and white colors were selected out of the possible range of colors available with the Pisces lights based on previous studies conducted on scallops and flatfish (Hannah et al., 2015; Lomeli et al., 2018; Meli et al., 2018; Southworth et al., 2020). For green and white colors, a constant light and a flashing light with a flash rate of 8Hz was tested. Also, for the green and white lights two lumen levels were tested: For the white light 46 and 79 lumens were tested. For the green light 55 and 79 lumens were tested. For the aqua blue light, only a constant light and 79 lumens were tested.

A CatchCam from SafetyNet Technologies was secured to the dredge in several locations to record species interactions with the dredge, avoidance behavior, and escapement in front of the dredge or through the twine top square mesh panel. The system consists of a camera and an LED light. The system was secured to the dredge frame during deterrent trials looking out from the dredge or into the mouth of the dredge. The system was secured in a steel housing for protection (Figure 5). For the attractant trials, the system was attached to the top of the twine top in different locations (Figure 5). The camera and LED light were protected with pvc pipe. Video was recorded for all tows.

Field Tests

One trip per month was conducted between August and October of 2022 in Closed Area II during a seasonal closure from August 15 – November 15, 2022. This closure is a management measure for the scallop fishery created to reduce the bycatch of windowpane and yellowtail flounder. Conducting sea trials during this time period ensured we would have a higher probability of catching both species of interest.

The experimental and control dredges were towed simultaneously in a paired experimental design. The control dredge was a 16 ft Turtle deflector dredge with a 7-row apron and a 2:1 hanging ratio for the twine top. The twine top was a 10-inch diamond mesh. For all deterrent balebar tests, the Pisces lights were always turned on for the experimental dredge. During the first trip for the attractant treatments, the Pisces lights were always turned on while on the dredges. For the second and third trips, the Pisces lights were turned on or off every other tow. This allowed us to test for the effect of the square mesh escape panel with and without the panel being illuminated. To test for a side effect, dredges were switched from one side of the vessel to the other every two days, unless weather conditions made this unsafe to do so. Commercial fishing conditions were replicated during sea trials. The captain selected the operational parameters; tow locations within Closed Area II, course, towing speed, and warp scope. Data from the Northeast Fisheries Observer program, the University of Massachusetts Dartmouth School for Marine Science and Technology, and the VIMS sea scallop dredge survey were used to inform target areas to increase the probability of encountering windowpane and yellowtail flounder.

Catch Sampling

Catch from each dredge was kept separate. Total scallop catch was quantified by placing all live scallops in bushels baskets to obtain the total number of bushels for each dredge. Other bycatch species of interest were enumerated, and total length measurements (mm) were taken. This included yellowtail flounder, windowpane flounder, fourspot flounder (*Hippoglossina oblonga*), winter flounder (*Pseudopleuronectes americanus*), summer flounder (*Paralichthys dentatus*), monkfish (*Lophius americanus*), barndoor skate (*Dipturus laevis*), and unclassified skates (i.e., all other six skate species). Other bycatch species not listed were enumerated but no length measurements taken. Subsampling for length measurements occurred for scallops and unclassified skates. One bushel basket of scallops was measured for each tow and dredge. For unclassified skates, subsampling varied depending on total catch.

Data Analysis

To test for significant differences in mean catch for the experimental and control gears a repeated measures ANOVA, with the ezANOVA function from the ez R package, was used (Lawerence, 2011). Differences in mean catch were tested for at the species or species group (i.e., unclassified skate and all flatfish), gear, and treatment levels. Flatfish were grouped together to increase the sample size due to low catch rates for some species. The same repeated ANOVA function was also used to test for significant differences in which side of the vessel the control and experimental dredges were fished from.

To model the relative length-based probability of capture for the experimental dredge by species or species group and treatment, the Selfisher R package was used (Brooks et al., 2020). These mixed effect models can be used to model catch comparison data, where both gears are selective. This type of model accounts for overdispersion, often observed in these types of experiments, by allowing for a random effect of the tow pair and allowing for bootstrapping of parameter estimate for the preferred model. These models can also account for differences in subsampling rates between gears and tows (referred to as the *qratio*) and tow distance between tow pairs through the addition of an offset term in the model that can occur during field trials. The models can be fit with either polynomial or spline methods for the length term.

Model selection followed methods described by Brooks et al. (2022). Models were developed for only the attractant trials for the experimental twine tops. Models were developed for scallops, flatfish (all species), monkfish, barndoor skate, and unclassified skates. These are the most common bycatch species for scallop dredge gear and had the greatest sample sizes. Scallop length data were binned into five mm length bins. All other species or species group length data were binned in one mm length bins. Tow pairs with zero catch for any species or species group were removed. The response variable was a proportion, the number of fish caught at length in the experimental dredge divided by the total number of fish caught at length in both dredges. First, models were developed with length as the sole predictor variable. Length was modelled as either a polynomial term to the third order or a spline with three degrees of freedom to determine the best fit to the data. The model with the lowest Bayesian information criterion (BIC) value was selected as the preferred model. After the length term modelling approach was determined, other predictor variables were added to the models with a forward selection approach to understand the effect of the Pisces lights. Predictor variables included Light on (whether the Pisces Light was turned on or off), light color, flash rate, and brightness level. “Light on” was the first variable added, followed by light color, brightness, and finally flash rate. The preferred model was selected by evaluating the BIC value and significance of predictor variables. For example, if a model had the lowest BIC value with the terms “Light on” and light color but Light on was not significant, the model with the next lowest BIC was selected as the preferred model. Confidence intervals for the preferred model were estimated with bootstrapping, after removing the random effect of tow, to evaluate population level estimates (replications n = 1,000). An offset term for differences in tow duration (log tow duration for each tow pair) was included in models, as well as a *qratio* (sampling $\text{ratio}_{\text{expermiental gear}}/\text{sampling ratio}_{\text{control gear}}$ for each tow pair) for each species or group. The logit link was the selected link function. All analyses were completed in R (R Core Team, 2021).

Results

Field Trial Summary

Three 8-10-day trips were conducted between August and October of 2022 onboard the F/V *KATE* out of New Bedford, MA. Tow locations by cruise are provided in Figure 6, tow locations by treatment are provided in Figure 7, and cruise information is provided in Table 2.

Deterrent Treatments

The deterrent treatments with the Pisces lights attached to the balebar were not successful in reducing the catch of yellow or windowpane flounder or other bycatch species of interest (i.e., monkfish or skates), regardless of the light color tested (Table 3). There was no significant difference in the mean catch by gear or species (all p-values < 0.3) (Figure 8). Treatment 2, constant green light, was significantly different than the other two balebar treatments with respect to catch by species (all p-values > 0.01). There was no effect of what side of the vessel the two gears were fished on (p-value = 0.6).

Attraction Treatments

Control Twine Top

For the control twine top treatments, there was no difference in the mean catch between the experimental and control gears for all species (all p-values > 0.2). For the two treatments tested, green and white constant light, there was also no difference in the catch (all p-values > 0.09) (Figure 9). There was no effect of what side of the vessel the two gears were fished on (p-value = 0.8).

SMPV1 Experimental Twine Top

There was no clear trend in catch results across all species for the SMPV1 twine top treatments (Table 5, Figure 10). There was a seven percent reduction in scallop catch in the experimental dredge, which was a significant reduction in catch relative to the control dredge (p-value = 0.005). The flatfish group catch was reduced by 12 percent in the experimental dredge. The majority of this reduction was for fourspot flounder, followed by windowpane flounder. This reduction in catch was not significant (p-value = 0.2). There were also reductions in skate catch; barndoor skate catch was reduced by eight percent and unclassified skate catch was reduced by five percent. There was an eight percent increase in monkfish catch. None of these reductions in catch were significantly lower than the control dredge catch (all p-values > 0.2). There was no side effect for these set of treatments (p-value = 0.6).

Modelling results for the SMPV1 treatments varied by species or species group. All spline models had a better fit to the data compared to the polynomial models. There was no effect of having the Pisces lights on the experimental twine top for all length classes of scallops (Table 7, Figure 11). Although the predicted model fit indicated the experimental gear caught less scallops of smaller sizes compared to the control gear. The preferred model had only the length term as a predictor. When the Light on variable was added to the model, there was no significant effect on scallop catch (p-value = 0.9). For flatfish, model results indicated having the Pisces lights illuminating the escape panel helped reduce the catch of flatfish (Light on p-value = 0.02), but there was no effect of the light color, the brightness or flash rate (Table 7, Figure 12). Model fit plots for tows with the Pisces lights on indicated reduced catches across all size classes. There was no effect of having the Pisces light illuminate the escape panel for the remaining bycatch species (Table 7 Figures 13-15). Model selection for barndoor skate indicated either a length only model or a length and Light on model were similar, with no difference in BIC values between the two models. The Light on term was not significant, with a p-value of 0.8. For unclassified skates, the model with the lowest BIC had length and Light on as predictors, but the Light on term was not significant (p-value = 0.16). The predicted catch at length model for the length and Light on models showed the 95% confidence intervals overlapped across the length range. Based on this and the Light on term not being significant, the length only model was selected as the preferred model.

SMPV2 Experimental Twine Top

During the third sea trial, only a green constant light was tested with the SMPV2 experimental twine top. This decision was based on examining catch data from the previous trips.

For the SMPV2 trials, reductions in catch for some bycatch species was observed (Table 6, Figure 16). There was a four percent reduction in flatfish catch. By species, the largest reduction was for yellowtail flounder (86%), followed by fourspot flounder (16%), and windowpane flounder (10%). The catch of unclassified skates was also reduced by 12 percent. Barndoor skate and monkfish catch increased by 50 and 24 percent, respectively. There was a four percent reduction in scallop catch in the experimental dredge. None of the differences in catch between dredges was significantly different (all p-values > 0.3), except for the reduction in unclassified skate catch (p-value < 0.001). There was no side effect for these set of treatments (p-value = 0.6).

The SMPV2 treatment models were similar across species or species group. All spline models had a better fit to the data compared to the polynomial models. For all five species/species groups there was no effect of having the Pisces lights illuminating the escape panel in the experimental twine top (Table 8). The only predictor in all preferred models was the length term. The predicted model fit for this gear differed from that for the SMPV1 gear with respect to the capture of scallops at length (Figure

17). This gear was predicted to have lower catches of small scallops. Although 95% confidence intervals for all lengths included zero. The p-value for the “Light on” term was 0.7 when added to the model. The predicted fit for flatfish is shown in Figure 18. The model predicted lower catches of smaller flatfish up to 300 mm. The predicted relative efficiency of the experimental gear for monkfish was similar to that of the control dredge for all sizes of fish captured (Figure 19). The experimental gear was predicted to catch more barndoor skates across all sizes up to 500 mm (Figure 20). For unclassified skates, both gears had similar relative efficiency for skates less than 650 mm. Skates larger than 650 mm were predicted to be captured by the experimental gear more than the control gear (Figure 21).

CatchCam

Over 2,500 videos were recorded during the project. There were some technical issues with the system on the first trip as well visibility issues that were a result of turbidity and or camera angle, the camera being blocked or the camera moving during a tow. Flatfish were observed swimming out of the square mesh escape panel. Select video can be viewed on SafetyNet Technologies’ website https://sntech.co.uk/products/catchcam/ and their YouTube Channel https://www.youtube.com/channel/UCLUYu4wJYEHPGpq7R5Fk1DA.

Presentations

Several presentations were given at scientific conferences for this project:

- 2024 National Shellfish Association Annual Meeting. March 17 - 21, 2024. Charlotte, NC.
- International Pectinid Workshop, April 25 – 20,2024. Douglas, Isle of Man.

Discussion

The use of Pisces lights as a deterrent on the balebar did not reduce the catch of flatfish. These findings are attributed to the tow speed used in the fishery (average 5 kts) in conjunction with the avoidance behavior of flatfish to towed fishing gear. Flatfish remain on or buried in the substrate to avoid detection, and at least for trawl gear, once disturbed move toward the center of the gear in an avoidance pattern (Ryer et al., 2008;

Winger et al., 2004). Flatfish also react to towed gear at close distances (Nguyen et al., 2023). Previous conservation engineering projects focused on scallop dredge modifications to reduce flatfish have demonstrated reductions in catch at slightly slower speeds (4.6 – 4.8 kts) (Smolowitz et al., 2012; Davis et al., 2013). The capture rate of aggregated flatfish observed from a study focused on a sea scallop survey dredge was 55 percent (Roman et al., 2023). The towing speed for this scallop survey dredge is 3.8 - 4 kts relative to the commercial tow speed of 5 kts. The commercial tow speed may also limit the ability of other bycatch species to react to the gear and move out of the dredge path before being overcome by the dredge. Nguyen et al. (2023) stated that monkfish have a similar avoidance behavior as flatfish to towed fishing gear, as well as a low swimming speed relative to the speed of the towed fishing gear and low swimming ability. The high capture rates for flatfish, skates, and monkfish at a lower towing speed should be an indicator that the capture rate at higher tow speeds could be greater due to the swimming ability and reaction to towed gear for these species.

The application of the Pisces lights in conjunction with a square mesh escape panel located in the middle of the twine top (SMPV1) reduced the catch of flatfish in the dredge. Reductions in the bycatch of the other species analyzed were mixed. This result should be expected based on the size of the square mesh escape panel mesh relative to the size of skates and monkfish. These fish are too large, both in length and body width, to escape through the square mesh escape panel. There was also a loss of scallop catch, although this reduction was not significant.

Results for the SMPV2 experimental twine top indicated the use of the Pisces lights did not impact the catch of any species or species group. There was a similar 12 percent reduction in flatfish catch compared to the SMPV1 trials. There was a greater reduction in catch for both windowpane and yellowtail flounder catch. Windowpane catch was reduced by 10 percent relative to 5 percent for the SMPV1 twine top. Yellowtail flounder catch was higher in the SMPV1 twine, while the SMPV2 twine top had a reduction. Catch of yellowtail flounder was low during the project, so result for this species should be viewed with caution. Low catch rates are probably related to the low biomass of the GB stock. The 86 percent reduction in catch for the SMPV2 twine top should be considered in the context of the number of fish caught. Seven fish were captured in the control dredge and one fish was caught in the experimental dredge. For the SMPV1 trials, five fish were caught in the control dredge and eight fish were caught in the experimental dredge across all treatments. The SMPV2 twine top also had a smaller reduction in scallop catch compared to the SMPV1 twine top. Model results for this twine top also indicated fewer small scallops were captured. The combination of a larger reduction in windowpane flounder catch coupled with a decrease in the catch of small scallops would be a benefit to the fishery.

While this approach showed promise for flatfish, hurdles exist for using this method as a regulated measure to reduce the bycatch of flatfish. The use of the Pisces lights would be a challenge to enforce, which is a considered by managers when implementing a new management measure. The placement of the lights on the twine top, light color, the lights being turned on would all have to be enforced and be able to be checked by the US Coast Guard during a boarding on a commercial vessel. The use of Pisces lights on a scallop dredge could be a voluntary measure adopted by stakeholders. This would require outreach to stakeholders to educate them on the use of the lights. Also, the square mesh escape panel twine top would have to be regulated for use in the fishery. The current regulations do not allow for this panel to be installed in a twine top for use during commercial fishing operations.

The project budget and project compensation are included as Appendix A.

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Figure 1. Image of the Pisces light designed by SafetyNet Technologies that was placed on the dredge in various configurations.

Figure 2. Image of the Pisces light attached to the balebar of a dredge in the deterrent configuration.

Figure 3. Image of the Pisces light attached to the experimental twine top square mesh escape panel located in the middle of the twine top referred to as SMPV1 in the attraction configuration.

Figure 4. Image of the Pisces light attached to the experimental twine top square mesh escape panel located at the bottom of the twine top referred to as SMVP2 in the attraction configuration.

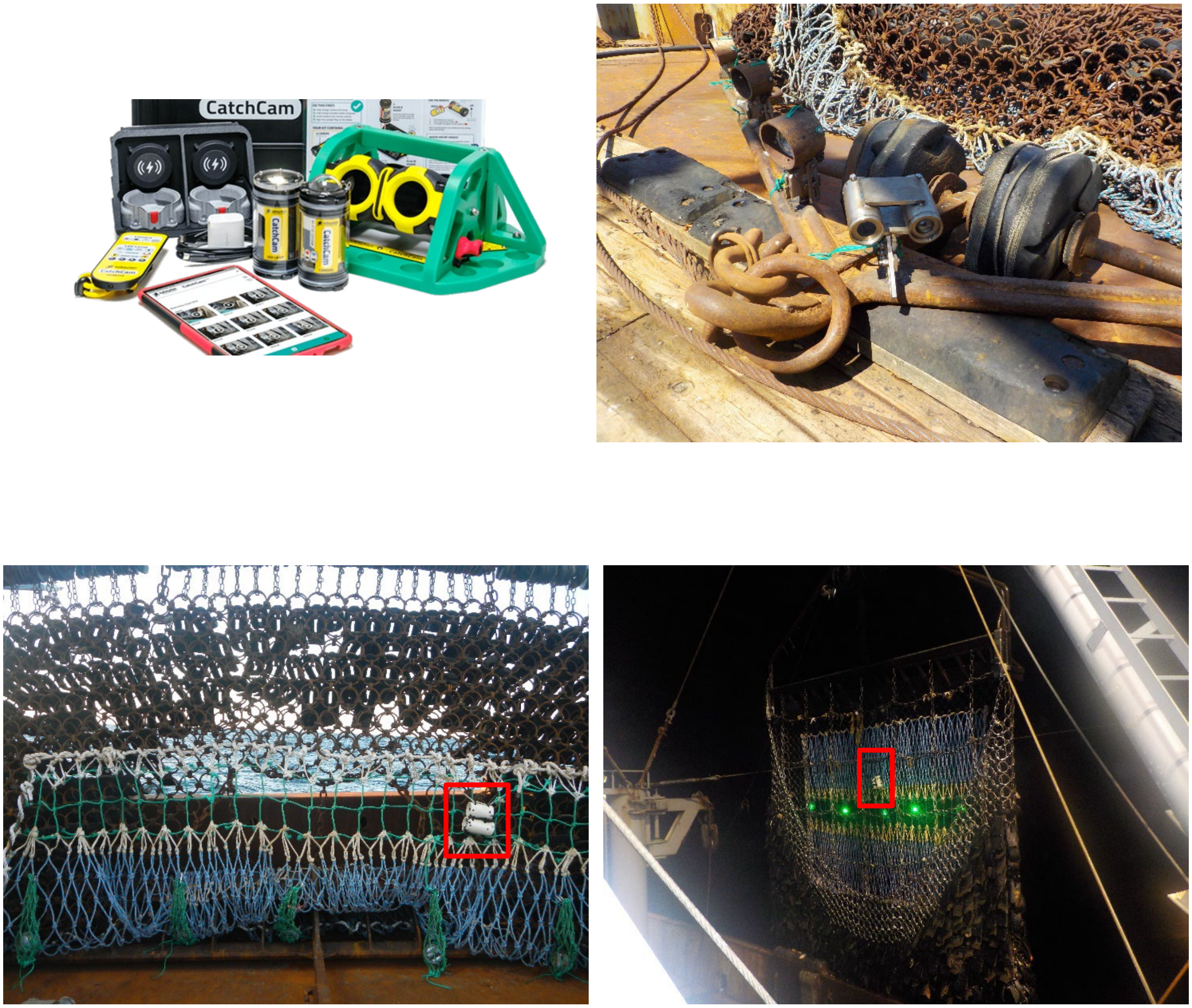

Figure 5. Images of the Pisces CatchCam system. The entire system is in the top left. The system attached to the dredge frame looking out from the dredge is in the top right. Examples of how the system was attached to the experimental twine top are shown in the bottom two photos (outlined in red).

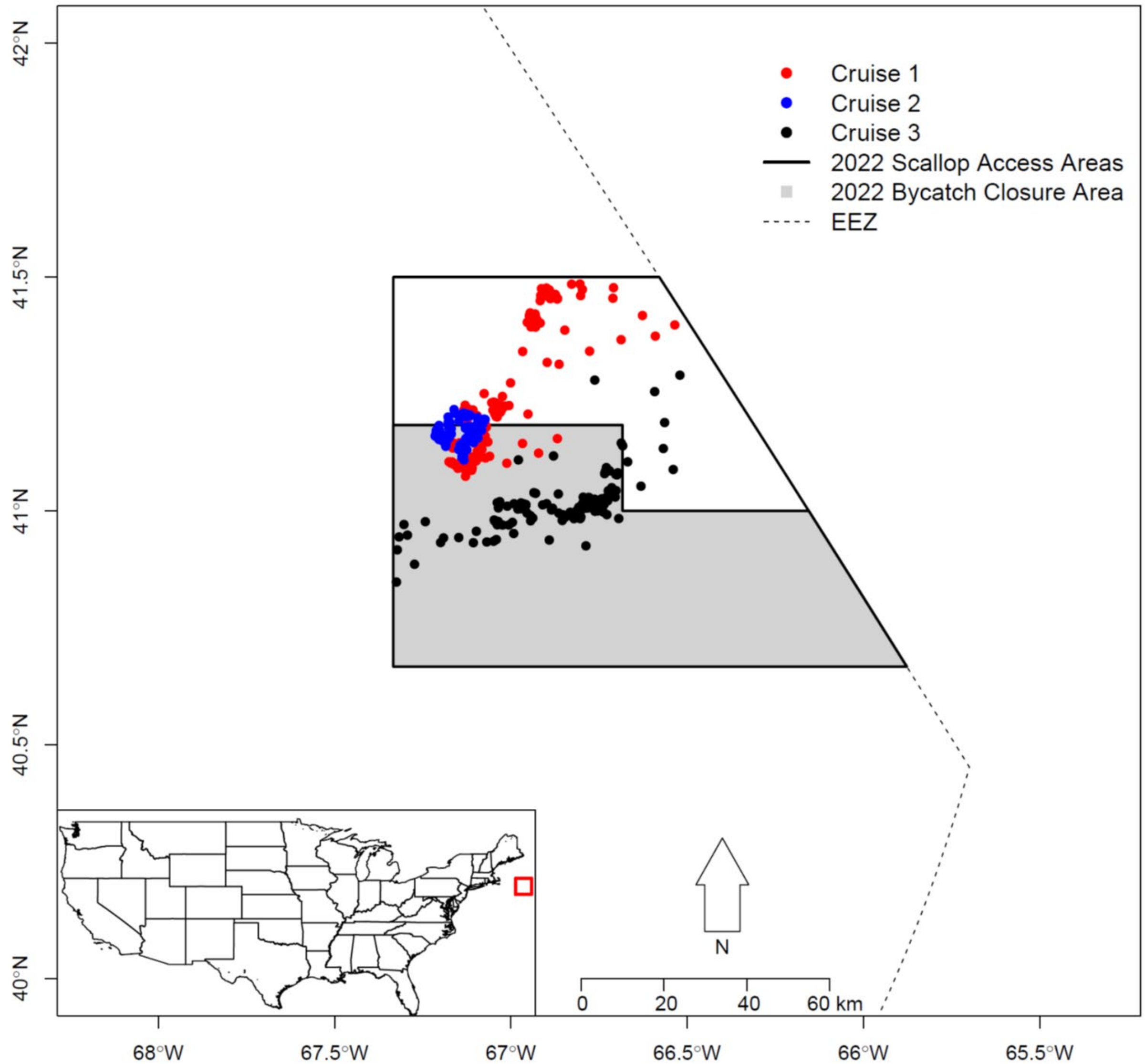

Figure 6. Tow locations by cruise.

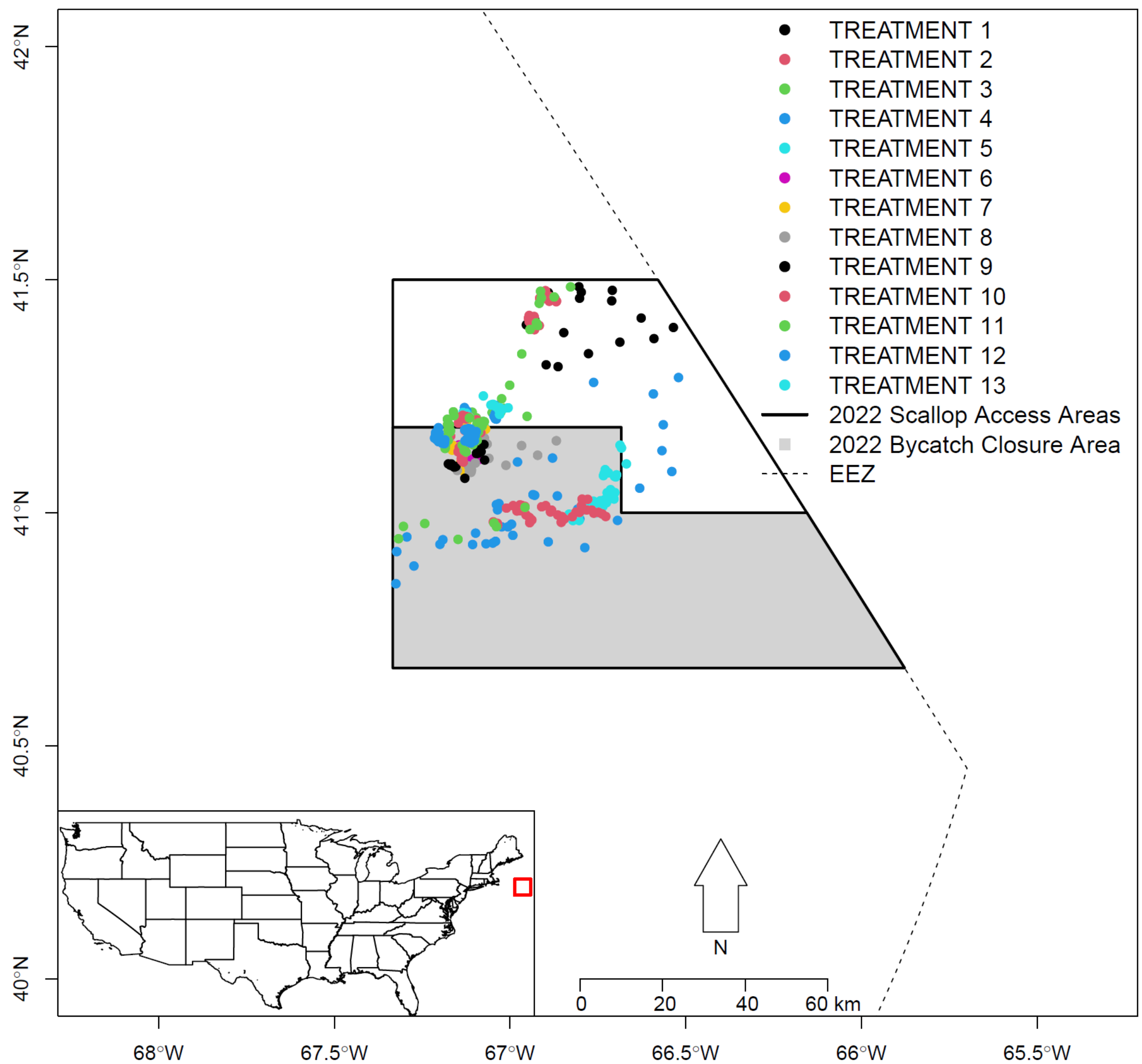

Figure 7. Tow locations by treatment.

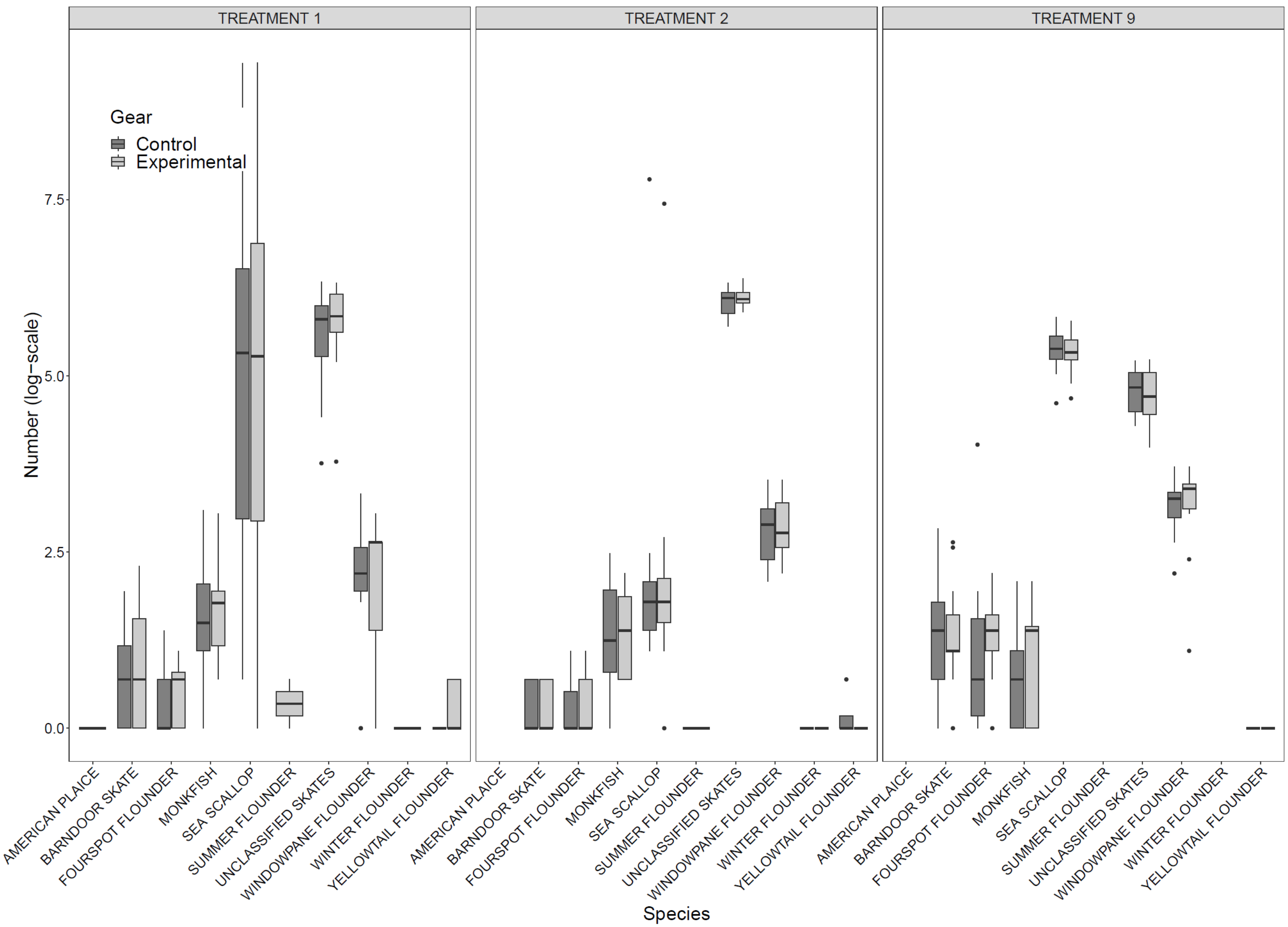

Figure 8. Boxplots of catch by species and gear for the deterrent balebar treatments.

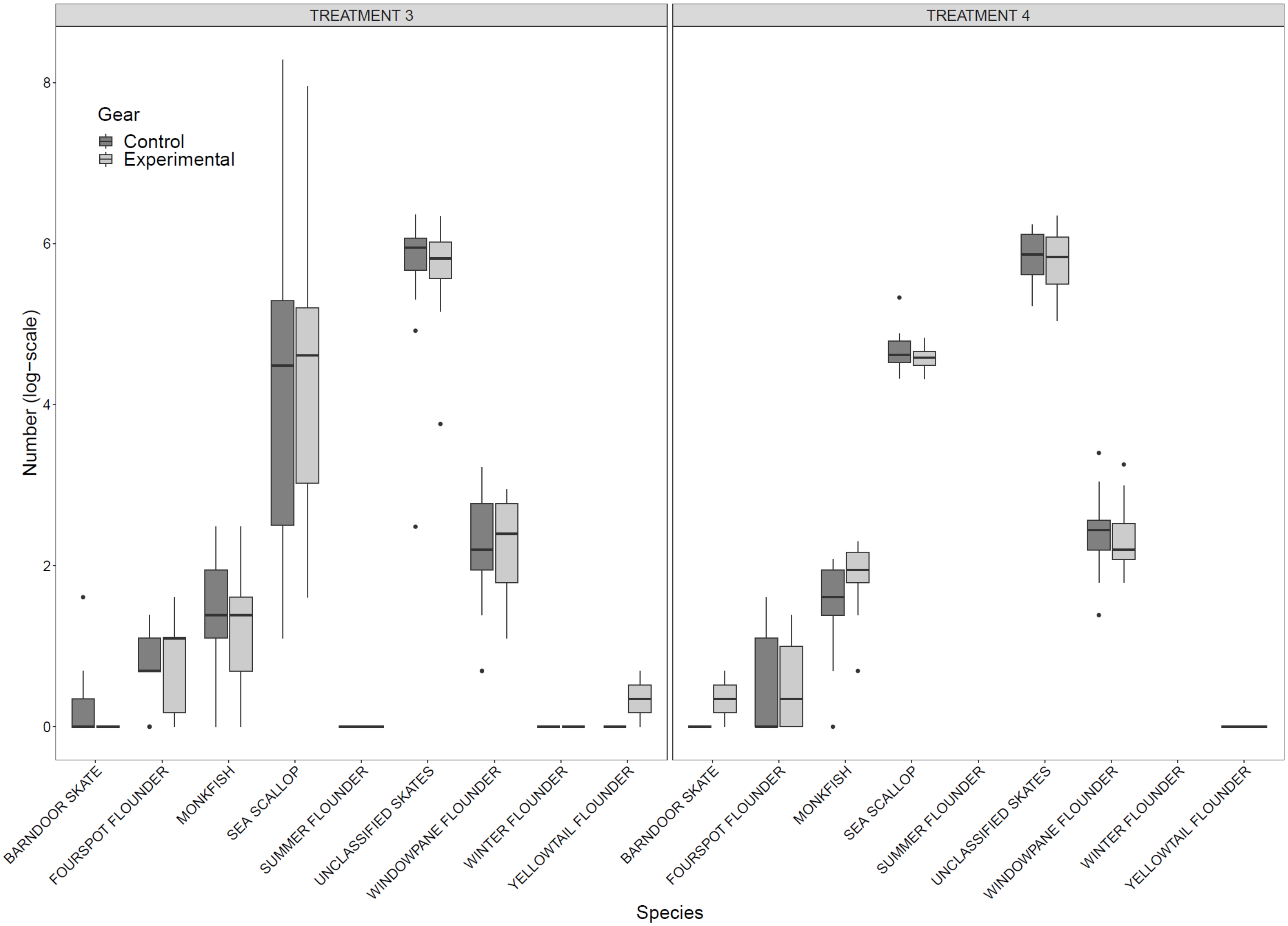

Figure 9. Boxplots of catch by species and gear for the attractant control twine top treatments.

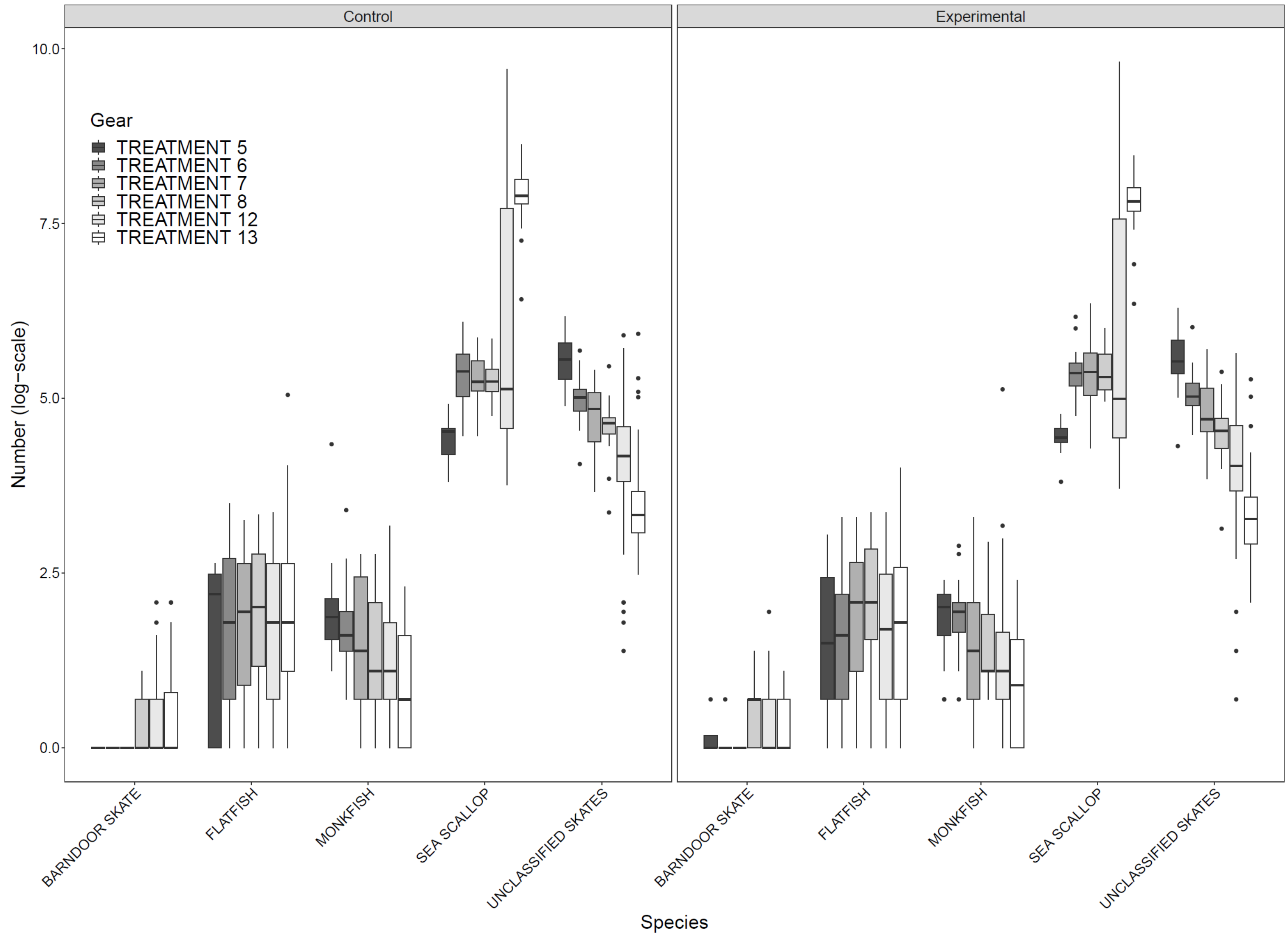

Figure 10. Boxplots of catch by species and gear for the attractant SMPV1 twine top treatments.

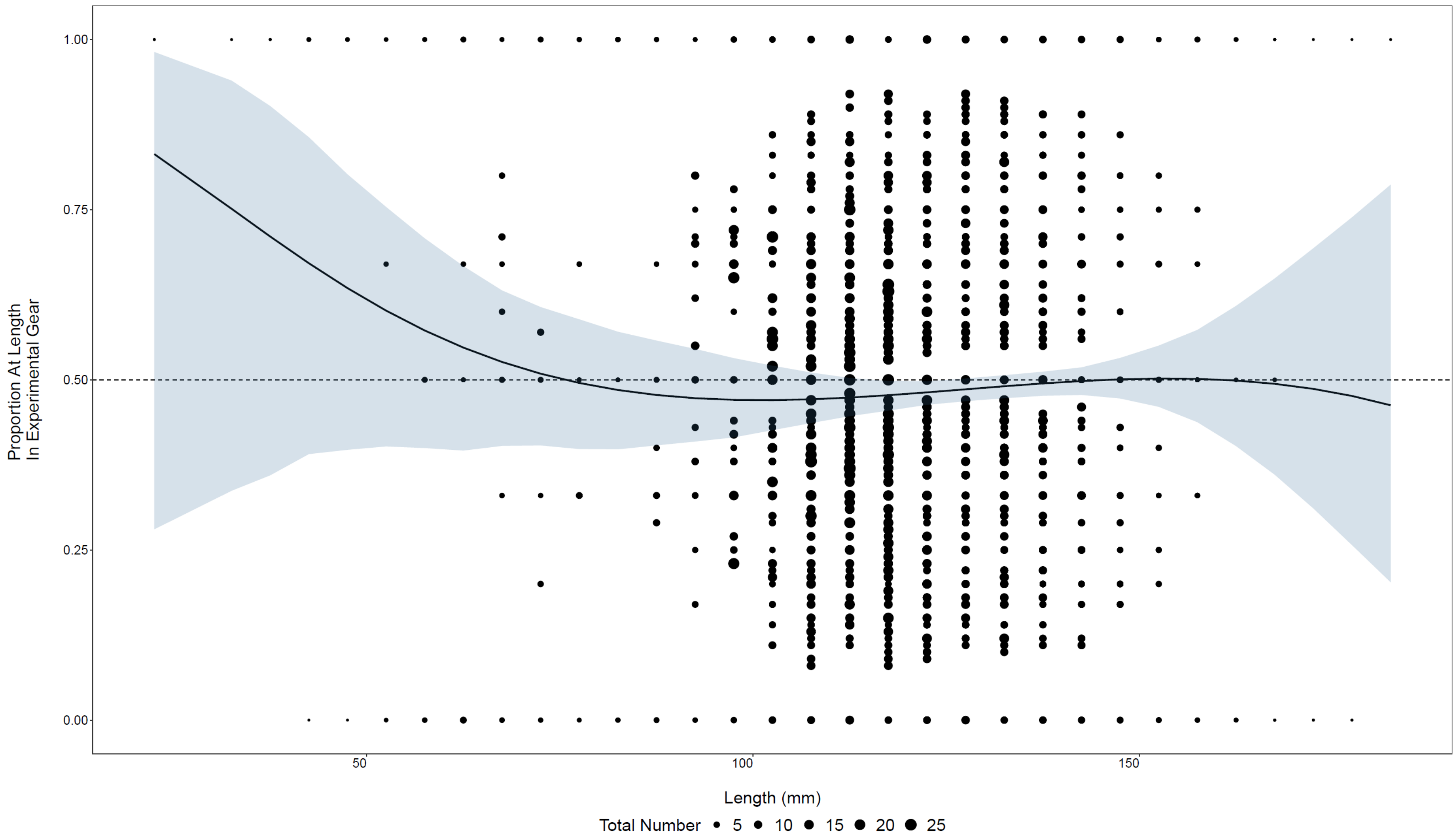

Figure 11. Preferred Selfisher model for scallops for the attractant SMPV1 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed unexpanded number of scallops caught at length for each tow pair.

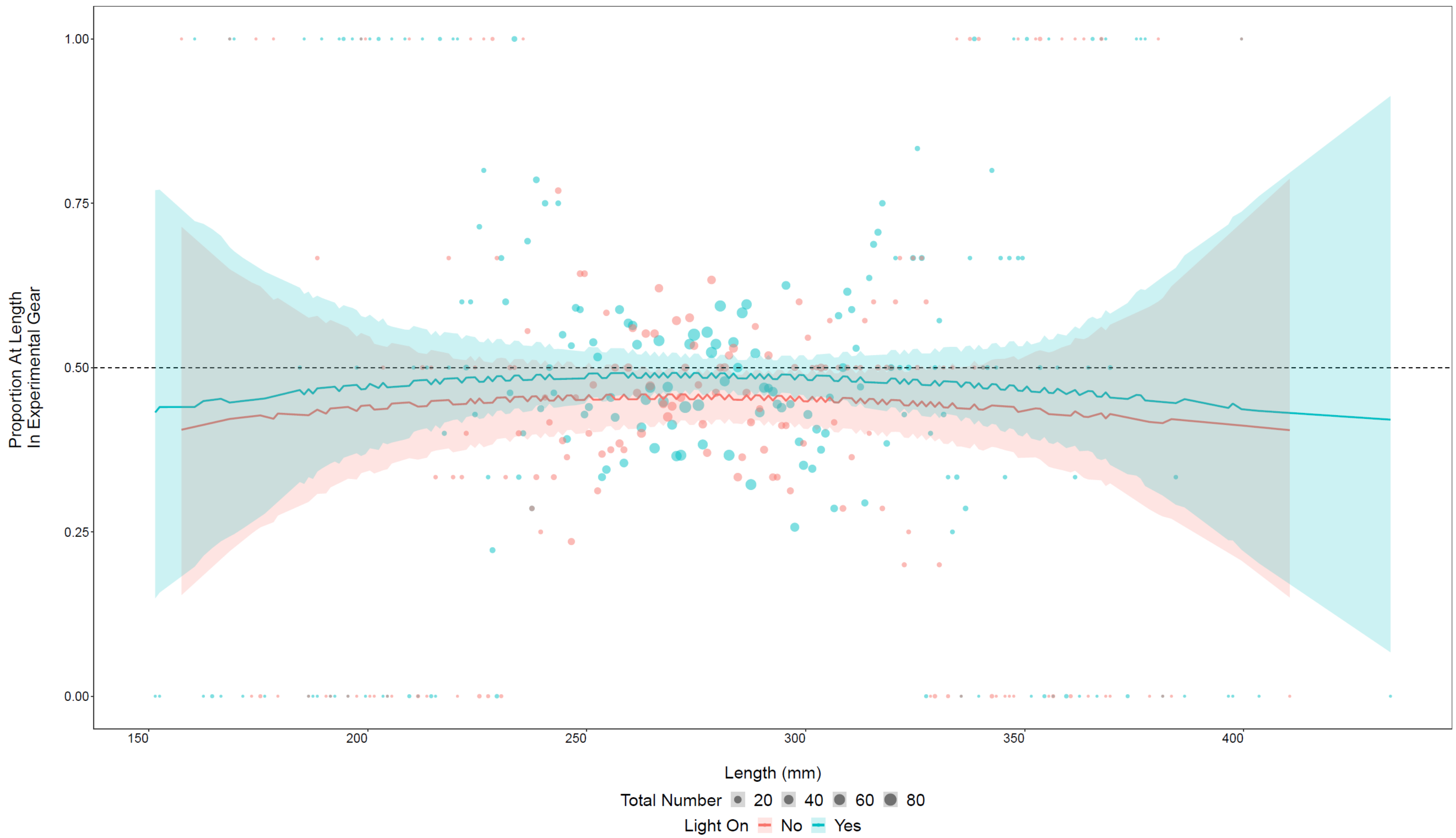

Figure 12. Preferred Selfisher model for flatfish for the attractant SMPV1 twine top trials with the Pisces light turned on (pink) and off (turquoise). The solid lines are the predicted proportion caught at length, the colored shaded area are the 95% confidence intervals, and the circles are the observed number of flatfish caught at length for each tow pair.

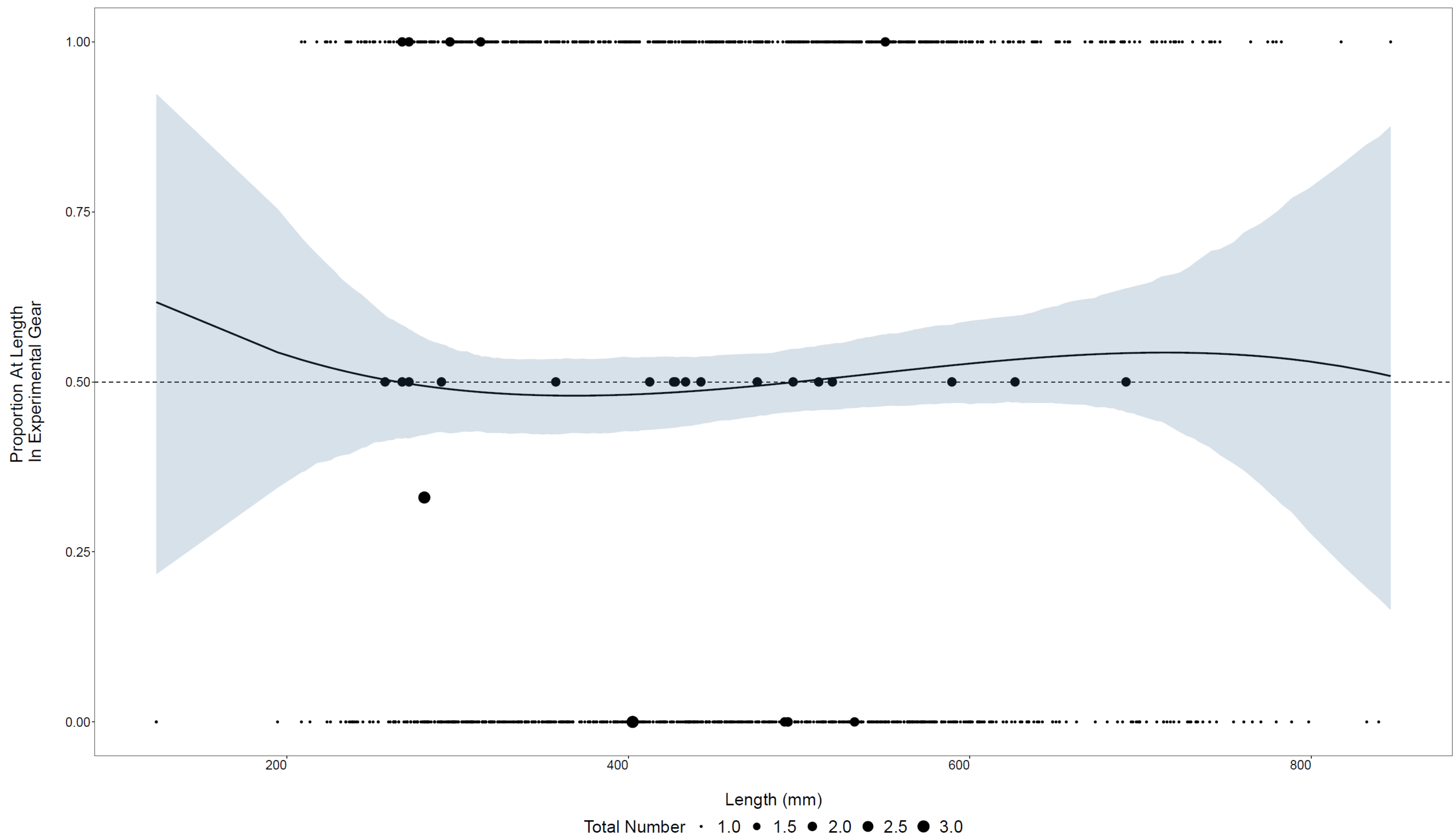

Figure 13. Preferred Selfisher model for monkfish for the attractant SMPV1 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

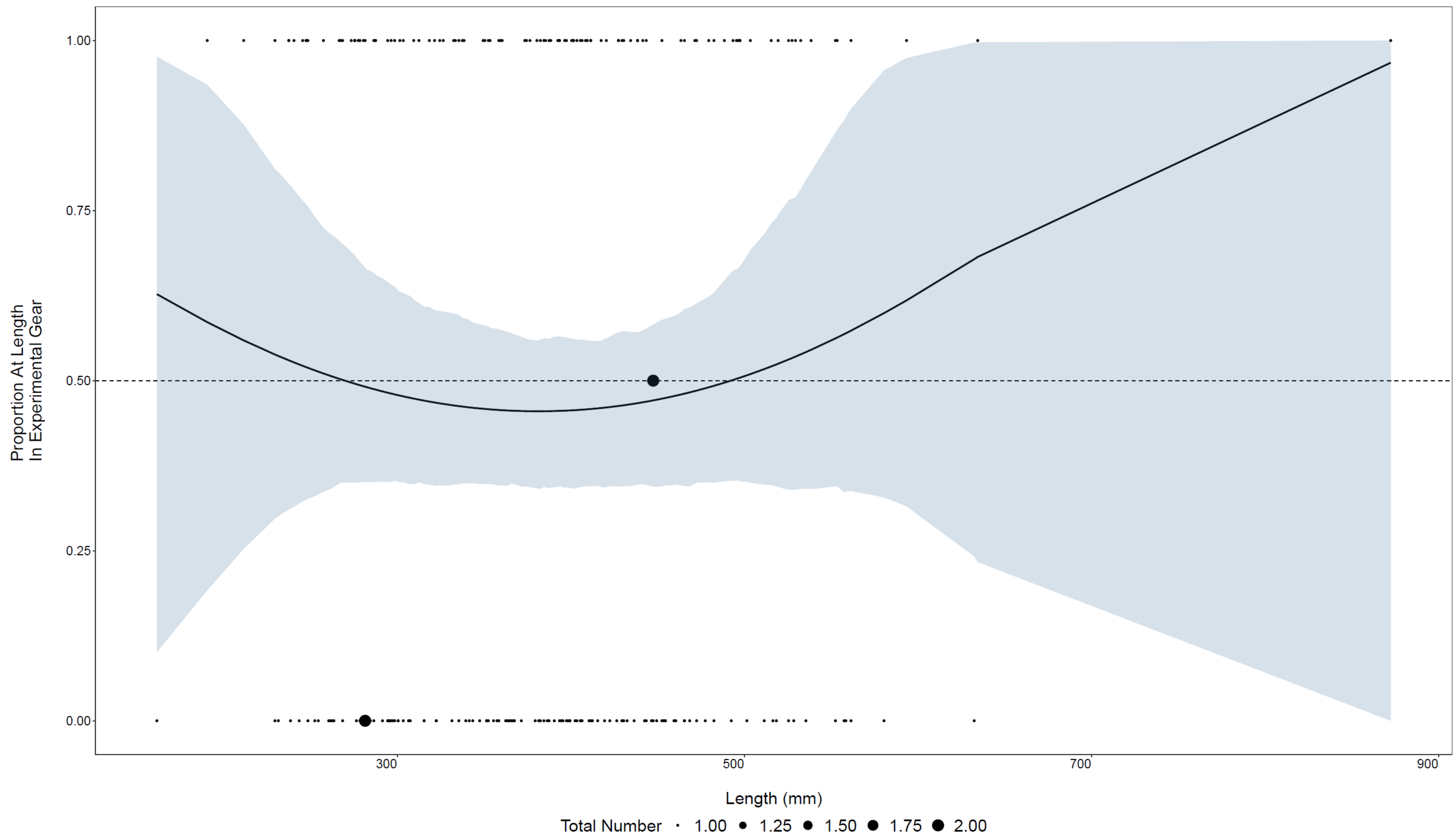

Figure 14. Preferred Selfisher model for barndoor skate for the attractant SMPV1 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

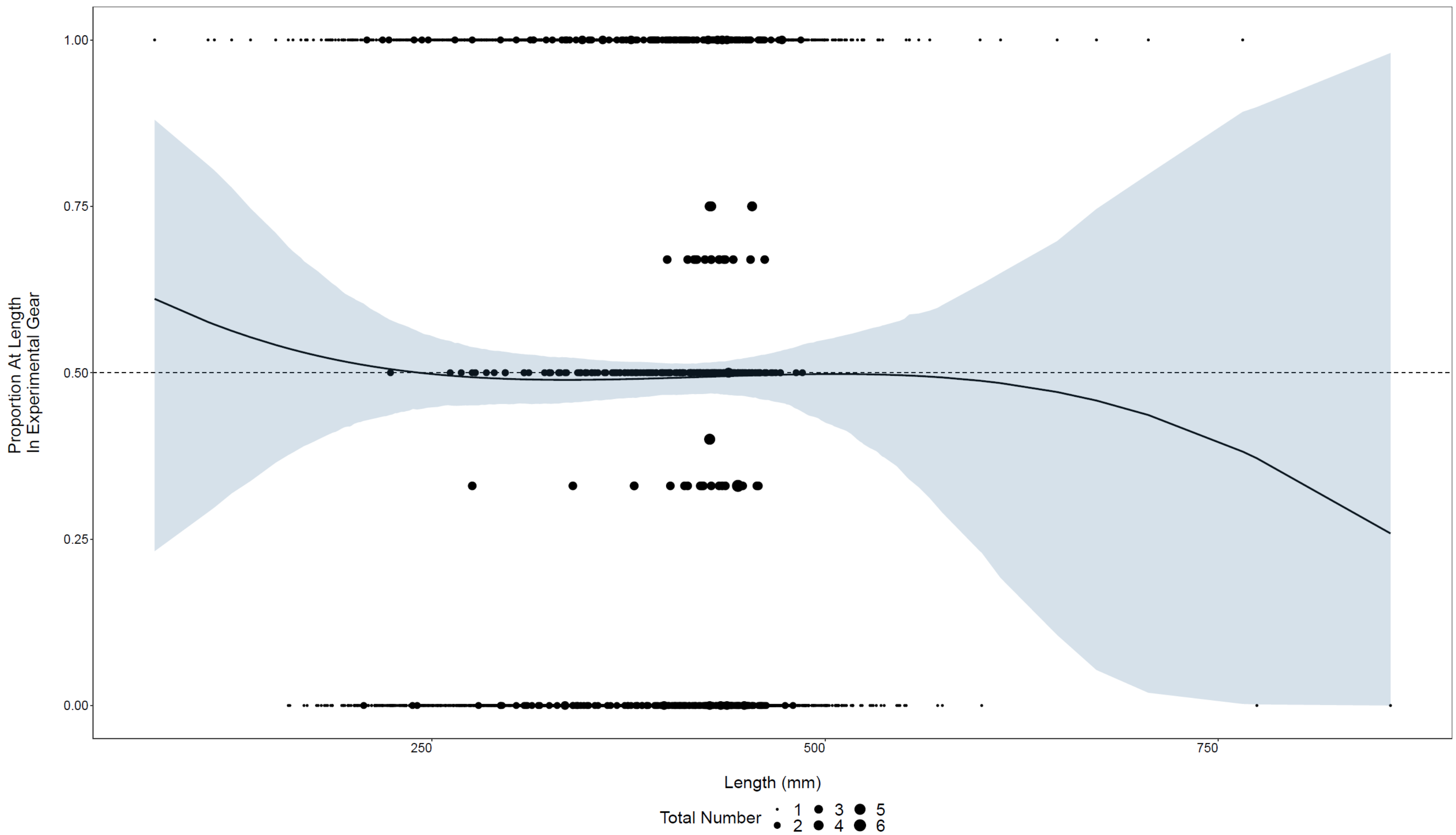

Figure 15. Preferred Selfisher model for unclassified skate for the attractant SMPV1 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

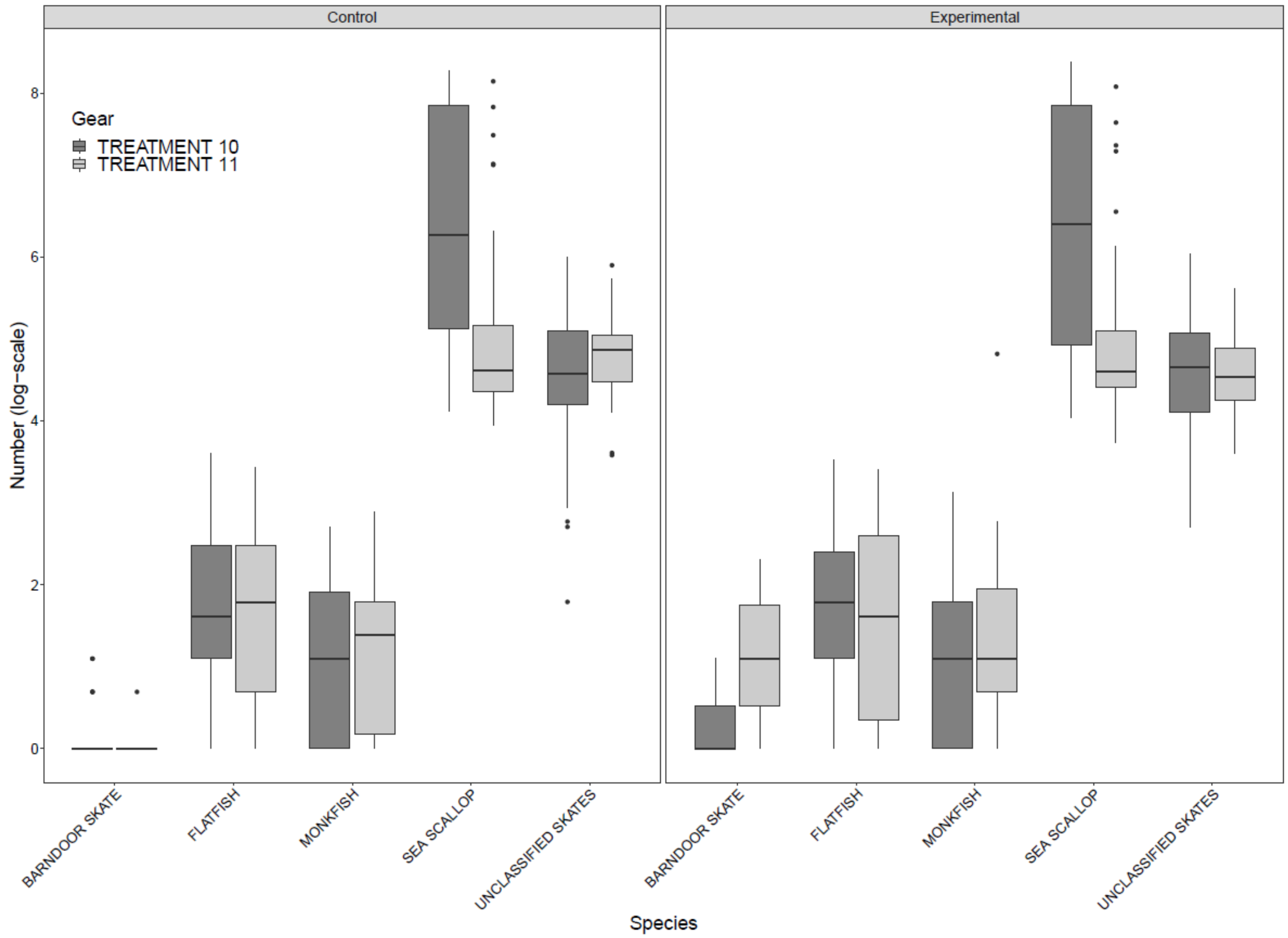

Figure 16. Boxplots of catch by species and gear for the attractant SMPV2 twine top treatments.

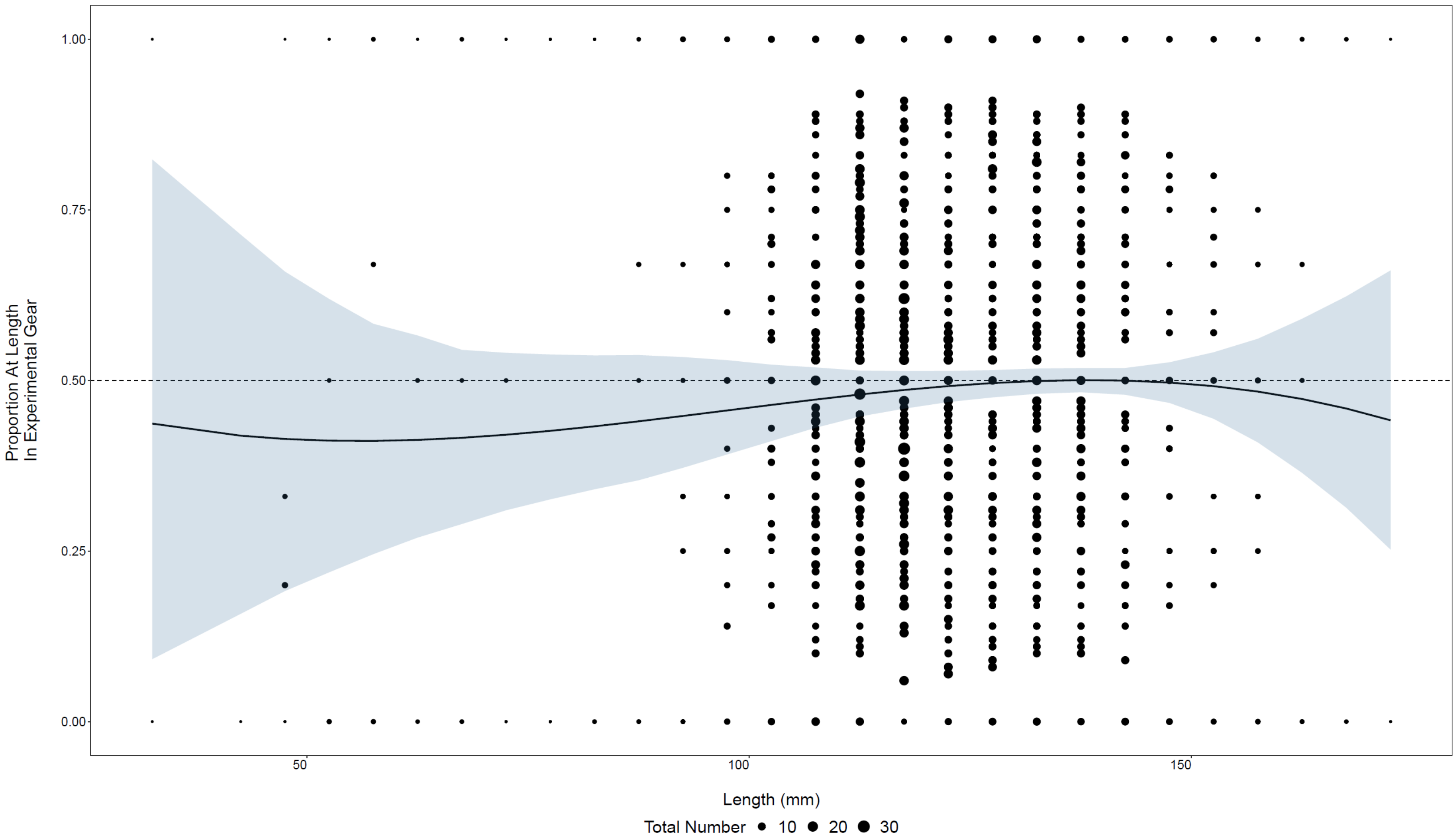

Figure 17. Preferred Selfisher model for scallops for the attractant SMPV2 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed unexpanded number of scallops caught at length for each tow pair.

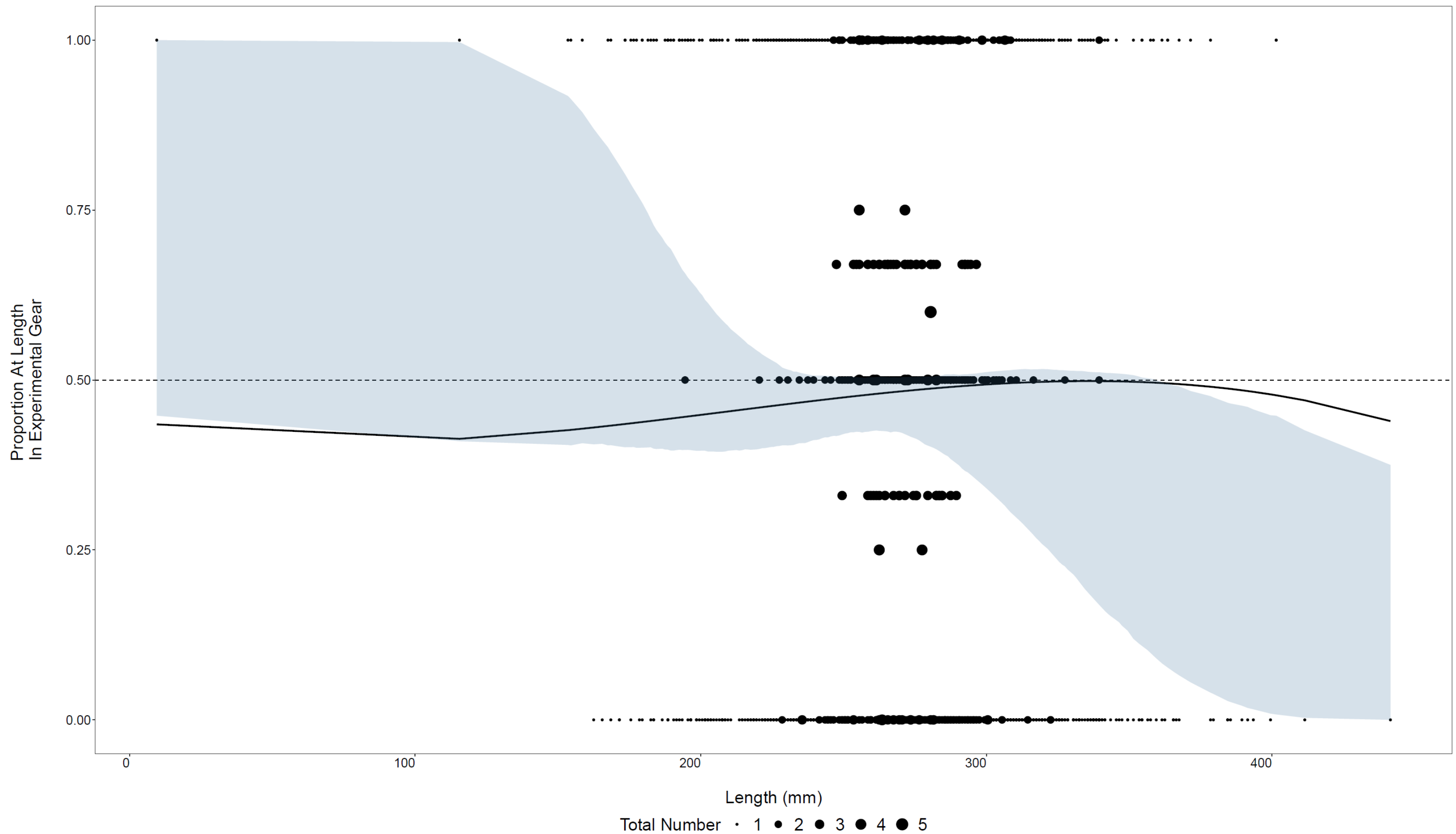

Figure 18. Preferred Selfisher model for flatfish for the attractant SMPV2 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of scallops caught at length for each tow pair.

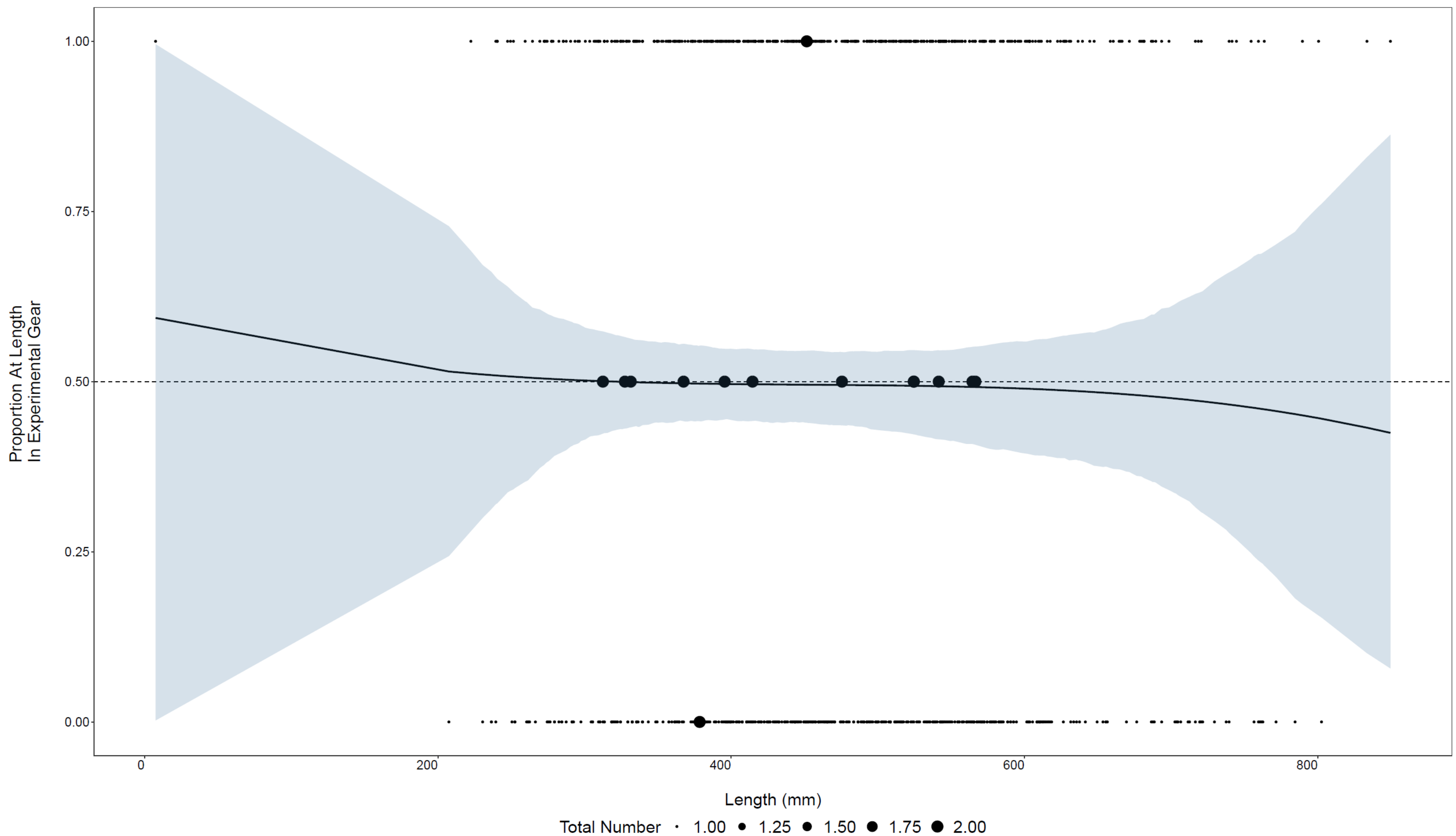

Figure 19. Preferred Selfisher model for monkfish for the attractant SMPV2 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

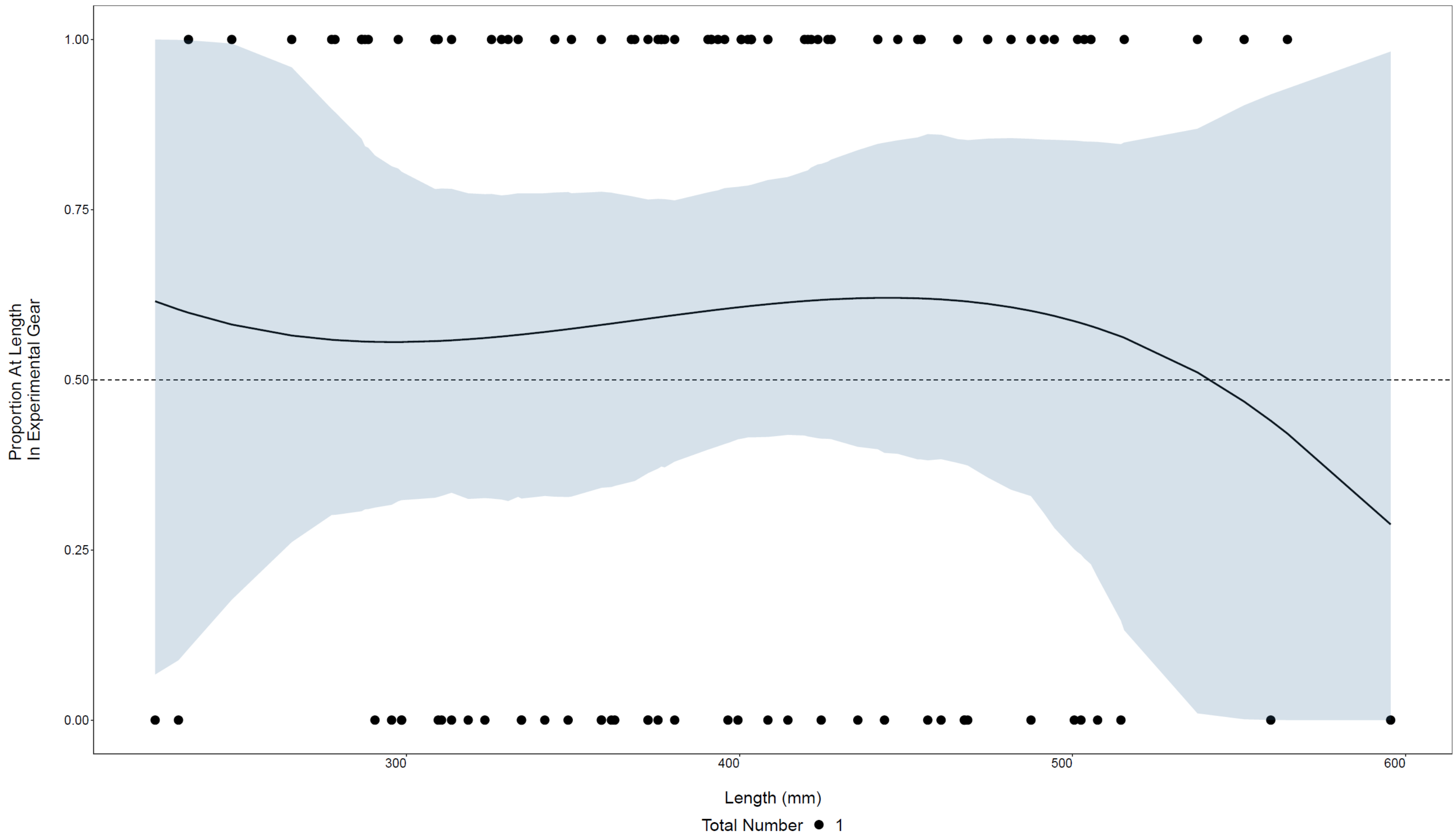

Figure 20. Preferred Selfisher model for barndoor skate for the attractant SMPV2 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

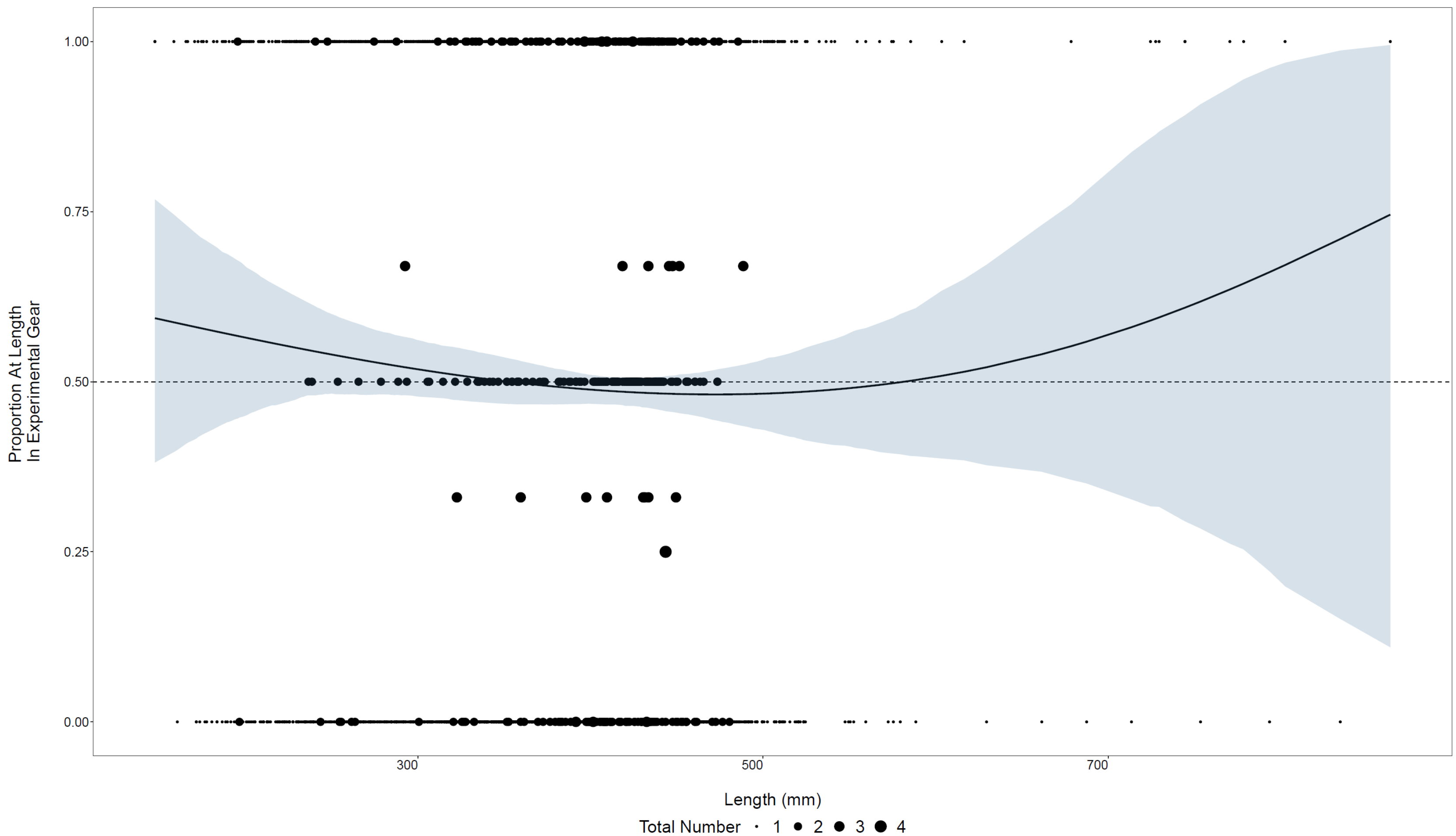

Figure 21. Preferred Selfisher model for unclassified skate for the attractant SMPV2 twine top trials. The black line is the predicted proportion caught at length, the gray shaded area are the 95% confidence intervals, and the black circles are the observed number of fish caught at length for each tow pair.

Table 1. Treatment number with the location of the Pisces lights, light color, flash rate, and lumen level tested.

Treatment	Light Location/Twine Top Type	Light Color	Flash Rate	Light Brightness Level (lumens)
1	Balebar	White	Constant	79
2	Balebar	Green	Constant	79
3	Twine Top/Control	White	Constant	79
4	Twine Top/Control	Green	Constant	79
5	Twine Top/SMPV1	White	Constant	79
6	Twine Top/SMPV1	Green	Constant	79
7	Twine Top/SMPV1	Aqua blue	Constant	79
8	Twine Top/SMPV1	Green	8 Hz	79
9	Balebar	White	8 Hz	79
10	Twine Top/SMPV2	Green	Constant	55
11	Twine Top/SMPV2	Green	8 Hz	55
12	Twine Top/SMPV1	Green	Constant	55
13	Twine Top/SMPV1	Green	8 Hz	55

Table 2. Number of tows, with cruise dates, mean speed, mean depth, mean tow duration, and mean tow distance by cruise and treatment.

Cruise	Dates	Treatment	Number of Tows	Mean Speed (kts)	Mean Depth (m)	Tow Time (mins)	Tow Distance (m)
1	8/18-8/27	TREATMENT 1	18	5.03	74.12	50.28	7,328.94
1		TREATMENT 2	19	4.96	63.66	50.42	7,483.37
1		TREATMENT 3	18	4.97	63.14	51.06	7,550.50
1		TREATMENT 4	14	4.89	61.70	49.79	7,444.57
1		TREATMENT 5	16	4.91	61.53	50.75	7,455.00
1		TREATMENT 6	18	4.72	61.41	51.50	7,100.17
1		TREATMENT 7	20	4.88	61.03	50.45	7,462.25
1		TREATMENT 8	18	4.97	63.03	51.44	7,359.28
1		TREATMENT 9	15	4.90	60.51	51.67	7,592.20
2	9/16-9/23	TREATMENT 10	40	4.97	60.12	50.15	7,576.28
2		TREATMENT 11	40	4.85	59.43	49.93	7,600.45
2		TREATMENT 12	39	4.94	59.22	50.36	7,688.10
3	10/19-10/26	TREATMENT 10	40	4.95	71.32	52.33	7,983.40
3		TREATMENT 11	7	4.93	74.25	56.43	8,587.00
3		TREATMENT 12	39	4.96	76.58	52.85	7,980.26
3		TREATMENT 13	40	5.06	74.34	52.48	8,147.60

Table 3. Catch in number of animals by treatment for the balebar deterrent trials.

Common Name	Treatment 1		Treatment 2		Treatment 9	
	Control	Experimental	Control	Experimental	Control	Experimental
	Light Off	Light On	Light Off	Light On	Light Off	Light On
BARNDOOR SKATE	33	33	12	17	68	64
MONKFISH	111	121	81	81	33	40
SEA SCALLOP	20,801	30,918	2,532	1,833	3,371	3,250
UNCLASSIFIED SKATES	5,724	6,058	8,161	8,646	1,871	1,758
WINDOWPANE FLOUNDER	145	138	331	354	370	405
YELLOWTAIL FLOUNDER	5	7	5	3	1	1
SUMMER FLOUNDER		3	2			
AMERICAN PLAICE	1					
BLACKBACK FLOUNDER		2	2	2		
FOURSPOT FLOUNDER	22	15	21	20	94	60
Total	26,842	37,295	11,147	10,956	5,808	5,578

Table 4. Catch in number of animals by treatment for the control twine top attractant trials.

Common Name	Treatment 3		Treatment 4	
	Control	Experimental	Control	Experimental
	Light Off	Light On	Light Off	Light On
BARNDOOR SKATE	12	8	1	3
MONKFISH	88	75	73	96
SEA SCALLOP	9,161	7,091	1,537	1,384
UNCLASSIFIED SKATES	6,395	5,322	4,995	4,818
WINDOWPANE FLOUNDER	186	179	173	156
YELLOWTAIL FLOUNDER	2	3	1	
SUMMER FLOUNDER		2		
BLACKBACK FLOUNDER	1	2		
FOURSPOT FLOUNDER	31	36	23	19
Total	15,876	12,718	6,803	6,476

Table 5. Catch in number of animals by treatment for the experimental twine top SMPV1 attractant trials.

Common Name	Treatment 5		Treatment 6		Treatment 7	
	Control	Experimental	Control	Experimental	Control	Experimental
	Light Off	Light On	Light Off	Light On	Light Off	Light On
BARNDOOR SKATE	3	5	5	7	5	4
MONKFISH	177	110	132	137	122	151
SEA SCALLOP	1,288	1,397	4,302	4,051	4,075	4,663
UNCLASSIFIED SKATES	4,348	4,503	2,772	3,100	2,535	2,544
WINDOWPANE FLOUNDER	165	170	254	206	270	298
YELLOWTAIL FLOUNDER	1	1				2
SUMMER FLOUNDER						
BLACKBACK FLOUNDER			2			
FOURSPOT FLOUNDER	13	24	35	35	45	48
Total	5,995	6,210	7,502	7,536	7,052	7,710

Table 5. Catch in number of animals by treatment for the experimental twine top SMPV1 attractant trials (continued).

Common Name	Treatment 8		Treatment 12				Treatment 13			
	Control	Experimental	Control		Experimental		Control		Experimental	
	Light Off	Light On	Light On	Light Off	Light On	Light Off	Light On	Light Off	Light On	Light Off
BARNDOOR SKATE	20	26	19	29	26	20	28	20	14	17
MONKFISH	84	104	162	161	302	115	53	60	52	58
SEA SCALLOP	3,757	4,029	50,024	68,492	70,520	43,679	60,393	56,333	49,173	53,462
UNCLASSIFIED SKATES	1,914	1,777	3,205	3,057	2,888	2,726	833	1,212	639	785
WINDOWPANE FLOUNDER	278	251	357	384	364	347	100	75	77	81
YELLOWTAIL FLOUNDER			3	1	1	3				1
SUMMER FLOUNDER			1	1	1	1				
BLACKBACK FLOUNDER										
FOURSPOT FLOUNDER	69	80	100	140	91	119	345	478	269	273
Total	6,122	6,266	53,871	72,265	74,193	47,010	61,752	58,178	50,224	54,677

Table 6. Catch in number of animals by treatment for the experimental twine top SMPV2 attractant trials.

Common Name	Treatment 10				Treatment 11			
	Control		Experimental		Control		Experimental	
	Light On	Light Off	Light On	Light Off	Light On	Light Off	Light On	Light Off
BARNDOOR SKATE	13	16	12	17	6	7	22	12
MONKFISH	148	125	131	141	109	82	82	223
SEA SCALLOP	55,720	56,447	54,074	55,029	9,484	6,438	5,798	8,278
UNCLASSIFIED SKATES	4,762	4,998	4,643	4,397	3,142	3,234	2,640	2,464
WINDOWPANE FLOUNDER	497	484	435	428	274	320	301	252
YELLOWTAIL FLOUNDER	1	1				5		1
SUMMER FLOUNDER	2		2	2			1	
BLACKBACK FLOUNDER	2			1				
FOURSPOT FLOUNDER	151	176	111	176	43	36	27	28
Total	61,296	62,247	59,408	60,191	13,058	10,122	8,871	11,258

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Table 7. Selfisher models for species or species group catch for the SMPV1 trials. Predictors in the model and the delta BIC are included. The preferred model has red text.

Common Name	Predictor Variable					ΔBIC
	Length	Light On	Light Color	Brightness	Flash Rate	
Scallops	✓					-
	✓	✓				4
	✓	✓	✓			10.5
	✓	✓	✓	✓		3.3
	✓	✓	✓	✓	✓	15.4
Flatfish	✓					1.3
	✓	✓				-
	✓	✓	✓			5.8
	✓	✓	✓	✓		12.5
	✓	✓	✓	✓	✓	19.1
Monkfish	✓					-
	✓	✓				2.1
	✓	✓	✓			9.4
	✓	✓	✓	✓		10.6
	✓	✓	✓	✓	✓	17.5
Barndoor Skate	✓					-
	✓	✓				-
	✓	✓	✓			5.3
	✓	✓	✓	✓		8.3
	✓	✓	✓	✓	✓	11.9
Unclassified Skate	✓					1.2
	✓	✓				-
	✓	✓	✓			7.1
	✓	✓	✓	✓		5.4
	✓	✓	✓	✓	✓	10.2

Table 8. Selfisher models for species of species group catch for the SMPV2 trials. Predictors in the model and the delta BIC are included. The preferred model has red text.

Common Name	Predictor Variable			ΔBIC
	Length	Light On	Flash Rate	
Scallops	✓			-
	✓	✓		3.2
	✓	✓	✓	9
Flatfish	✓			-
	✓	✓		1.8
	✓	✓	✓	9.7
Monkfish	✓			-
	✓	✓		6.6
	✓	✓	✓	13
Barndoor Skate	✓			-
	✓	✓		0.2
	✓	✓	✓	3.9
Unclassified Skate	✓			-
	✓	✓		0.5
	✓	✓	✓	7.8