

# **Improvement of Trawl Net Selectivity in the Directed Butterfish Fishery Using Square Mesh and T-90 Codend Liners to Reduce Juvenile Butterfish**

Final project report to the Commercial Fisheries Research Foundation

Revised as of July 29, 2015 incorporating the suggestions and comments of the CFRF Conservation Engineering Review Panel

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## **Abstract**

The Cornell Cooperative Extension Marine Program, with funding from Commercial Fisheries Research Foundation, conducted a proof of concept experimental fishing research project to evaluate the effectiveness of two experimental codend mesh configurations at reducing the capture of juvenile butterfish. This was a proactive effort focused on increasing the knowledge of gear selectivity relative to butterfish and protecting a rebuilt resource for sustained future harvest. Based on the fact that 50% of butterfish are mature at 12 cm, the specific goal of this project was to determine the effectiveness of the two experimental codends at reducing the capture of 12 cm butterfish by a minimum of 50%. A trawl net was modified to accommodate a “trouser trawl” design to tow the control codend and the experimental codend simultaneously. The experimental codend was constructed of 6.5” square mesh with two interchangeable codend liners: (1) an 8 cm square-mesh constructed codend liner and (2) an 8 cm T-90 mesh constructed codend liner. A standard 6 cm diamond mesh codend liner typically used in the squid fishery was used as the control. We analyzed the difference in butterfish catches in the two experimental codends compared to the control codend and compared the length frequency distribution of butterfish in the experimental and the control codends. For both the square mesh and T-90 codends, results of the statistical analysis showed a significant difference in the catch weights of butterfish compared to the control codend. Also the square mesh codend and the T-90 codend effectively reduced the catch of 12 cm butterfish by 66.5% and 67.1% respectively. According to the length frequency distributions and selectivity curves, juvenile butterfish were drastically reduced in both experimental codends as hypothesized. Both experimental codends were as effective in releasing juvenile butterfish as the 3 inch diamond mesh currently required in the directed butterfish fishery. This limited proof of concept study shows that both of these experimental codends have the potential to release juvenile butterfish equivalent to the current required codend. This suggests that a more extensive and robust test be implemented to verify the effectiveness of these two experimental codends to reduce the capture of juvenile butterfish.

## **Introduction**

Cornell Cooperative Extension conducted an at-sea experimental fishing research project to evaluate the effectiveness of two codend mesh configurations at reducing the capture of juvenile butterfish. This project, which was funded by the Commercial Fisheries Research Foundation, was conducted in partnership with Glenn Goodwin of SeaFreeze Ltd., Jonathan Knight of Superior Trawl Inc., and Phil Ruhle Jr., Captain of the F/V Prevail. This collaboration was a proactive effort focused on increasing the knowledge of gear selectivity relative to butterfish and protecting a rebuilt resource for sustained future harvest. Further this project and the mesh size and configuration of the codends was suggested by the fishing industry. This proof of concept study compared, under commercial fishing conditions in the mid-Atlantic trawl fishery for

butterfish, catch composition, commercial yields, retention efficiency, discards, and size selectivity parameters of two experimental codends. The experimental codend was constructed of a 6.5" square mesh strengtheners with two interchangeable codend liners: (1) an 8 cm square-mesh constructed codend liner and (2) an 8 cm T-90 mesh constructed codend liner. A standard 6 cm diamond-mesh codend liner typically used in the squid fishery was used as the control. The net was modified to accommodate a "trouser trawl" design to tow the control and an experimental codend simultaneously. If proven to be effective, the use of these codends could be implemented, with approval, as an alternative to diamond mesh in the directed butterfish fishery. This could provide another "tool" in the "toolbox" for fishermen to use to sustain the state of the resource and to reduce the impact of the fishery on the resource. Reducing the capture of small fish, could also help the fishery by minimizing the handling and sorting time of catches and improving the quality of landings.

The butterfish stock was most recently assessed at SARC 58 in 2014 and utilized data from the time period of 1989 through 2012. A new modeling approach was used in this assessment as compared to the previous assessment conducted in 2009. The SARC independent peer review panel accepted the assessment and all its reference points. The most current (2012) fishing mortality rate was well below the overfishing reference point accepted by SARC 58 (Patterson, 1992). The most current (2012) spawning stock biomass (SSB) was well above the accepted biomass reference point. Therefore, based on the point estimates, the stock is considered rebuilt. Overfishing is not occurring and the stock is not overfished (<http://nefsc.noaa.gov/publications/crd/crd1403/>). With the newfound knowledge that for the entirety of the time frame reviewed (1989-2012) the stock has been above the targeted biomass and overfishing has not occurred, the commercial fishing industry based out of the northeast is anticipating the expansion of the directed butterfish fishery led by increased quotas for this species.

The SARC 58 butterfish assessment specifically states, "butterfish are relatively short lived and have a high natural mortality rate which results in the spawning stock biomass being strongly dependent on recruitment". It is an accepted idea that bycatch of juveniles negatively affects recruitment. Of particular concern is the mortality associated with bycatch of large numbers of juveniles of commercially important species, since this is thought to reduce the recruitment, biomass, and yield of stock that form the basis of fisheries (NEFSC, 2014).

The typical life span of a butterfish is estimated to be 2-3 years (Bigelow and Schroeder 2002). Butterfish mature at age 1 (Horn, 1970) and the median length at maturity for females is 12.0 cm and for males the median length at maturity is 11.4 cm (O'Brien et al., 1993). 50% of butterfish are mature at a length of 12.0 cm (4 3/4 inches) (O'Brien et al., 1993). Current regulation for the directed butterfish fishery requires that trawl vessels may only fish with nets having a minimum codend of 3 inch (7.62 cm) diamond mesh, inside stretch measure, applied throughout the

codend in order to allow for 50% escapement of 12 cm butterfish. [76 FR 60618, Sept. 29, 2011, as amended at 77 FR 16479, Mar. 21, 2012; 77 FR 51865, Aug. 27, 2012; 78 FR 3354, Jan. 16, 2013; 79 FR 18842, Apr. 4, 2014]. This regulation is based on a pound net selectivity study that showed that a 2 5/8 inch diamond mesh will release 50% of 12 cm butterfish. (Meyer and Merriner, 1976). The regulation increased the mesh size to 3.0 inches to allow for mesh distortion and possible restriction by the codend strengthener cover. Based on the fact that 50% of butterfish are mature at 12 cm, and that the current mesh size regulation is based on 50% escapement of 12 cm fish, the specific goal of this project was to prove the effectiveness of the two experimental codends at reducing the capture of 12 cm butterfish by 50%.

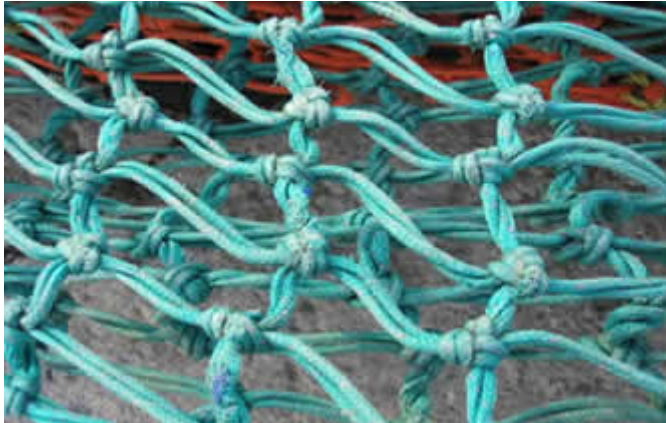
Improvements in gear selectivity can contribute to minimizing the capture of juveniles by regulating the size at first capture, increasing the yield per recruit of targeted species, and reducing the discards and hence the impact of fishing on ecosystems (Armstrong et al., 1990; MacLennan, 1992; Knuckey et al., 2008; Dixon et al., 2013). Size and shape of the mesh in the codend have been demonstrated as the main factors influencing the selectivity of trawl catches (e.g. Robertson and Stewart, 1988; Reeves et al., 1992). Diamond-shaped mesh in trawl nets stretches under tension during the haul and has a tendency to close when the codend fills, thus reducing its effective selectivity compared with square mesh, which remains open during a tow (Robertson and Stewart, 1988). Mesh openings in diamond mesh codends towed under the stress of a load also become distorted and the effective mesh size of the codend is reduced because the cover creates a masking effect by overlaying the entire codend (Stewart & Robertson 1985, Robertson & Stewart 1988, Kynoch et al., 2004).

Based primarily on industry input, as well as on existing research on T-90 and square mesh nets (e.g. MacLennan, 1992; Campos et al., 2002; Dixon et al., 2013), the following two codend options were recommended for use in this proof of concept study. Evaluating codend liners constructed of square mesh and T-90 can prove that an increased opening can have positive effects in reducing juvenile butterfish catch while maintaining economically viable catches.

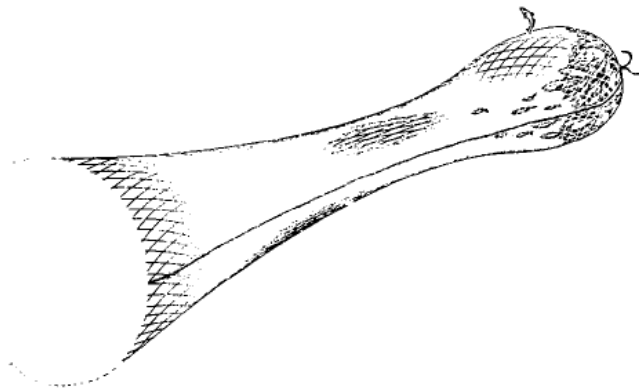
#### Experimental Codend #1 - 6.5" square mesh strengthener constructed with an 8 cm square mesh liner

Experimental codend #1 was constructed of square mesh (See Figure 1) as opposed to diamond mesh. This is mesh that is specifically manufactured to be square and to be fished open square. Water flow through diamond mesh creates a bulbous bag that can twist and sway easily. Figure 2 depicts the constriction of diamond mesh under strain compared to square mesh. When rigged correctly, square mesh codends take on an open cylindrical shape (Figure 3). Square mesh allows for increased water flow and allows for the codend to remain open allowing more area for escapement. Square mesh also has an added benefit of increased fuel efficiency due to decreased drag and restriction.

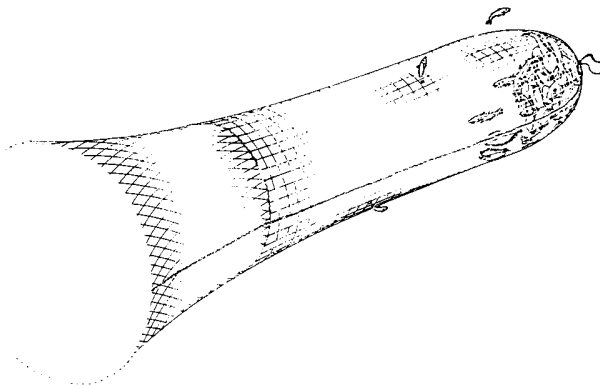
**Figure 1. Image of Square Mesh**



**Figure 2. A Schematic Representation of the Constriction in Diamond Mesh Codends Caused by the Closing of Meshes**



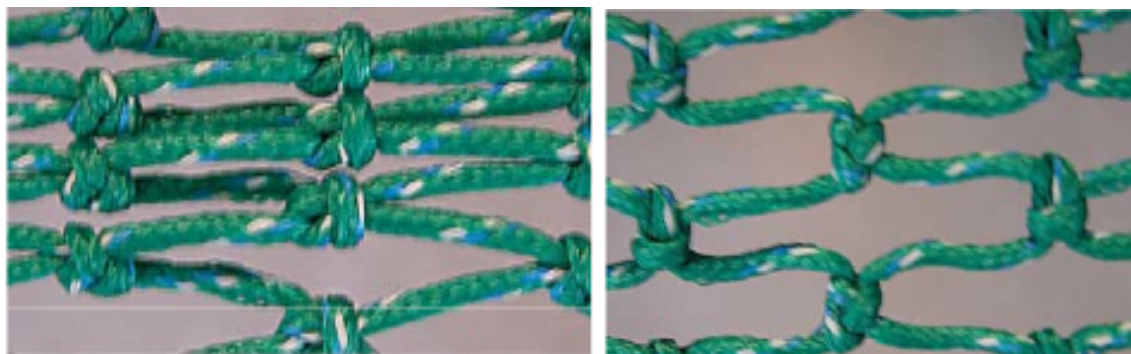
**Figure 3. A Schematic Representation of the Open Cylindrical Shape of the Square Mesh Codend**



Experimental Codend #2 - 6.5” square mesh strengthener constructed with an 8 cm T-90 liner

The T-90 net design is traditional diamond trawl mesh that has been turned 90 degrees to hang open in a square configuration. This allows the holes of the mesh to remain fully open when trawled through the water, even with large catches (Figure 4). As a result, small fish escape more easily and towing efficiency improves. With the traditional configuration, the diamond shaped holes of the mesh tend to close as the net is pulled through the water, making it difficult for small fish to escape, while reducing towing efficiency. Originally this was done to stabilize the codend and improve the quality of the catch (Digre et al., 2006), but it had the added benefit of also allowing smaller fish to escape (Hansen 2006). T-90 nets have been shown in international studies to improve both selectivity and towing efficiency. It is also suggested that T-90 nets have the added benefit of being “gentler” on the catch than standard nets because turbulence in the codend is reduced (Roberts, 2011).

**Figure 4. Standard diamond mesh (left) Vs. T-90 mesh (right)**



Control Codend- 6.5” diamond mesh strengthener constructed with a 6 cm inch diamond liner.

This codend configuration is the standard use (and required) in the trimester 1 and 2 longfin squid fishery, and is smaller than the butterfish directed fishery required 3.0 inch diamond mesh. The 6 cm liner was specifically chosen to allow us to retain small butterfish in the control codend in order to more effectively determine the ability of the two experimental codends to reduce the catch of small butterfish.

As the butterfish fishery returns and becomes a directed fishery as it has in the past, the current situation affords industry, management, and science the opportunity to address anticipated issues prior to them reaching a crucial stage. This project aims to assist with the re-establishment of a sustainable butterfish fishery in the northeast by identifying promising conservation gear modification options that will effectively reduce juvenile butterfish bycatch, which is a foreseeable conservation concern associated with a targeted butterfish fishery.

## **Methodology**

This proof of concept study was designed to compare the catch composition, commercial yield, retention efficiency, discards, and size selectivity parameters of two experimental codends in the commercial, butterfish trawl fishery in the Mid-Atlantic region. This was accomplished using a standard 6 cm diamond-mesh codend liner typically used in the long-finned squid fishery as a control to be compared against two experimental codends: (1) 8 cm square-mesh constructed codend liner and (2) a codend liner constructed of 8 cm T-90 mesh. The main objective of this project was to analyze the effectiveness of these experimental codends for use as a possible codend option to help sustain the state of the butterfish resource by reducing the capture of juvenile fish.

A single vessel was used during this research to tow a trouser trawl. The trouser trawl design (a single trawl net with two separate, individual codends) allowed a control codend to be compared with an experimental codend on the exact same course during each tow. Therefore, each individual tow made by the vessel was in of itself a replicate tow due to the inherent nature of the trouser trawl net design. Replicate tows are defined to mean a comparison of sequentially exact tows using control and experimental gear. The trouser trawl was created by removing the back end of a typical trawl used in the butterfish fishery (420 x 16 cm, 4 seam trawl with a 38 meter bottom hanging line) by vessels with similar parameters to the vessel used during this research. For this project, the trawl was cut off 2.5 meshes behind the top of the 1<sup>st</sup> belly for the entire circle of the trawl. The removed back end was replaced with a two legged back end creating a “trouser”. The “trouser” itself was constructed from 12 cm and 6 cm webbing. The legs of the “trouser” were then completed with a control codend of 6.5 inch diamond mesh and a 6 cm liner on one side. This liner was supplied by the contracted fishing vessel. The other side or leg of the “trouser” was completed with a 6.5" square mesh codend coupled with one of the two interchangeable experimental liners. The experimental liners, also described above were an 8 cm, knot to knot full mesh (KKFM) liner in a square geometry and an 8 cm KKFM liner of diamond mesh turned 90 degrees (T-90). The codends were ringed to facilitate switching them between the legs. The butterfish retained by each codend were compared, based on size, to determine if the mesh types being tested proved to be an effective means of reducing juvenile fish. Utilizing a single vessel towing a trouser trawl during this project eliminated problems that may have arose if the experimental design employed two vessels towing side-by-side to conduct replicate tows or a single vessel operating with an alternating tow protocol. Since butterfish are very patchy and catches can vary widely, using two vessels side-by side even at close proximity presents problems as one boat may encounter a high concentration of fish and the other will find low concentrations or none. Similarly, using one boat with an alternating paired tow design could create similar problems due to the time incurred as the boat hauls the gear back, changes codends, and repeats the tow over the same ground. This unavoidable delay could allow the fish

to move or rise up in the water column thus avoiding capture and skewing results when comparing relative data.

The F/V Prevail was chartered to conduct five days of at-sea research using the trouser trawl during this project. The vessel's homeport is Pt. Judith, Rhode Island. The F/V Prevail is a 77.9 foot, 140 gross tonnage, steel stern trawler built in 1980. The vessel has 755 H.P., two hydraulic net reels, and an ITI Trawl Monitoring System (door mounted sensors that report net spread). Aboard the Prevail we were effectively conducting two sets of experiments in which Treatment A (square mesh) was paired with the control and Treatment B (T-90 mesh) was compared with the control. As such, we had three codends in use; control, Treatment A (square mesh), and Treatment B (T-90 mesh). At the request of CFRF, and in order to ensure a reasonable sample size for one experiment in the case that the five at-sea days of research fishing could not be completed due to vessel breakdown or inclement weather, the higher priority experimental codend was deemed Treatment A (square mesh) and was towed with the control first. During the five-days of research fishing, we were attempting a minimum of 8 tows per day with additional tows if time permitted. This would result in a minimum of 20 replicate tows with the square mesh codend and 20 replicate tows with the T-90 codend. During each day of fishing, the codends were switched port and starboard following an ABBA protocol. CCE used the ABBA protocol for all the research fishing that occurred during this project. The ABBA protocol is a comparative system by which control gear and experimental gear are fished and compared using an alternating, paired methodology (DeAltaris and Castro, 1991). This system was used to reduce any bias that may occur relative to port and starboard by randomizing the experimental and control codends across both "sides" of the trouser trawl during each day. The 6.5 inch diamond strengthener always stayed with the control liner when switched side to side, and the 6.5 inch square strengthener always stayed with the experimental liners. We attempted to standardize tow duration to the extent possible. 30 minute tow durations were the goal during this study to maximize the number of tows conducted per trip and still remain within the range of commercial tow durations. However, because of patchy distribution of butterfish or other environmental factors, tow durations could vary. All tows were timed and all "couplets" (control and experimental pair) had the same tow duration. Tows were made during both day and night. Depth, GPS position, time of day, door spread, and tow cable length were recorded for the start and end of each tow. Depth and bottom water temperature were logged remotely at 1-minute intervals using a Vemco sensor attached to the top of the net at the center of the head rope. Tow speeds and tow cable length were consistently maintained across all tows and this data was also recorded.



### Number of Trips and Tows

This project included one scientific trip that encompassed 5 days of research fishing. CCE had aimed to complete a minimum of 8 tows per day and more if time permitted. This would have resulted in at least 40 completed replicate tows. Unfortunately, due to foul weather, the F/V Prevail was forced to stop fishing for a period of 24 hours between days 2 and 3 until conditions were safe to work on deck again. As sea conditions worsened, only 3 tows were completed on day 2 and by the time sea conditions subsided only 3 tows were completed on day 3. At the conclusion of the 5 days of research fishing a total of 29 replicate tows comparing the experimental gear to the control gear had been completed. As per CFRF's request (discussed previously in this report), CCE focused on completing 20 tows with the higher priority square mesh experimental codend to make certain of a practical sample size. Once 20 tows were completed with the square mesh the experimental codend was switched to the T-90. During the remaining at-sea time 12 tows were completed with the T-90 codend. There was no data collected from 3 of these tows due to extreme catches of dogfish. Estimated weights of dogfish for these 3 tows ranged between 5,000 to 9,000 lbs. per codend. In these 3 cases the trawl was not brought aboard the vessel and the catch was released with the net still in the water. In summary, there were 29 completed replicate tows with data collected that can be separated into 20 tows completed with the square mesh codend and 9 tows completed with the T-90 codend.

### Timing, Area, and Fishing Practice

In order to take advantage of known concentrations of butterfish, the experimental, research fishing was completed in February 2015. The study vessel departed from Pt. Judith, RI on Feb. 23, 2015. Research fishing ensued during the following 5 days (2/24/15 – 2/28/2015) and the vessel returned to port on March 1, 2015. The research fishing was conducted offshore along the continental shelf between Block and Atlantis Canyons following the 60 fathom depth contour. This area is located in NMFS statistical area 537. Exact fishing locations were the captain's decision based on his knowledge of the fishery and reported locations of butterfish at that time. Tow procedure had the vessel essentially fish as it would in a standard commercial fishing trip, with the exception that all tows were 30 minutes in length as justified above. The vessel operated with a single trouser trawl built by Jon Knight (Superior Trawl) and the same 92 inch type 4 Thyboron trawl doors throughout the project. The standard control codend outfitted on the trouser trawl was a 6 cm diamond liner inside a 6.5 inch diamond strengthener. This is a codend that the vessel would use normally in a standard commercial small mesh trip. The experimental codends were either an 8 cm square mesh liner or an 8 cm T-90 liner inside of a 6.5 inch square mesh strengthener. Tows were made oriented along slope. A repetitive ABBA protocol was used to alternate the control and experimental codends from port and starboard as described above in an effort to reduce any bias associated with side. Depths, locations, and gear deployment

methodology were standard for the fishery. Tow speed and tow cable length and scope were maintained consistently across all tows.

### On Board Catch Processing

The catch of each codend (experimental vs. control) was kept separated during haul-back and release on-deck. The onboard catch processing followed standard NMFS survey methods. Our target was butterfish relative to quantifying differences in retention and size distribution between the control and experimental codends. As such, total butterfish in each codend during each replicate tow was accurately weighed. Butterfish were also sampled for length frequency. The goal was minimally 200 random length measurements per codend per tow. If fewer individuals were caught, all were measured. The total weight of all species combined in each codend during each tow was also obtained either by direct weighing of the total catch, or by sub-sampling in the case of large catches.

### Results

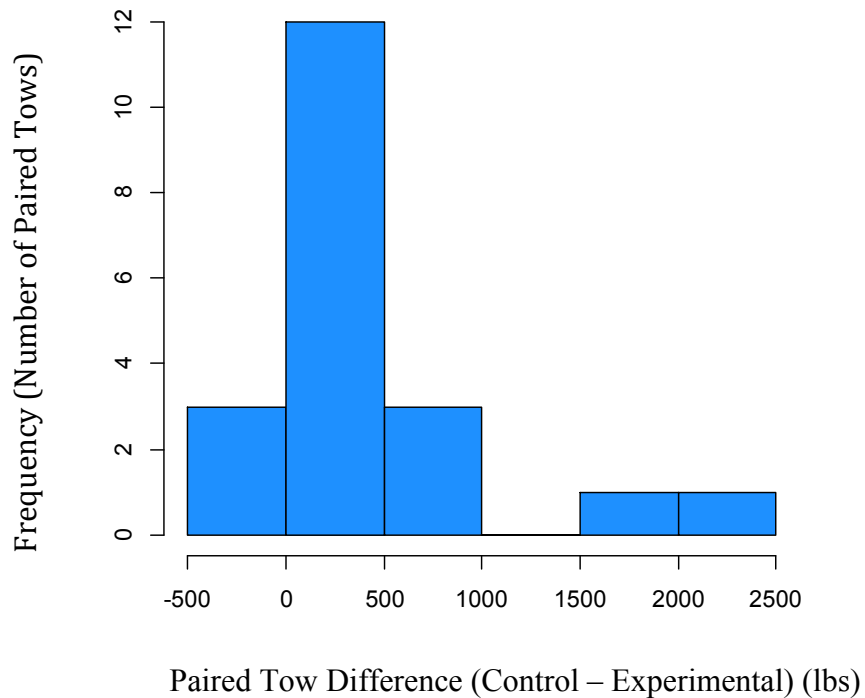
Below is a quantitative evaluation and summary of the data analysis. Data were analyzed to determine if a statistical difference exists in the catch of butterfish between the control codend and each experimental codend and to further quantify what the difference was. Analysis was based primarily on the paired tow difference in catch (control minus experimental). Analysis was conducted in weights. All statistics were at the  $\alpha = .05$  level. More importantly, we tested for difference in length frequencies between the nets with a goal of reducing the catch of 12 cm butterfish by 50%. Data from 20 paired tows are used for the square mesh codend comparison and data from 9 paired tows are used for the T-90 codend comparison.

Since only one vessel was used there was no vessel effect in the analysis relative to the catch between tows or between codends. Since only one net was used, the gear effect was only related to the codend installed. Depth and temperature were randomized and did not affect the data.

The ABBA protocol (see Methodology) was used to reduce any bias that may occur relative to port and starboard by randomizing the experimental and control codends across both “sides” of the trouser trawl during each day. Time of day and day itself did not affect the difference in catch between control and experimental since paired tows were conducted simultaneously and are compared that way in the statistics.

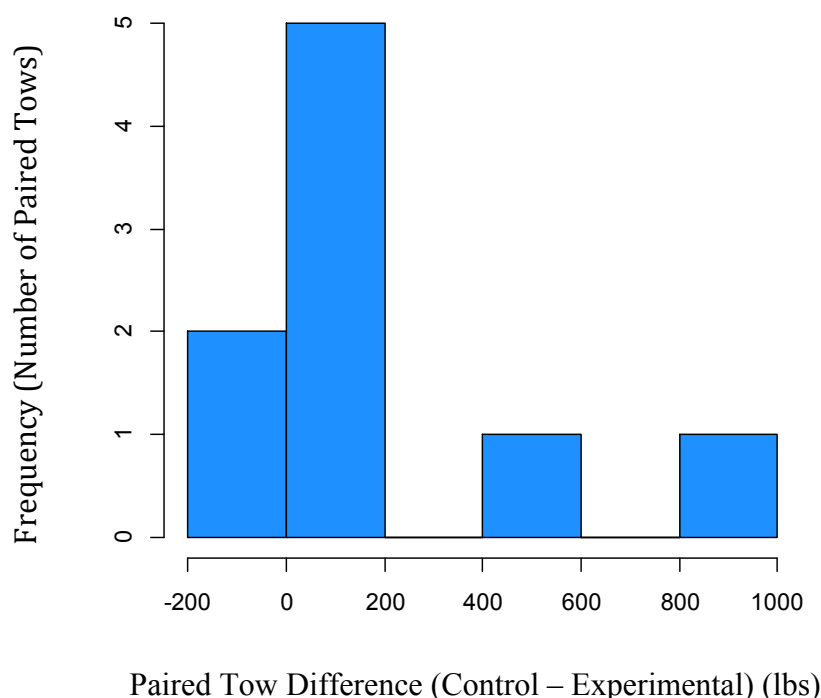
First, statistical analysis of the data was conducted to determine if either the square mesh experimental codend (Figure 5) or the T-90 experimental codend (Figure 6) significantly affected retention of total catches of butterfish relative to the standard control codend.

**Figure 5. Distribution of Paired Tow Differences for Butterfish (lbs) in the Square Mesh Codend**



Initially a paired t-test was conducted and the results showed a significant difference in butterfish catch weight between the control and the square mesh experimental codend ( $t = 2.6734$ ,  $df = 19$ , **p-value = 0.01503**, mean of  $x = 390.395$ ). However, the data appear to be not Gaussian according to a Shapiro-Wilk normality test ( $p\text{-value} < 0.0001$ ). Therefore, a bootstrap analysis was conducted since it is the more appropriate statistical test to use for nonparametric data. The bootstrap analysis also showed a significant difference in butterfish catch weight between the control codend and the square mesh experimental codend (**p-value < 0.0001**).

**Figure 6. Distribution of Paired Tow Differences for Butterfish (lbs) in the T-90 Codend**

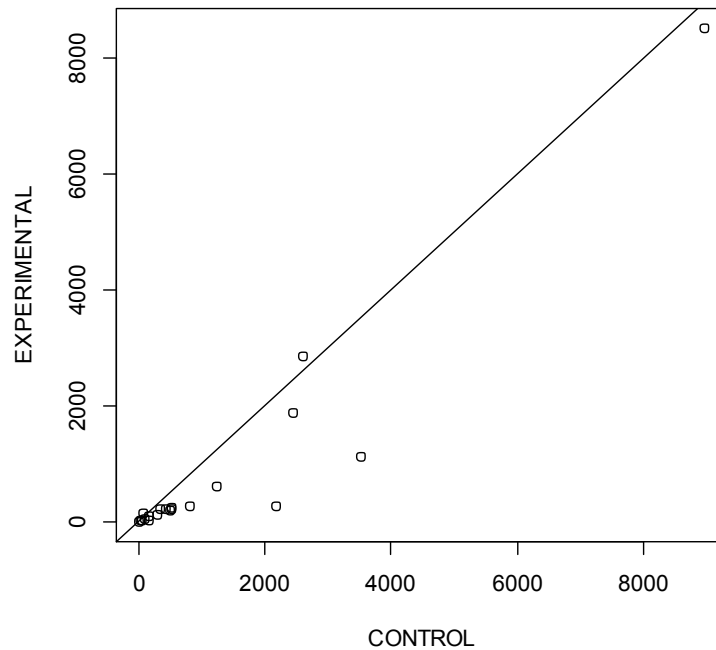


For the T-90 codend, a paired t-test was initially conducted and the results showed no significant difference in butterfish catch weight between the control and experimental codends ( $t = 1.833$ ,  $df = 8$ , **p-value = 0.1042**, mean of  $x = 204.222$ ). However, the data for this experimental codend also appeared to be not Gaussian according to a Shapiro-Wilk normality test ( $p\text{-value} = 0.001757$ ). Therefore, a bootstrap analysis was conducted since it is the more appropriate statistical test to use for nonparametric data. The bootstrap analysis showed a significant difference in butterfish catch weight between the control codend and the T-90 experimental codend (**p-value < 0.0001**). Since the bootstrap is the more appropriate test here, the difference in catch between control and T-90 is significant.

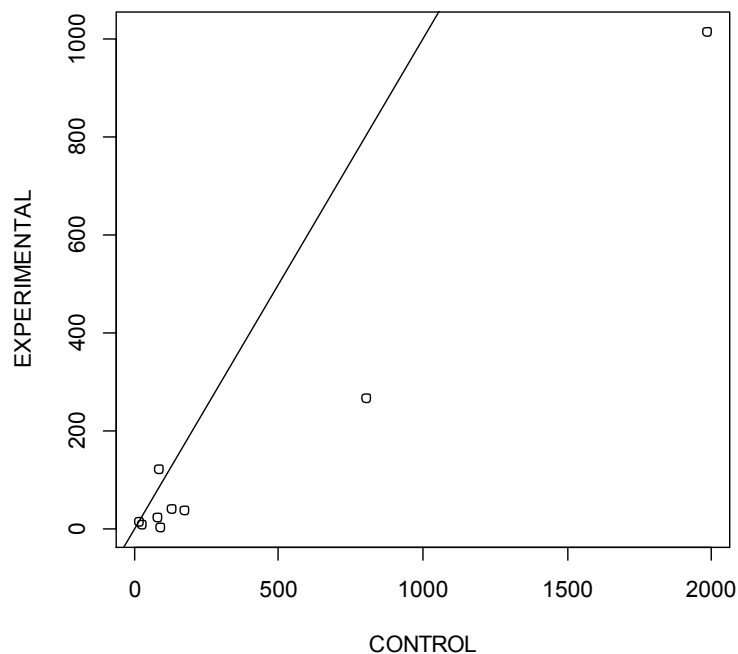
As expected, for both experimental codends, there was a significant difference between butterfish catch weight in the control and both experimental codends. The experimental codend released more fish (specifically the smaller fish as discussed below) than the control codend retains. Recall that the control codend is a standard squid liner used in order to retain as much of the butterfish catch as possible for comparison purposes. We did not test for differences in catch between the two experimental codends.

The relationship between butterfish catch in the experimental and control codends is plotted in Figure 7 (square mesh) and Figure 8 (T-90).

**Figure 7. Total Weight of Butterfish Caught By Tow In the Control Codend Plotted Against the Total Catch Weight of Butterfish in the Square Mesh Experimental Codend**



**Figure 8. Total Weight of Butterfish Caught By Tow In the Control Codend Plotted Against the Total Catch Weight of Butterfish in the T-90 Experimental Codend**



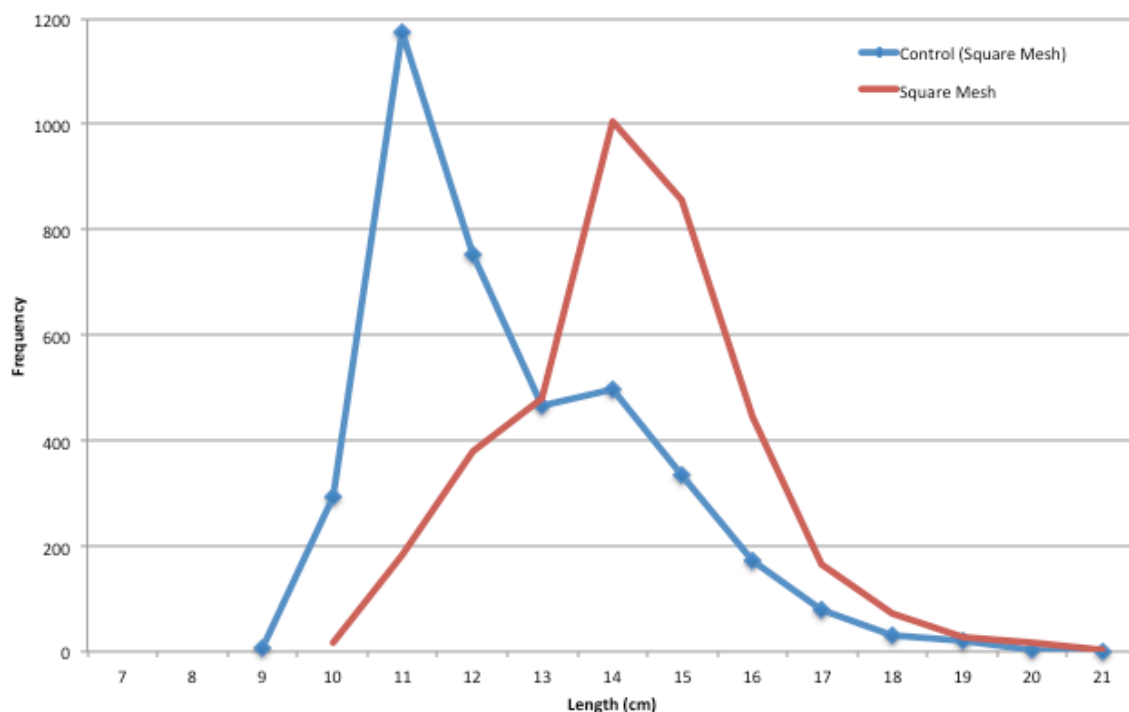
As indicated by Figures 7 and 8, butterfish catch was greater in the control codend compared to the experimental codend. Again, the experimental codend released more fish than the control codend. As discussed in the Length Frequency section below, the fish released by both experimental codends are the smaller, juvenile fish.

### Length Frequency

Next, we looked at the effect of both experimental codends on the length frequency distribution of butterfish. As explained above, successful gear modification would reduce the capture of 12 cm butterfish by 50% to be consistent with the current diamond mesh regulation.

Figure 9 below shows the length frequency distribution of our sub-samples of butterfish in the square mesh codend compared to the paired control codend for all square mesh tows.

**Figure 9. Length Frequency Distribution of Butterfish sub-samples in the Square Mesh Experimental Codend Vs. Control Net**



As shown in Figure 9, the length frequency distributions for both the control and square mesh codends show a unimodal distribution. In the square mesh codend, the greatest quantity of butterfish was measured at 14 cm. In the control codend, the greatest quantity of butterfish was

measured at 11 cm. A 3 cm difference is substantial in a fish that ranges in size from 9 to 21 cm. The square mesh codend is effectively reducing the catch of smaller sized butterfish.

Figure 10 below shows the same length frequency distribution of butterfish but in bar graph format.

**Figure 10. Length Frequency Distribution of Butterfish in the Experimental Codend and Control Codend for All Square Mesh Tows Combined**

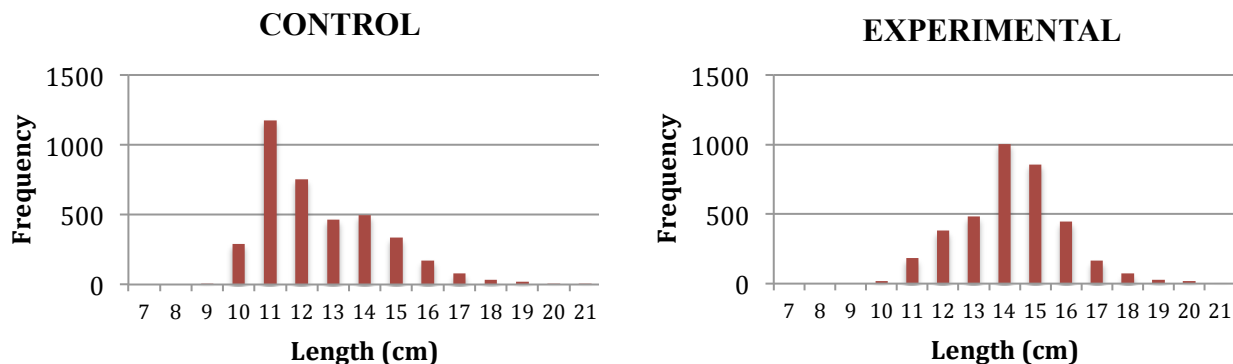
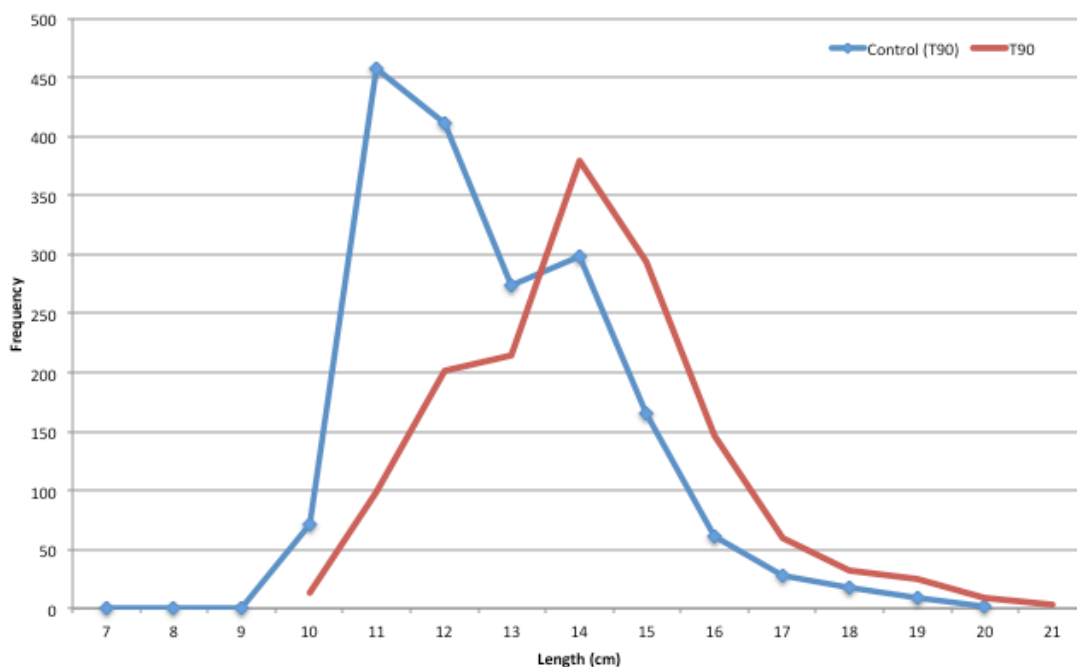


Figure 11 shows the length frequency distribution of our sub-samples of butterfish in the T-90 codend compared to the paired control codend for all T-90 tows.

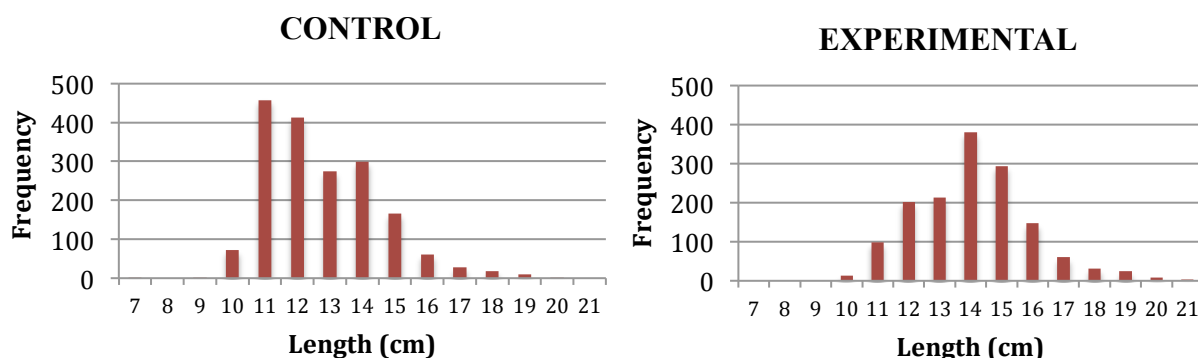
**Figure 11. Length Frequency Distribution of Butterfish sub-samples in the T-90 Experimental Codend Vs. Control Codend**



As shown in Figure 11, the length frequency distributions for both the control and T-90 codends show a unimodal distribution. In the T-90 codend, the greatest quantity of butterfish was measured at 14 cm. In the control codend, the greatest quantity of butterfish was measured at 11 cm. The distributions and modal peaks of the experimental and the control are similar to the length frequency distributions with the square mesh codend. As with the square mesh codend, a 3 cm difference is substantial in a fish that ranges in size from 7 to 21 cm. The T-90 codend is effectively reducing the catch of smaller sized butterfish.

Figure 12 below shows the same length frequency distribution of butterfish but in a bar graph format.

**Figure 12. Length Frequency Distributions of Butterfish in the Experimental Codend and Control Codend for All T-90 Tows Combined**



The length frequencies in Figures 9, 10, 11, and 12 are based on the number of fish at each size interval of our cumulative sub-samples for each tow for each codend. Even though we see more large fish in the experimental codend this represents a reduction of smaller fish in the experimental codend sub-samples, not an accumulation of large fish in the actual total catch of the experimental codends. Each experimental codend does not actually catch more larger fish. However since there are less small fish in the experimental codend the larger fish makeup a larger proportion of the sample (and thus of the catch) in each experimental codend.

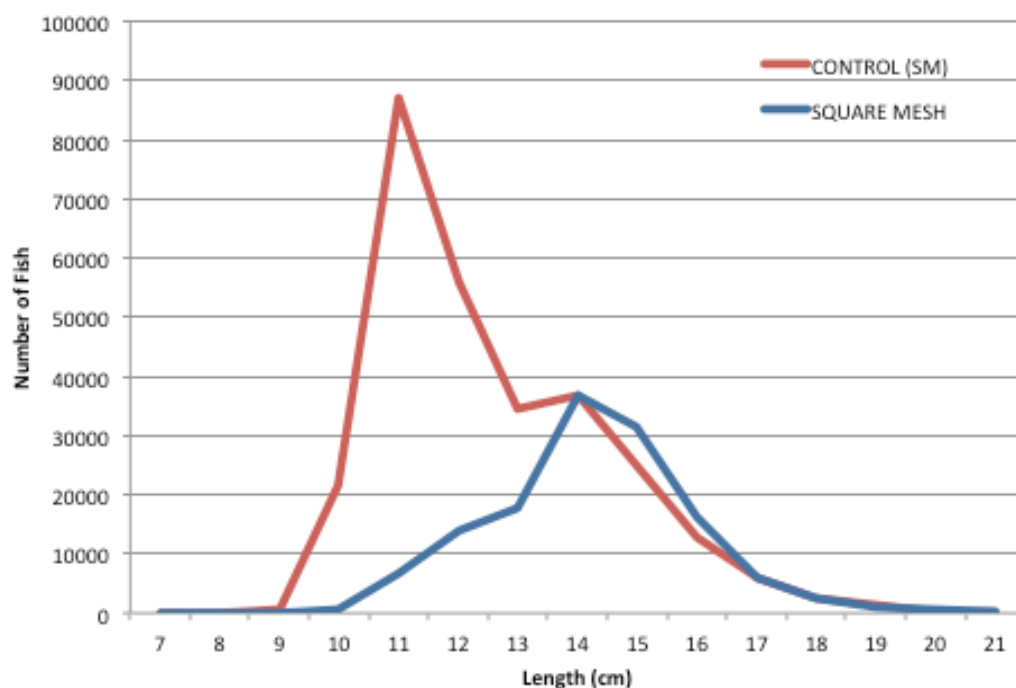
In order to look at the length frequency distributions of the butterfish the entire catch for each experimental codend and its paired control codend we need to scale up the sub-sample to the entire catch for each tow and codend. This was done according to the following formula:

$$\frac{\text{total weight of catch (lbs)}}{\text{weight of sub-sample (lbs)}} \times \frac{\# \text{ of fish at length interval}}{\text{length interval}} = \text{extrapolated \# of fish at length interval}$$

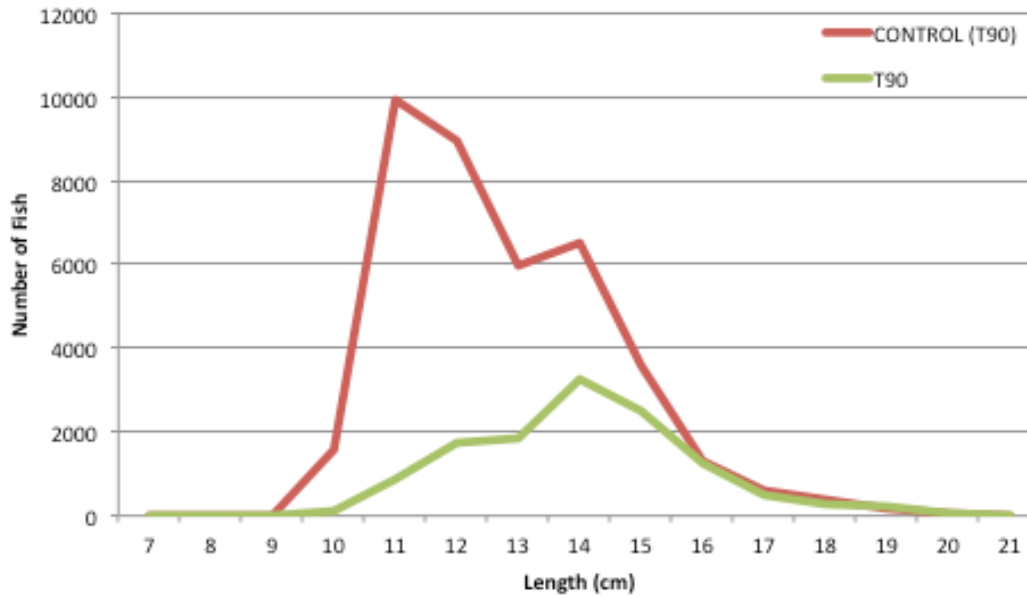


The results of the conversion are presented below in Figure 13 for the paired square mesh tows and in Figure 14 for the paired T-90 tows. For the paired square mesh tows, both codends caught the same amount of fish 14 cm and larger. The experimental codend caught a lot fewer fish less than 14 cm. For the paired T-90 tows both codends caught the same amount of fish 16 cm and larger. The experimental codend caught a lot fewer fish less than 16 cm. For the limited amount of T-90 tows it seems that the T-90 selects for even larger fish then the square mesh.

**Figure 13. Extrapolated Length Frequency Distribution of Total Butterfish Catch for Paired Square Mesh Codends**

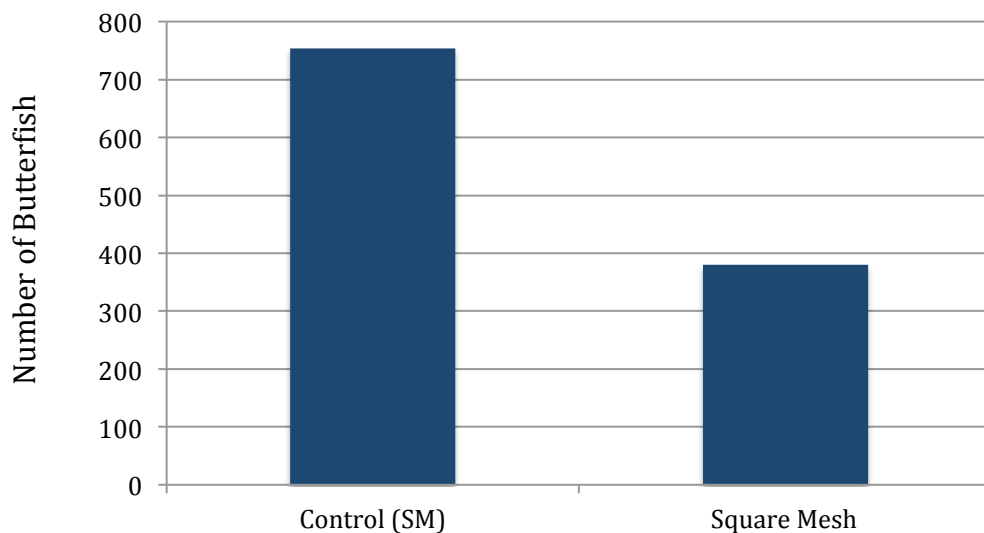


**Figure 14. Extrapolated Length Frequency Distribution of Total Butterfish Catch for Paired T-90 Codends**

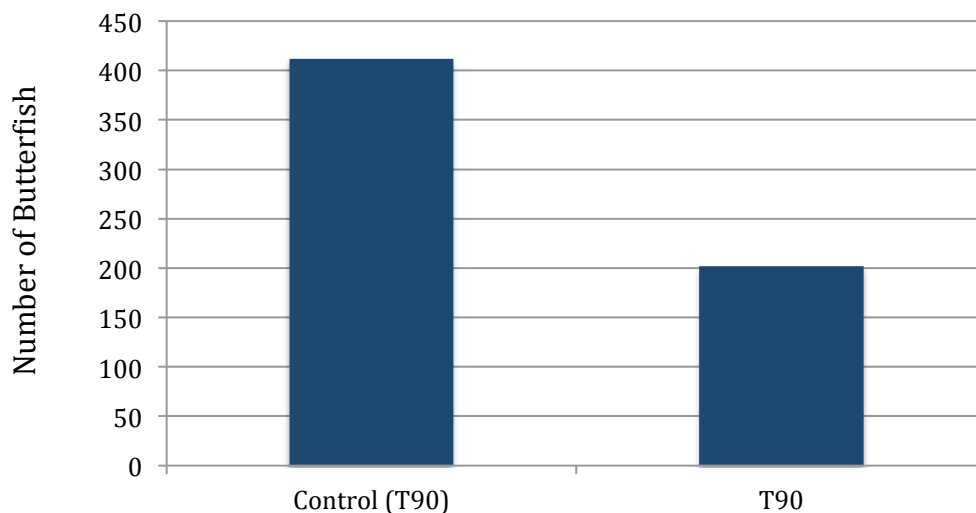


Most importantly, for either of these gears to be determined to be effective for the purpose of this project, the gear must reduce the number of 12 cm fish by 50% to be consistent with the current diamond mesh regulation in the directed butterfish fishery. The total number of 12 cm fish in the square mesh codend and in the T-90 codend compared to the control codend are shown in Figures 15 and 16. (Data are for sub-samples and are not scaled up to the entire catch. Results for total catch are similar to the sub-sample results.)

**Figure 15. Total Number of 12 cm Butterfish in the Control and Square Mesh Experimental Codends for All Square Mesh Tows Combined**



**Figure 16. Total Number of 12 cm Butterfish in the Control and T-90 Experimental Codends for All T-90 Tows Combined**

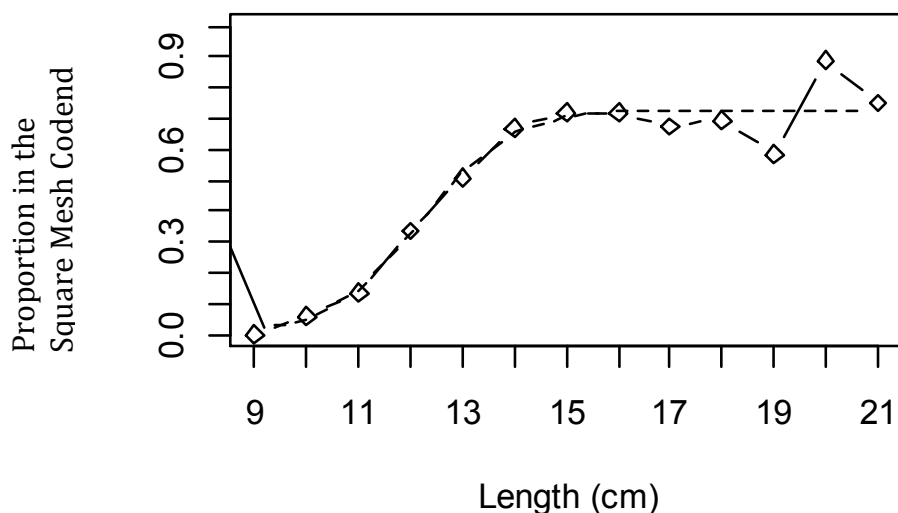


For all square mesh tows combined, the experimental square mesh codend retained only 50% of the 12 cm butterfish as were retained by the control codend (square mesh N=380; control N=754). For all T-90 tows combined, the experimental T-90 codend retained only 49% of the 12 cm butterfish as were retained by the control codend (T-90 N=202; control N=412). Both experimental codends released many of the 12 cm fish that the control codend retain.

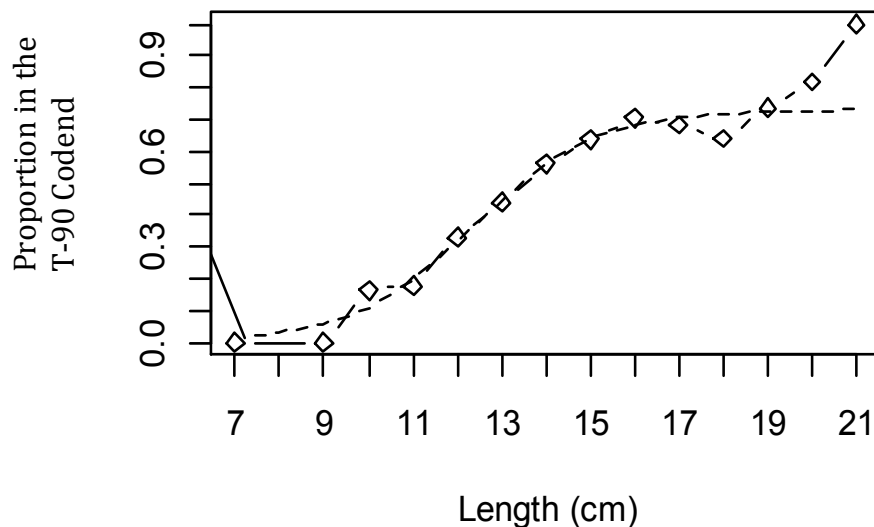
With the limited data available for this project we attempted to look at selectivity patterns for the two experimental codends. We followed the method used by Hendrickson (2011) to look at selectivity of butterfish and other species in the longfin squid fishery. Hendrickson used the SELECT model (Share Each LENGTH's Catch Total) based on Millar (1992) and Millar and Walsh (1992) as well as the "tffit" function in the "Trawlfunctions" programs for R (Millar et al., 2004). The model uses a maximum likelihood estimation based on the expected proportion of catch in the experimental codend relative to the total catch in both nets for each length interval. The combined hauls approach was used to account for between haul variability. The results of the SELECT logistic model provide the best fit of the data and are shown in Figure 15 and Figure 16, along with the plot of the actual calculated proportion of catch by length for each experimental codend. The results of the logistic model fit should be considered relative (Wileman et al., 1996) since the control net likely does not exhibit 100% retention of all size classes.

In Figures 17 and 18 below, the curve of solid lines connecting open diamonds shows the calculated proportion of the total butterfish catch (control and experimental) that is retained in the experimental codend. The dotted line curve is the logistic model fit of the data. Similar plots for each individual tow are included in the Appendix.

**Figure 17. Proportion of Catch by Length in Square Mesh Codend For All Square Mesh Tows Combined**

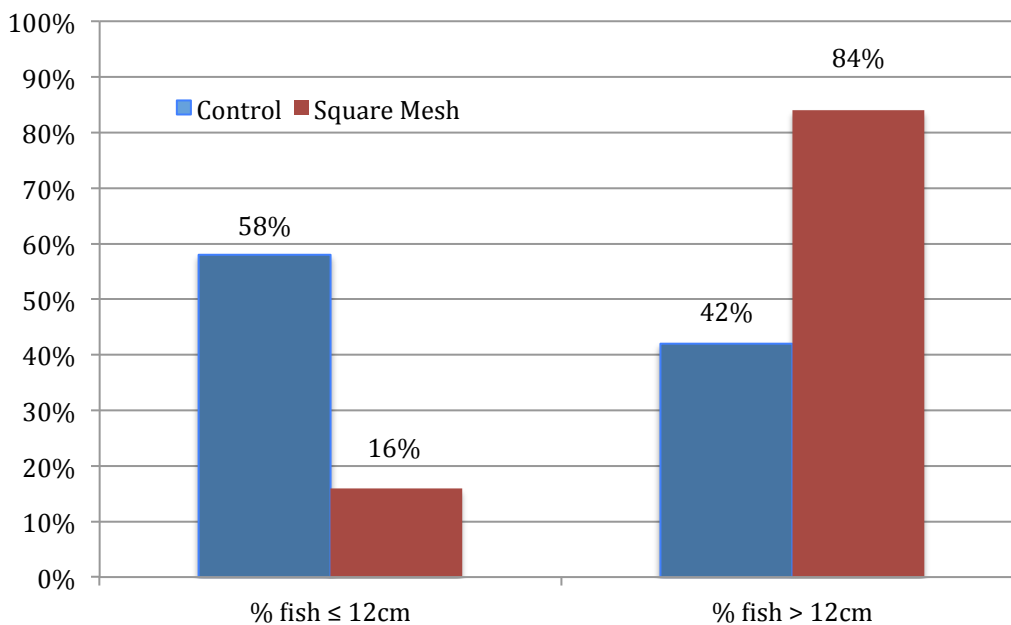


**Figure 18. Proportion of Catch by Length in the T-90 Codend For All T90 Tows Combined**



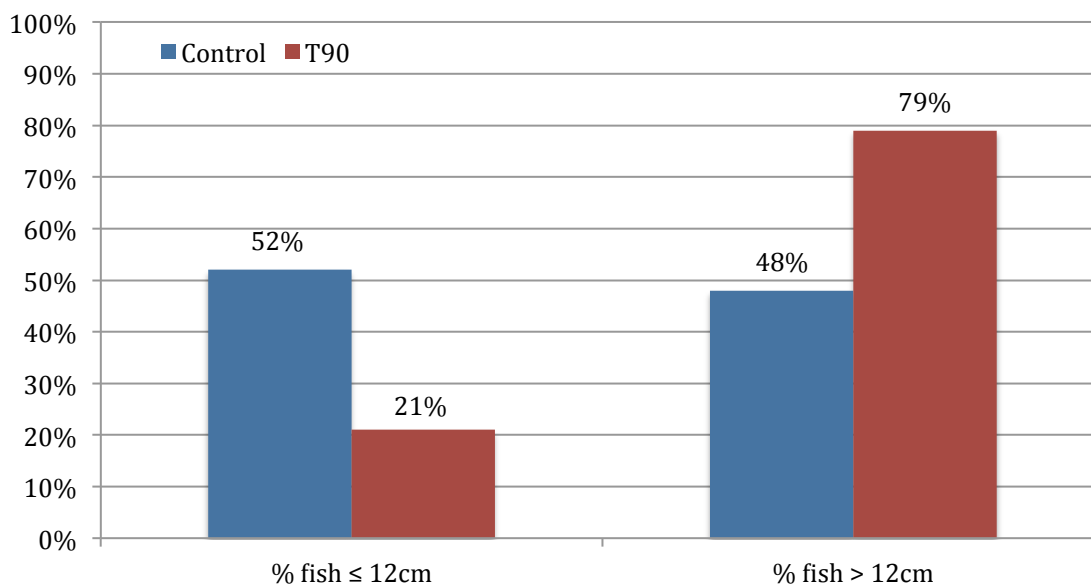
We also grouped butterfish into two categories by size. The two size categories identified were the “small” category which included butterfish  $\leq 12$  cm and the “large” category which included butterfish  $> 12$  cm. These categories were chosen for this study and are not specifically based on market size categories. The retention of butterfish in these categories is shown in Figure 19 for the square mesh codend and Figure 20 for the T-90 codend as compared to the control codends.

**Figure 19. Retention of Butterfish in Square Mesh Experimental Codend Vs. Control Codend**



As indicated by Figure 19, a drastic reduction in the catch of small sized butterfish occurred with the use of the square mesh codend. A total of 58% of the butterfish catch was “small” in the control codend while only 16% of the butterfish catch was small in the experimental codend. The square mesh codend effectively reduced the catch of small butterfish and increased the proportion of large butterfish in the catch. A greater proportion of the catch (84%) is comprised of the larger sized fish in the experimental square mesh codend.

**Figure 20. Retention of Butterfish in T-90 Experimental Codend Vs. Control Codend**



When using the T-90 codend, a drastic reduction in the catch of small sized butterfish also occurred. A total of 52% of the butterfish catch was “small” in the control codend and only 21% of the butterfish catch was small in the experimental codend. The T-90 codend effectively reduced the catch of small butterfish and increased the proportion of large butterfish. A greater proportion of the catch (79%) is comprised of the larger sized fish which are being retained by experimental T-90 codend.

During research fishing very little escapement was observed as the net came to the surface behind the boat. It was not overly noticeable that butterfish was excessively escaping out of the net. No butterfish were observed coming out of the net as the bag was brought aboard the vessel and moved to the forward pen to be dumped.

During one day of research fishing squid seemed to be more prevalent mixed in the catch. This day started off using the square mesh as the experimental codend. It was observed that the square mesh codend was retaining less squid than the control which was to be expected. Half

way through the day the experimental codend was switched to the T-90 mesh. After this was done it was observed that the experimental codend was then retaining more squid than the control codend. Please note these squid catches were at the highest 50 pounds and squid was not the target species. This observation was made only a handful of times with very small amounts of squid but made an impression upon the Captain.

### **Summary of Research Findings**

This project explored the difference in butterfish catches for two experimental codends (square mesh and T-90) compared to the control codend. We also compared the length frequency distribution of butterfish difference in the experimental codends and the control codend. As expected, for both the square mesh and T-90 codends, statistical analysis results showed a significant difference in the catch weights of butterfish compared to the control codend. More importantly, both the square mesh codend and T-90 codend effectively reduced the catch of 12 cm butterfish by 66.5% and 67.1% respectively. This reduction in 12 cm butterfish was the main goal of this proof of concept project. Both experimental codends released many small butterfish that the control codend retained. Computed selectivity curves show that the proportion of larger sizes of butterfish caught in both experimental codends is greater than in the control.

### **Conclusions**

Based on the results of the project, both the square mesh and T-90 codends proved to perform effectively at reducing the capture of juvenile butterfish while retaining a greater proportion of larger sized fish. The square mesh codend reduced the capture of 12 cm butterfish by 66.5% and the T-90 codend reduced the catch of 12 cm butterfish by 67.1%. According to the length frequency distributions and selectivity curves, juvenile butterfish were drastically reduced in both experimental codends. Both experimental codends were as effective in releasing juvenile butterfish as the 3 inch diamond mesh currently required in the directed butterfish fishery. The experimental codend is a good tool for fishermen to use if they prefer to use square mesh as an alternative to diamond mesh.

According to the vessel captain based on this proof of concept, both codends are viable options and are an improvement over the current regulation gear. Captain Ruhle reports that he seems to prefer the T-90 codend slightly over the square mesh codend since the T-90 codend retained more squid. The square mesh codend did not retain as much squid as he would have thought. It was also suggested by the vessel captain that the two experimental gears also be tested in the squid fishery to determine if the codends have an effect on the capture of the squid since butterfish and squid are often caught together. It would be important for fishermen targeting

squid that the codends not reduce the harvest of squid to levels below economic viability.

This initial field evaluation identifies both the square mesh codend and T-90 codend as promising gear adaptations for reducing juvenile butterfish bycatch. Since this was a proof of concept project only, the number of tows completed was relatively low. A total of 20 tows were completed for the square mesh experimental gear. For the T-90 experimental codend, only 9 tows were completed since inclement weather reduced the fishing time and thus the number of tows. In this experiment both experimental codends were as effective in releasing butterfish as the 3 inch diamond mesh currently required in the directed fishery. Therefore no additional modifications are being suggested for either experimental codend. This limited proof of concept study shows that both of these experimental codends have the potential to release juvenile butterfish equivalent to the current required codend. This suggests that a more extensive and robust test be implemented to verify the effectiveness of these two experimental codends to reduce the capture of juvenile butterfish. In fact the results of this proof of concept have been used to justify a more extensive test of both of these two experimental codends. These tests will add to the total number of tows to increase statistical strength and will be conducted over different seasons, water depths and areas.

As the butterfish harvest increases based on the rebuilt stock and becomes a targeted fishery once again, there is concern that bycatch of juvenile butterfish will become increasingly problematic. It is important for the fishing and science communities to continue to conduct this type of research now to address this anticipated conservation problem and help sustain the state of the butterfish resource by reducing the capture of undersized fish. If proven to be effective, the use of these codends could be implemented, with approval, as an alternative to diamond mesh in the directed butterfish fishery. This could provide another “tool” in the “toolbox” for fishermen to use to sustain the state of the resource and to reduce the impact of the fishery on the resource. Reducing the capture of small fish, could also help the fishery by minimizing the handling and sorting time of catches and improving the quality of landings.



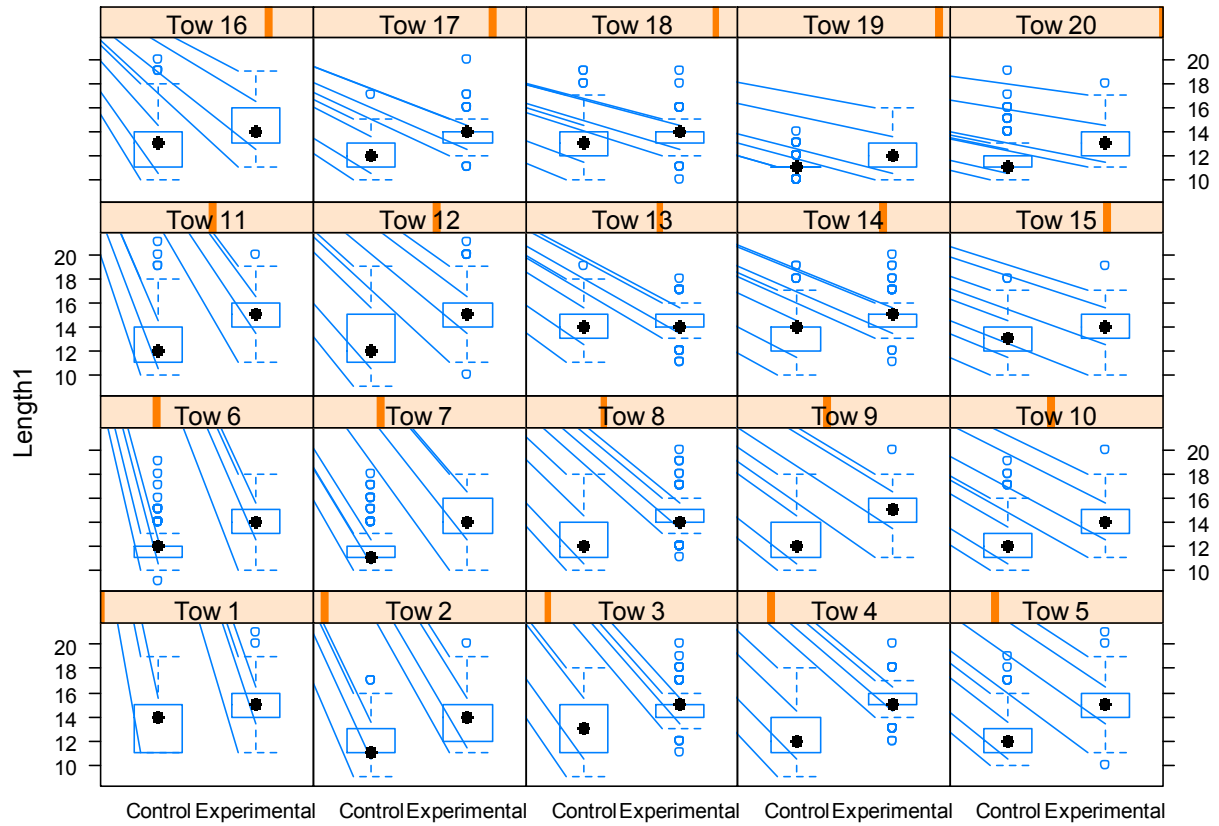
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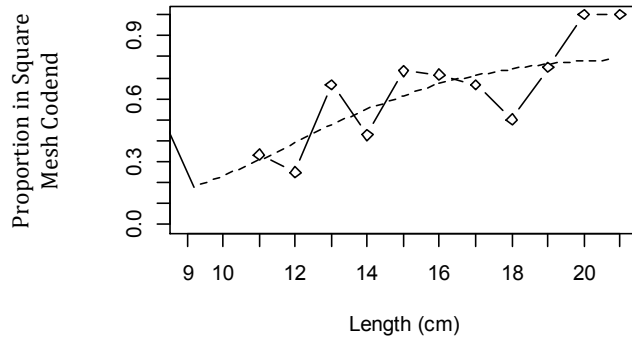
## Appendix A

### Square Mesh Selectivity Analysis

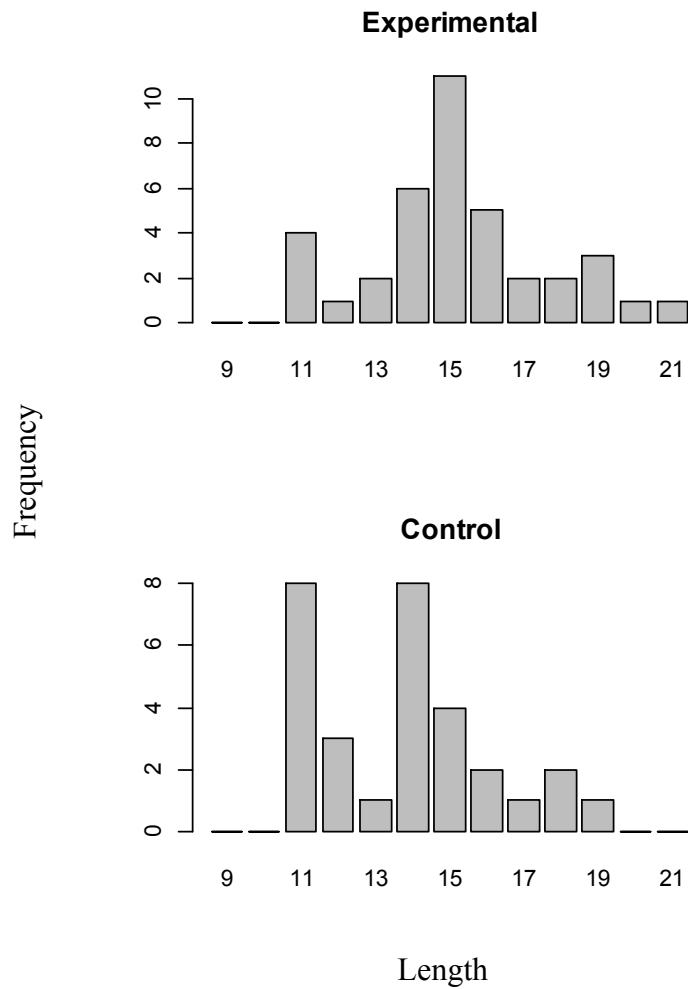


# TOW 1

## Proportion of Butterfish Catch By Length in Square Mesh Codend - Tow 1

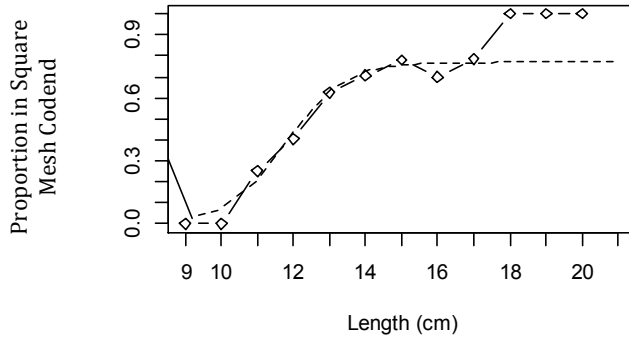


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 1

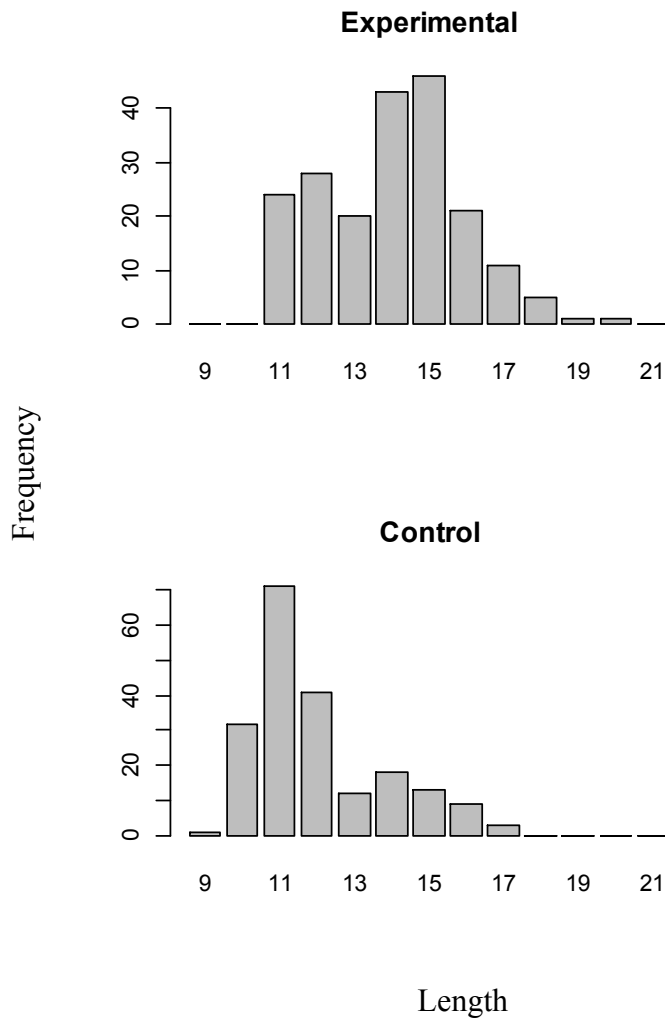


## TOW 2

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 2

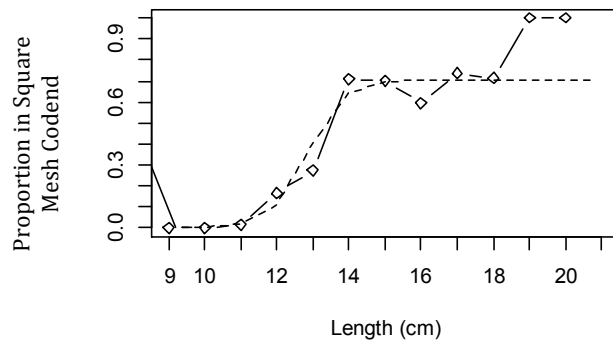


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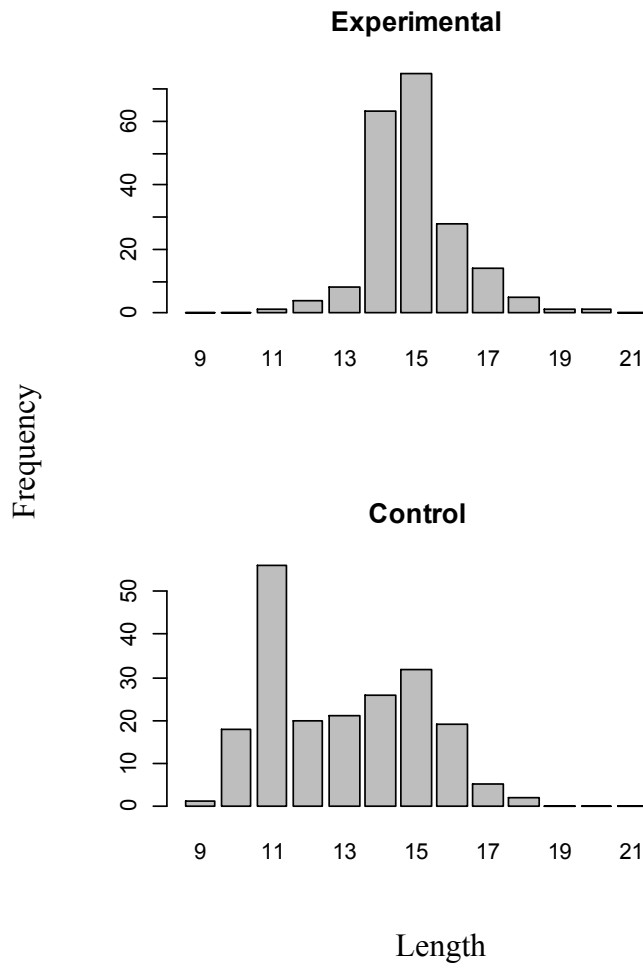


# TOW 3

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 3

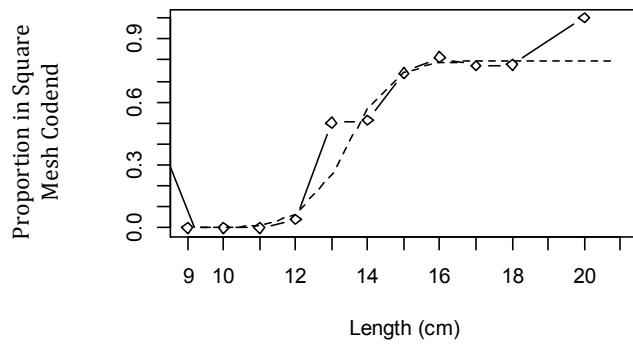


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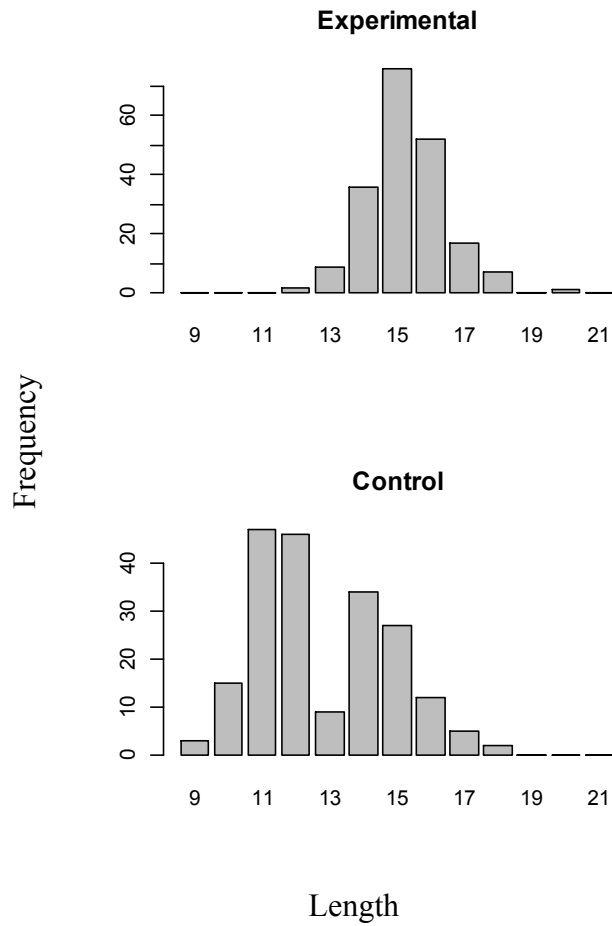


# TOW 4

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 4

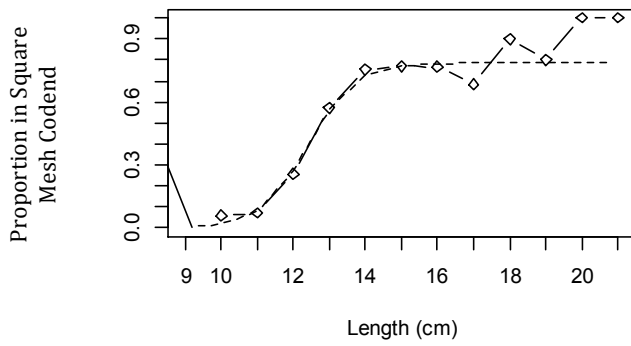


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 4

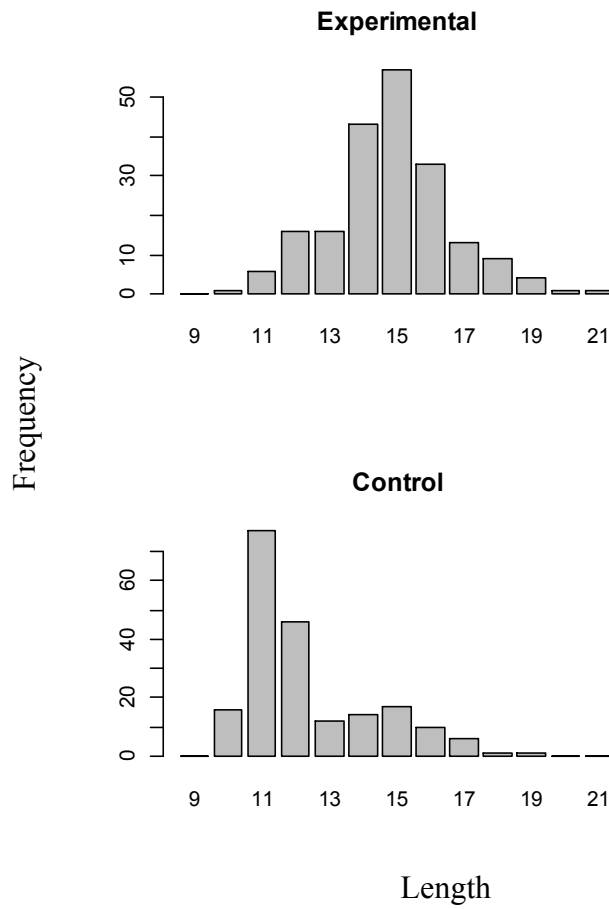


# TOW 5

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 5



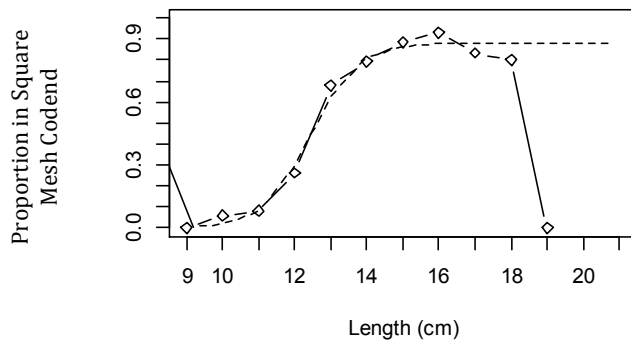
## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 5



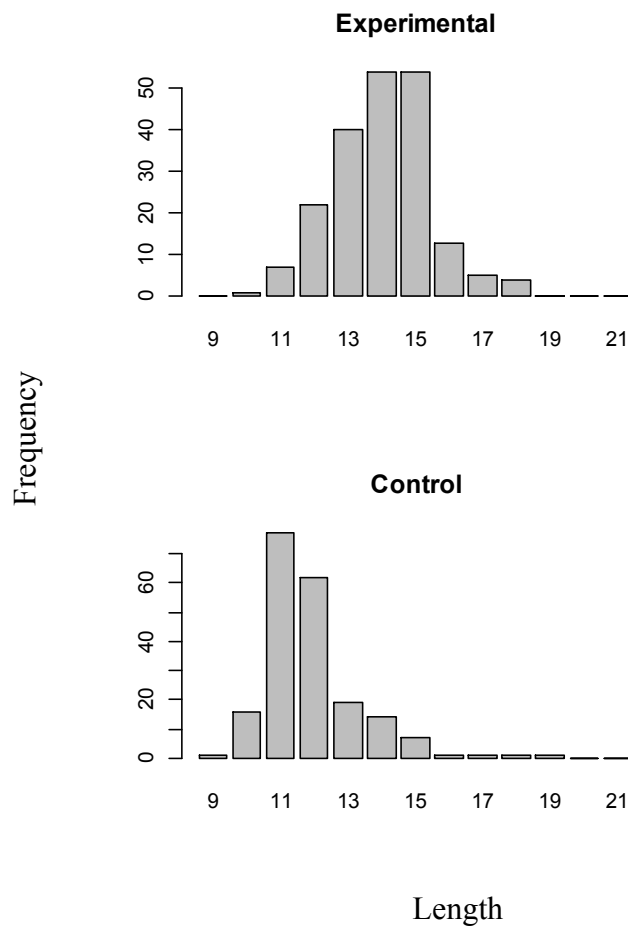


# TOW 6

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 6

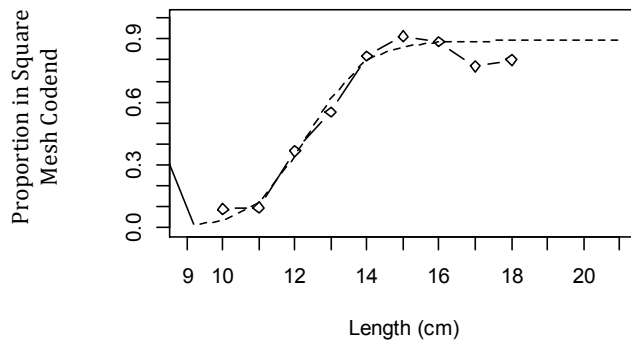


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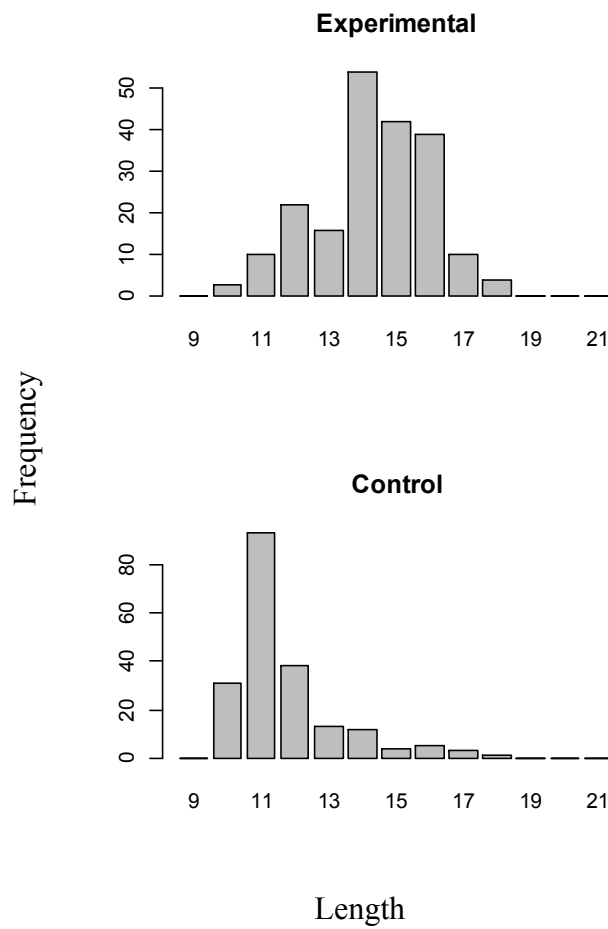


# TOW 7

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 7

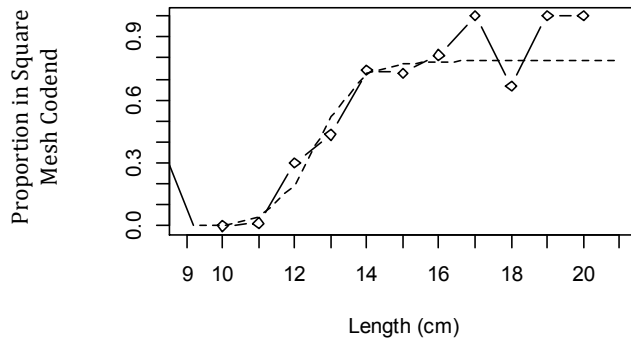


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 7

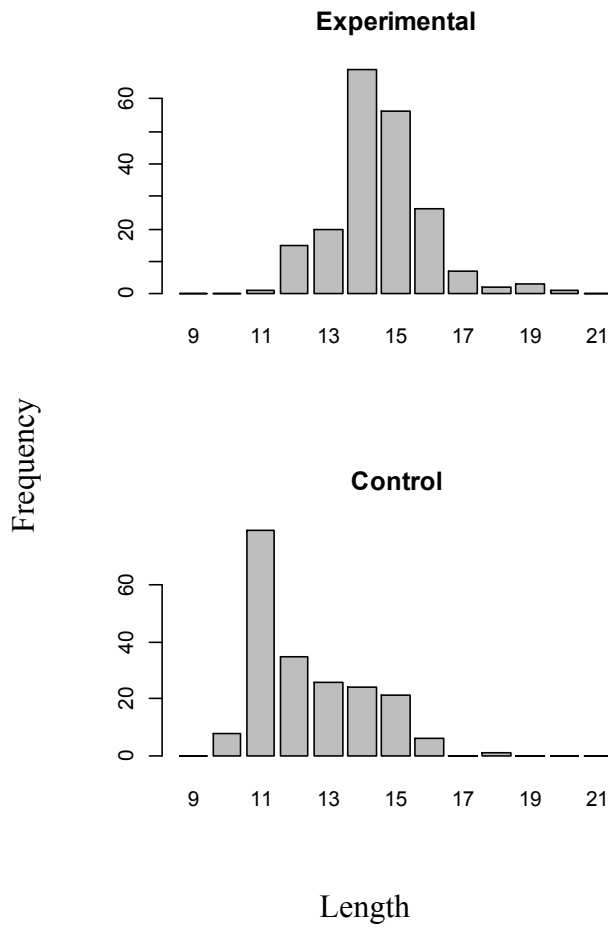


# TOW 8

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 8

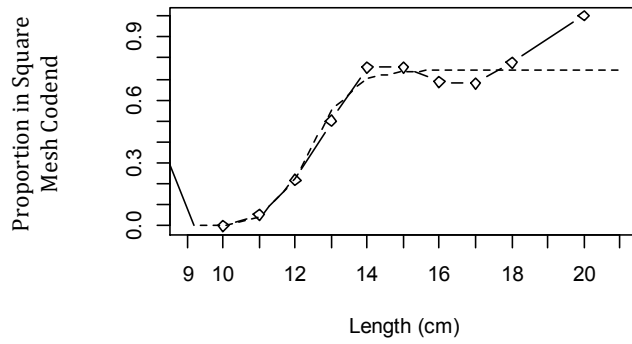


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 8

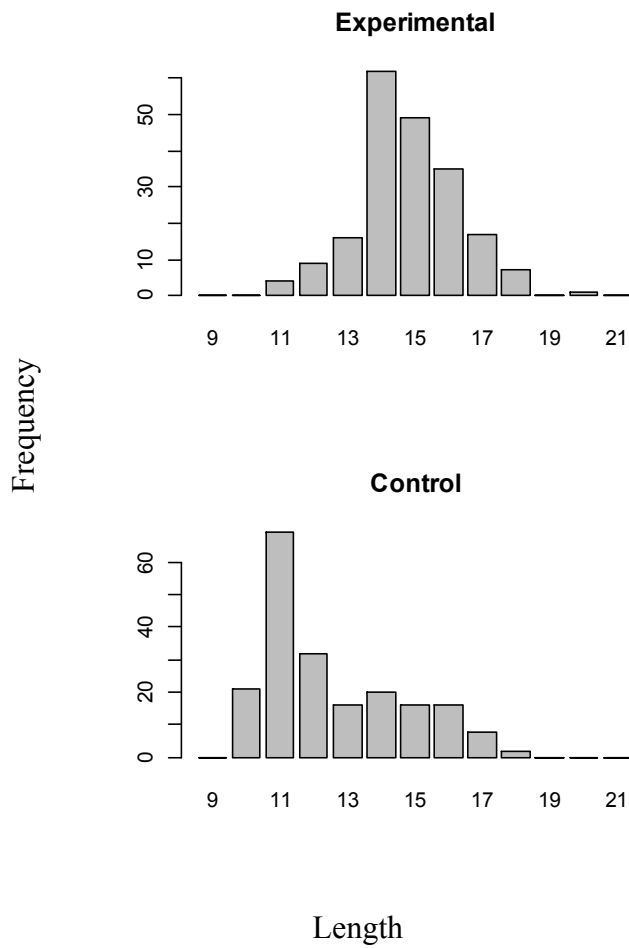


# TOW 9

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 9

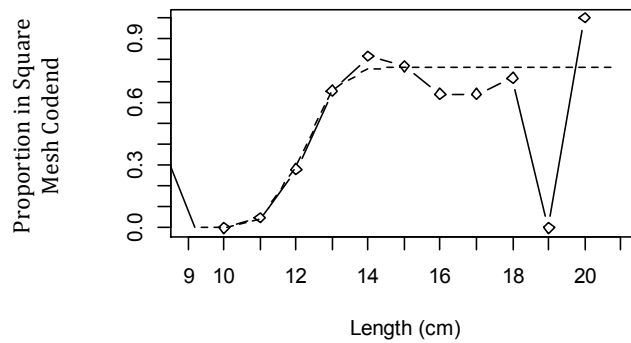


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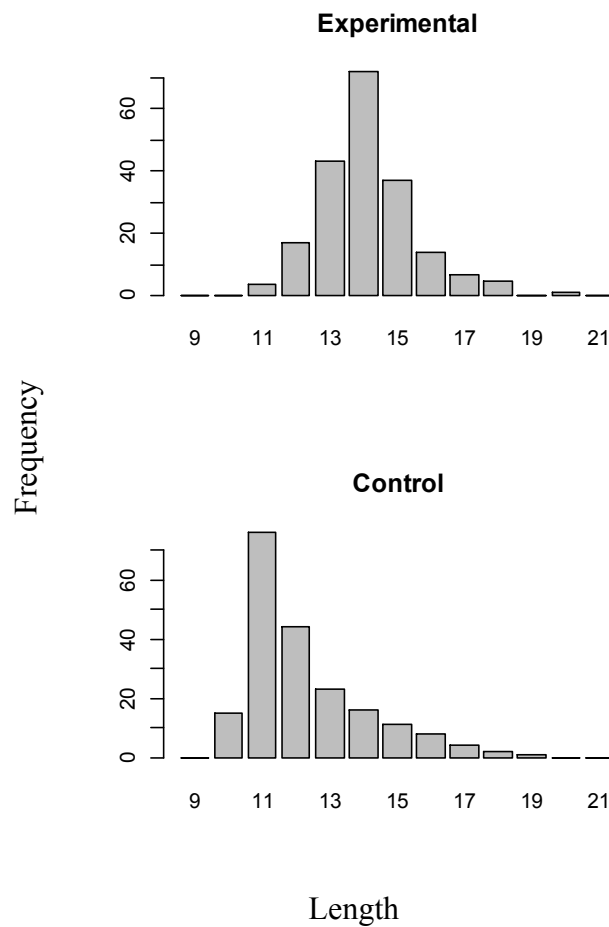


## TOW 10

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 10

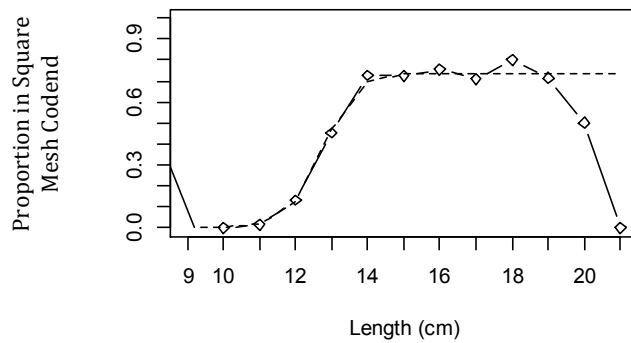


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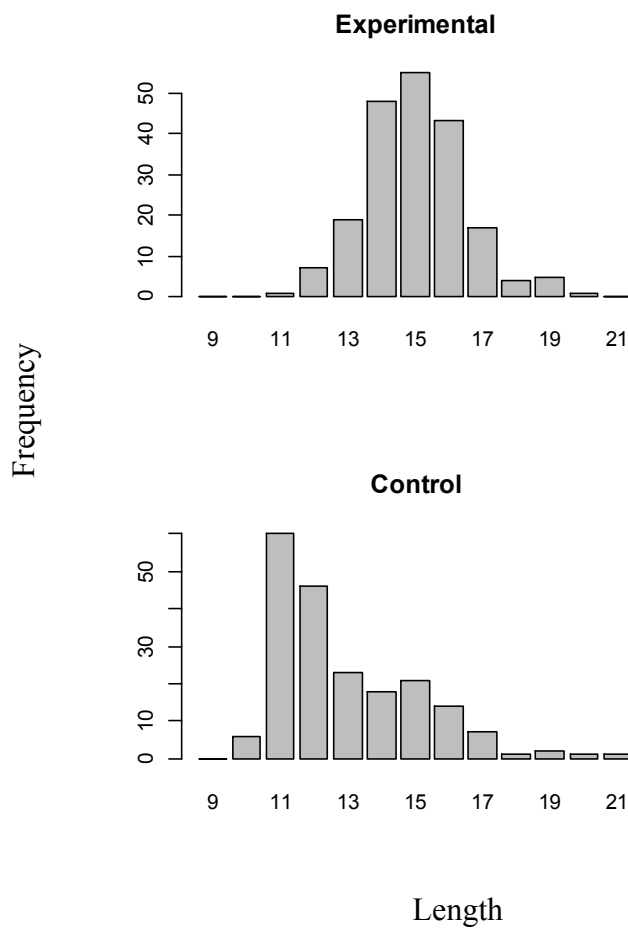


## TOW 11

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 11

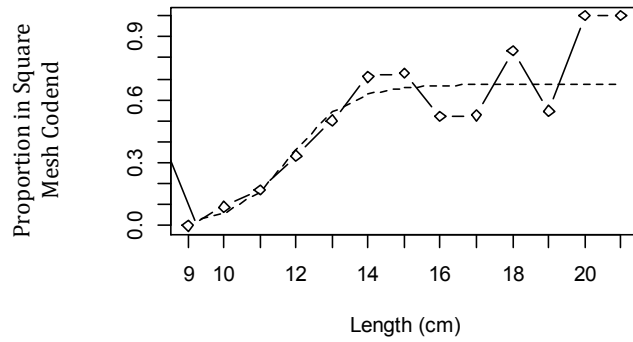


### Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 11

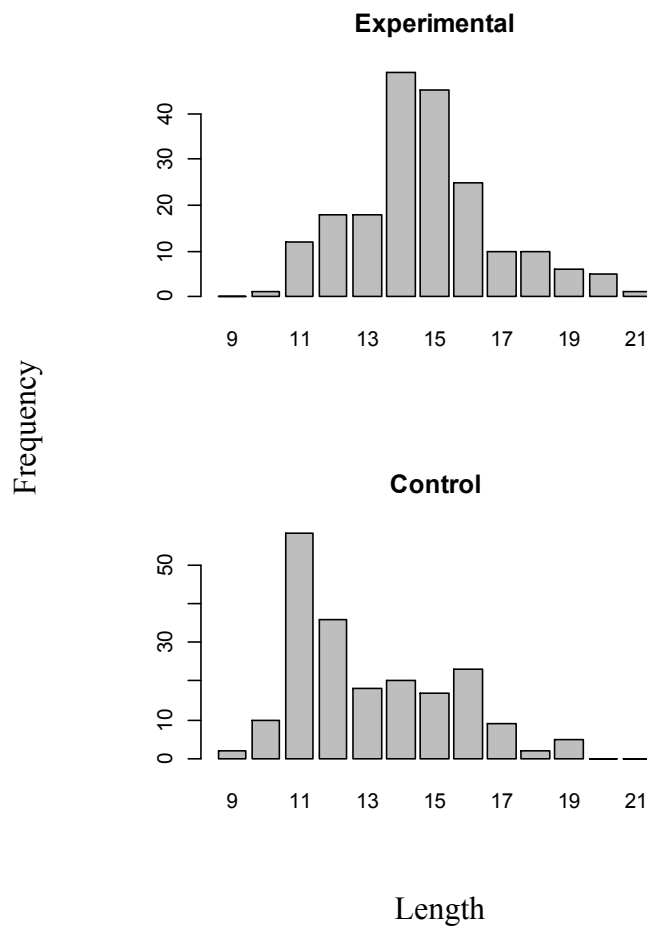


## TOW 12

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 12

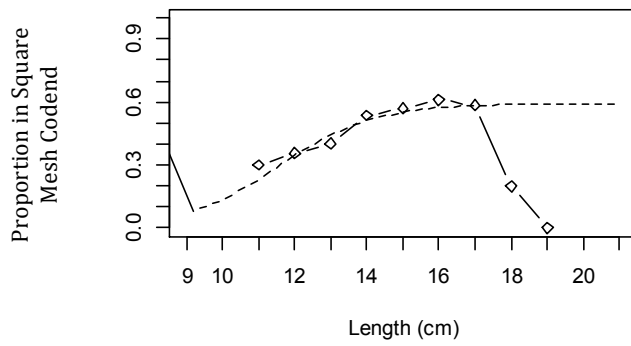


### Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 12

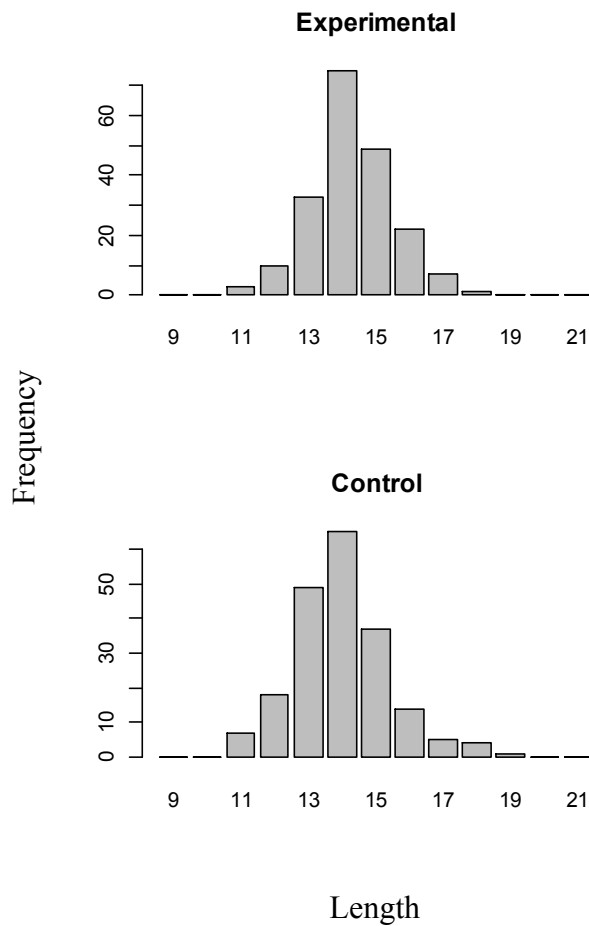


## TOW 13

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 13



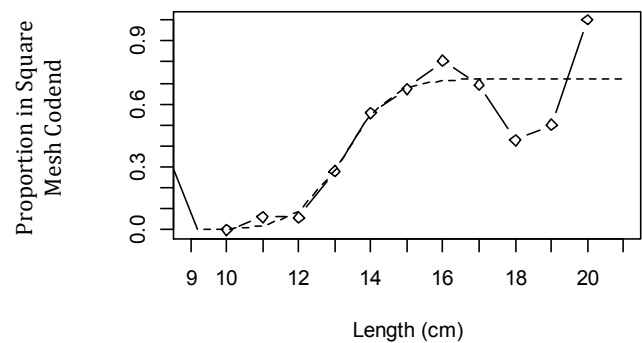
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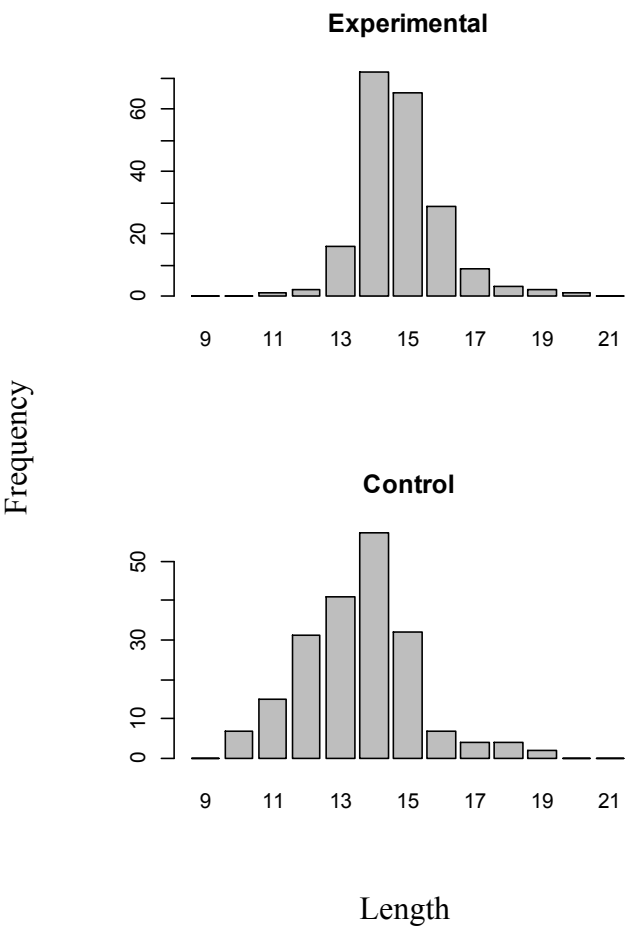


# TOW 14

Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 14

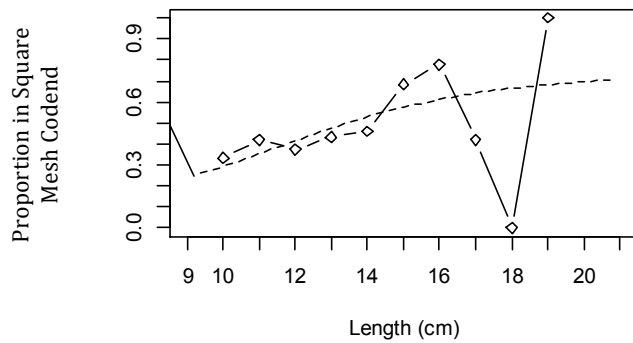


Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 14

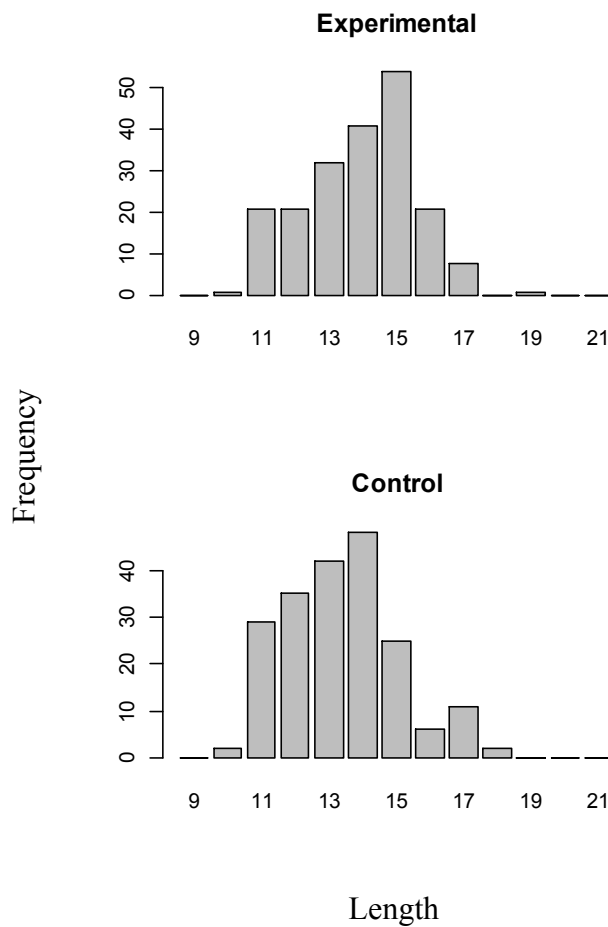


# TOW 15

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 15

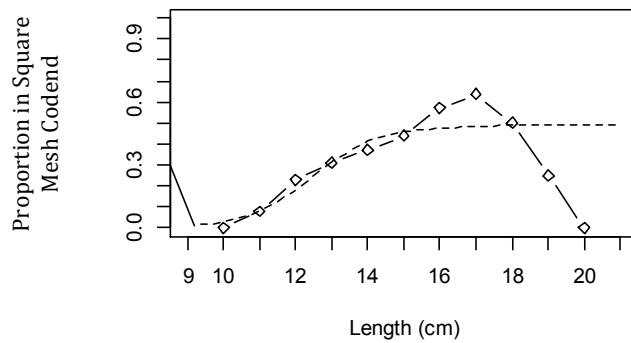


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 15

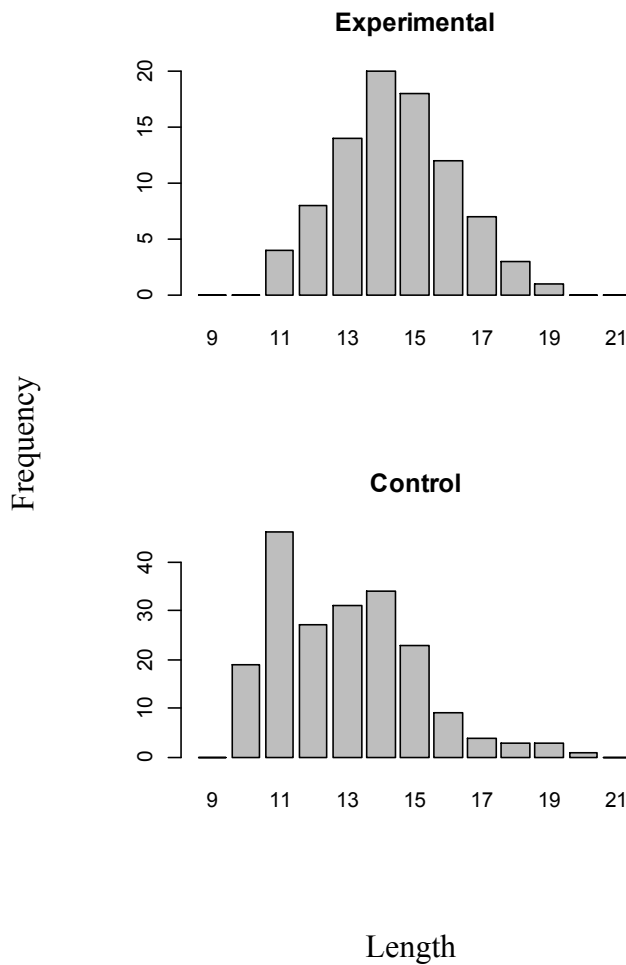


# TOW 16

## Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 16

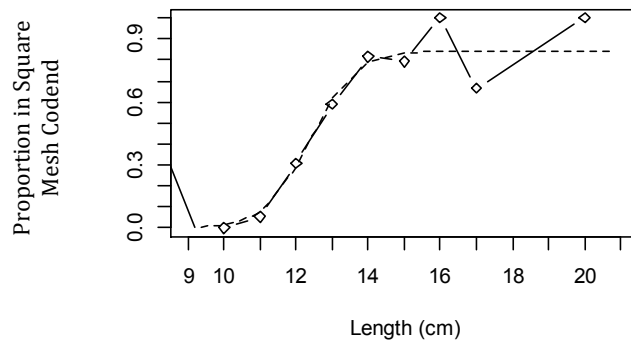


## Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 16

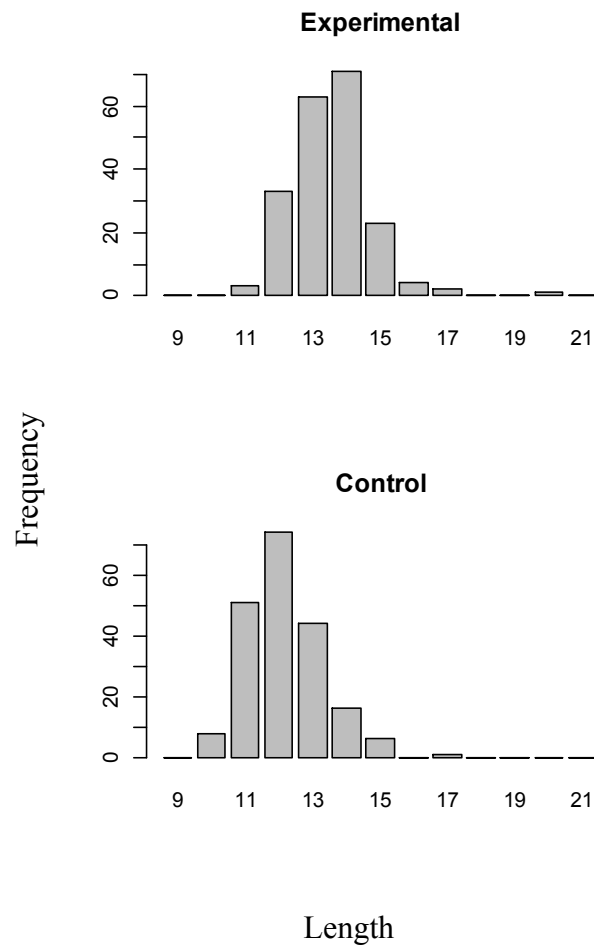


## TOW 17

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 17

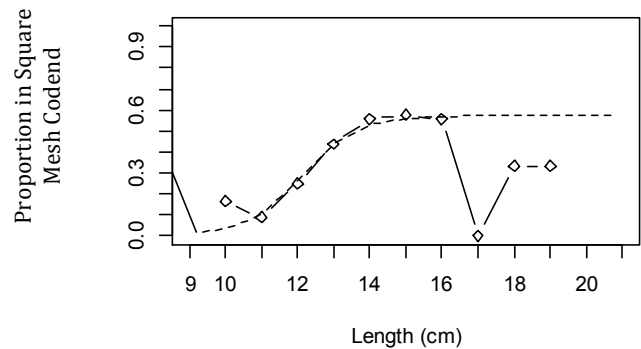


### Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 17

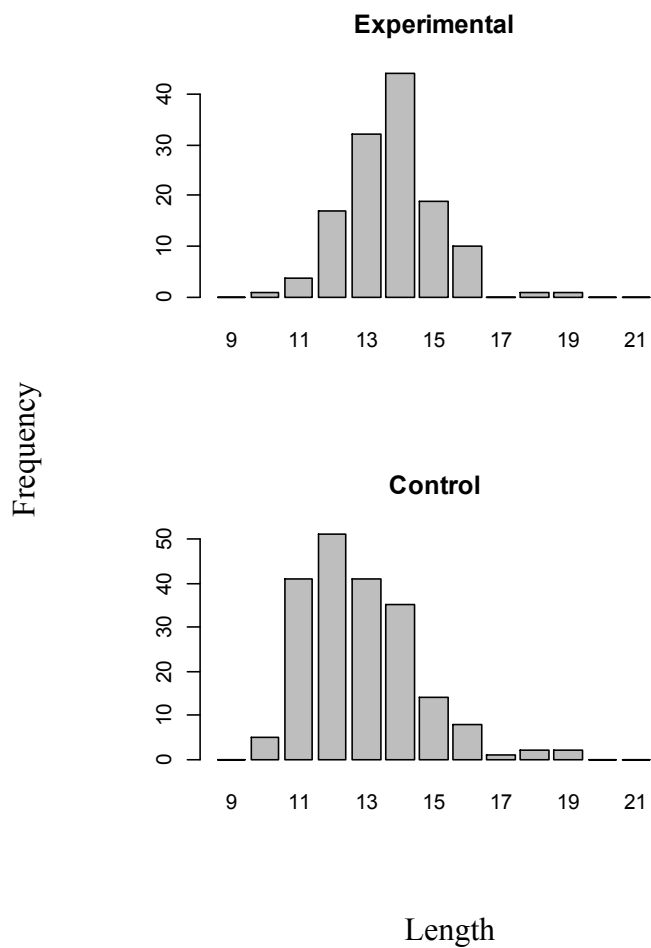


# TOW 18

Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 18

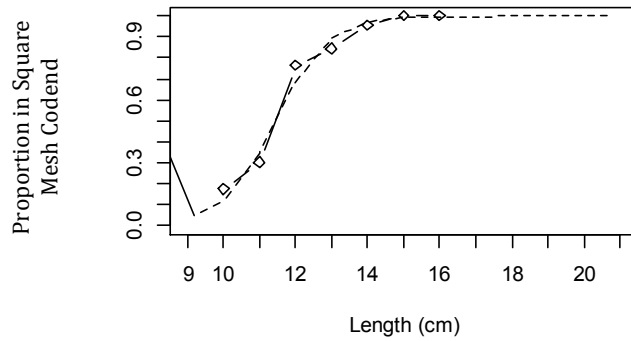


Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 18

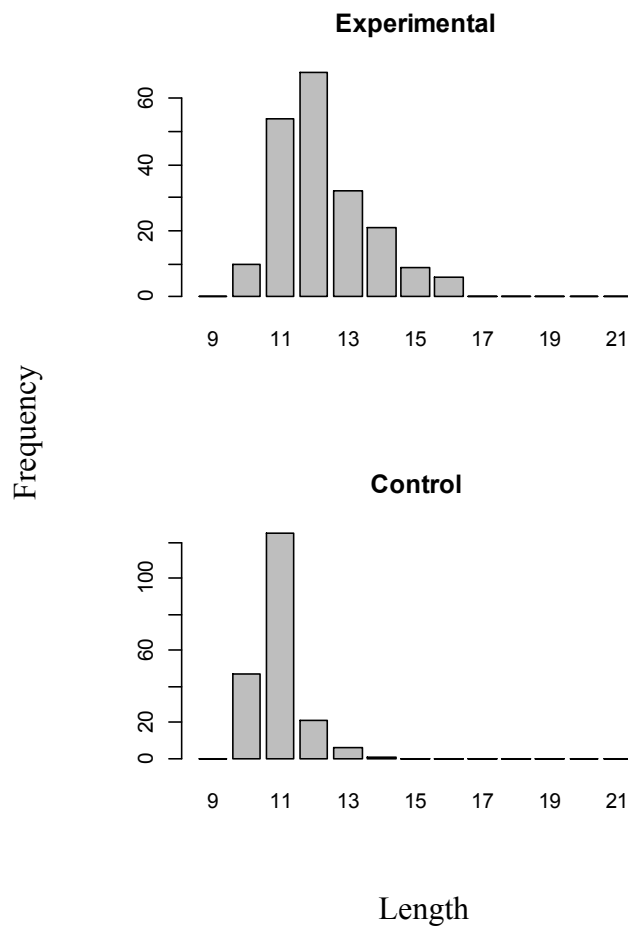


## TOW 19

### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 19

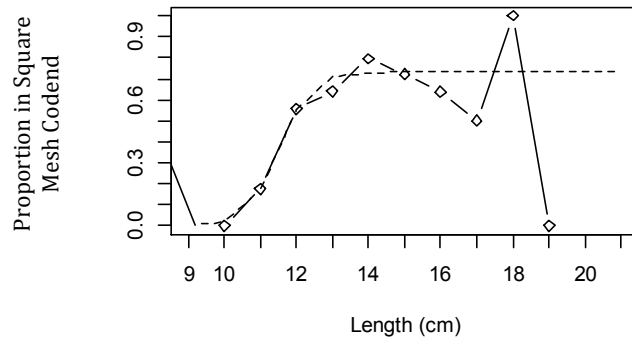


### Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 19

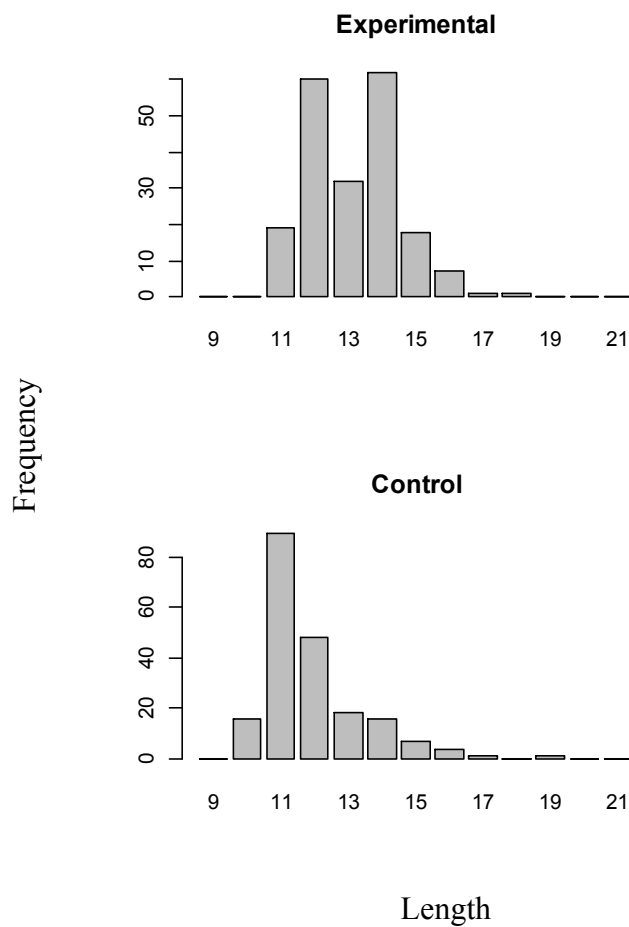


## TOW 20

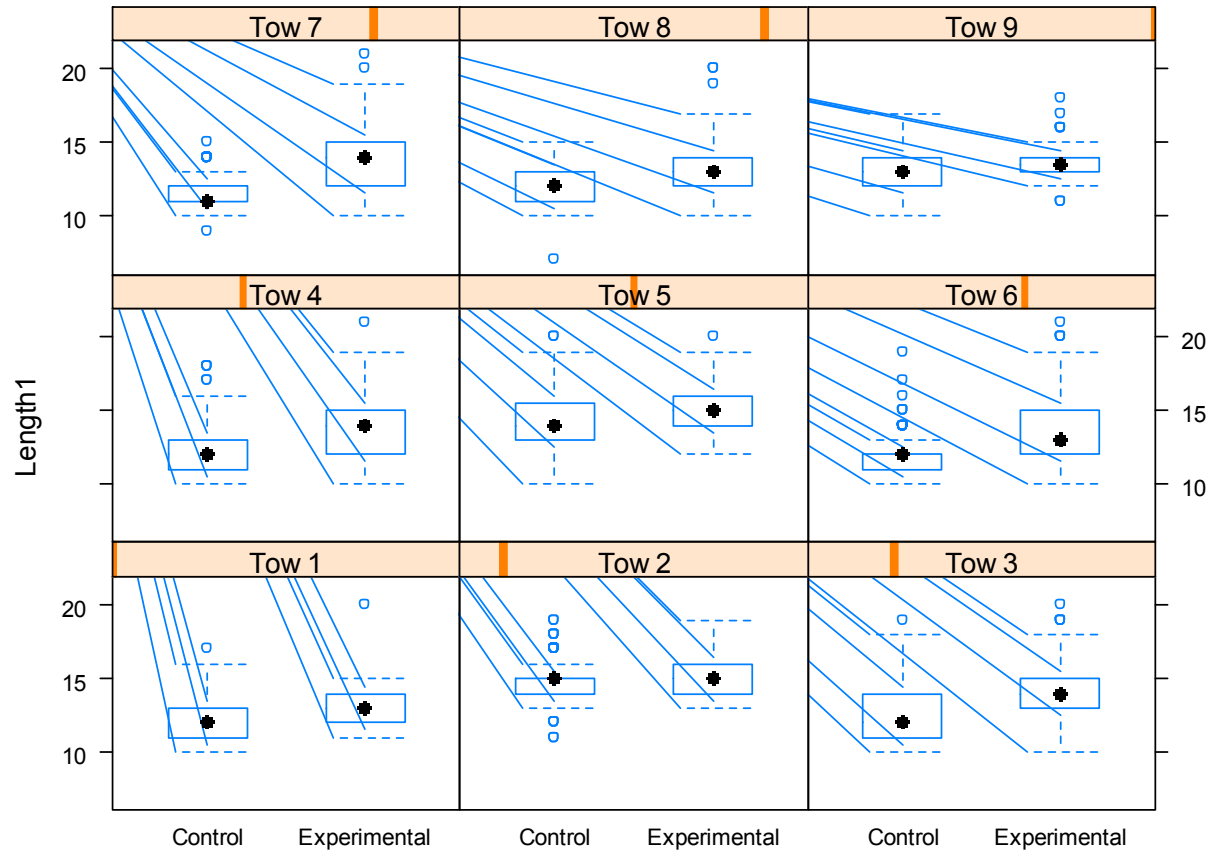
### Proportion of Butterfish Catch By Length in Square Mesh Codend – Tow 20



### Length Frequency Distribution of Butterfish in the Square Mesh Experimental Codend and in the Control Codend for Tow 20



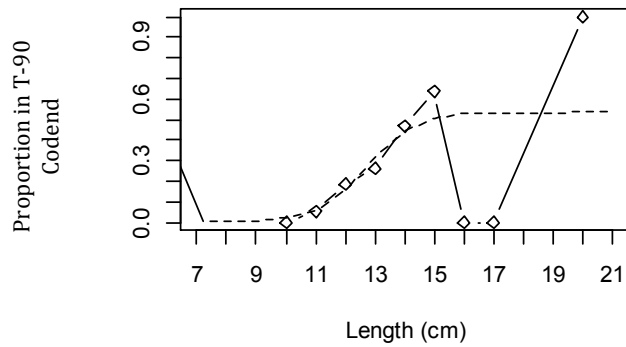
# T-90 Selectivity Analysis



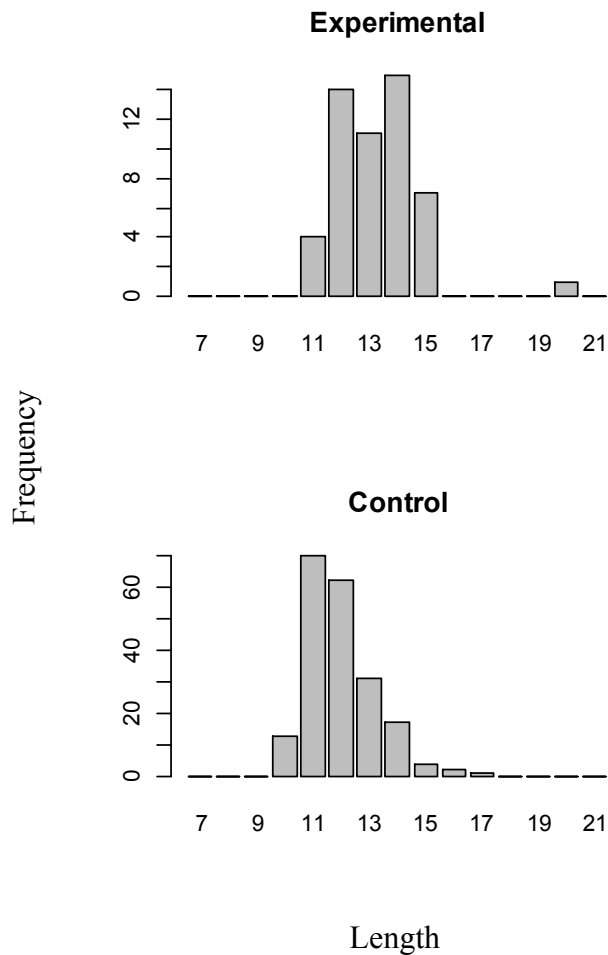


## TOW 21

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 21

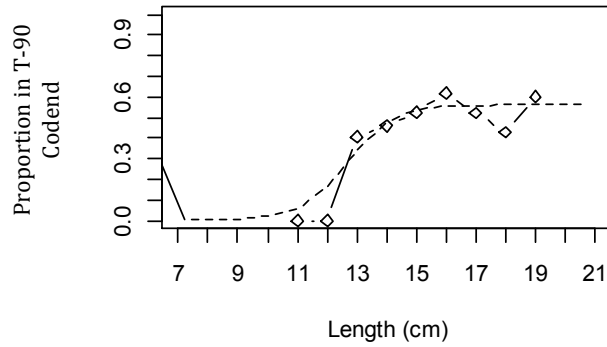


### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 21



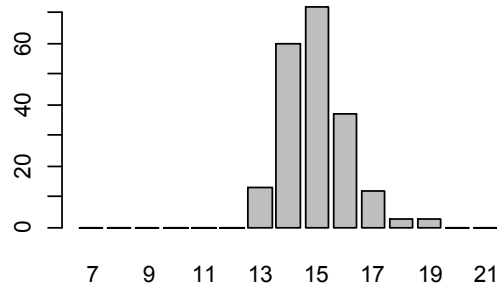
## TOW 22

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 22



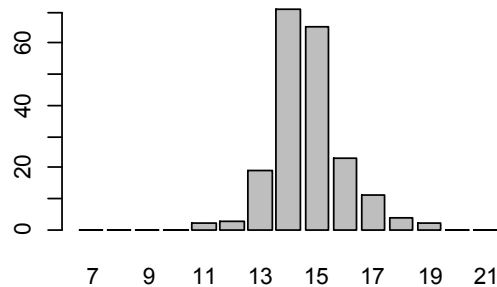
### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 22

#### Experimental



Frequency

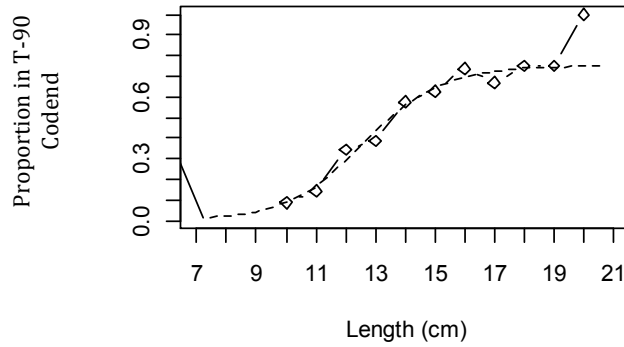
#### Control



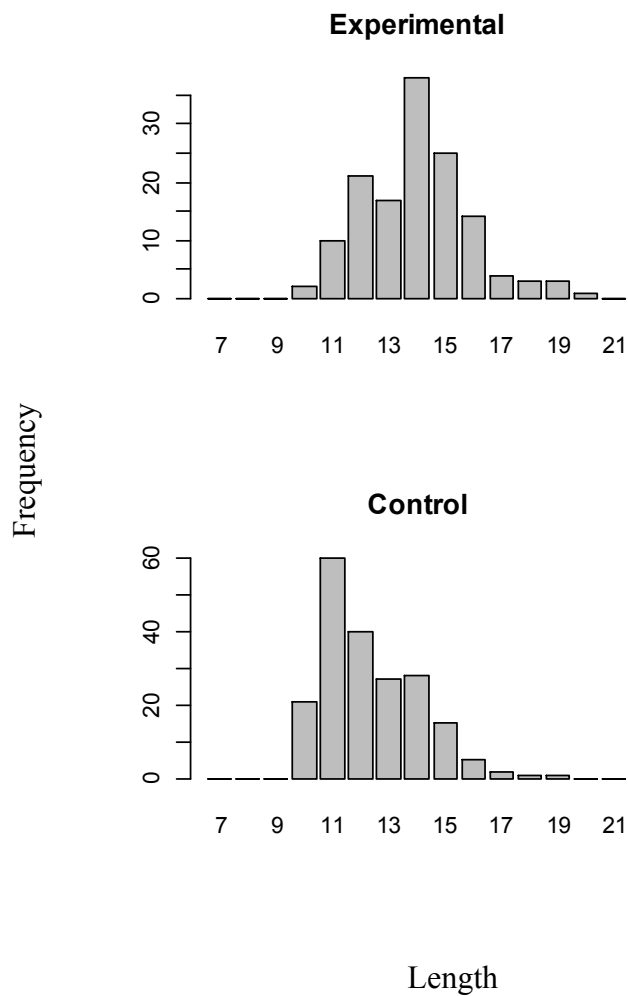
Length

# TOW 23

## Proportion of Butterfish Catch By Length in T-90 Codend – Tow 23

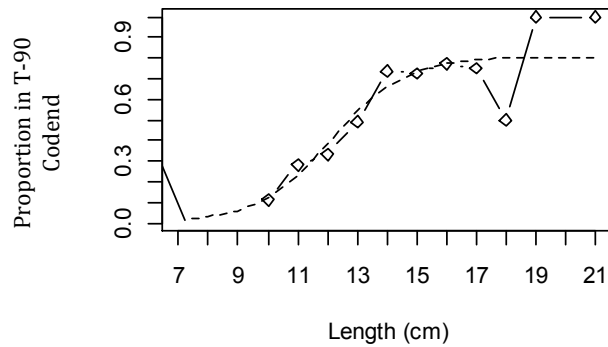


## Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 23

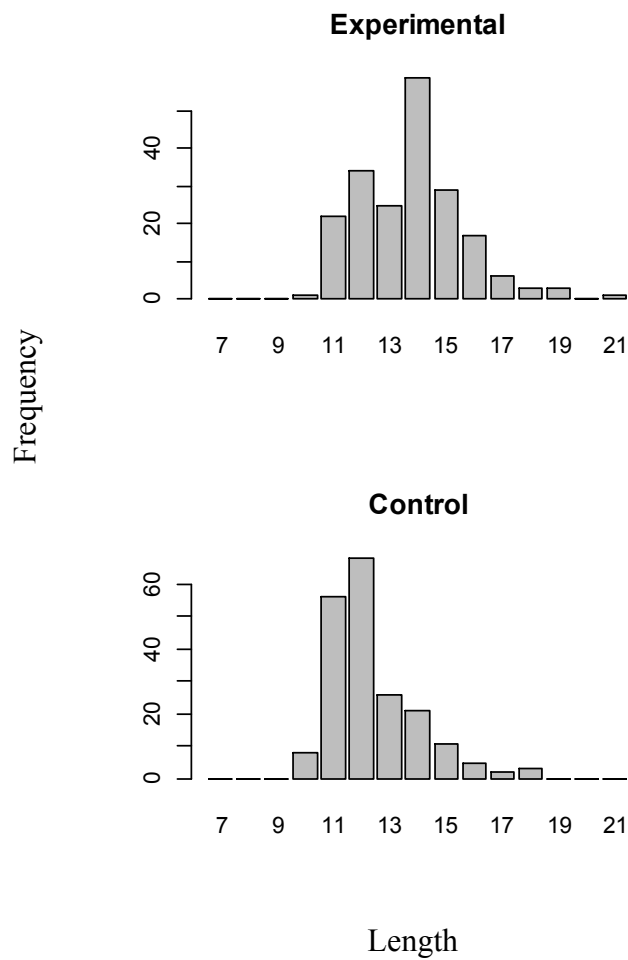


## TOW 24

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 24

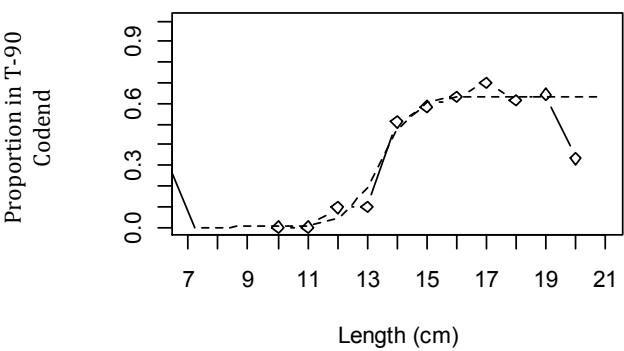


### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 24

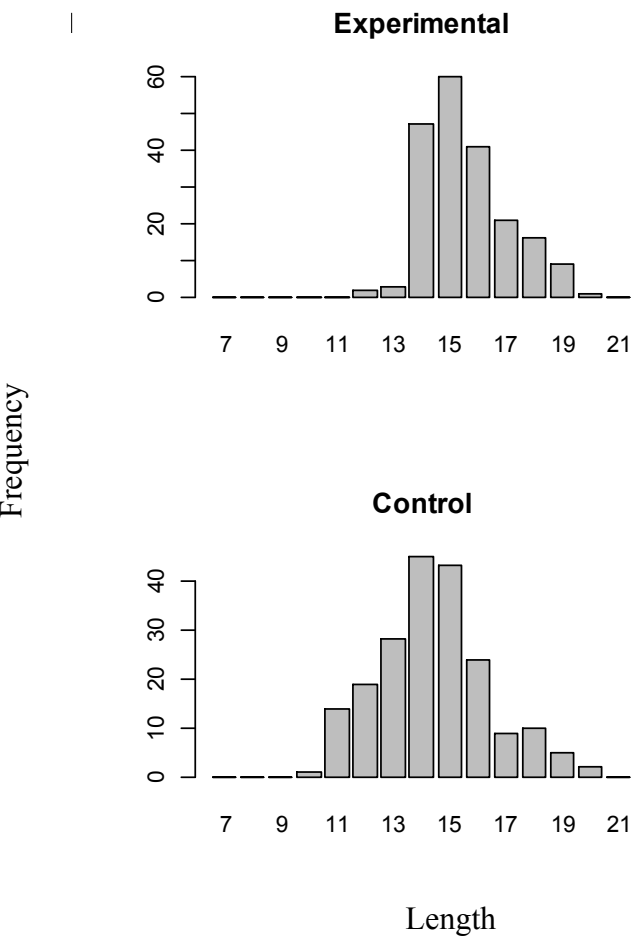


# TOW 25

Proportion of Butterfish Catch By Length in T-90 Codend – Tow 25

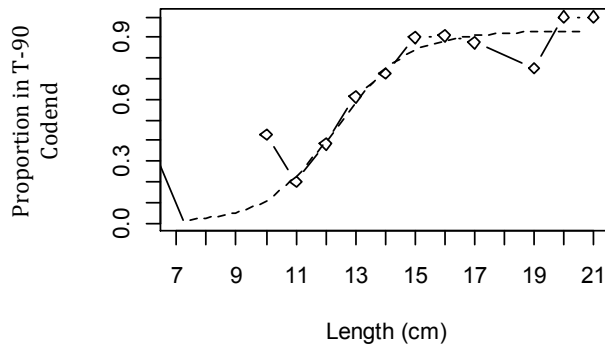


Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 25

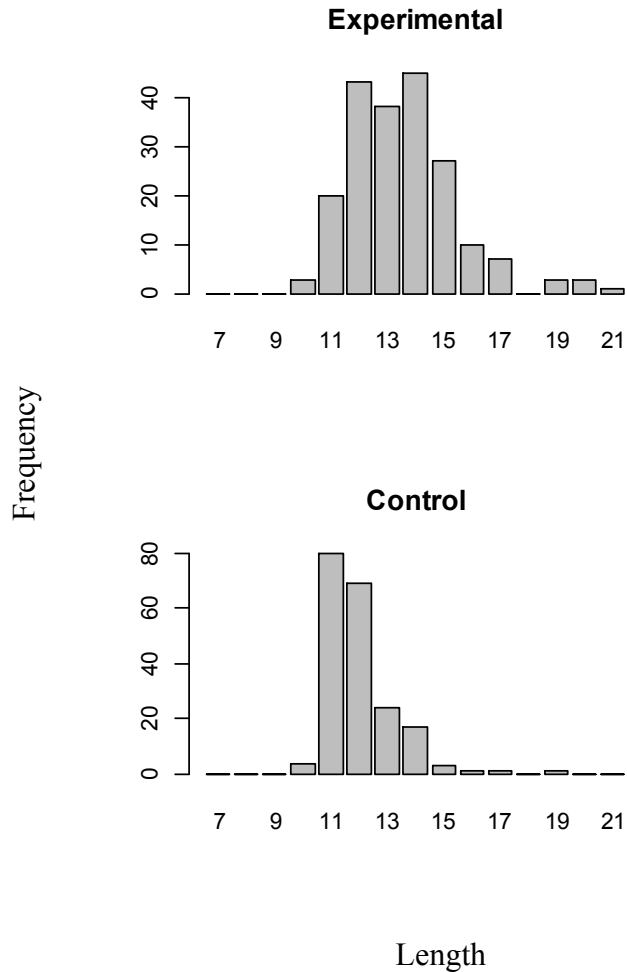


## TOW 26

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 26

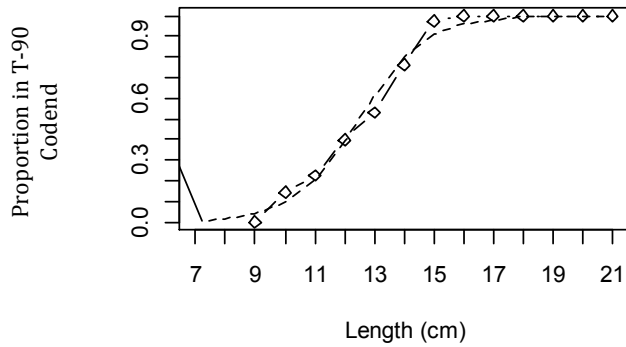


### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 26

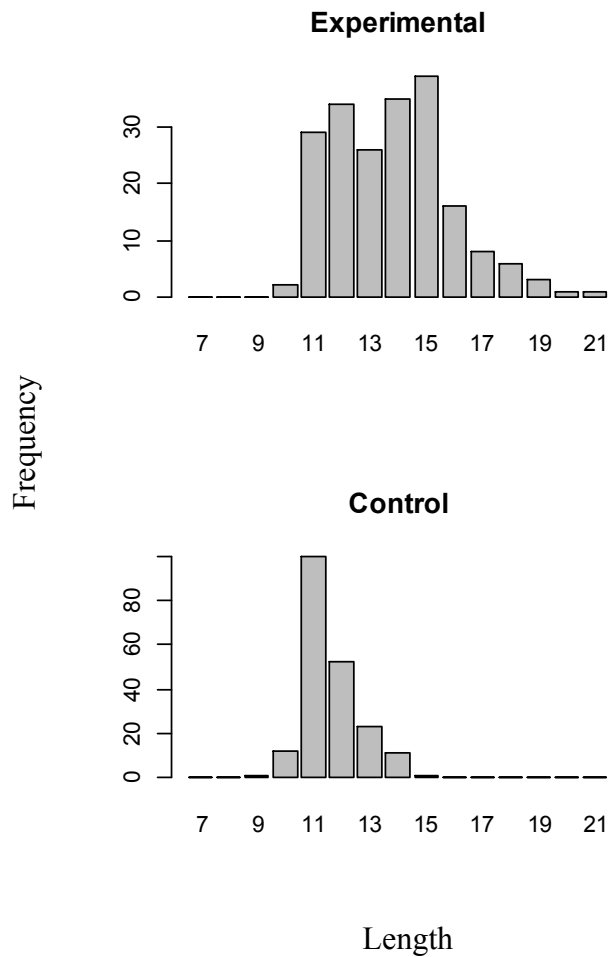


## TOW 27

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 27

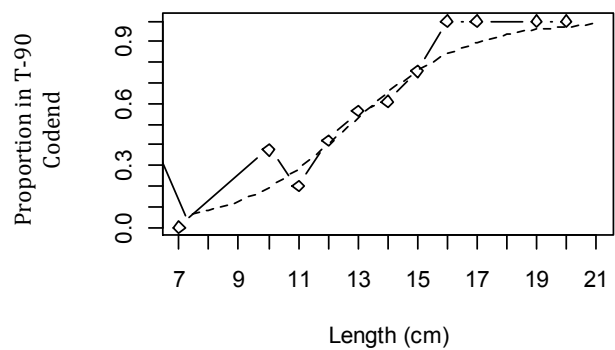


### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 27

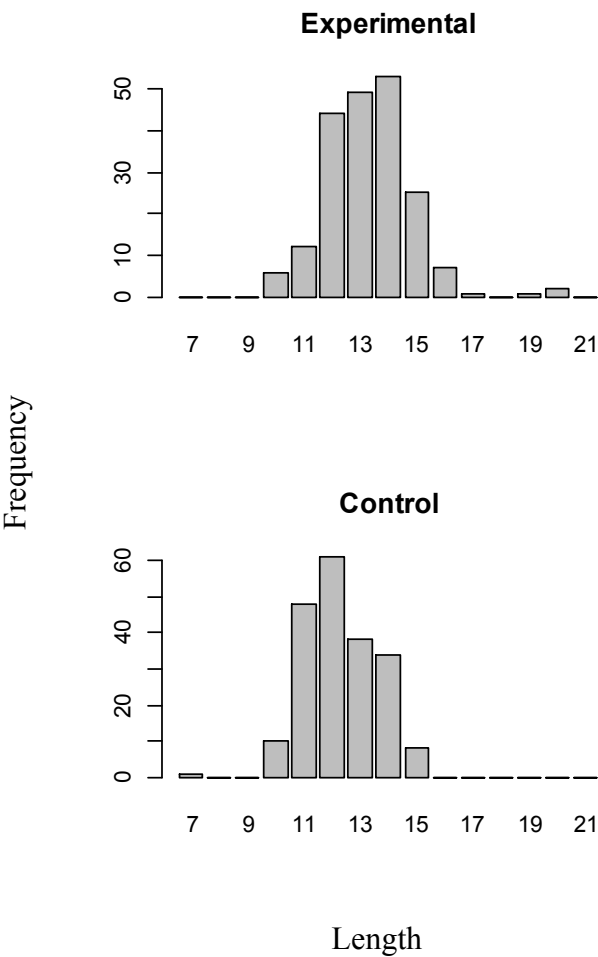


# TOW 28

Proportion of Butterfish Catch By Length in T-90 Codend – Tow 28



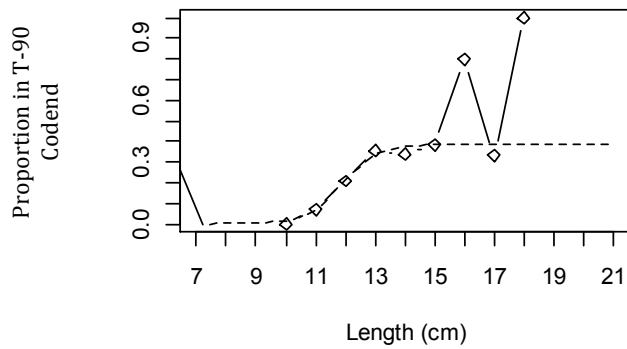
Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 28





## TOW 29

### Proportion of Butterfish Catch By Length in T-90 Codend – Tow 29



### Length Frequency Distribution of Butterfish in the T-90 Experimental Codend and in the Control Codend for Tow 29

