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Understanding Dredge Performance for a Lined versus Unlined NMFS Sea Scallop Dredge: Final Report

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Final Report

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Project Summary

The sea scallop fishery is typically supported by several primary survey methods (i.e., dredge and optical surveys), which provide multiple, spatially explicit biomass estimates on an annual basis. Since 2015, significant divergence in area-specific biomass estimates between the optical and dredge survey methods has been noted. The divergent estimates are associated with areas of high scallop densities within the Nantucket Lightship Access Area (NL) and the Elephant Truck Access Area (ET). In 2018 and 2019, the disparity in biomass estimates between the different survey methods in the ET was reduced, but in the NL, the issue has continued. Evidence suggests gear saturation is occurring for the survey dredge upon the examination of the 2016 and 2017 survey results for these areas of high scallop density (NEFSC, 2018). This effect is currently the main explanation for the difference in biomass estimates between survey methods. While several independent sources of biomass estimates are beneficial for successful management of the resource, divergent area-specific estimates can contribute to uncertainty when setting annual specifications. Understanding all sources of uncertainty in survey dredge gear performance should be investigated to fully comprehend how and why survey dredge estimates differ from optical survey estimates.

Several studies have been conducted by the Virginia Institute of Marine Science (VIMS) in conjunction with the Northeast Fisheries Science Center (NEFSC) and the University of Delaware through the Scallop Research Set Aside (RSA) Program to investigate dredge performance and efficiency in relation to density *in situ*. To document dredge performance in relation to survey protocols (i.e., liner usage, scope to dept ratio, towing speed, etc.) under ideal conditions, a scale survey dredge was tested in the flume tank at the Fisheries and Marine Institute of Memorial University of Newfoundland. The survey dredge was tested with and without the traditional liner to understand the impact of the dredge liner on performance. Tow speeds ranging from 3.5 – 4.5 kts, varying scope to depth ratios, and simulated catches were also tested. Dye tabs were placed on the survey dredge to observe the hydrodynamic flow through the dredge. Video footage was recorded of all trials. While each trial was being completed, warp tension, maximum height of the dredge bag, height of the twine top, wire angle, and height of the wheel off the bottom were measured. Still images from the video footage were used to calculate dredge angle.

Results indicated the liner did not negatively impact dredge performance compared to an unlined version of the survey dredge. The liner improved overall bag shape, height of the bag, height of the twine top, and hydrodynamic flow. Other findings indicated catch volume increased dredge angle and the height of the wheel off the conveyor belt. The impact of catch volume was observed at lower speeds when the survey dredge was fished with a smaller diameter tow wire. Based on these results, we recommend that tow speeds should be kept under 4.3 kts to improve dredge performance and have the dredge fish more consistently. Doubling the size of the pressure plate increased warp tension and therefore we do not recommend this as a future possible modification. Survey groups that conduct dredge surveys would benefit from further discussions regarding optimal dredge angle and fishing configuration, as this topic has not been addressed. Flume tank trials indicate for the VIMS dredge survey, towing speed could be increased to potentially improve dredge performance relative to the performance of the dredge under current protocols.

Project Background

The sea scallop, *Placopecten magellanicus*, supports a fishery that landed over 50 million pounds of meats with an ex-vessel value in excess of US $ 500,000,000 in 2017 (NMFS, 2018). These landings resulted in the sea scallop fishery being one of the most valuable single species fisheries along the East Coast of the United States. While historically subject to extreme cycles of productivity, the fishery has benefited from management measures intended to bring stability and sustainability, as well as a data rich situation resulting from dedicated research funded via the Sea Scallop RSA Program.

This funding source typically identifies resource assessment surveys as high priorities and supports several dredge and optical surveys to be conducted on an annual basis at various spatial scales. Biomass estimates from these surveys are made available to managers and stock assessment scientists for use in setting specifications for the upcoming fishing year and to manage rotational access areas on an annual basis. Since 2015, there has been a divergence between the dredge and optical survey methods with respect to area-specific biomass estimates referred to as Scallop Area Management Simulator Areas (SAMS Areas) (Figure 1). The observed divergence in biomass estimates appears to be pronounced in the high density areas, specifically, the ET in what is currently referred to as the ET Flex SAMS Area and the West and South Deep SAMS Areas in the NL. In 2018 and 2019, the disparity in biomass estimates between the different survey methods in the ET were reduced, but the difference in the NL SAMS Areas has continued to be an issue. The current primary explanation for this discrepancy is a gear saturation effect for survey dredge gear. Preliminary examinations of the 2016 and 2017 SAMS Area estimates for the VIMS dredge survey and the NEFSC HabCam optical survey suggests that dredge efficiency is reduced at very high densities (NEFSC, 2018) (Figure 2).

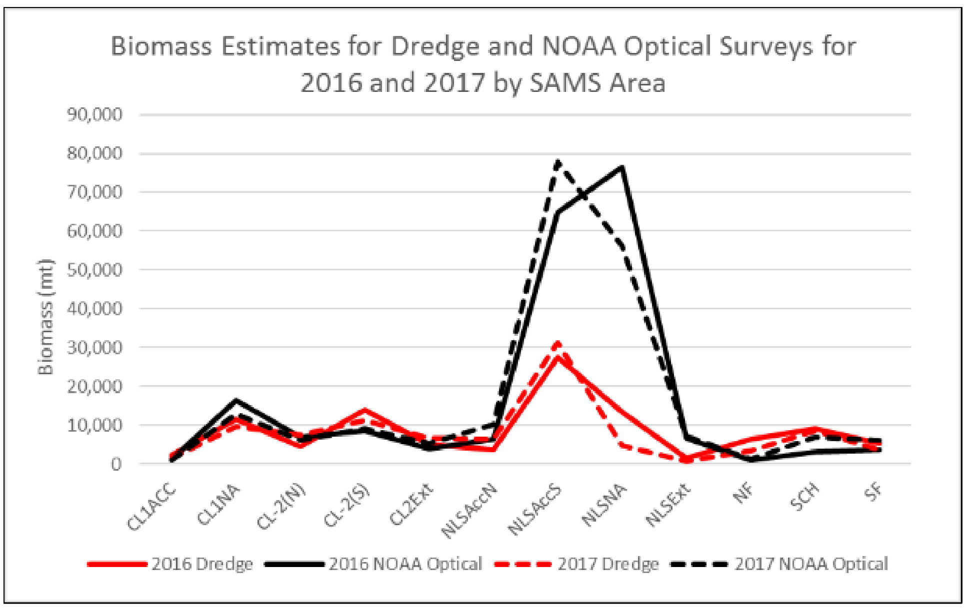

Figure 1. Absolute biomass estimates (mt) for optical surveys (black) and dredge surveys (red) for 2016-2017 for SAMS Areas on Georges Bank. The NLSAccS on the x axis is the South Deep SAMS Area and the NLSNA is the West SAMS Area.

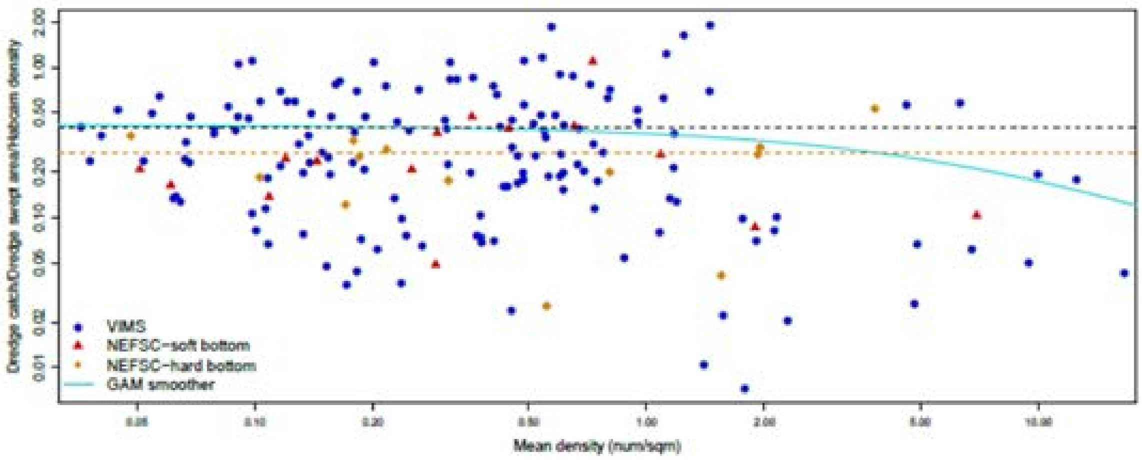

Figure 2. Dredge to Habcam density ratio plotted against mean density (scallops/m^2) for 2016 - 2017 taken from the 2018 benchmark assessment. Dredge data are from VIMS and the NEFSC surveys. Habcam data are from the NEFSC optical survey. The solid blue line is a generalized additive model (GAM) fit, the black dashed line is the assumed dredge efficiency value of 0.4 for soft substrate, and the yellow dashed line is the assumed dredge efficiency value of 0.27 for hard substrate (NEFSC, 2018).

Absolute biomass of scallops for dredge surveys is estimated by scaling the observed catch (in numbers or biomass) with an experimentally derived dredge catchability coefficient (*q*) of 0.40 or 0.27, depending on substrate type. A *q* of 0.40 is applied for all soft substrate, which makes up the majority of the surveyed area. A *q* of 0.27 is applied for hard bottom substrate in particular strata. These values were estimated from a field study conducted by the NEFSC in 2008-2009 (Miller et al., 2019). Since this field study was conducted, resource conditions have changed. Overall biomass has increased almost three fold and several high density aggregations of scallops have been observed in the NL and ET (NEFSC, 2018). If fewer scallops are captured by the gear as a result of gear saturation, this implies reduction in *q* and applying the assumed stationary *q* will lead to an underestimate of scallop biomass (NEFSC, 2014; NEFSC, 2018; Miller et al., 2019). Optical surveys are assumed to be 100 percent efficient and no scaling factor is required for biomass estimates (NEFSC, 2018).

Gear saturation may be occurring in the dredge for several reasons and impacting performance. The main explanation behind this phenomenon is that scallop density is affecting gear performance. A standard survey dredge tow is 15 minutes in duration from the time the survey dredge winch brake is locked. The standard area swept for a 15-minute tow is 4,515 m^2 and the dredge can hold approximately 50 baskets of scallops. In high density areas, the hypothesis is that the dredge becomes filled over the course of a tow and scallops may not be retained in the dredge during the latter part of the tow (Shumway and Parsons, 2006). Under low and normal scallop densities, a 15-minute tow is acceptable and biomass estimates are comparable to optical survey estimates (Figure 1). Average densities observed outside the high density areas in the NL and ET ranged from 0.01 to 0.78 scallops per m^2 in 2018 and 2019.

The average densities calculated for the NL and ET SAMS areas, while still underestimated, ranged from 0.76 in the ET to 1.84 scallops per m^2 in the NL in 2018 and 2019. Another possible reason for gear saturation is similar in that for areas of high sand dollar abundance, the dredge may become filled with sand dollars and scallops may not be retained once the dredge is full (Shumway and Parsons, 2006).

The use of a 1.5-inch liner in the survey dredge may also be compounding dredge efficiency and performance. The liner is used in the dredge to retain small scallops that would pass through the 2-inch rings on the dredge bag. Several studies have cited work conducted by Serchuk and Smolowitz (1980) that showed the use of a dredge liner decreases dredge efficiency (NEFSC, 2004; Yochum and DuPaul, 2008). This may be a result of decreased water pressure and flow through the dredge that negatively impacts performance and results in lower catch rates. One explanation of how hydrodynamic flow is altered is that reverse hydrodynamic flow can occur if the liner becomes clogged with debris or scallop catch, limiting further entry of scallops into the dredge bag. The liner may also be affecting dredge performance in other ways, although how this changes the behavior of the dredge is not fully known, and competing theories exist. Ultimately, understanding the effect of the survey dredge liner on dredge performance will assist in providing a complete picture of survey dredge performance.

To understand the impact of scallop density on survey dredge performance, several studies have been conducted by the Virginia Institute of Marine Science (VIMS) in conjunction with the Northeast Fisheries Science Center (NEFSC) and the University of Delaware (UD) *in situ*. Funding through the Scallop Research Set Aside (RSA) Program allowed VIMS to conduct a tow duration study to investigate the impact of a reduced 10 minute tow on dredge catch rates. Results in high density areas in the ET and NL did not indicate a reduced tow time reduced catch rates or affected the length composition of catches (Rudders et al., 2019). Dredge efficiency over a range of scallop densities was estimated from a field study conducted in the NL by VIMS and UD (Rudders et al., 2019). Results indicated an estimate of q of 0.13 at high densities, and this value was similar to a reduced q used in the 2018 benchmark assessment to adjust biomass estimates in high density areas for the dredge survey (NESFC, 2018). Additional field studies with the NESFC to estimate q have been conducted since 2017, but results are not yet available.

While these efforts have provided valuable information on dredge performance and efficiency, studies on understanding how the survey dredge fishes have been limited, especially in the recent time period. Methods to assess gear performance include *in situ* camera observational field work or observational studies conducted in a flume tank. *In situ* filed studies can be time consuming and cost prohibitive, while flume tank studies offer the ability to provide direct measurements and observation of a scale model of fishing gear. Scale models in flume tanks have been used widely to study fishing gear under experimental conditions and this method is viewed as a beneficial approach for assessing fishing gear performance (Winger et al., 2006; Sala et al., 2009). This approach has been used to test new scallop dredge designs, such as the Coonamessett Farm Turtle Deflector Dredge CFTDD) turtle dredge, in New England (Smolowtiz et al., 2006, Smolowitz et al., 2012).

This project provides an analysis of overall survey dredge performance through direct measurements of several gear metrics and visual inspection of gear performance. The main goal of the project was to understand the effect of the use of a 1.5 inch liner in the survey dredge. Other dredge gear performance and survey protocol metrics were also evaluated under a range of conditions and scenarios. Having a holistic understanding of survey dredge performance will enable scientists to make informed decisions regarding any potential modifications needed to the survey dredge to address performance issues.

Methods

Survey Dredge and Protocols

The standard National Marine Fisheries Service (NMFS) sea scallop survey dredge used since the 1970s is a New Bedford style dredge, 8 ft. in width and equipped with 2-inch rings, and a 3.5-inch diamond mesh twine top (NEFSC, 2018). A 1.5-inch diamond mesh liner is installed inside the dredge to retain small scallops that would otherwise pass through the rings. In certain hard bottom strata, mainly in the South Channel, rock excluder chains have been added to the dredge since 2004 (NEFSC, 2018). There are differences between the VIMS and NEFSC dredge surveys. The main difference is that the VIMS survey is conducted onboard commercial fishing vessels, while the NEFSC survey is conducted onboard research vessels. The survey dredge was shown to be robust to the effect of vessel and in comparative studies; no difference was detected between commercial vessel catches and research vessel catches (NEFSC, 2018). The use of commercial vessels by VIMS lead to variability in the tow wire diameter used because the wire diameter is boat dependent. Commercial vessel gear characteristics including tow wire diameter are recorded for each vessel that participates in the VIMS surveys. Tow wire diameter has ranged from 1 inch to 1 1/8 inch since 2015 on vessels participating in the VIMS dredge surveys. The NEFSC tow wire on the *R/V Sharp* is 9/16 inch in diameter. Survey protocols for fishing the dredge include a 15 minute tow duration, tow speed range of 3.8-4 kts, and scope to depth ratio of 3:1.

Flume Tank

Flume tank testing was conducted over two days (March 19-20, 2019) at the Fisheries and Marine Institute of Memorial University of Newfoundland's flume tank in St. John's, Newfoundland. The flume tank facility has a data acquisition and flow monitoring system for the collection of dredge performance metrics (Marine Institute Fisheries and Marine Institute of Memorial University of Newfoundland, 2017) (Figure 3). Along with a visual assessment of dredge performance, the flume tank has the ability to take still images and video of the dredge during testing. Dredge survey protocols dictate that the survey dredge be towed at 3.8 to 4 knots. A maximum speed of 4.5 kts was also tested, along with 0.1 kts increments from 4–4.5 kts. The maximum speed of 4.5 kts was tested because this speed has been observed during VIMS surveys and can be related to environmental conditions including tide, wave height, and wind speed. In order to assess dredge performance at the speeds desired, a scale model was required. All trials were conducted at a depth of 4 m. George Legge, Facilities Supervisor for the flume tank, provided specifications for the scaling of the dredge and input on dredge performance during trials.

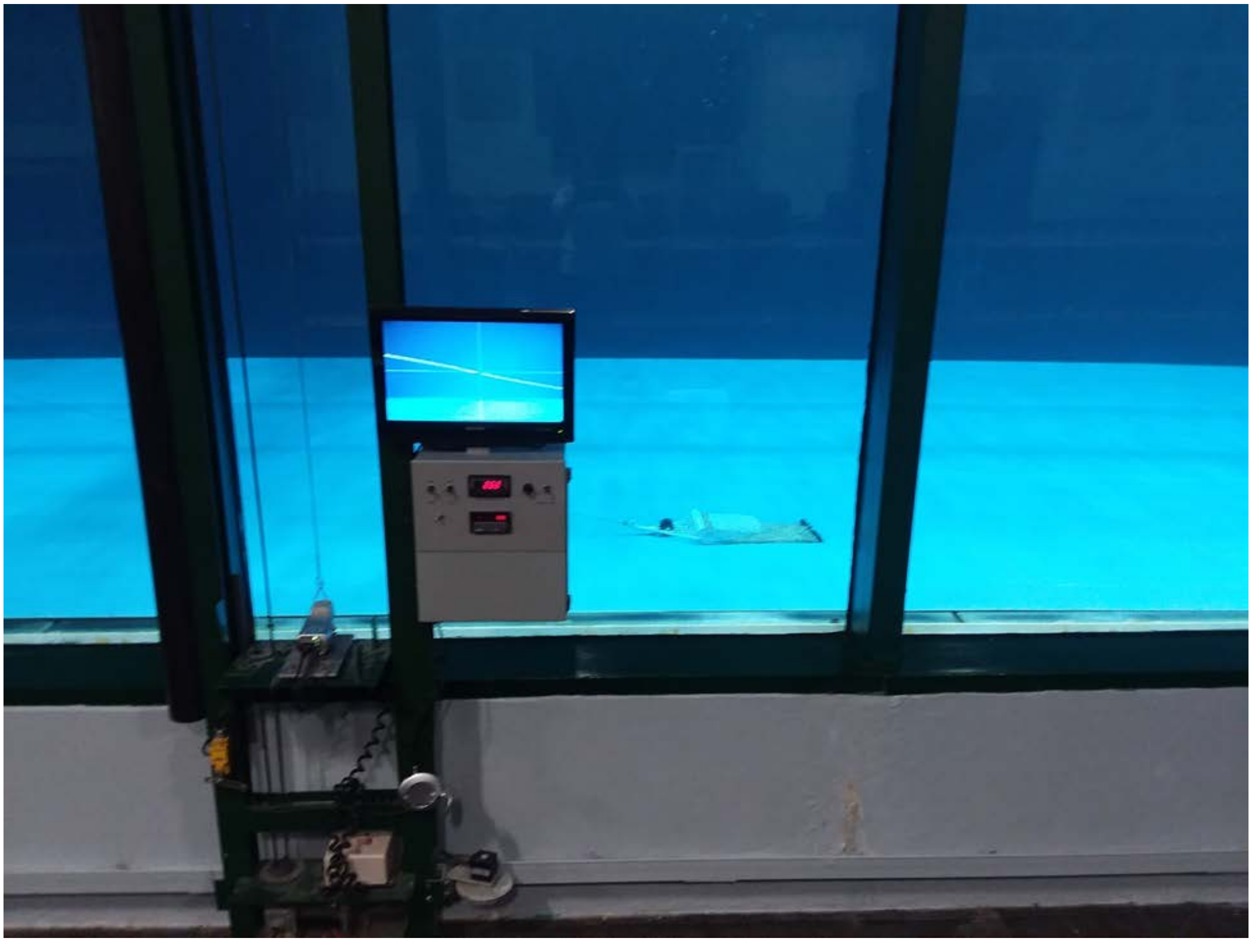

Figure 3. Image of the data acquisition system used to take measurements of the scale survey dredge. In this image the tow wire angle is being measured.

Scale Survey Dredge

Mr. Tor Bendiksen of Reidar's Trawl Gear and Marine Supply Company in New Bedford, MA, with scaling information provided by George Legge, built a 1:6.65 scale survey dredge with a liner (Figure 4). Rock excluder chains were also built, but were not attached to the dredge for any trials due to time constraints and the limited use of rock excluder chains by VIMS. Two scale tow wire diameters were tested to represent the different diameters used by VIMS (26.6 mm) and the NEFSC (16 mm). The 16 mm tow wire diameter value was not known until half way through the first day of testing, so not all trials were repeated with the smaller tow wire diameter. All attempts were made to have comparable trials between lined and unlined versions of each trial.

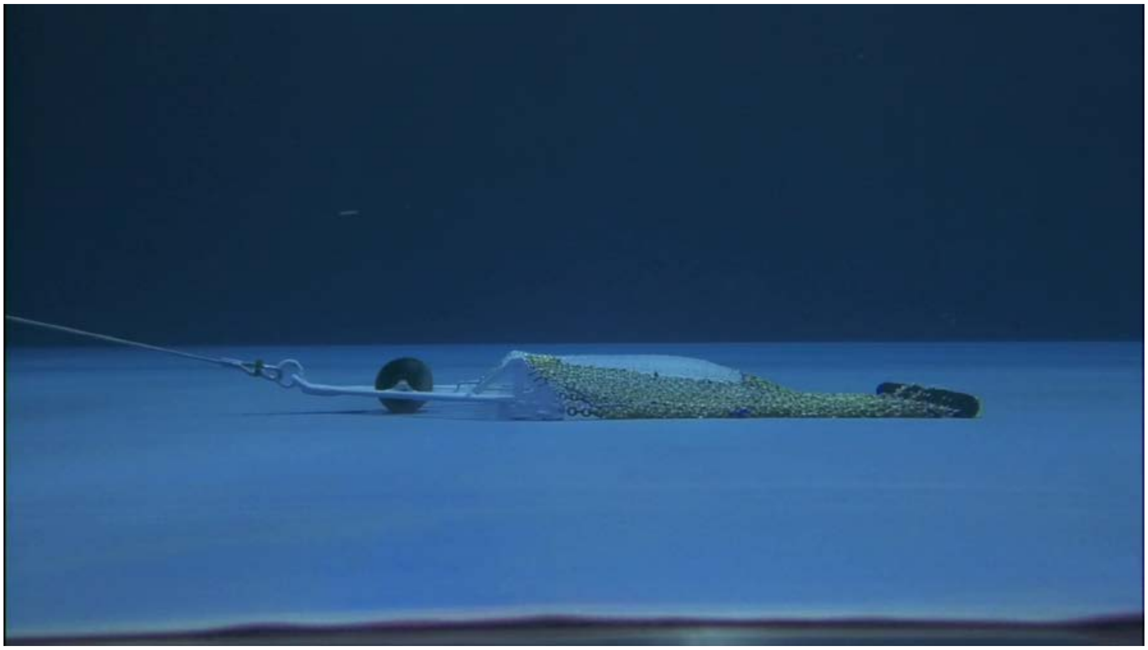

Figure 4. Image of scale survey dredge in the flume tank.

Flume Tank Trials

In order to assess overall survey dredge performance, several dredge metrics were evaluated. All trials on the first day were conducted with the liner installed and all trials on the second day were completed with the liner removed. Video footage was taken for all trials. The following measurements were taken using the data acquisition system for a subset of trials:

- Tow speed (kts). Speed of the conveyor belt was controlled by flume tank staff.
- Warp tension (unit kilogram-force (kgf))
- Maximum bag height (mm) (Figure 5, A)
- Height at the twine top end (mm) (Figure 5, B)
- Wire angle (degrees) (Figure 3)
- Height of the wheel off bottom (mm) (Figure 5, C)

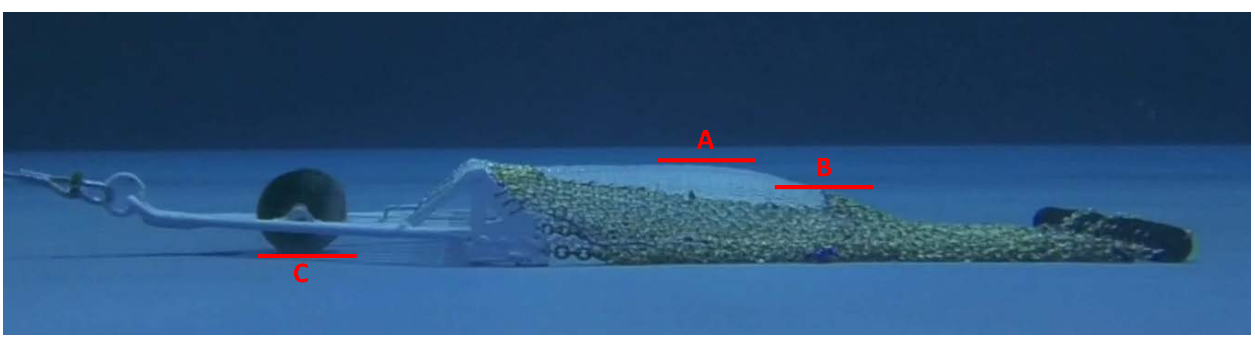

Figure 5. Location of measurements taken for the maximum height of the bag (A), height at the twine top end (B), and height of the wheel off bottom (C).

The following trials were completed for the dredge configuration with the liner installed and again without the liner:

1. Regular Trials
   1.1. Dredge tested at speeds of 3, 3.5, 3.8, 4, and 4.5 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire.
   1.2. Dredge tested at speeds of 3, 3.5, 3.8, 4, and 4.5 kts at a 3:1 scope to depth ratio and 16 mm towing wire.
2. Simulated Catch Trials
   2.1. Dredge tested with simulated catch using 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire (Figure 6).
   2.2. Dredge tested with simulated catch of 100 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts and a 16 mm towing wire.
   2.3. Dredge tested with simulated catch of 100 BioRings at intervals of 0.1 kts from 4 to 4.5 kts with 26.6 mm towing wire.

Figure 6. Image of a BioRing used to simulate catch in the scale survey dredge. Each BioRing either had a weight in the center of the ring or a weight attached to the outside of the ring, as shown in this picture.

3. Hydrodynamic Catch Trials
    3.1. Dredge tested with simulated catch of 100 BioRings at 3.8 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire. Dye tabs were fixed to the dredge to allow for visual examination of water flow through the dredge (Figure 7).
    3.2. Dredge tested with simulated catch of 100 BioRings at 3.8 kts at a 2.5:1 scope to depth ratio and 26.6 mm towing wire.
    3.3. Dredge tested with simulated catch of 100 BioRings at 4.5 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire.
    3.4. Dredge tested with simulated catch of 100 BioRings at 4.5 kts at a 3:1 scope to depth ratio, 26.6 mm towing wire, and increased pressure plate size.

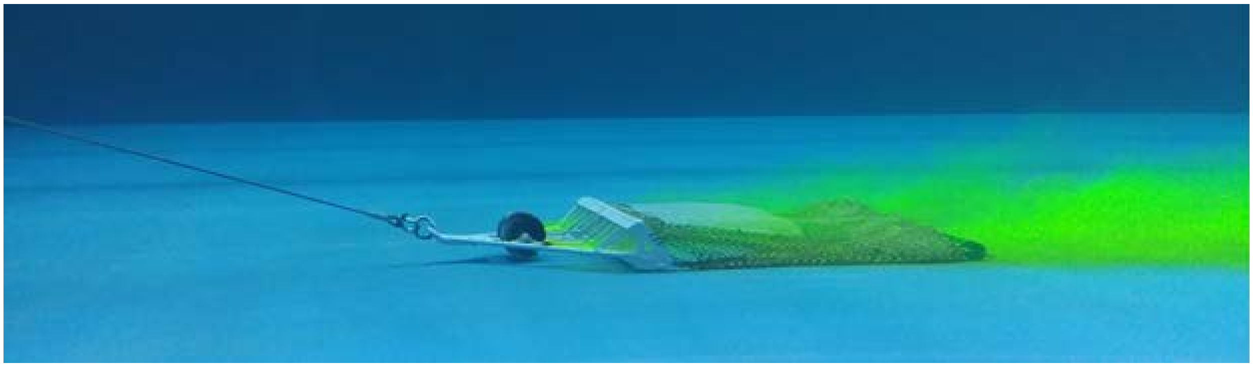

Figure 7. Image of scale survey dredge hydrodynamic trial with dye tabs.

4. Scope to Depth Ratio Trials
    4.1. Dredge tested with a simulated catch of 100 BioRings at a scope to depth ratio of 3.1:1, a speed of 3.8 kts, and 26.6 mm towing wire.
    4.2. Dredge tested with a simulated catch of 100 BioRings at a scope to depth ratio of 3.1:1, a speed of 3.8 kts, and 16 mm towing wire.
    4.3. Dredge tested with a simulated catch of 100 BioRings at scope to depth ratios of 2.5:1, 3.25:1, and 3.5:1 at a speed of 4.5 kts and 26.6 mm towing wire.
    4.4. Dredge tested with a simulated catch of 100 BioRings at scope to depth ratios of 2.5:1, 3.25:1, and 3.5:1 at a speed of 4.5kts and 16 mm towing wire.
5. Pressure Plate Trials
    5.1. The size of the pressure plate was doubled and tested with a simulated catch of 100 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 26.6 mm towing wire, and no liner installed.

Tables 1-5 provide summary information for the trial type, trial number, trial description, information indicating if the liner was installed, and if video and/or dredge measurements were collected. Trial number is numbered sequentially within a trial. For example, trial number 2.1.1 is the first trial for simulated catches of 30, 100, 150, or 300 BioRings with a 26 mm towing wire at speeds ranging from 3 to 4.5 kts and a scope to depth ratio of 3:1.

Table 1. Regular trial summary information broken down by trial number, description, liner indicator, and if video and/or measurements were taken.

Trial	Trial Number	Trial Description	Liner Installed	Video	Measurements Taken
Regular	1.1.1	3 kts, 3:1 ratio, no catch, 26.6 mm tow wire	Y	Y	Y
Regular	1.1.2	3.5 kts, 3:1 ratio, no catch, 26.6 mm tow wire	Y	Y	Y
Regular	1.1.3	3.8 kts, 3:1 ratio, no catch, 26.6 mm tow wire	Y	Y	Y
Regular	1.1.4	4 kts, 3:1 ratio, no catch, 26.6 mm tow wire	Y	Y	Y
Regular	1.1.5	4.5 kts, 3:1 ratio, no catch, 26.6 mm tow wire	Y	Y	Y
Regular	1.1.6	3 kts, 3:1 ratio, no catch, 26.6 mm tow wire	N	Y	Y
Regular	1.1.7	3.5 kts, 3:1 ratio, no catch, 26.6 mm tow wire	N	Y	Y
Regular	1.1.8	3.8 kts, 3:1 ratio, no catch, 26.6 mm tow wire	N	Y	Y
Regular	1.1.9	4 kts, 3:1 ratio, no catch, 26.6 mm tow wire	N	Y	Y
Regular	1.1.10	4.5 kts, 3:1 ratio, no catch, 26.6 mm tow wire	N	Y	Y
Regular	1.1.11	3 kts, 3:1 ratio, no catch, 16 mm tow wire	N	Y	N
Regular	1.1.12	3.5 kts, 3:1 ratio, no catch, 16 mm tow wire	N	Y	N
Regular	1.1.13	3.8 kts, 3:1 ratio, no catch, 16 mm tow wire	N	Y	N

Regular	1.1.14	4 kts, 3:1 ratio, no catch, 16 mm tow wire	N	Y	N
Regular	1.1.15	4.5 kts, 3:1 ratio, no catch, 16 mm tow wire	N	Y	N

Table 2. Simulated Catch trial summary information broken down by trial number, description, liner indicator, and if video and/or measurements were taken.

Trial	Trial Number	Trial Description	Liner Installed	Video	Measurements Taken
Simulated Catch	2.1.1	3 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.2	3.5 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.3	3.8 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.4	4 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.5	4.5 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.6	3 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.7	3.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.8	3.8 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	Y

Simulated Catch	2.1.9	4 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.10	4.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.11	3 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.12	3.5 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.13	3.8 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.14	4 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.15	4.5 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.16	3 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.17	3.5 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.18	3.8 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.19	4 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	Y	Y	Y

Simulated Catch	2.1.20	4.5 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	Y	Y	Y
Simulated Catch	2.1.21	3 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.22	3.5 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.23	3.8 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.24	4 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.25	4.5 kts, 3:1 ratio, 30 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.26	3 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.27	3.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.28	3.8 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.29	4 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.30	4.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	Y

Simulated Catch	2.1.31	3 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.32	3.5 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.33	3.8 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.34	4 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.35	4.5 kts, 3:1 ratio, 150 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.36	3 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.37	3.5 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.38	3.8 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.39	4 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.1.40	4.5 kts, 3:1 ratio, 300 BioRings, 26.6 mm tow wire	N	Y	Y
Simulated Catch	2.2.1	3 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	Y
Simulated Catch	2.2.2	3.5 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	Y

Simulated Catch	2.2.3	3.8 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	Y
Simulated Catch	2.2.4	4 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	Y
Simulated Catch	2.2.5	4.5 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	Y
Simulated Catch	2.2.6	3 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	Y
Simulated Catch	2.2.7	3.5 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	Y
Simulated Catch	2.2.8	3.8 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	Y
Simulated Catch	2.2.9	4 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	Y
Simulated Catch	2.2.10	4.5 kts, 3:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	Y
Simulated Catch	2.3.1	4 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	N
Simulated Catch	2.3.2	4.1 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	Dredge Angle only
Simulated Catch	2.3.3	4.2 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	Dredge Angle only
Simulated Catch	2.3.4	4.3 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	Dredge Angle only
Simulated Catch	2.3.5	4.4 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	Dredge Angle only
Simulated Catch	2.3.6	4.5 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	Y	Y	Dredge Angle only
Simulated Catch	2.3.7	4 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only

Simulated Catch	2.3.8	4.1 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only
Simulated Catch	2.3.9	4.2 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only
Simulated Catch	2.3.10	4.3 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only
Simulated Catch	2.3.11	4.4 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only
Simulated Catch	2.3.12	4.5 kts, 3:1 ratio, 100 BioRings, 26 mm tow wire	N	Y	Dredge Angle only

Table 3. Hydrodynamic trial summary information broken down by trial number, description, liner indicator, and if video and/or measurements were taken.

Trial	Trial Number	Trial Description	Liner Installed	Video	Measurements Taken
Hydrodynamic	3.1.1	3.8 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, dye tabs	Y	Y	N
Hydrodynamic	3.1.2	3.8 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, dye tabs	N	Y	N
Hydrodynamic	3.2.1	4.5 kts, 2.5:1 ratio, 100 BioRings, 26.6 mm tow wire, dye tabs	N	Y	N
Hydrodynamic	3.3.1	4.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, dye tabs	N	Y	N
Hydrodynamic	3.4.1	4.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, increased pressure plate size, dye tabs	N	Y	N

Table 4. Scope to Depth trial summary information broken down by trial number, description, liner indicator, and if video and/or measurements were taken.

Trial	Trial Number	Trial Description	Liner Installed	Video	Measurements Taken
Scope to Depth Ratio	4.1.1	3.8 kts, 3.1:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.1.2	3.8 kts, 3.1:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	N
Scope to Depth Ratio	4.2.1	3.8 kts, 3.1:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.2.2	3.8 kts, 3.1:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	N
Scope to Depth Ratio	4.3.1	4.5 kts, 2.5:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.3.2	4.5 kts, 3.25:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.3.3	4.5 kts, 3.5:1 ratio, 100 BioRings, 26.6 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.3.4	4.5 kts, 2.5:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	N
Scope to Depth Ratio	4.3.5	4.5 kts, 3.25:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	N
Scope to Depth Ratio	4.3.6	4.5 kts, 3.5:1 ratio, 100 BioRings, 26.6 mm tow wire	N	Y	N
Scope to Depth Ratio	4.4.1	4.5 kts, 2.5:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.4.2	4.5 kts, 3.25:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	N
Scope to Depth Ratio	4.4.3	4.5 kts, 3.5:1 ratio, 100 BioRings, 16 mm tow wire	Y	Y	N

Scope to Depth Ratio	4.4.4	4.5 kts, 2.5:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	N
Scope to Depth Ratio	4.4.5	4.5 kts, 3.25:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	N
Scope to Depth Ratio	4.4.6	4.5 kts, 3.5:1 ratio, 100 BioRings, 16 mm tow wire	N	Y	N

Table 5. Pressure plate trial summary information broken down by trial number, description, liner indicator, and if video and/or measurements were taken.

Trial	Trial Number	Trial Description	Liner Installed	Video	Measurements Taken
Pressure Plate	5.1.1	3 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, double size pressure plate	N	Y	Y
Pressure Plate	5.1.2	3.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, double size pressure plate	N	Y	Y
Pressure Plate	5.1.3	3.8 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, double size pressure plate	N	Y	Y
Pressure Plate	5.1.4	4 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, double size pressure plate	N	Y	Y
Pressure Plate	5.1.5	4.5 kts, 3:1 ratio, 100 BioRings, 26.6 mm tow wire, double size pressure plate	N	Y	Y

Dredge Angle Calculations

Dredge angle was calculated for all videos taken during the flume tank visit after returning to VIMS. Dredge angle was calculated by taking five still images from each video. The software program ImageJ was used to calculate dredge angle by drawing one line from the goose neck to the back end of the heel of the shoe for each image. A second line was drawn parallel to the flume tank belt to the back end of the heel of the shoe. The angle calculated from ImageJ was recorded as the dredge angle (Figure 8). Dredge angle was also measured five times for one randomly selected image for each video to ascertain variability in dredge angle measurements taken by VIMS staff. The mean dredge angle and standard error for each trial were calculated from the individual angle data. No dredge angle was calculated for trials where speed or scope to depth ratio were changed.

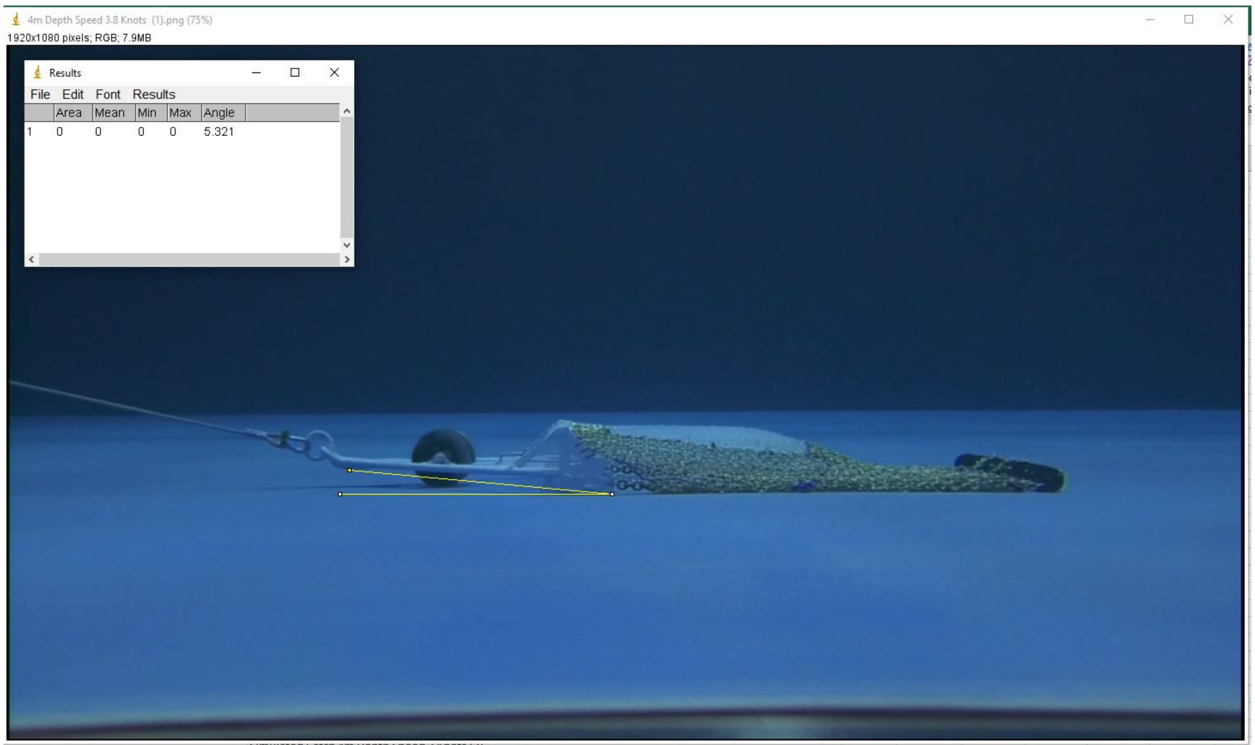

Figure 8. Still image from one flume tank trial with dredge angle lines and angle calculated from lines (upper left corner) using ImageJ.

Dredge performance was discussed during the trials. Additional time at the end of day 2 was spent viewing the hydrodynamic trial video to discuss how the liner impacted hydrodynamics in the dredge. These discussions included Sally Roman, Tor Bendiksen, and George Legge.

Results

In total, 115 videos were taken over the two day period. Of these videos, 103 are reported in the trial information provided in the report. Measurements were taken on 35 trials with the liner installed and 40 trials with no liner in the dredge.

All attempts were made to include NEFSC sea scallop survey staff in the process. NEFSC staff were furloughed during the planning process to set a date to visit Memorial University. No staff were able to attend in person due to scheduling conflicts. Memorial University staff also attempted to set up a Skype connection, but this was also unsuccessful. All video trial footage has been shared with Peter Chase, Ecosystems Surveys Branch Chief at the NEFSC. We also communicated with Mr. Chase that all data and a copy of the final report would be provided upon completion of analysis and the final report.

Tables 6-8 provide measurement data for all trials where measurements were taken. Tables 9-11 provide repeated measurement information for still images along with the mean and standard error of the mean. Figures 9-16 provide graphical interpretations of the different measurements taken by trial and tow wire diameter. A subset of video trials were added to the VIMS sea scallop program YouTube channel at https://www.youtube.com/channel/UCUJpqwOCoiY89gd6Ok0rtxw.

Table 6. Measurements taken for Regular trials by trial number for speeds of 3, 3.5, 3.8, 4, and 4.5 kts. Measurements taken include warp tension (kgf), maximum bag height (mm), height at the twine top end (mm), warp angle (degrees), wheel height off bottom (mm), dredge angle (degrees), and standard error of the dredge angle.

Trial	Trial Number	Tow Speed (kts)	Warp Tension (kgf)	Maximum Bag Height (mm)	Height at Twine Top End (mm)	Warp Angle (degrees)	Wheel Height off Bottom (mm)	Dredge Angle (degrees)	Dredge Angle (SE)
Regular	1.1.1	3	431.12	405.65	312.55	11.00	0	4.84	0.01
Regular	1.1.2	3.5	498.76	418.95	319.20	12.80	0	4.94	0.02
Regular	1.1.3	3.8	546.99	418.95	339.15	13.70	0	5.39	0.01
Regular	1.1.4	4	591.98	438.90	352.45	14.70	0	5.29	0.02
Regular	1.1.5	4.5	684.03	452.20	372.40	16.40	59.85	6.66	0.01
Regular	1.1.6	3	399.95	399.00	219.45	9.30	0	5.16	0.01
Regular	1.1.7	3.5	468.47	405.65	239.40	11.60	0	5.30	0.03
Regular	1.1.8	3.8	522.87	405.65	259.35	13.30	0	5.32	0.01
Regular	1.1.9	4	546.69	405.65	279.30	14.20	0	5.34	0.01
Regular	1.1.10	4.5	622.27	425.60	299.25	15.50	26.6	5.52	0.01

Table 7. Measurements taken for Simulated Catch trials by trial number for speeds of 3, 3.5, 3.8, 4, and 4.5 kts. Measurements taken include warp tension (kgf), maximum bag height (mm), height at the twine top end (mm), warp angle (degrees), wheel height off bottom (mm), dredge angle (degrees), and standard error of the dredge angle.

Trial	Trial Number	Tow Speed (kts)	Warp Tension (kgf)	Maximum Bag Height (mm)	Height at Twine Top End (mm)	Warp Angle (degrees)	Wheel Height off Bottom (mm)	Dredge Angle (degrees)	Dredge Angle (SE)
Simulated Catch	2.1.1	3	450.53	399.00	266.00	11.00	0	4.72	0.01
Simulated Catch	2.1.2	3.5	525.81	412.30	292.60	13.20	0	4.96	0.01
Simulated Catch	2.1.3	3.8	563.46	425.60	319.20	14.00	0	5.57	0.01
Simulated Catch	2.1.4	4	600.80	418.95	325.85	14.80	0	5.71	0.01
Simulated Catch	2.1.5	4.5	688.73	445.55	379.05	16.60	66.50	6.60	0.02
Simulated Catch	2.1.6	3	469.94	399.00	339.15	11.60	0	4.88	0.02
Simulated Catch	2.1.7	3.5	555.22	405.65	379.05	13.80	0	5.19	0.01
Simulated Catch	2.1.8	3.8	593.75	418.95	372.40	14.40	0	5.12	0.02

Simulated Catch	2.1.9	4	625.51	412.30	379.05	14.80	19.95	5.35	0.02
Simulated Catch	2.1.10	4.5	700.20	445.55	392.35	16.50	66.50	7.05	0.03
Simulated Catch	2.1.11	3	487.58	405.65	379.05	11.40	0	5.30	0.02
Simulated Catch	2.1.12	3.5	569.04	418.95	399.00	13.30	0	5.21	0.02
Simulated Catch	2.1.13	3.8	618.74	438.90	405.65	14.60	0	5.05	0.01
Simulated Catch	2.1.14	4	644.62	452.20	405.65	15.30	13.30	5.27	0.00
Simulated Catch	2.1.15	4.5	741.08	478.80	452.20	16.80	99.75	7.84	0.01
Simulated Catch	2.1.16	3	499.94	538.65	532.00	11.90	0	5.41	0.01
Simulated Catch	2.1.17	3.5	591.98	585.20	551.95	13.80	0	5.26	0.01
Simulated Catch	2.1.18	3.8	644.92	585.20	571.90	14.50	0	5.60	0.01
Simulated Catch	2.1.19	4	677.56	591.85	578.55	15.10	39.90	5.95	0.00

Simulated Catch	2.1.20	4.5	788.43	625.10	598.50	16.40	106.40	9.08	0.02
Simulated Catch	2.2.1	3	446.12	399.00	345.80	15.90	0	5.85	0.02
Simulated Catch	2.2.2	3.5	531.11	405.65	379.05	16.80	6.65	5.91	0.01
Simulated Catch	2.2.3	3.8	578.16	425.60	379.05	17.30	19.95	6.07	0.02
Simulated Catch	2.2.4	4	602.86	445.55	392.35	17.50	66.50	7.03	0.01
Simulated Catch	2.2.5	4.5	716.97	492.10	418.95	18.20	146.30	11.49	0.01
Simulated Catch	2.1.21	3	411.12	392.35	246.05	10.30	0	4.99	0.02
Simulated Catch	2.1.22	3.5	488.76	399.00	272.65	12.10	0	5.21	0.02
Simulated Catch	2.1.23	3.8	528.76	405.65	312.55	13.20	0	5.36	0.02
Simulated Catch	2.1.24	4	552.87	412.30	319.20	14.20	0	5.45	0.01
Simulated Catch	2.1.25	4.5	636.09	432.25	345.80	15.70	39.90	5.69	0.01

Simulated Catch	2.1.26	3	446.12	405.65	312.55	10.80	0	5.27	0.02
Simulated Catch	2.1.27	3.5	518.46	405.65	319.20	13.20	0	5.20	0.02
Simulated Catch	2.1.28	3.8	574.34	405.65	345.80	14.40	0	5.25	0.01
Simulated Catch	2.1.29	4	600.80	418.95	365.75	14.60	0	5.56	0.02
Simulated Catch	2.1.30	4.5	679.91	438.90	379.05	0.00	39.90	6.73	0.02
Simulated Catch	2.1.31	3	427.30	438.90	399.00	10.90	0	5.10	0.03
Simulated Catch	2.1.32	3.5	529.93	445.55	412.30	13.70	0	5.43	0.01
Simulated Catch	2.1.33	3.8	567.28	438.90	405.65	14.50	0	5.42	0.01
Simulated Catch	2.1.34	4	614.92	438.90	399.00	15.30	0	5.34	0.02
Simulated Catch	2.1.35	4.5	682.56	438.90	405.65	16.40	33.25	6.17	0.02
Simulated Catch	2.1.36	3	471.41	545.30	545.30	11.60	0	5.43	0.02

Simulated Catch	2.1.37	3.5	580.81	545.30	545.30	13.50	0	5.60	0.01
Simulated Catch	2.1.38	3.8	638.74	551.95	551.95	14.40	19.95	5.57	0.03
Simulated Catch	2.1.39	4	677.56	545.30	545.30	15.10	26.60	5.69	0.02
Simulated Catch	2.1.40	4.5	774.61	571.90	571.90	16.10	59.85	8.96	0.02
Simulated Catch	2.2.6	3	410.24	392.35	312.55	15.60	0	5.15	0.02
Simulated Catch	2.2.7	3.5	508.17	405.65	345.80	16.80	0	5.31	0.01
Simulated Catch	2.2.8	3.8	533.17	405.65	345.80	17.40	19.95	5.76	0.02
Simulated Catch	2.2.9	4	557.87	412.30	385.70	17.30	39.90	6.22	0.02
Simulated Catch	2.2.10	4.5	686.38	492.10	418.95	18.30	113.05	6.81	0.01
Simulated Catch	2.3.1	4						5.43	0.03
Simulated Catch	2.3.2	4.1						5.03	0.08

Simulated Catch	2.3.3	4.2	5.29	0.03
Simulated Catch	2.3.4	4.3	5.64	0.10
Simulated Catch	2.3.5	4.4	6.05	0.12
Simulated Catch	2.3.6	4.5	6.82	0.14
Simulated Catch	2.3.7	4	5.64	0.05
Simulated Catch	2.3.8	4.1	5.77	0.11
Simulated Catch	2.3.9	4.2	5.66	0.08
Simulated Catch	2.3.10	4.3	6.02	0.09
Simulated Catch	2.3.11	4.4	6.68	0.18
Simulated Catch	2.3.12	4.5	6.80	0.12

Table 8. Measurements taken for Pressure Plate trials by trial number for speeds of 3, 3.5, 3.8, 4, and 4.5 kts. Measurements taken include warp tension (kgf), maximum bag height (mm), height at the twine top end (mm), warp angle (degrees), wheel height off bottom (mm), dredge angle (degrees), and standard error of the dredge angle.

Trial	Trial Number	Tow Speed (kts)	Warp Tension (kgf)	Maximum Bag Height (mm)	Height at Twine Top End (mm)	Warp Angle (degrees)	Wheel Height off Bottom (mm)	Dredge Angle (degrees)	Dredge Angle (SE)
Pressure Plate	5.1.1	3.00	470.82	412.30	305.90	9.50	0	4.95	0.02
Pressure Plate	5.1.2	3.50	556.99	438.90	299.25	13.00	0		
Pressure Plate	5.1.3	3.80	597.86	452.20	319.20	13.70	0	5.19	0.01
Pressure Plate	5.1.4	4.00	630.51	452.20	332.50	14.30	0	4.98	0.02
Pressure Plate	5.1.5	4.50	713.73	472.15	372.40	15.80	26.60	5.42	0.02

Table 9. Repeated dredge angle measurements (degrees) taken for Regular trials by trial number along with the mean dredge angle and standard error of the mean dredge angle.

Trial	Trial Number	1	2	3	4	5	Mean	SE
Regular	1.1.1	4.78	4.71	4.72	4.78	4.74	4.75	0.01
Regular	1.1.2	4.88	4.87	4.87	4.88	4.89	4.87	0.01
Regular	1.1.3	5.44	5.44	5.47	5.41	5.49	5.46	0.01
Regular	1.1.4	5.19	5.17	5.18	5.19	5.19	5.17	0.01
Regular	1.1.5	6.64	6.65	6.64	6.65	6.64	6.65	0.01
Regular	1.1.6	5.15	5.18	5.19	5.15	5.16	5.17	0.01
Regular	1.1.7	5.41	5.45	5.46	5.47	5.41	5.44	0.01
Regular	1.1.8	5.34	5.34	5.33	5.32	5.32	5.33	0.01
Regular	1.1.9	5.40	5.30	5.40	5.40	5.32	5.36	0.02
Regular	1.1.10	5.52	5.50	5.59	5.50	5.58	5.54	0.02

Table 10. Repeated dredge angle measurements (degrees) taken for Simulated Catch trials by trial number along with the mean dredge angle and standard error of the mean dredge angle.

Trial	Trial Number	1	2	3	4	5	Mean	SE
Simulated Catch	2.1.1	4.64	4.69	4.66	4.70	4.64	4.67	0.01
Simulated Catch	2.1.2	4.90	4.90	4.92	4.93	4.92	4.91	0.00
Simulated Catch	2.1.3	5.59	5.52	5.55	5.59	5.52	5.56	0.01
Simulated Catch	2.1.4	5.75	5.76	5.76	5.76	5.75	5.76	0.01
Simulated Catch	2.1.5	6.73	6.75	6.79	6.75	6.75	6.76	0.01
Simulated Catch	2.1.6	4.74	4.79	4.73	4.72	4.70	4.73	0.01
Simulated Catch	2.1.7	5.23	5.24	5.25	5.29	5.21	5.24	0.01
Simulated Catch	2.1.8	5.13	5.18	5.15	5.38	5.28	5.24	0.04
Simulated Catch	2.1.9	5.48	5.47	5.48	5.35	5.48	5.45	0.02

Simulated Catch	2.1.10	6.80	6.88	6.88	6.79	6.65	6.80	0.04
Simulated Catch	2.1.11	5.32	5.33	5.43	5.43	5.32	5.35	0.03
Simulated Catch	2.1.12	5.38	5.36	5.30	5.31	5.38	5.36	0.02
Simulated Catch	2.1.13	5.08	5.17	5.08	5.09	5.05	5.09	0.02
Simulated Catch	2.1.14	5.25	5.28	5.29	5.26	5.26	5.26	0.01
Simulated Catch	2.1.15	7.90	7.90	7.81	7.90	7.93	7.89	0.02
Simulated Catch	2.1.16	5.34	5.31	5.34	5.32	5.34	5.33	0.01
Simulated Catch	2.1.17	5.33	5.33	5.24	5.27	5.26	5.26	0.03
Simulated Catch	2.1.18	5.62	5.63	5.62	5.63	5.62	5.64	0.03
Simulated Catch	2.1.19	5.97	5.93	5.93	5.92	5.94	5.94	0.01
Simulated Catch	2.1.20	9.08	9.08	9.11	9.17	9.11	9.10	0.02

Simulated Catch	2.2.1	5.94	5.97	5.97	5.97	5.85	5.94	0.02
Simulated Catch	2.2.2	5.93	5.94	5.93	6.02	6.00	5.97	0.02
Simulated Catch	2.2.3	5.90	5.88	6.00	5.90	5.90	5.92	0.02
Simulated Catch	2.2.4	6.94	7.00	6.86	6.87	7.02	6.96	0.04
Simulated Catch	2.2.5	11.58	11.46	11.46	11.58	11.46	11.51	0.03
Simulated Catch	2.1.21	4.86	4.82	4.84	4.84	4.87	4.85	0.01
Simulated Catch	2.1.22	5.07	5.02	5.05	5.07	5.04	5.06	0.01
Simulated Catch	2.1.23	5.27	5.27	5.28	5.28	5.28	5.27	0.00
Simulated Catch	2.1.24	5.45	5.45	5.44	5.43	5.48	5.45	0.01
Simulated Catch	2.1.25	5.64	5.64	5.64	5.66	5.66	5.66	0.01
Simulated Catch	2.1.26	5.32	5.35	5.39	5.35	5.39	5.36	0.01

Simulated Catch	2.1.27	5.19	5.17	5.16	5.16	5.17	5.17	0.01
Simulated Catch	2.1.28	5.16	5.18	5.17	5.18	5.17	5.17	0.01
Simulated Catch	2.1.29	5.68	5.64	5.64	5.67	5.68	5.66	0.01
Simulated Catch	2.1.30	6.69	6.67	6.69	6.67	6.66	6.66	0.01
Simulated Catch	2.1.31	5.16	5.17	5.15	5.15	5.18	5.16	0.01
Simulated Catch	2.1.32	5.44	5.48	5.48	5.47	5.49	5.47	0.01
Simulated Catch	2.1.33	5.34	5.35	5.36	5.34	5.36	5.34	0.01
Simulated Catch	2.1.34	5.22	5.24	5.23	5.22	5.21	5.23	0.01
Simulated Catch	2.1.35	6.02	6.00	6.03	6.06	6.08	6.04	0.01
Simulated Catch	2.1.36	5.48	5.48	5.48	5.47	5.47	5.47	0.00
Simulated Catch	2.1.37	5.66	5.65	5.65	5.61	5.65	5.64	0.01

Simulated Catch	2.1.38	5.77	5.74	5.77	5.76	5.71	5.76	0.01
Simulated Catch	2.1.39	5.57	5.56	5.55	5.60	5.59	5.57	0.01
Simulated Catch	2.1.40	9.00	8.95	8.99	8.92	8.95	8.96	0.02
Simulated Catch	2.2.6	5.16	5.19	5.18	5.11	5.18	5.16	0.01
Simulated Catch	2.2.7	5.39	5.34	5.30	5.35	5.30	5.33	0.02
Simulated Catch	2.2.8	5.61	5.69	5.70	5.69	5.70	5.68	0.02
Simulated Catch	2.2.9	6.17	6.11	6.17	6.14	6.15	6.15	0.01
Simulated Catch	2.2.10	6.88	6.90	6.88	6.84	6.84	6.86	0.01
Simulated Catch	2.3.1	4	5.37	5.46	5.49	5.40	5.49	0.02
Simulated Catch	2.3.2	4.1	4.86	4.88	4.86	4.86	4.87	0.02
Simulated Catch	2.3.3	4.2	5.25	5.29	5.24	5.24	5.28	0.01

Simulated Catch	2.3.4	4.3	5.38	5.37	5.34	5.39	5.24	0.02
Simulated Catch	2.3.5	4.4	5.58	5.57	5.57	5.54	5.53	0.01
Simulated Catch	2.3.6	4.5	7.01	7.01	7.04	7.03	7.01	0.01
Simulated Catch	2.3.7	4	5.53	5.52	5.52	5.57	5.52	0.01
Simulated Catch	2.3.8	4.1	5.95	6.09	6.09	6.09	6.00	0.03
Simulated Catch	2.3.9	4.2	5.63	5.67	5.63	5.66	5.66	0.01
Simulated Catch	2.3.10	4.3	6.21	6.21	6.22	6.25	6.25	0.01
Simulated Catch	2.3.11	4.4	6.82	6.80	6.85	6.83	6.80	0.01
Simulated Catch	2.3.12	4.5	6.69	6.67	6.69	6.67	6.6	0.01

Table 11. Repeated dredge angle measurements (degrees) taken for Pressure Plate trials by trial number along with the mean dredge angle and standard error of the mean dredge angle.

Trial	Trial Number	1	2	3	4	5	Mean	SE
Pressure Plate	5.1.1	5.02	5.00	5.00	5.03	5.03	5.03	0.01
Pressure Plate	5.1.2							
Pressure Plate	5.1.3	5.28	5.27	5.29	5.29	5.25	5.27	0.01
Pressure Plate	5.1.4	5.09	5.09	5.08	5.08	5.05	5.08	0.01
Pressure Plate	5.1.5	5.30	5.39	5.31	5.30	5.30	5.32	0.02

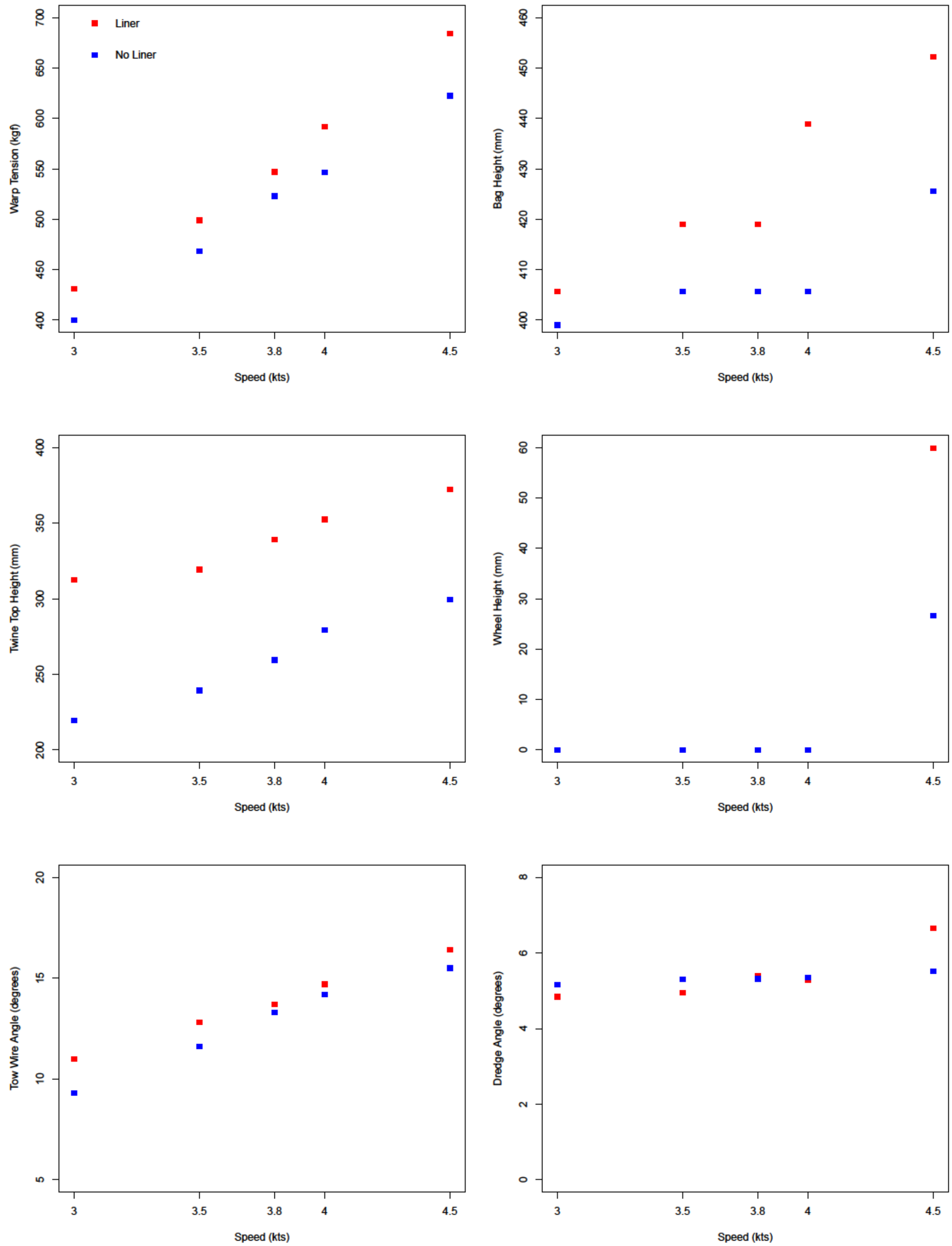

Figure 9. Plots of warp tension (kgf), bag height (mm), twine top height (mm), wheel height (mm), tow wire angle (degrees), and dredge angle (degrees) measurements taken for Regular trials at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

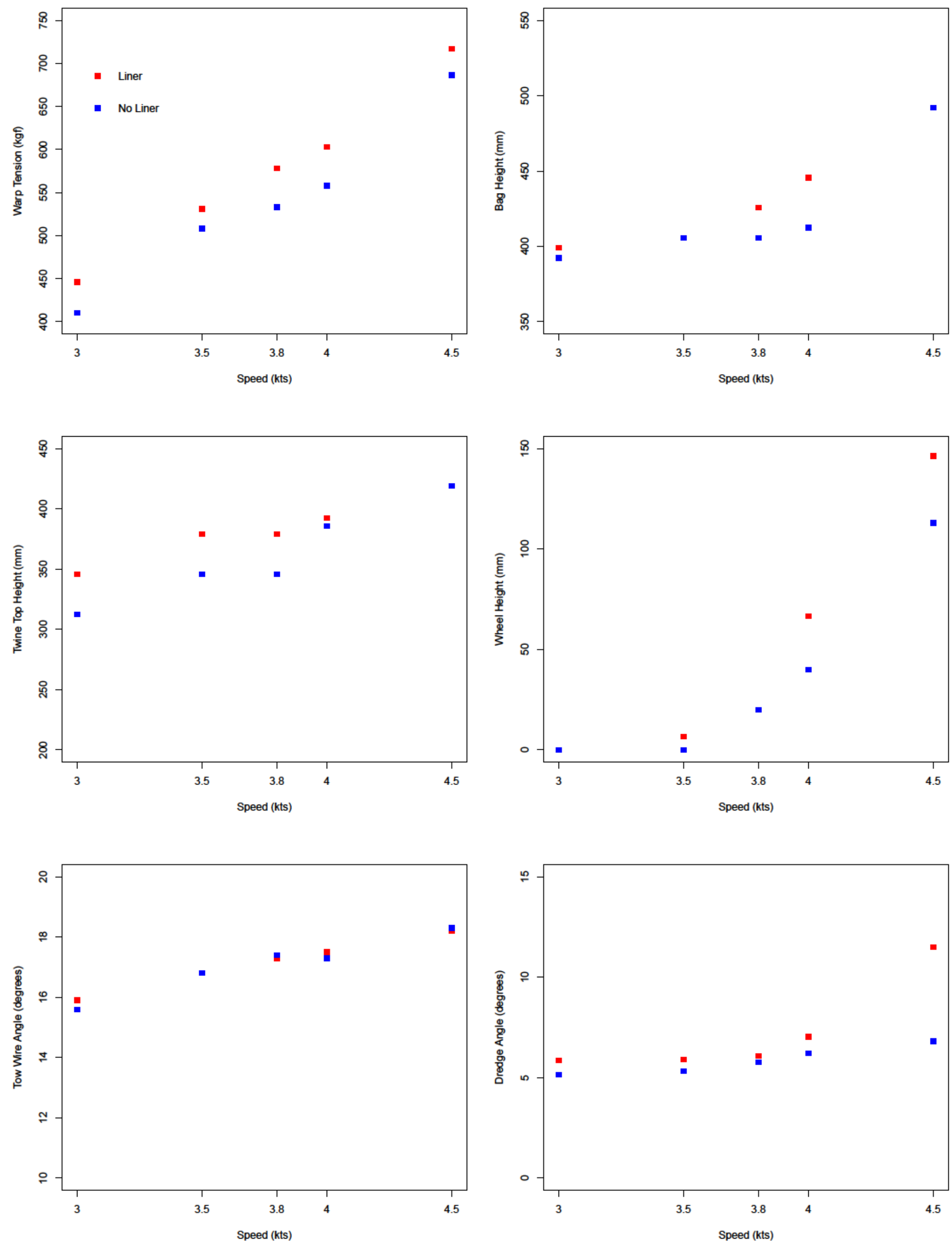

Figure 10. Plots of warp tension (kgf), bag height (mm), twine top height (mm), wheel height (mm), tow wire angle (degrees), and dredge angle (degrees) measurements taken for the Simulated Catch trials of 100 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 16 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

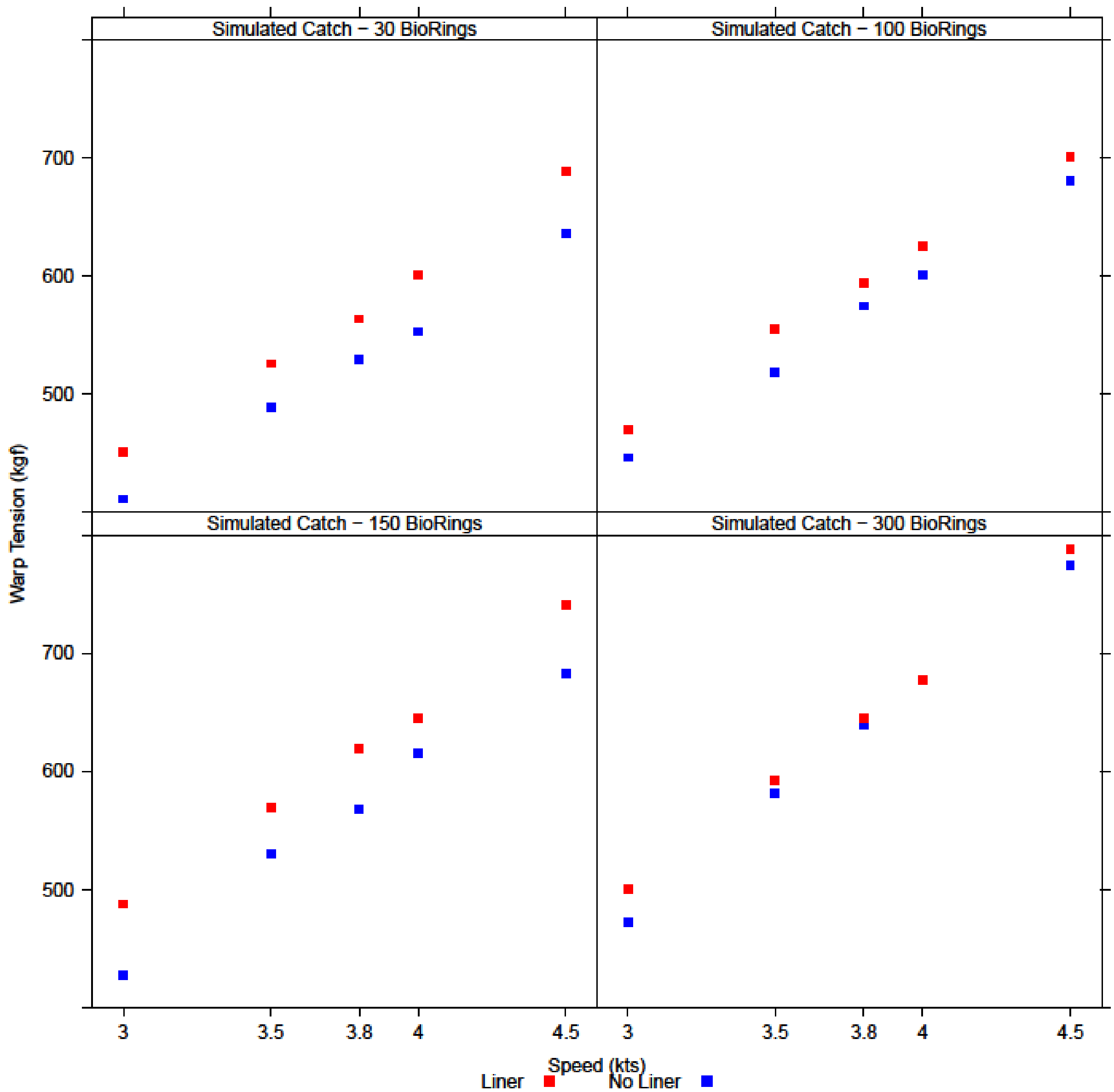

Figure 11. Plots of warp tension (kgf) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

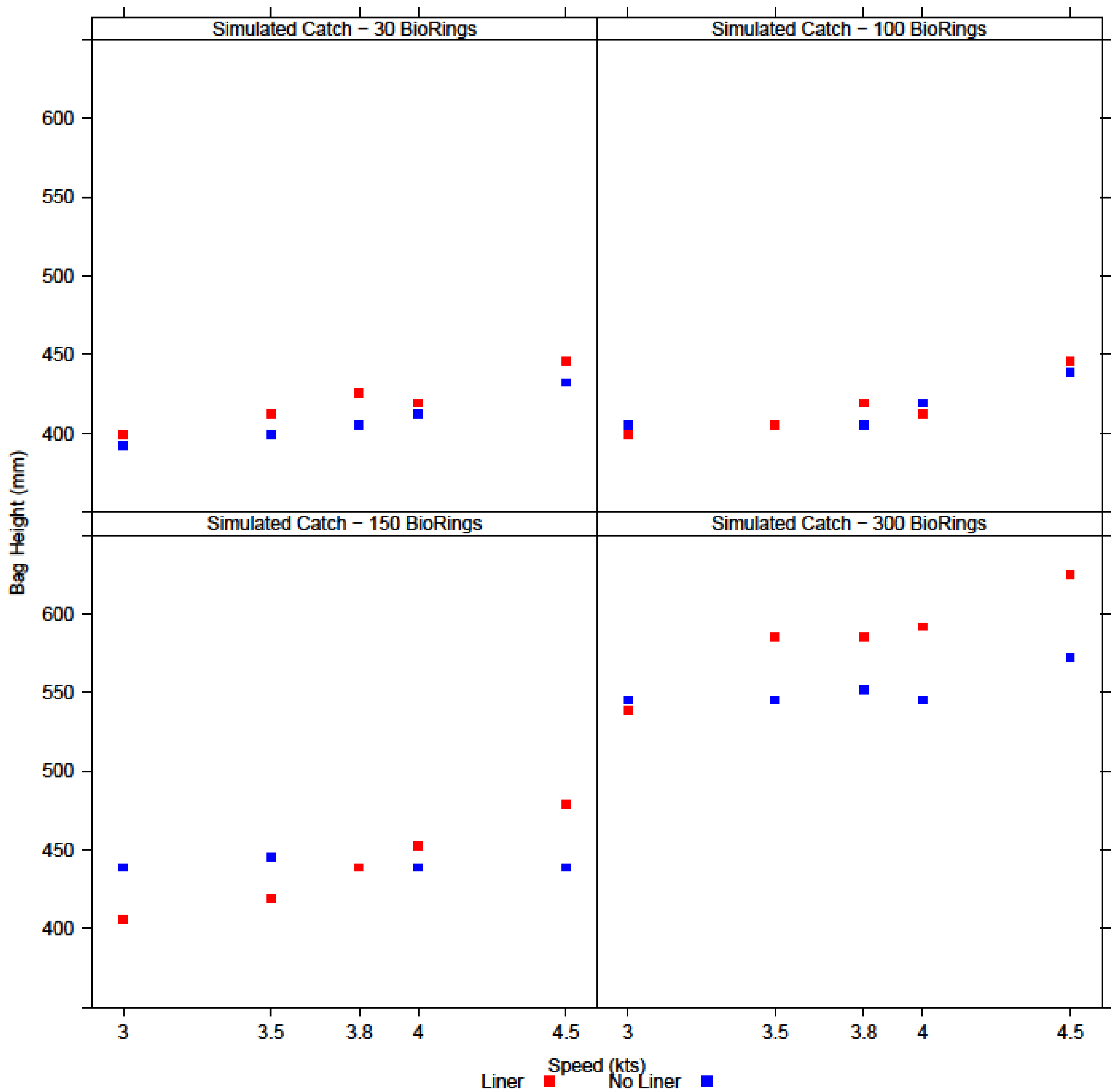

Figure 12. Plots of bag height (mm) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

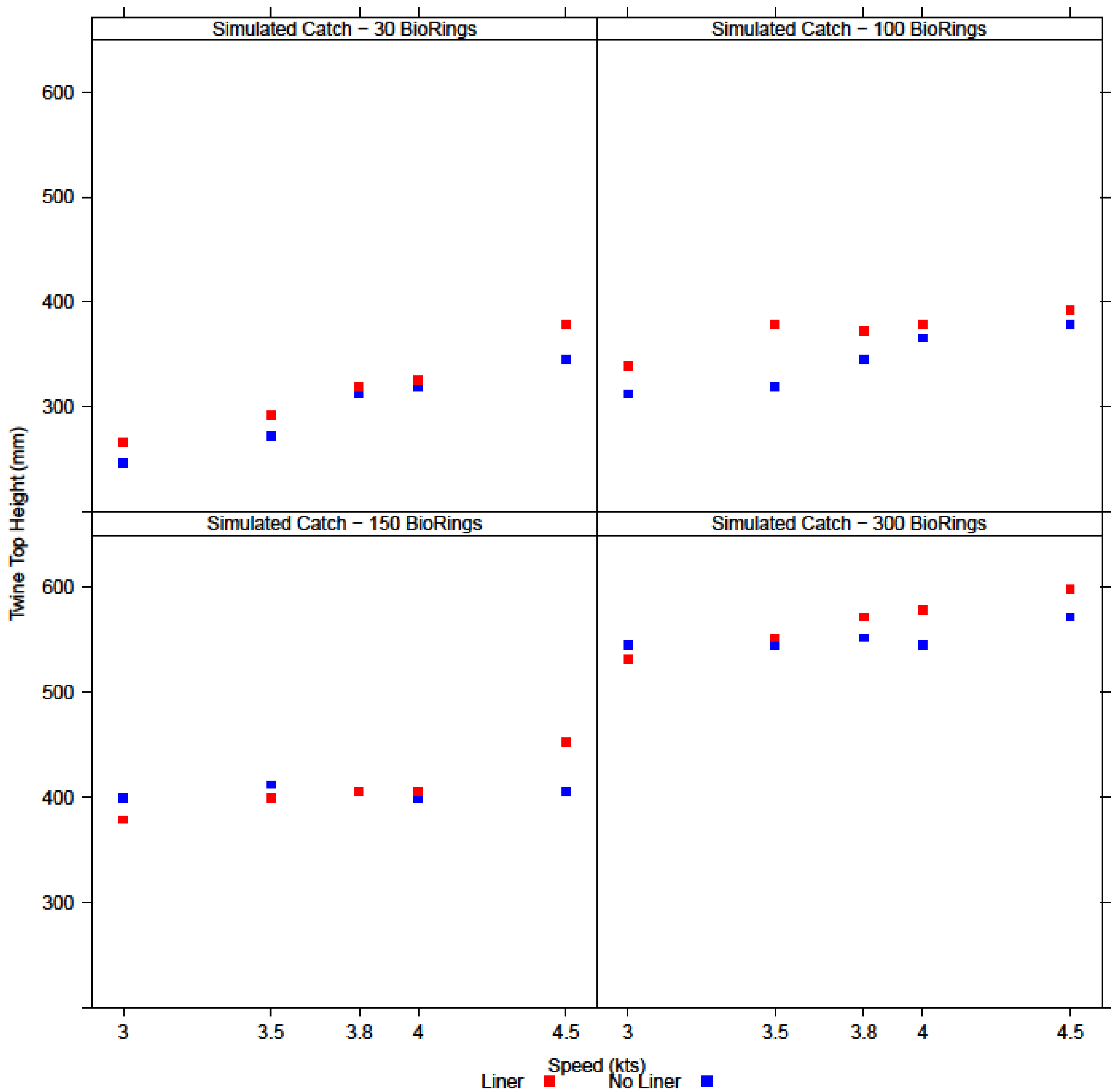

Figure 13. Plots of twine top height (mm) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

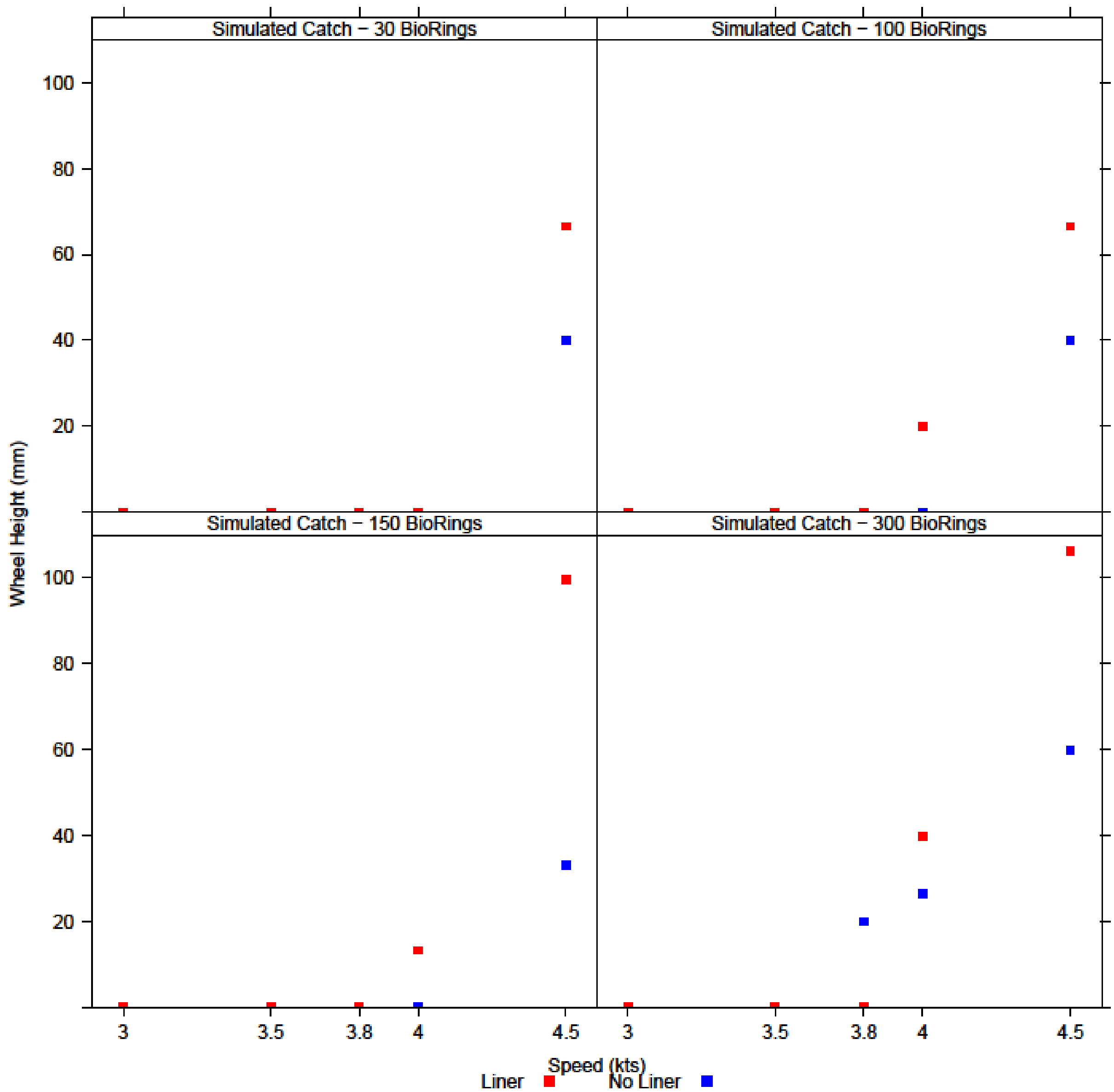

Figure 14. Plots of wheel height (mm) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

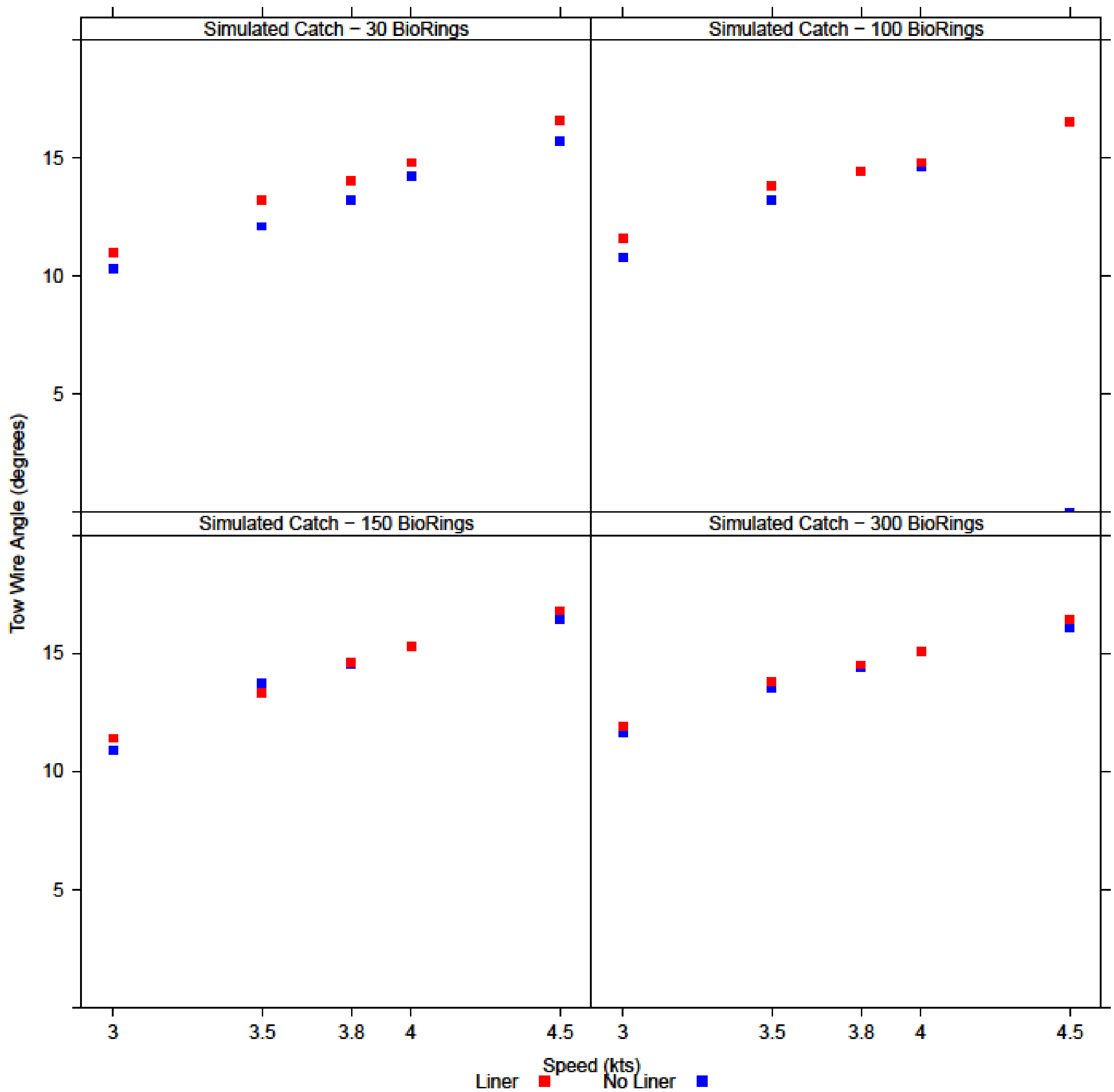

Figure 15. Plots of tow wire angle (degrees) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

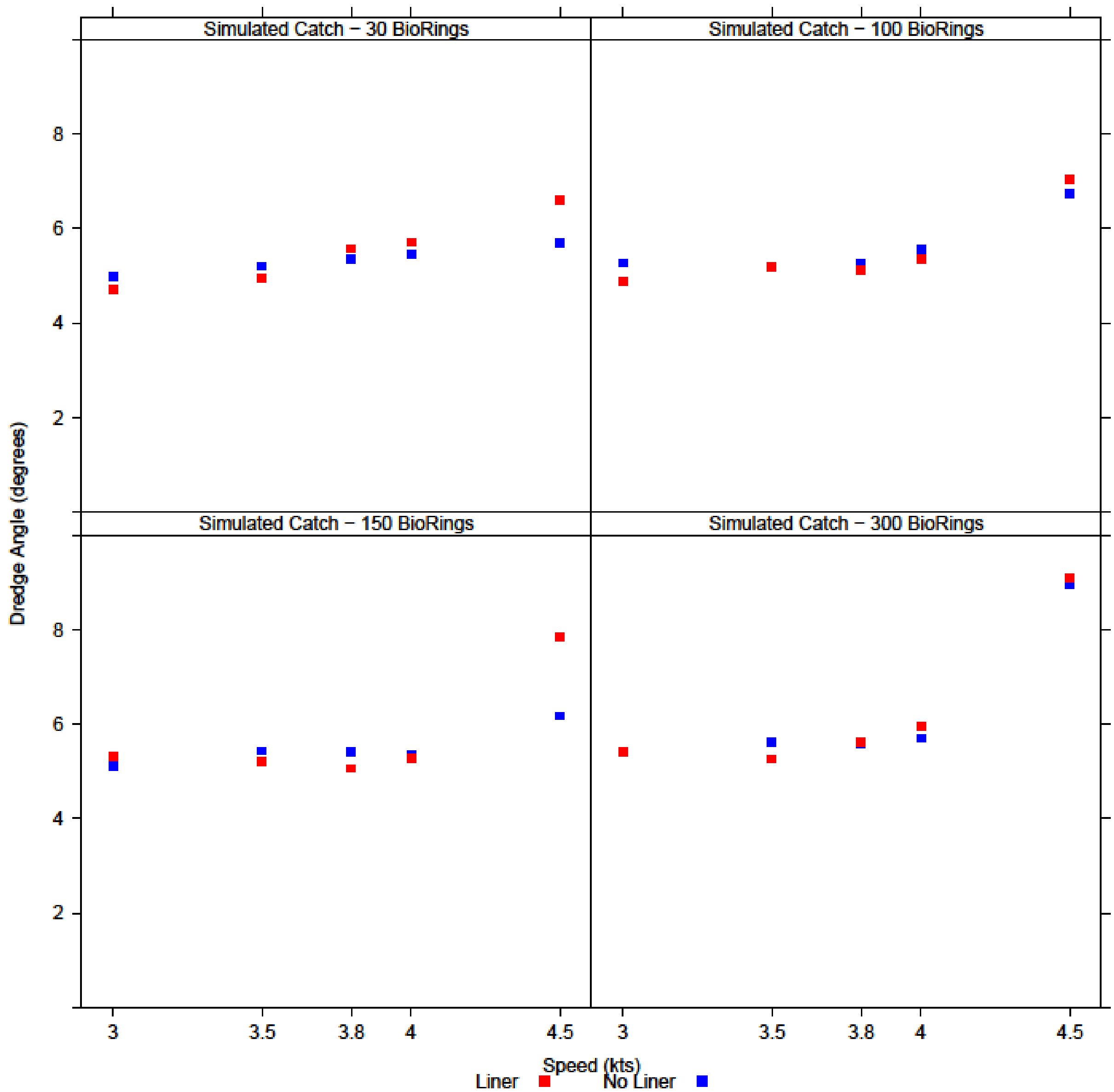

Figure 16. Plots of dredge angle (degrees) measurements taken for the Simulated Catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

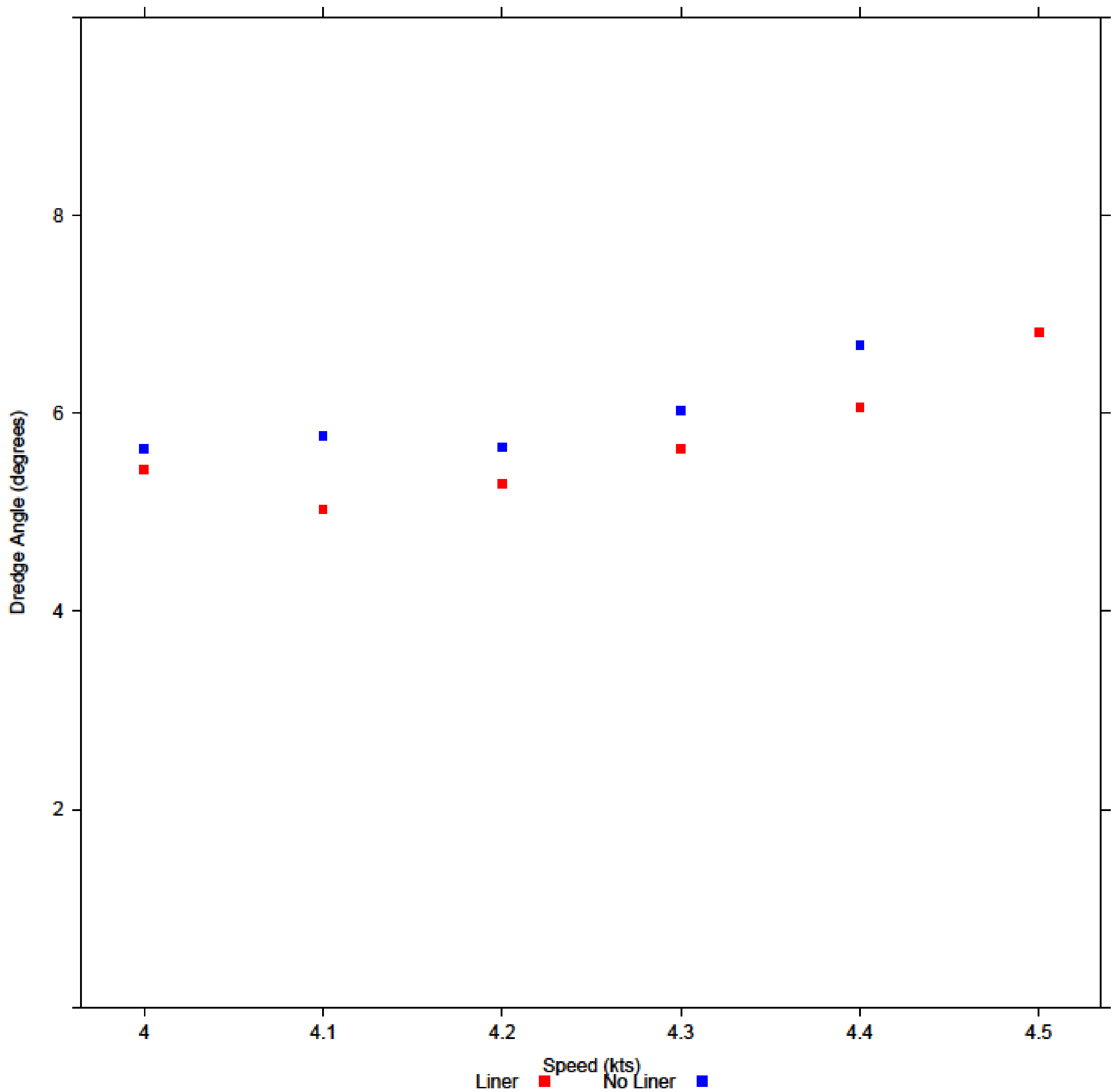

Figure 17. Plot of dredge angle (degrees) measurements taken for the Simulated Catch trials of 100 BioRings at speeds of 4, 4.1, 4.2, 4.3, 4.4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge configurations.

Dredge Angle Variability

Variability in dredge angle measurements was minimal across all trial types and speeds. For the Regular trials, standard errors of the mean dredge angle ranged from 0.01-0.02 (Table 9). Across Simulated Catch trials, standard errors ranged from 0.001-0.04 (Table 10). Only four images were measured for the Pressure Plate trials, but standard errors were similar to the other two trial types, ranging from 0.01-0.02 (Table 11). These results show measured dredge angles were precise.

Regular Trials

For Regular trials with a 26 mm tow wire, no catch, and a 3:1 scope to depth ratio, the majority of measurement data indicated the lined dredge had higher values than the unlined dredge (Trials 1.1.1-1.1.15) (Table 6, Figure 9). There was also a generally consistent increase in measurement values as speed increased for both the lined and unlined trials (Figure 9). There is a positive linear relationship between warp tension and speed, tow wire angle and speed, and twine top height and speed for both the lined and unlined dredge. The wheel was only observed to come off the bottom at the greatest speed of 4.5 kts, otherwise the wheel maintained contact with the conveyer belt. Observations of the dredge shoes at 4.5 kts showed the shoe heels were the only component that had contact with the conveyor belt and that the shoes moved around much more than at lower speeds. The greatest values for the twine top height and bag height increased with speed, but there was no corresponding increase in the wheel height off bottom for speeds less than 4.5 kts. Dredge angle was relatively consistent across all speeds, although an increase was observed at 4.5 kts. For the lined dredge the average angle was 6.66 degrees, and for the unlined dredge, the average was 5.52 degrees. This increase was greater for the lined dredge (i.e., 1.4 degree increase compared to a 0.2 increase for the unlined dredge when comparing these values to the mean dredge angles at 4 kts). At the required tow speed range of 3.8-4 kts, dredge angles for both the lined and unlined dredge were consistent. Average dredge angles were 5.39 and 5.29 for the lined dredge at 3.8 and 4 kts, respectively. For the unlined dredge, the average dredge angle at 3.8 kts was 5.32 degrees and 5.34 degrees at 4 kts. Comments made by both George Legge and Tor Bendiksen indicated that without any catch, the lined dredge opened higher and had a better overall shape compared to the unlined version.

Simulated Catch Trials

Simulated Catch trials for the 26 mm tow wire and a 3:1 scope to depth ratio indicated catch impacted some dredge measurements (Trials 2.1.1-2.1.40). Overall, results were similar to the Regular trial results in terms of the lined dredge versus the unlined dredge. The lined dredge tended to have higher values for all measurements. The lined dredge also had a greater bag height and a better shape compared to the unlined dredge. There was a positive linear relationship between warp tension and speed, as well as tow wire angle and speed, regardless of catch volume, for both the lined and unlined dredge trials (Figures 11, 15). The values for warp tension and tow wire angle were consistent across all catch volume trials (Figures 11, 15). Twine top height, bag height, and the height of the wheel off bottom all increased for the greatest catch volume of 300 BioRings (Figures 12-14). Twine top height values tended to have higher values as catch increased (Figure 13), which is in contrast to the bag height measurements, which only increased at the greatest catch volume (Figure 12). The wheel height off bottom value started to increase at 3.8 kts at the greatest catch volume for the unlined dredge. For the lined dredge, the wheel height increased for catch volumes of 100, 150, and 300 BioRings at 4 kts, and the greatest distance off bottom was observed at 4.5 kts (Figure 14). The height off bottom for the greatest catch volume of 300 BioRings at 4 kts was double that of the observed height off bottom at low speeds and catch volumes. Dredge angle increased as a function of speed and catch volume for the lowest two catch trials of 30 and 100 BioRings for both dredge configurations (Figure 16). For all catch volumes, the greatest dredge angle was observed at 4.5 kts for both the lined and unlined dredge trials. At the required speed of 3.8-4 kts the difference in dredge angle between the two configurations was minimal across all catch volumes.

Simulated Catch trials (2.3.1-2.3.12) looking at a simulated catch of 100 BioRings, with a 26 mm tow wire, and speeds from 4-4.5 kts at 0.1 kt intervals were conducted after the initial Simulated Catch trials were completed. These trials were conducted to determine at what speed the wheel came off bottom and to determine dredge angle and performance at a finer scale. Again, the lined dredge configuration had higher dredge angle values compared to the unlined dredge across all speeds except at 4.5 kts, where angles were similar (Figure 17). Dredge angle for both configurations was relatively consistent for speeds of 4-4.2 kts (Figure 17). Dredge angle began to increase at 4.3 kts, and increased again at 4.4 and 4.5 kts for both dredge configurations (Figure 17). For the unlined dredge, dredge angle increased to 5.64 degrees at 4.3 kts, 6.05 degrees at 4.4 kts, and 6.82 degrees at 4.5 kts (Table 7). For the lined dredge, dredge angle increased to 6.02 degrees at 4.3 kts, 6.68 degrees at 4.4 kts, and 6.80 degrees at 4.5 kts (Table 7). While the height of the wheel off the conveyor belt was not measured, video indicated that at 4.2 kts, for both dredge configurations, the wheel did not always remain in contact with the conveyor belt. At 4.3 kts, the wheel was completely off bottom, and the greatest height off bottom was observed at 4.5 kts.

Results for the Simulated Catch trials for the 16 mm tow wire, 100 BioRings, and a 3:1 scope to depth were slightly different from the 26 mm findings. The positive linear relationship between warp tension and speed and tow wire angle and speed were similar to the 26 mm results for both dredge configurations (Figure 10). The 16 mm dredge also showed there was a positive linear relationship between twine top height and speed, as well as bag height and speed (Figure 10). These relationships differ from the 26 mm dredge, where no strong relationship was observed. Another large difference between the 16 mm and 26 mm dredges was the increased height of the wheel off the bottom with increased speed for the 16 mm dredge for both the lined and unlined trials. The wheel began to come off the bottom starting at 3.5 kts for the lined dredge and 3.8 kts for the unlined dredge (Figure 10). The height off bottom was also greater for the 16 mm unlined and lined dredges compared to the 26 mm trials. The dredge angle for the 16 mm lined and unlined dredges was also generally greater than what was measured for the 26 mm dredge configurations (Figure 10). At the required speed range, the 16 mm lined dredge angles were 6.07 (3.8 kts) and 7.03 degrees (4 kts) and the unlined dredge angles were 5.76 (3.8 kts) and 6.22 degrees (4 kts). The difference between the 26 mm and 16 mm dredge angle was greatest for the lined dredge trials, where at 3.8 kts the 16 mm dredge angle was greater by almost 1 degree and at 4 kts the difference was 1.7 degrees (Table 7).

Hydrodynamic Trials

Hydrodynamic trials (Trials 3.1.1), with 100 BioRings, a 26 mm tow wire, and the liner installed, indicated water flowed under the pressure plate through the dredge and exited at the back of the bag near the club stick. The same trial with no liner (Trial 3.1.2) showed water flowed under the pressure plate and mainly up through the twine top and not through the entire dredge. This difference in hydrodynamic flow should explain why the lined dredge has a better shape while being towed.

Other hydrodynamic trials (Trials 3.2.1, 3.3.1) confirmed that the hydrodynamic flow was not modified when the scope to depth ratio or speed was changed. Hydrodynamics were altered when the pressure plate size was increased (Trial 3.4.1). More water was forced up and over the pressure plate instead of through the dredge bag.

Scope to Depth Ratio Trials

Scope to depth ratio trials were assessed with video observations only (4.1.1-4.4.6). For lined dredge trials, a shorter scope to depth ratio of 2.5:1 showed that the dredge angle increased, the wheel was completely of bottom, and only the heels of the shoes were in contact with the conveyor belt. Increased scope to depth ratios did not impact dredge angle or dredge contact with the conveyor belt at speeds of 3.8-4 kts. At 4.5 kts, a greater scope to depth ratio of 3.25 or 3.5:1 improved shoe and wheel contact with the conveyor belt. This will likely reduce dredge angle. Results for the unlined scope to depth ratio trials were similar to the lined dredge configurations.

Pressure Plate Trials

Doubling the size of the pressure plate had a negative impact on dredge performance (trials 5.5.1-5.1.5) for a 26 mm tow wire dredge with no liner installed and 100 BioRing catch. Warp tension was greater across all speeds, while warp angle, dredge angle, bag height, and twine top height decreased across all speeds (Table 8). This increased warp tension leads to greater drag that would cause a vessel to have to increase speed and be less efficient. Based on the performance of the lined dredge during other trials, we assume there will also be a similar decline in overall dredge performance for a lined dredge, as well as a dredge towed with a 16 mm tow wire.

Outreach and Education

An industry report summarizing flume tank trials was composed and distributed to interested industry members (Appendix A). A subset of videos was posted to the VIMS sea scallop program YouTube channel at https://www.youtube.com/channel/UCUJpqwOCoiY89gd6Ok0rtxw. Information pertaining to the VIMS sea scallop program YouTube channel was also posted to the VIMS Marine Advisory Program's Facebook page at https://www.facebook.com/VIMSMarineAdvisory/. Information about the project will also be posted to the Sea Scallop Research Program website after the site is finished being upgraded.

A presentation on project results was given at the virtual 2020 RSA Share Day on May 19, 2020 (Appendix B). This annual meeting is organized by the New England Fishery Management Council. Attendees included Scallop PDT members, Scallop Advisory members, stakeholders, fishery managers, scientists, and interested public.

We have another RSA funded project, in collaboration with the University of Massachusetts School for Marine Science and Technology (SMAST), that will be conducting field research in the late spring/fall of 2020. The main objective of this project is to place cameras on the survey dredge to record dredge performance under *in situ* conditions. Once this project is completed, information pertaining to survey dredge performance from all projects will be collated and distributed to interested parties.

Discussion

These flume tank trials represent the first time the sea scallop survey dredge has been observed dredge performance metrics measured in a flume tank that has been published. This opportunity provided a chance to understand dredge performance under a range of conditions, including survey protocols that have been used to fish the dredge since the 1970s. Information collected from these trials will help to inform the understanding of survey dredge performance, as well as potentially guide future discussions about survey dredge protocols and dredge modifications.

The main caveat of flume tank testing is that these trials represent the ideal or optimal conditions under which the dredge is fished. There are limitations to tests that can be conducted in the flume tank, and environmental conditions such as wave height, weather, tide, substrate type, and substrate condition (i.e., sand lumps) cannot be accounted for. These variables may have an impact on dredge performance that can only potentially be quantified *in situ*. Other factors including catch volume and debris catch (i.e., sand dollars, rocks, and mud) can only be replicated to a certain degree, and we only focused on trying to understand the impact of catch volume on dredge performance. The degree to which the BioRings replicate scallop catch is not understood. We attempted to fill the dredge bag to levels that have been observed during surveys, but were not able to replicate the largest catches observed in the high density areas to the extent observed during surveys due to a limit on the number of BioRings. But based on information from this study, larger catches should lead to increased dredge angle and height of the wheel off the substrate, at a minimum, compared to values observed during the trials. To understand the impact of debris catch on survey dredge performance, especially with a liner installed, *in situ* observations may provide more insight. Information collected from an observational camera field study that will be conducted with SMAST in 2020 will help to inform dredge performance in relation to conditions described above. The combination of these two studies will provide a more holistic understanding of survey dredge performance.

Based on the Regular and Simulated Catch trials, the use of a liner in the survey dredge does not appear to negatively affect dredge performance. The survey dredge had a better overall shape based on the opinion of the individuals at the trials, as well as measurements of the bag and twine top height. Hydrodynamic flow was also improved when the liner was installed in the dredge. Dredge angle did not differ greatly between the lined and unlined dredge configurations. Removal of the liner would decrease the catch of smaller scallops and affect the catch time series for the dredge survey that extends back to the 1970s (NEFSC, 2018; Rudders et al., 2019). This loss of information should be considered if there is a desire to remove the liner in the future. Catch data from past surveys could be adjusted using selectivity information for the survey dredge.

An issue bought up during the trials was that there was no known optimal dredge angle or fishing configuration for the survey dredge. At towing speeds of 3.8-4 kts with no catch, the survey dredge shoes and wheel were in complete contact with the conveyor belt. George Legge and Tor Bendiksen indicated commercial dredges tend to be fished with the wheel off the substrate and only the back half of the shoes in contact with the substrate, so that the dredge angle is greater. If the survey dredge is supposed to be fished in a similar configuration, then the tow speed protocols may need to be increased to account for this. Based on the flume tank data, an optimal towing speed could range from 4.1-4.3 kts for the VIMS survey conducted onboard commercial fishing vessels contracted as research platforms that use a larger tow wire diameter. The tow speed for the NMFS vessel may not need to be modified. A change in tow speed for the VIMS survey would increase tow distance. This would have to be accounted for in biomass calculations if changes were made to survey protocols in the future. One possibility would be to standardized all tows to 1 nautical mile. The topic of optimal dredge angle and fishing configuration is a discussion that would be well suited for the Scallop PDT and Scallop Committee, as well as including NMFS sea scallop dredge survey staff.

Increased catch volume did appear to affect survey dredge performance with both the lined and unlined configurations. At the largest catch volume of 300 BioRings, the wheel was off the conveyor belt at 4 kts for both the 26 and 16 mm tow wires. Dredge angle also increased. This information could be useful in understanding the reduced efficiency of the survey dredge in high density areas. Reduced efficiency could be a combination of gear saturation and reduced performance.

Trials highlighted two topics that should be avoided in the future. The first is that a tow speed greater than 4.3 kts negatively impacts dredge performance. We tested the survey dredge at speeds up to 4.5 kts because a speed of 4.5 kts has been observed during VIMS surveys. Captains take great care to ensure the tow speed protocols are met, but sometimes due to weather conditions or tide, the vessel can reach a speed of 4.5 kts before the captain makes adjustments. In the future, VIMS staff will ensure communication with captains about dredge performance at 4.5 kts to minimize the negative impacts associated with towing the survey dredge at high speeds. Trials also indicated doubling the pressure plate had no positive impact on dredge performance. The larger size of the pressure plate increased warp tension, which increased drag and decreased fuel efficiency. There has been some discussion with a few captains in the past about how increasing the pressure plate would give the survey dredge more weight.

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Appendix A

Industry Report

Understanding Dredge Performance for a Lined versus Unlined NMFS Sea Scallop Dredge

VIMS Marine Resource Report: 2020-6

Submitted to:

Sea Scallop Fishing Industry

Submitted by:

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March 29, 2020

Virginia Institute of Marine Science
Marine Advisory Program

Project Summary

The Virginia Institute of Marine Science (VIMS) tested a scale model of the sea scallop survey dredge in the flume tank at the Fisheries and Marine Institute of Memorial University over two days in March of 2019. This work was conducted to understand how the liner, survey protocols, and catch volume effect dredge performance. Tow speed, warp tension, maximum bag height, height at the twine top end, wire angle, wheel height of bottom, and dredge angle were measured for the trials. Tow speeds tested ranged from 3-4.5 kts. Video footage of trials was recorded and can be viewed at the VIMS Sea Scallop Program youtube channel: https://www.youtube.com/channel/UCUJpqwOCoiY89gd6Ok0rtxw.

Results indicated the liner did not negatively impact dredge performance compared to an unlined version of the survey dredge. The liner improved overall bag shape, dredge bag height, and twine top height, as well as hydrodynamic flow through the dredge. Other findings indicated catch volume increased dredge angle and the height of the wheel off bottom, especially as speed increased. Tow speeds should be kept under 4.3 kts to improve dredge performance and have the dredge fish more consistently.

Project Description

Survey Dredge and Protocols

The standard National Marine Fisheries Service (NMFS) sea scallop survey dredge used since the 1970s is a New Bedford style dredge, 8 ft. in width and equipped with 2-inch rings, and 3.5-inch diamond mesh twine top (NEFSC, 2018). A 1.5-inch diamond mesh liner is installed in the dredge to retain small scallops that would otherwise pass through the rings. Survey protocols for fishing the dredge include a 15 minute tow duration, tow speed range of 3.8-4 kts and scope to depth ratio of 3:1.

Flume Tank

Flume tank testing was conducted at the Fisheries and Marine Institute of Memorial University of Newfoundland's flume tank in St. John's Newfoundland. The flume tank facility has a data acquisition and flow monitoring system for data collection of dredge performance metrics (Marine Institute Fisheries and Marine Institute of Memorial University of Newfoundland, 2017) (Figure 1).

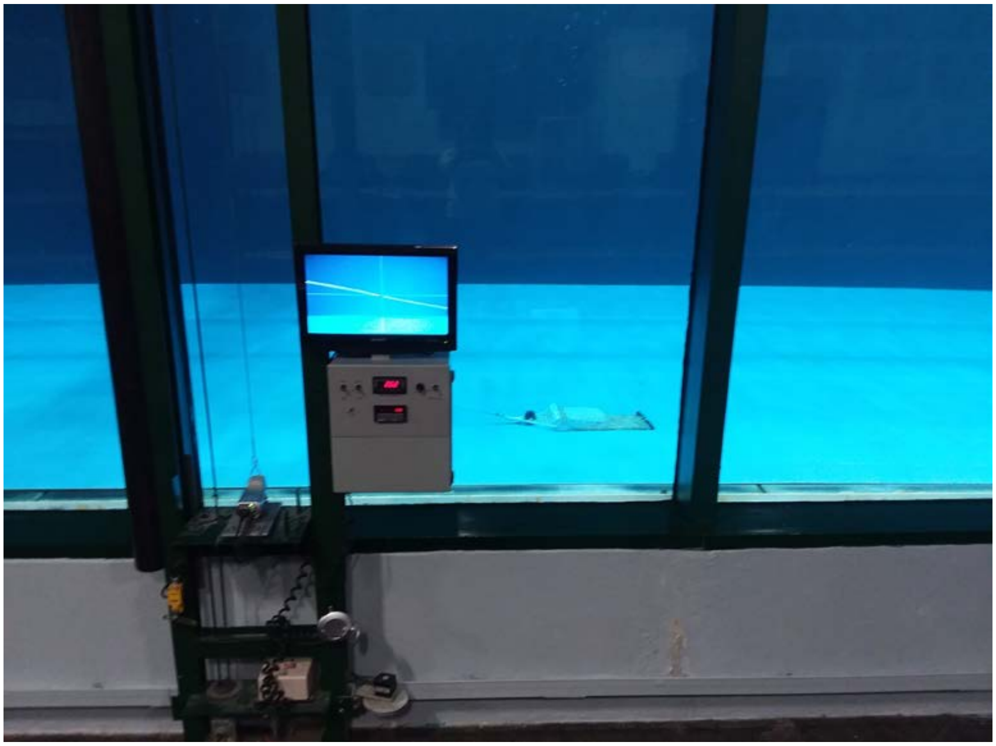


Figure 1. Image of the data acquisition system used to take measurements of the scale survey dredge. In this image the towing wire angle is being measured.

Scale Survey Dredge

Mr. Tor Bendiksen of Reidar's Trawl Gear and Marine Supply Company in New Bedford, MA built a 1:6.65 scale survey dredge with a liner (Figure 2). Two scale towing wire diameters were tested to represent the different diameters used by VIMS (26.6 mm = 2 inch diameter wire) and the NMFS (16 mm = 9/16 inch diameter wire). We only report on trials in this report where the 26 mm tow wire was used since VIMS surveys are conducted on commercial vessels.

Flume Tank Trials

All trials on the first day were conducted with the liner installed and all trials on the second day were completed with the liner removed. Trials on day 2 were identical to day 1 trials to determine the effect of the dredge liner. The following measurements were taken using the data acquisition system for a subset of trials:

- Tow speed (kts). Controlled by the speed of the conveyer belt.
- Warp tension (unit kilogram-force (kgf))
- Maximum bag height (mm) (Figure 2, A)
- Height at the twine top end (mm) (Figure 2, B)
- Wire angle (degrees) (Figure 1)
- Height of the wheel of bottom (mm) (Figure 2, C)

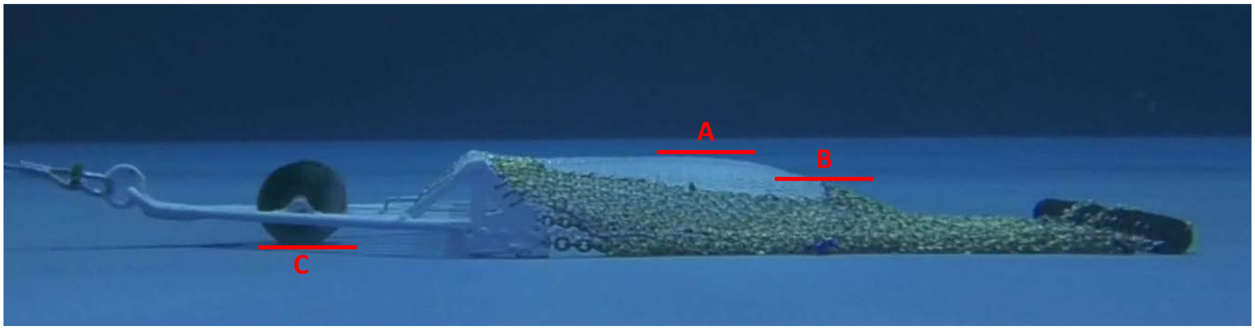


Figure 2. Location of measurements taken for the maximum height of the bag (A), height at the twine top end (B), and height of the wheel of bottom (C).

The following trials were completed for the dredge configuration with the liner installed and again without the liner:

1. Regular Trials
   1.1. Dredge tested at speeds of 3, 3.5, 3.8, 4, and 4.5 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire.
2. Simulated Catch Trials
   2.1. Dredge tested with simulated catch using 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire (Figure 3).
   2.2. Dredge tested with simulated catch of 100 BioRings at intervals of 0.1 kts from 4 to 4.5 kts with 26.6 mm towing wire.

Figure 3. Image of a BioRing used to simulate catch in the scale survey dredge. Each BioRing either had a weight in the center of the ring or weight attached to the outside of the ring, as shown in this picture.

3. Hydrodynamic Catch Trials
   3.1. Dredge tested with simulated catch of 100 BioRings at 3.8 kts at a 3:1 scope to depth ratio and 26.6 mm towing wire. Dye tabs were fixed to the dredge to allow for visual examination of water flow through the dredge (Figure 4).
   3.2. Dredge tested with simulated catch of 100 BioRings at 3.8 kts at a 2.5:1 scope to depth ratio and 26.6 mm towing wire.

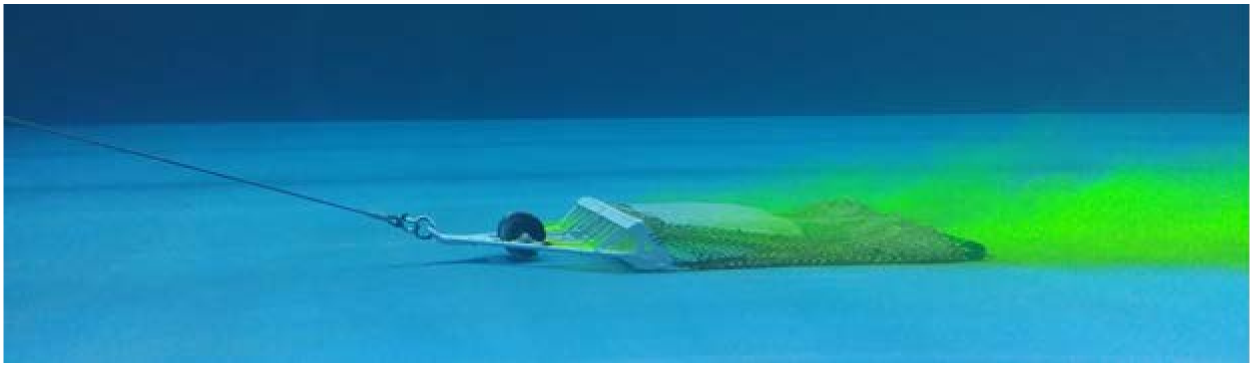


Figure 4. Image of scale survey dredge hydrodynamic trial with dye tabs.

4. Scope to Depth Ratio Trials
   4.1. Dredge tested with a simulated catch of 100 BioRings at a scope to depth ratio of 3.1:1, a speed of 3.8 kts, and 26.6 mm towing wire.
   4.2. Dredge tested with a simulated catch of 100 BioRings at scope to depth ratios of 2.5:1, 3.25:1, and 3.5:1 at a speed of 4.5 kts, and 26.6 mm towing wire.
   4.3. Dredge tested with a simulated catch of 100 BioRings at scope to depth ratios of 2.5:1, 3.25:1, and 3.5:1 at a speed of 4.5kts, and 16 mm towing wire.

Dredge Angle Calculations

Dredge angle was calculated by from still images from each video. The software program ImageJ was used to calculate dredge angle by drawing one line from the goose neck to the back end of the heel of the shoe. A second line was drawn parallel to the flume tank conveyor belt to the back end of the heel of the shoe. The angle calculated from the ImageJ software was recorded as the dredge angle (Figure 5).

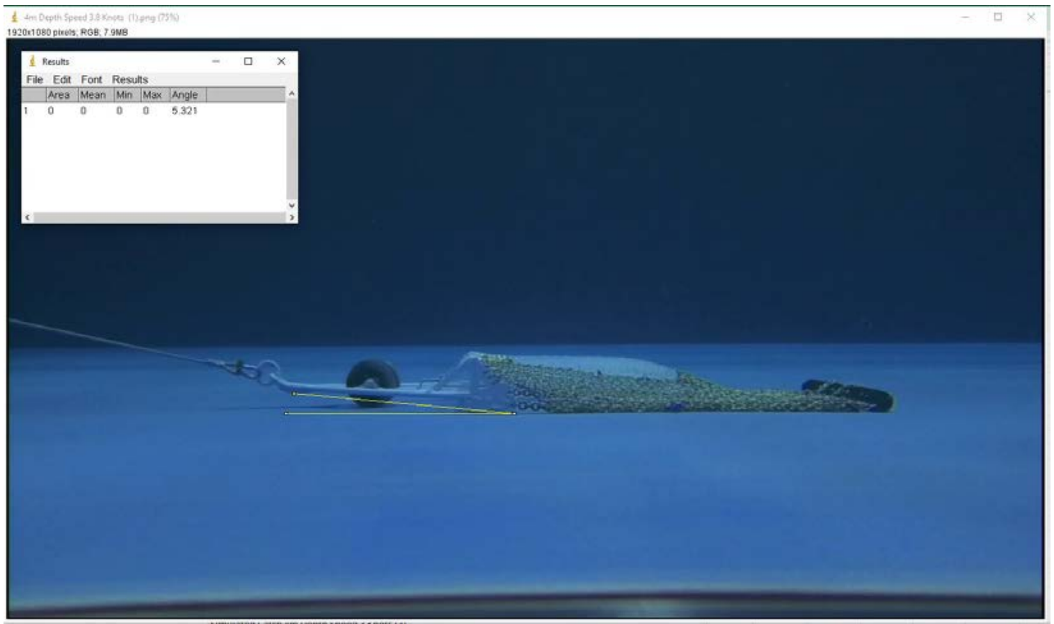


Figure 5. Still image from one flume tank trial with dredge angle lines and angle calculated from the lines (upper left corner) using ImageJ.

Results

Tables 1-2 provide measurement data for trials. Figures 6-13 provide graphical interpretations of the different measurements taken by trial.

Table 1. Measurements taken for trials with no catch, a 26 mm tow wire, and speeds of 3, 3.5, 3.8, 4, and 4.5 kts. Trials were completed with the liner installed and without a liner, indicated by the Liner in Dredge column. Measurements include warp tension (kgf), maximum bag height (mm), height at the twine top end (mm), warp angle (degrees), wheel height of bottom (mm), and dredge angle (degrees).

Liner in Dredge	Tow Speed (kts)	Warp Tension (kgf)	Maximum Bag Height (mm)	Height at Twine Top End (mm)	Warp Angle (degrees)	Wheel Height off Bottom (mm)	Dredge Angle (degrees)
Y	3	431.12	405.65	312.55	11.00	0	4.84
Y	3.5	498.76	418.95	319.20	12.80	0	4.94
Y	3.8	546.99	418.95	339.15	13.70	0	5.39
Y	4	591.98	438.90	352.45	14.70	0	5.29
Y	4.5	684.03	452.20	372.40	16.40	59.85	6.66
N	3	399.95	399.00	219.45	9.30	0	5.16
N	3.5	468.47	405.65	239.40	11.60	0	5.30
N	3.8	522.87	405.65	259.35	13.30	0	5.32
N	4	546.69	405.65	279.30	14.20	0	5.34
N	4.5	622.27	425.60	299.25	15.50	26.6	5.52

Table 2. Measurements taken for trials with simulated catch, 26 mm tow wire, and speeds of 3-4.5 kts. Trials were completed with the liner installed and without a liner, indicated by the Liner in Dredge column. The number of BioRings is indicated in the Catch Volume column. Measurements include warp tension (kgf), maximum bag height (mm), height at the twine top end (mm), warp angle (degrees), wheel height of bottom (mm), and dredge angle (degrees). For the last 12 columns only dredge angle was calculated.

Liner in Dredge	Catch Volume	Tow Speed (kts)	Warp Tension (kgf)	Maximum Bag Height (mm)	Height at Twine Top End (mm)	Warp Angle (degrees)	Wheel Height off Bottom (mm)	Dredge Angle (degrees)
Y	30 BioRings	3	450.53	399.00	266.00	11.00	0	4.72
Y	30 BioRings	3.5	525.81	412.30	292.60	13.20	0	4.96
Y	30 BioRings	3.8	563.46	425.60	319.20	14.00	0	5.57
Y	30 BioRings	4	600.80	418.95	325.85	14.80	0	5.71
Y	30 BioRings	4.5	688.73	445.55	379.05	16.60	66.50	6.60
Y	100 BioRings	3	469.94	399.00	339.15	11.60	0	4.88
Y	100 BioRings	3.5	555.22	405.65	379.05	13.80	0	5.19
Y	100 BioRings	3.8	593.75	418.95	372.40	14.40	0	5.12

Y	100 BioRings	4	625.51	412.30	379.05	14.80	19.95	5.35
Y	100 BioRings	4.5	700.20	445.55	392.35	16.50	66.50	7.05
Y	150 BioRings	3	487.58	405.65	379.05	11.40	0	5.30
Y	150 BioRings	3.5	569.04	418.95	399.00	13.30	0	5.21
Y	150 BioRings	3.8	618.74	438.90	405.65	14.60	0	5.05
Y	150 BioRings	4	644.62	452.20	405.65	15.30	13.30	5.27
Y	150 BioRings	4.5	741.08	478.80	452.20	16.80	99.75	7.84
Y	300 BioRings	3	499.94	538.65	532.00	11.90	0	5.41
Y	300 BioRings	3.5	591.98	585.20	551.95	13.80	0	5.26
Y	300 BioRings	3.8	644.92	585.20	571.90	14.50	0	5.60
Y	300 BioRings	4	677.56	591.85	578.55	15.10	39.90	5.95

Y	300 BioRings	4.5	788.43	625.10	598.50	16.40	106.40	9.08
N	30 BioRings	3	411.12	392.35	246.05	10.30	0	4.99
N	30 BioRings	3.5	488.76	399.00	272.65	12.10	0	5.21
N	30 BioRings	3.8	528.76	405.65	312.55	13.20	0	5.36
N	30 BioRings	4	552.87	412.30	319.20	14.20	0	5.45
N	30 BioRings	4.5	636.09	432.25	345.80	15.70	39.90	5.69
N	100 BioRings	3	446.12	405.65	312.55	10.80	0	5.27
N	100 BioRings	3.5	518.46	405.65	319.20	13.20	0	5.20
N	100 BioRings	3.8	574.34	405.65	345.80	14.40	0	5.25
N	100 BioRings	4	600.80	418.95	365.75	14.60	0	5.56
N	100 BioRings	4.5	679.91	438.90	379.05	0.00	39.90	6.73

N	150 BioRings	3	427.30	438.90	399.00	10.90	0	5.10
N	150 BioRings	3.5	529.93	445.55	412.30	13.70	0	5.43
N	150 BioRings	3.8	567.28	438.90	405.65	14.50	0	5.42
N	150 BioRings	4	614.92	438.90	399.00	15.30	0	5.34
N	150 BioRings	4.5	682.56	438.90	405.65	16.40	33.25	6.17
N	300 BioRings	3	471.41	545.30	545.30	11.60	0	5.43
N	300 BioRings	3.5	580.81	545.30	545.30	13.50	0	5.60
N	300 BioRings	3.8	638.74	551.95	551.95	14.40	19.95	5.57
N	300 BioRings	4	677.56	545.30	545.30	15.10	26.60	5.69
N	300 BioRings	4.5	774.61	571.90	571.90	16.10	59.85	8.96
Y	100 BioRings	4						5.43

Y	100 BioRings	4.1	5.03
Y	100 BioRings	4.2	5.29
Y	100 BioRings	4.3	5.64
Y	100 BioRings	4.4	6.05
Y	100 BioRings	4.5	6.82
N	100 BioRings	4	5.64
N	100 BioRings	4.1	5.77
N	100 BioRings	4.2	5.66
N	100 BioRings	4.3	6.02
N	100 BioRings	4.4	6.68
N	100 BioRings	4.5	6.80

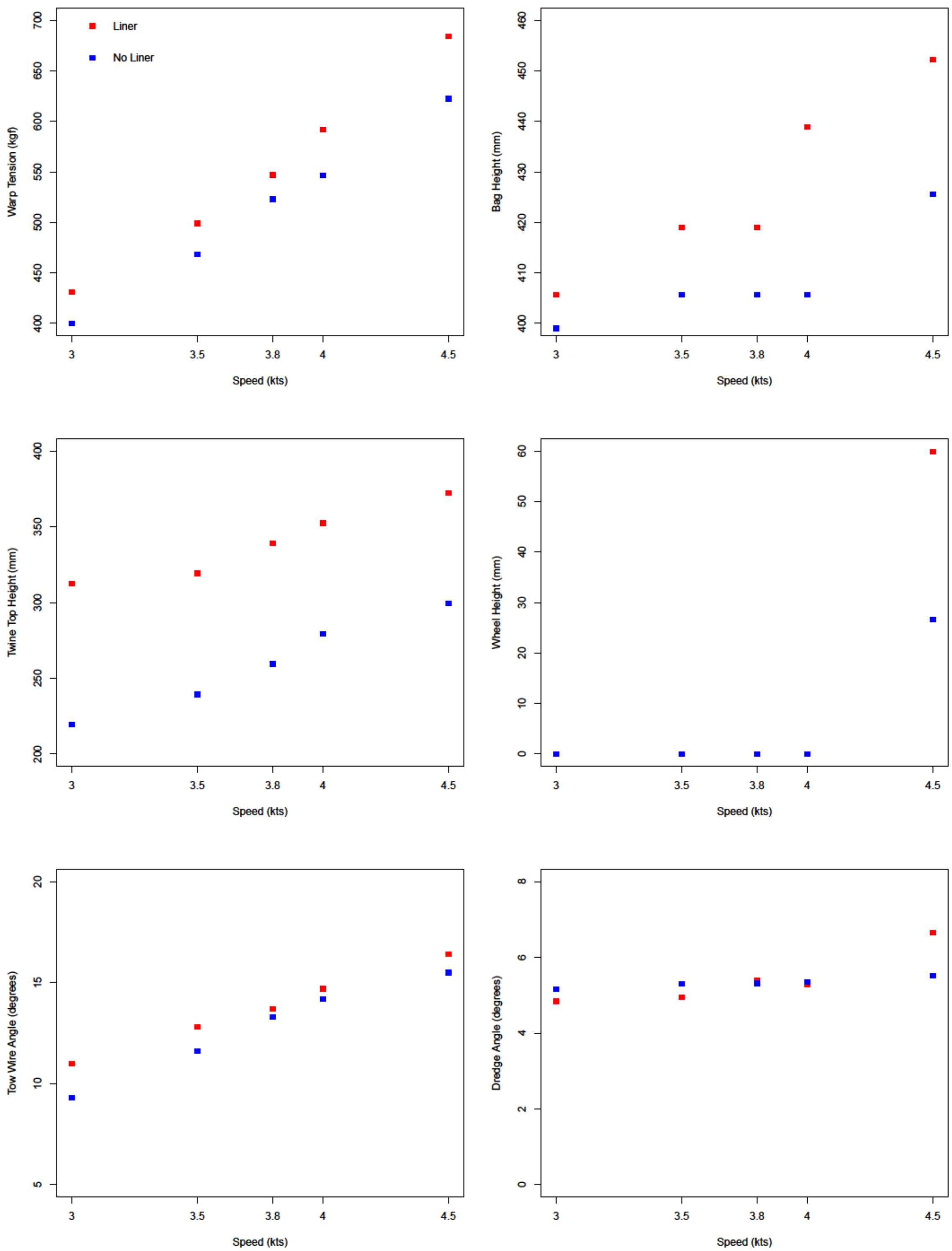


Figure 6. Plots of warp tension (kgf), bag height (mm), twine top height (mm), wheel height (mm), tow wire angle (degrees), and dredge angle (degrees) measurements taken for trials at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, no catch, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

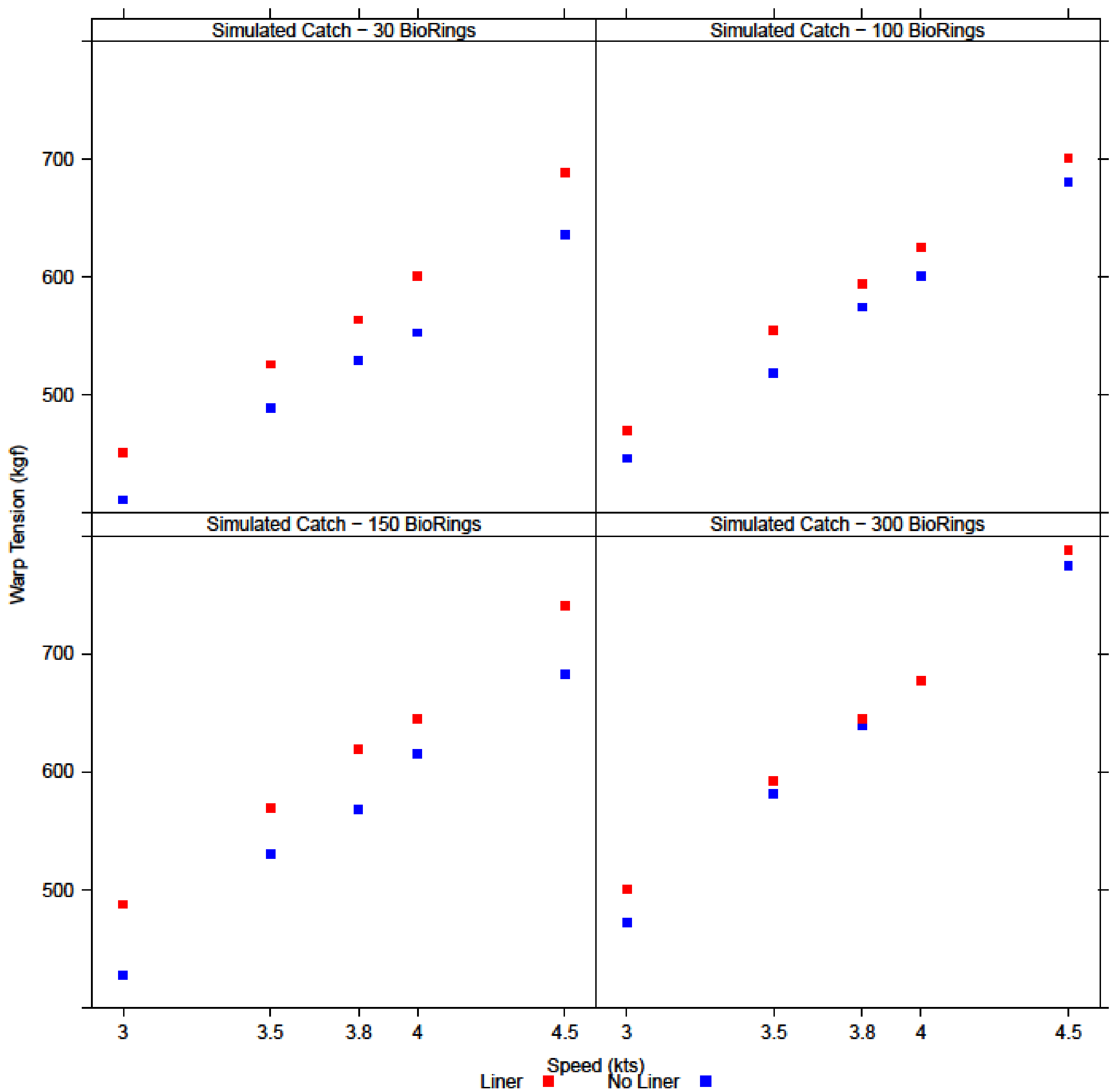


Figure 7. Plots of warp tension (kgf) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

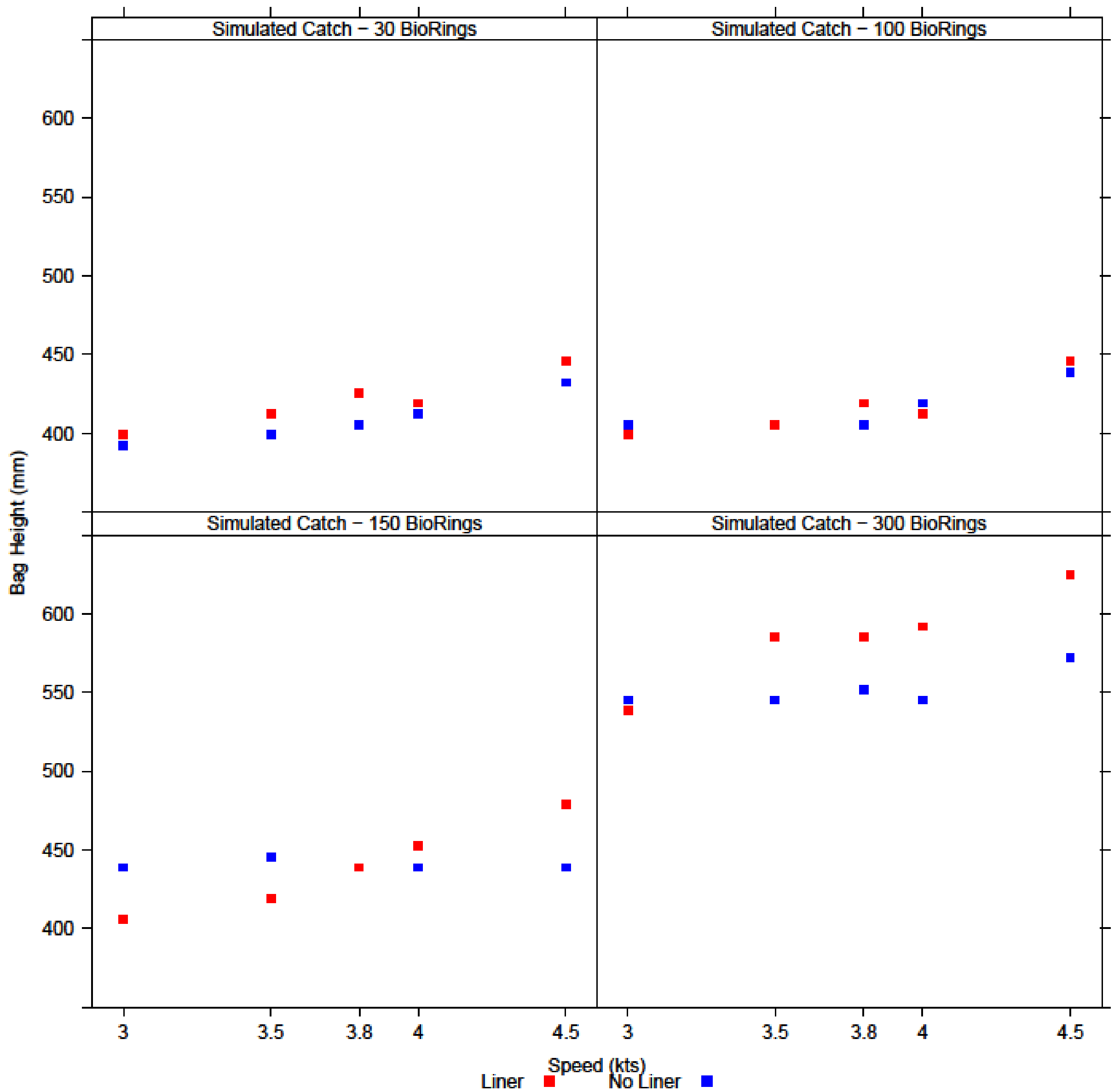


Figure 8. Plots of bag height (mm) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

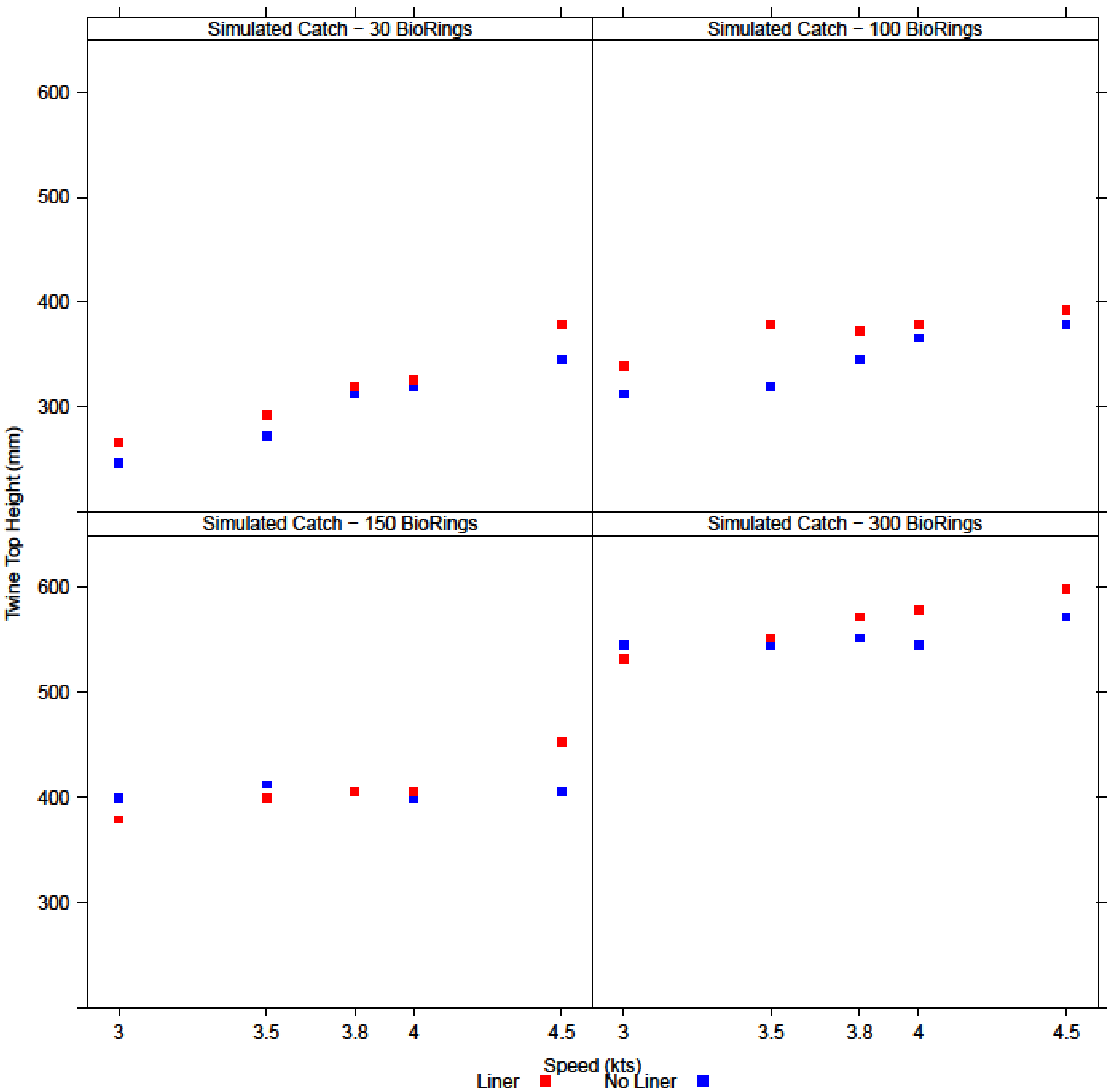


Figure 9. Plots of twine top height (mm) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

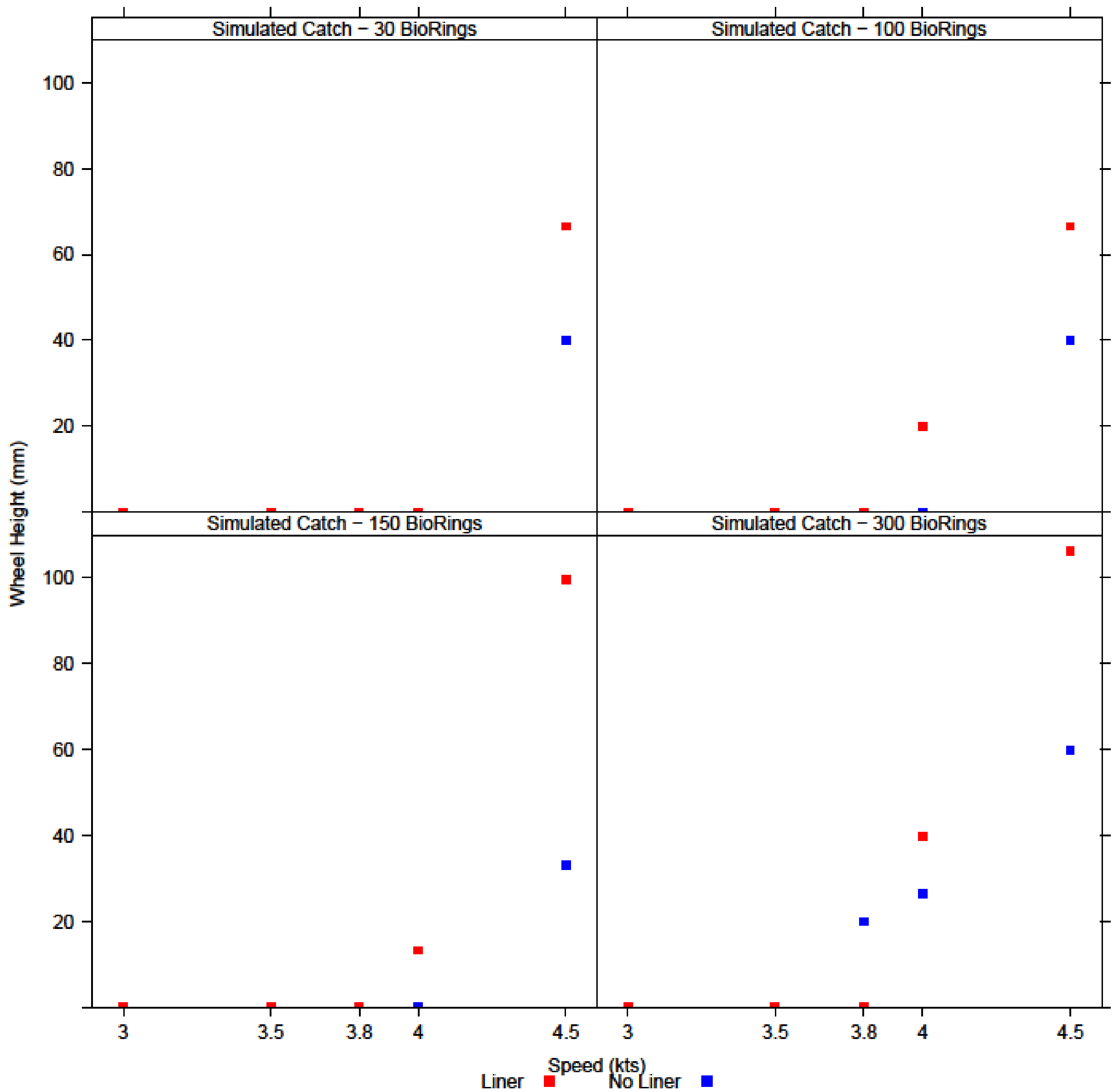


Figure 10. Plots of wheel height (mm) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

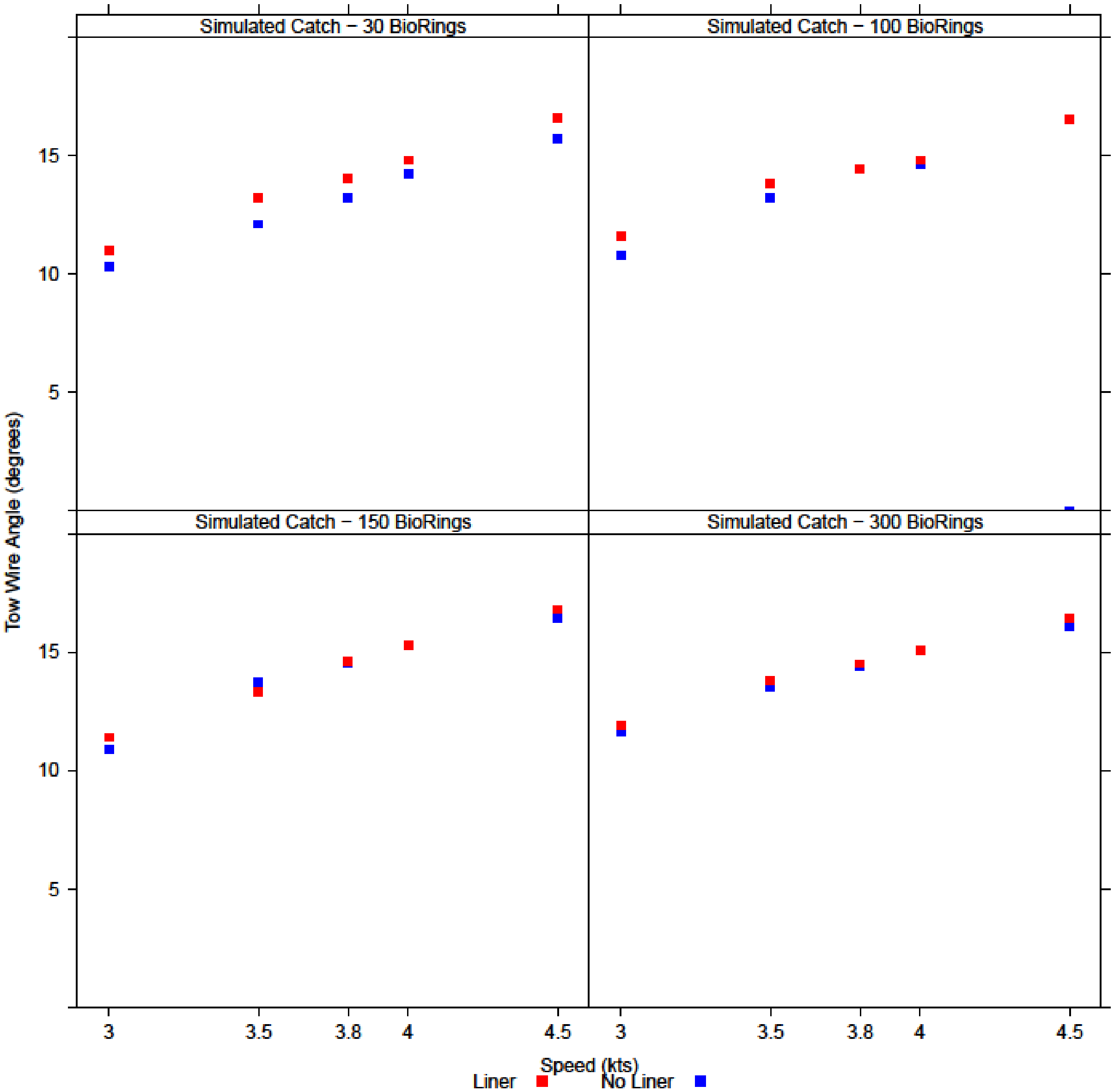


Figure 11. Plots of tow wire angle (degrees) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

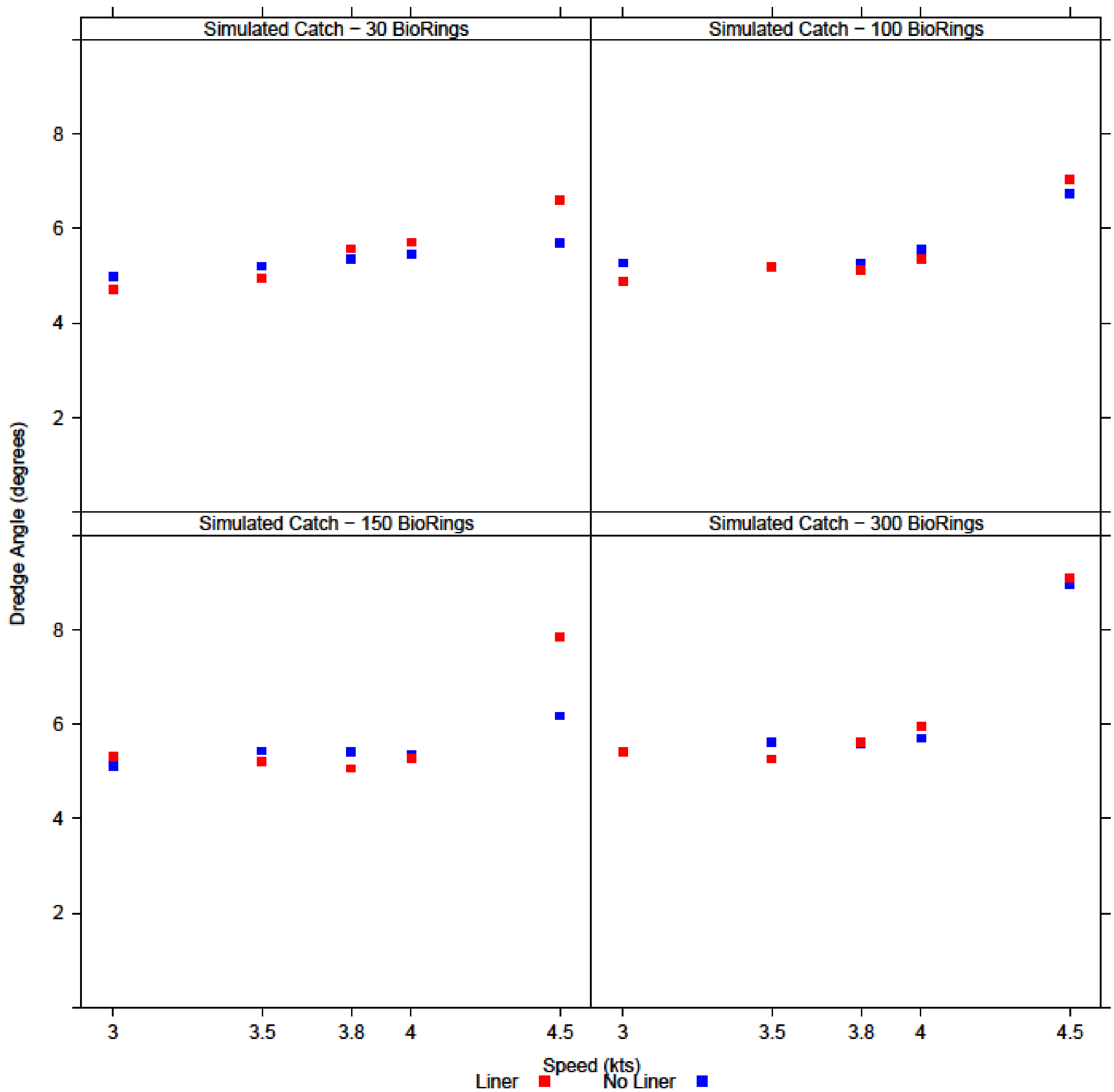


Figure 12. Plots of dredge angle (degrees) measurements taken for the simulated catch trials of 30, 100, 150, and 300 BioRings at speeds of 3, 3.5, 3.8, 4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

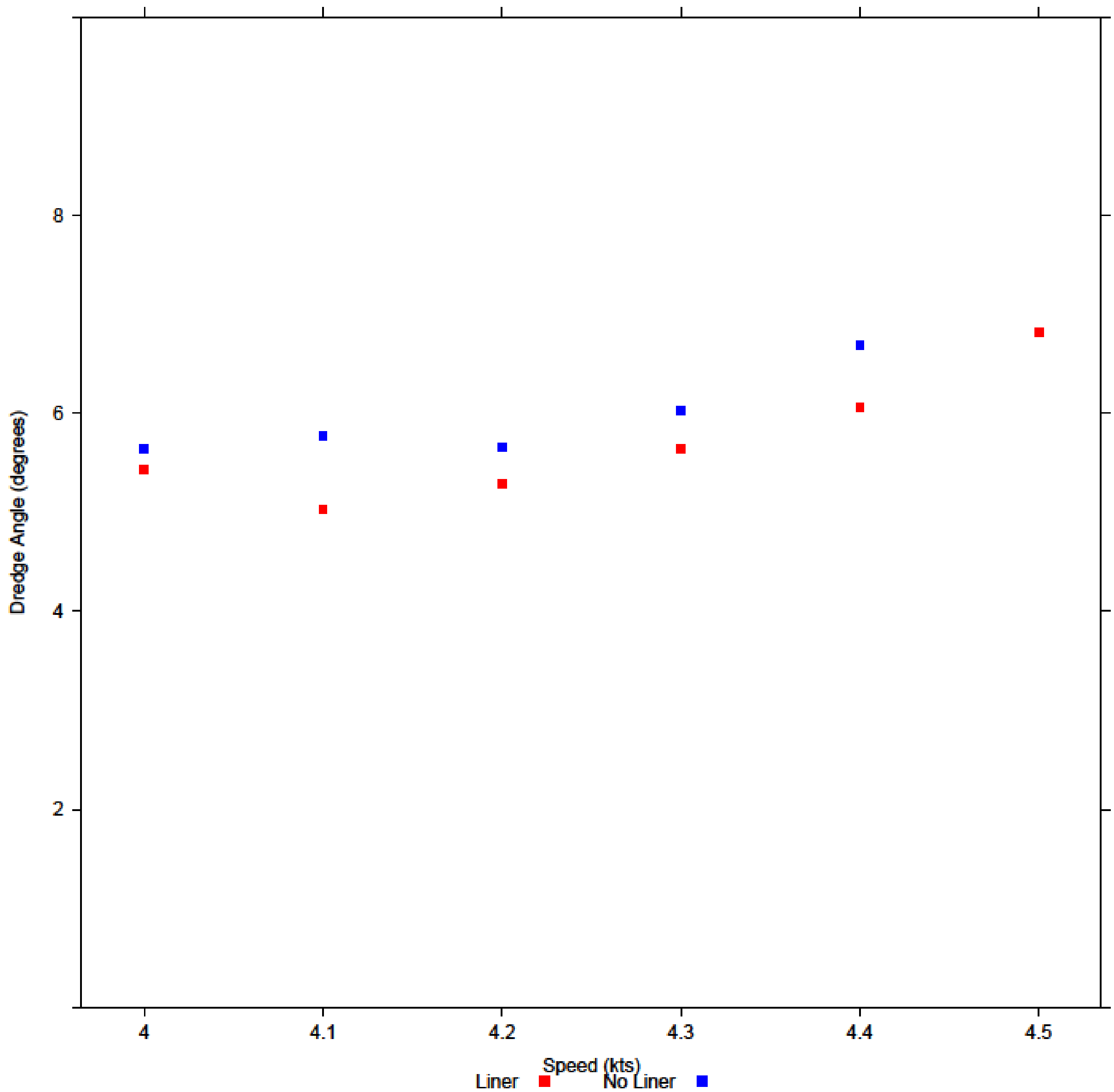


Figure 13. Plot of dredge angle (degrees) measurements taken for the simulated catch trials of 100 BioRings at speeds of 4, 4.1, 4.2, 4.3, 4.4, and 4.5 kts, a 3:1 scope to depth ratio, and a 26 mm tow wire for the lined (red) and unlined (blue) dredge.

Regular Trials

For Regular trials with a 26 mm tow wire, no catch, and a 3:1 scope to depth ratio, most measurements indicated the lined dredge had higher values than the unlined dredge. There was also a generally consistent increase in measurement values as speed increased for both the lined and unlined trials. The wheel was only observed to come off the bottom at the greatest speed of 4.5 kts, otherwise the wheel maintained contact with the conveyer belt. Observations of the dredge shoes at 4.5 kts showed the shoe heels were the only component that had contact with the conveyor belt and that the shoes moved around much more than at lower speeds. The greatest values for the twine top height and bag height increased with speed, but did not correspond to an increase in the wheel height off bottom. Dredge angle was relatively consistent across all speeds, although an increase was observed at 4.5 kts. For the lined dredge the average angle was 6.66 degrees and the unlined dredge the average was 5.52 degrees. At the required tow speed range of 3.8-4 kts, dredge angles for both the lined and unlined dredge were consistent. Average dredge angles were 5.39 and 5.29 for the lined dredge at 3.8 and 4 kts, respectively. For the unlined dredge the average dredge angle at 3.8 kts was 5.32 degrees and at 4 kts was 5.32 degrees.

Simulated Catch Trials

Simulated Catch trials for the 26 mm tow wire and a 3:1 scope to depth ratio indicated catch impacted some dredge measurements. Overall, results were similar to the Regular trial results in terms of the lined dredge versus the unlined dredge. The lined dredge tended to have higher values for all measurements. The lined dredge also had a greater bag height and a better shape compared to the unlined dredge. Twine top height, bag height, and the height of the wheel off bottom all increased for the greatest catch volume of 300 BioRings. Twine top height values tended to have higher values as catch increased, which is in contrast to the bag height measurements, which only increased at the greatest catch volume. The wheel height off bottom value started to increase at 3.8 kts at the greatest catch volume for the unlined dredge. For the lined dredge, the wheel height increased for catch volumes of 100, 150, and 300 BioRings at 4 kts, and the greatest distance off bottom was observed at 4.5 kts. The height off bottom for the greatest catch volume of 300 BioRings at 4 kts was double that of the observed height of bottom at low speeds and catch volumes. Dredge angle increased as speed and catch volume increased for the lowest two catch trials of 30 and 100 BioRings for both dredge configurations. For all catch volumes, the greatest dredge angle was observed at 4.5 kts for both the lined and unlined dredge trials. At the required speeds of 3.8 and 4 kts the difference in dredge angle between the two configurations was minimal across all catch volumes.

Simulated catch trials looking at a simulated catch of 100 BioRings, with a 26 mm tow wire, and speeds from 4-4.5 kts at 0.1 kt intervals indicated the lined dredge configuration had higher dredge angle values compared to the unlined dredge across all speeds except at 4.5 kts. At 4.5 kts dredge angles were similar. Dredge angle for both configurations was relatively consistent for speeds of 4-4.2 kts. Dredge angle began to increase at 4.3 kts, and again at 4.4 and 4.5 kts for both dredge configurations. For the lined dredge, dredge angle increased to 5.64 degrees at 4.3 kts, 6.05 degrees at 4.4 kts, and 6.82 degrees at 4.5 kts. For the unlined dredge, dredge angle increased to 6.02 degrees at 4.3 kts, 6.68 degrees at 4.4 kts, and 6.80 degrees at 4.5 kts. While the height of the wheel of the conveyor belt was not measured, video indicated that at 4.2 kts for both dredge configurations the wheel did not always remain in contact with the conveyor belt. At 4.3 kts the wheel was completely off bottom, and the greatest height off bottom was observed at 4.5 kts.

Hydrodynamic Trials

Hydrodynamic trials with 100 BioRings, a 26 mm tow wire, and the liner installed, indicated water flowed through the dredge and exited at the back of the bag near the club stick. The same trial with no liner showed water flowed mainly out of the dredge through the twine top and not through the entire dredge. This difference in hydrodynamic flow should explain why the lined dredge has a better shape while being towed.

Scope to Depth Ratio Trials

Scope to depth ratio trials were assessed with video observations only. For lined dredge trials, a shorter scope to depth ratio of 2.5:1 showed that the dredge angle increased, the wheel was completely of bottom, and only the heels of the shoes were in contact with the conveyor belt. Increased scope to depth ratios did not impact dredge angle or dredge contact with the conveyor belt at speeds of 3.8-4 kts. At 4.5 kts, a greater scope to depth ratio of 3.25 or 3.5:1 improved shoe and wheel contact with the conveyor belt. This will likely reduce dredge angle. Results for the unlined scope to depth ratio trials were similar to the lined dredge configurations.

Appendix B

Understanding Dredge Performance for a Lined versus Unlined NMFS Sea Scallop Dredge

2018 RSA NOAA Award NA18NMF4540012

Sally Roman

David Rudders

Virginia Institute of Marine Science

VIMS | William & Mary
Virginia Institute of Marine Science
Marine Advisory Program

2020 Virtual RSA Share Day
May 19, 2020

Project Objectives

- 2018 RSA Priority: Investigation of variability in dredging efficiency across habitats, times, areas and gear designs to improve dredge survey estimates

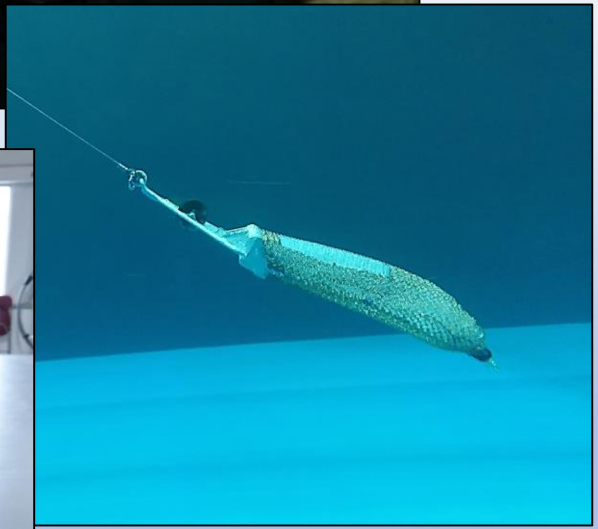
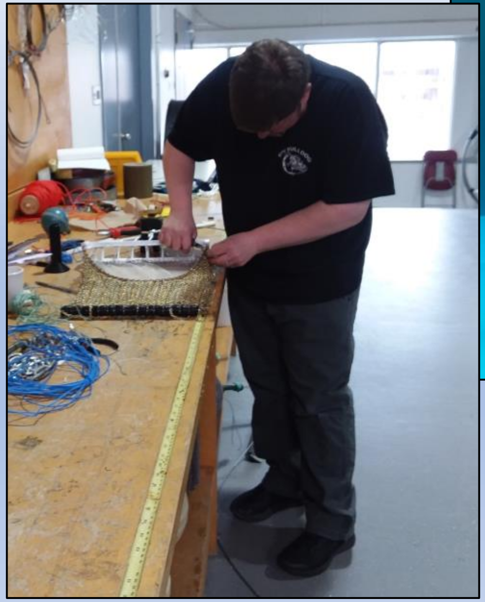
- Divergent biomass estimates in ET Flex, NL West & NL South Deep SAMS Areas

- Result of dredge saturation

- Main objective:
  - Assess dredge performance with & without liner

- Secondary objectives:
  - Assess dredge performance for a range of survey protocols
    Tow speed
    Scope to depth ratio
  - Assess performance with simulated catch

Project Overview

- Scale survey dredge was tested at Memorial University Marine Institute's flume tank
- March 19-20, 2019
- Collaborators:
  - George Legge, Facilities Supervisor for the flume tank
  - Tor Bendiksen, Reidars Manufacturing

Project Overview

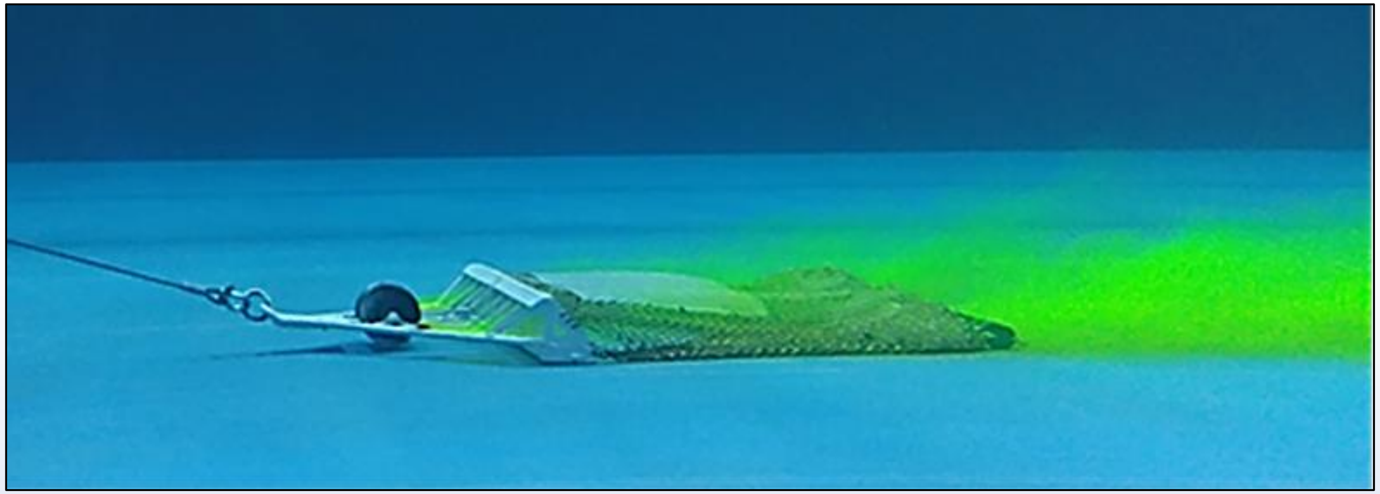
- Scale survey dredge 1:6.65 model
- 2 tow wire diameters tested
- Tested dredge under standard protocols

- Test with and without liner installed
- Speeds tested:
  - 3,3.5, 3.8, 4 & 4.5 kts
  - 4-4.5 kts at 0.1 kt intervals
- Scope to depth ratios tested:
  - 2.5:1, 3:1, 3.1:1, 3.25:1 & 3.5:1

Project Overview

- Hydrodynamic tests
- Simulated catch tests:
  30, 100, 150 & 300 BioRings
- Pressure plate size test

Dye tabs placed on dredge for hydrodynamic tests

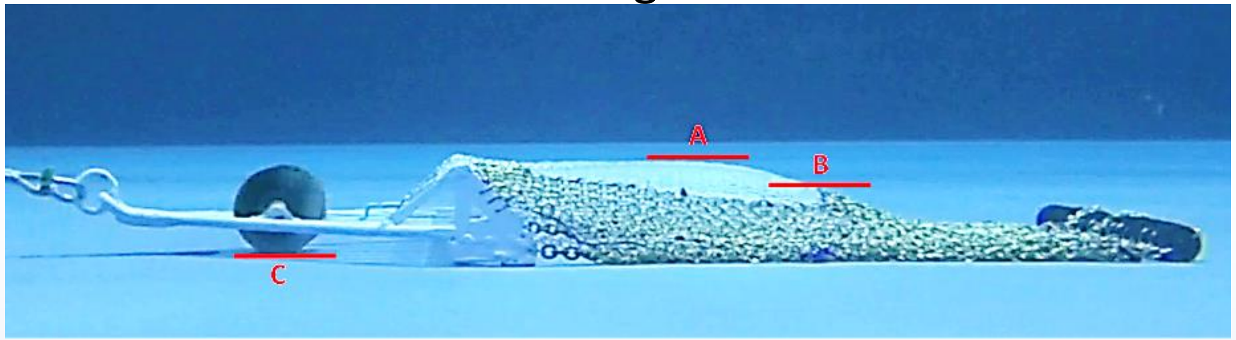


BioRing used in simulated catch tests

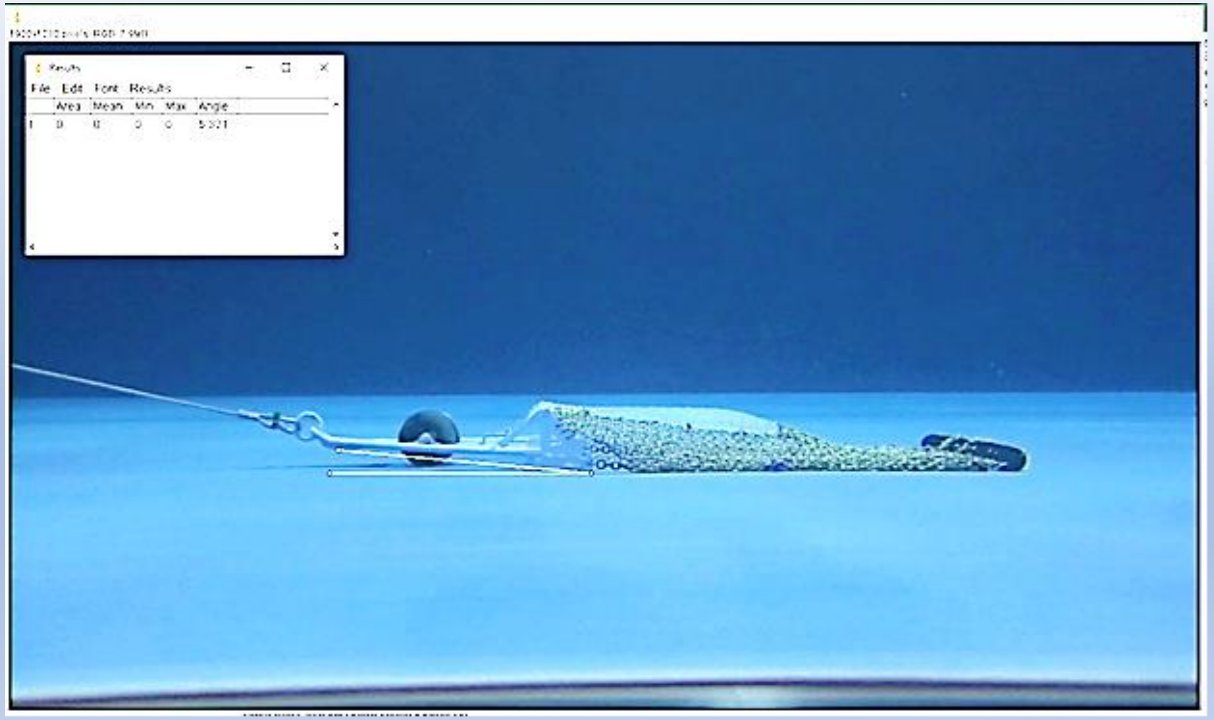
Project Overview

- Warp tension (unit kilogram-force (kgf))
- Maximum bag height (mm) (A)
- Height at the twine top end (mm) (B)
- Height of the wheel of bottom (mm) (C)
- Wire angle (degrees)
- Video for most tests
- Dredge angle calculated from video still images (ImageJ)

Location of dredge measurements



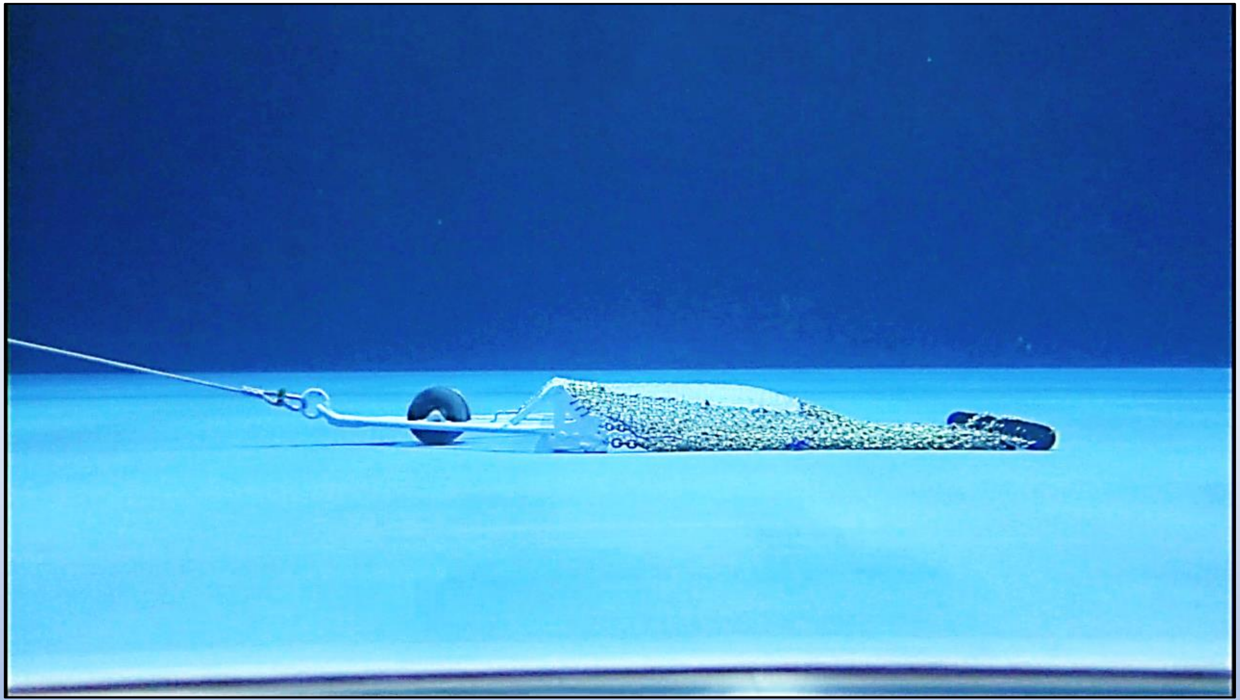
Dredge angle measurement



Results – Liner vs No Liner

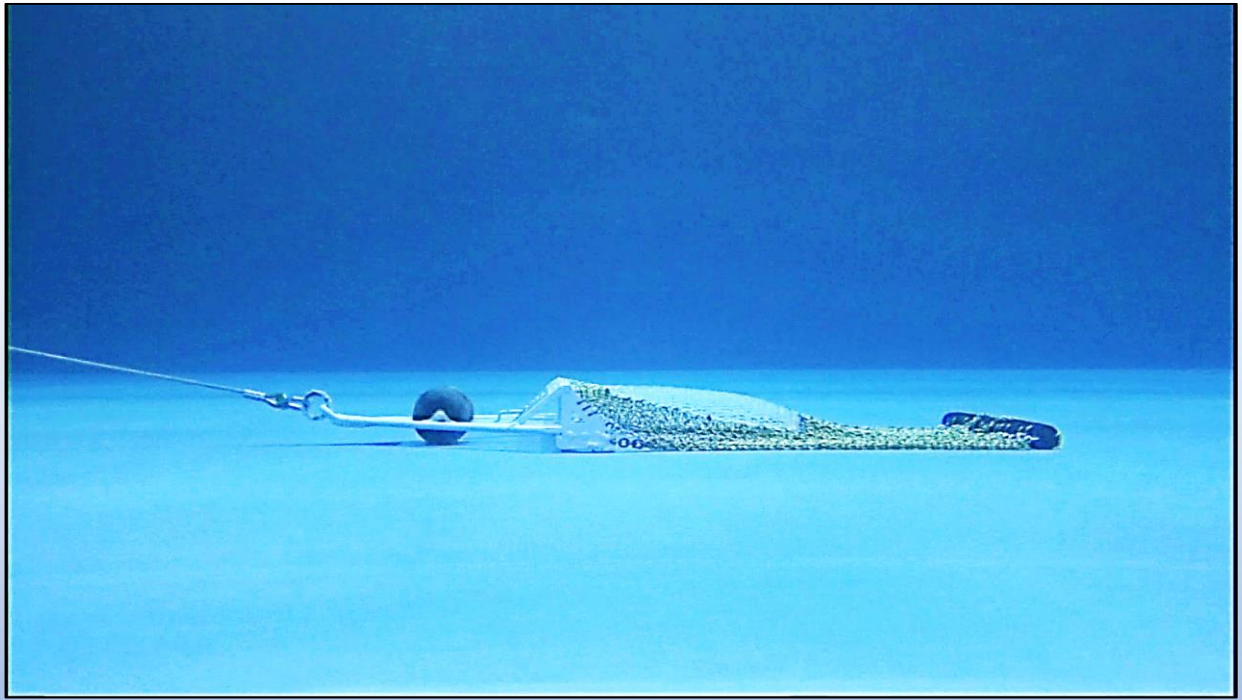
Lined Dredge

3:1 Scope to Depth Ratio, 3.8 kts



Unlined Dredge

3:1 Scope to Depth Ratio, 3.8 kts

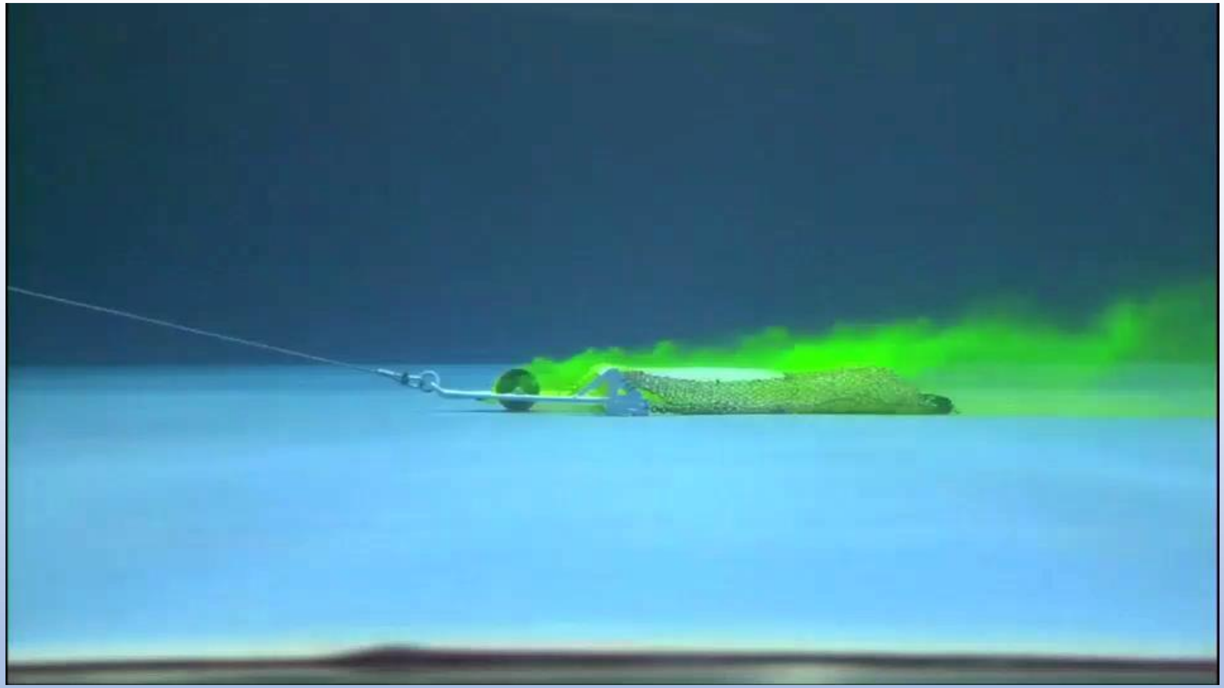


Dredge had a better overall shape based on the opinion of the individuals at the trials, as well as measurements of the bag and twine top height.

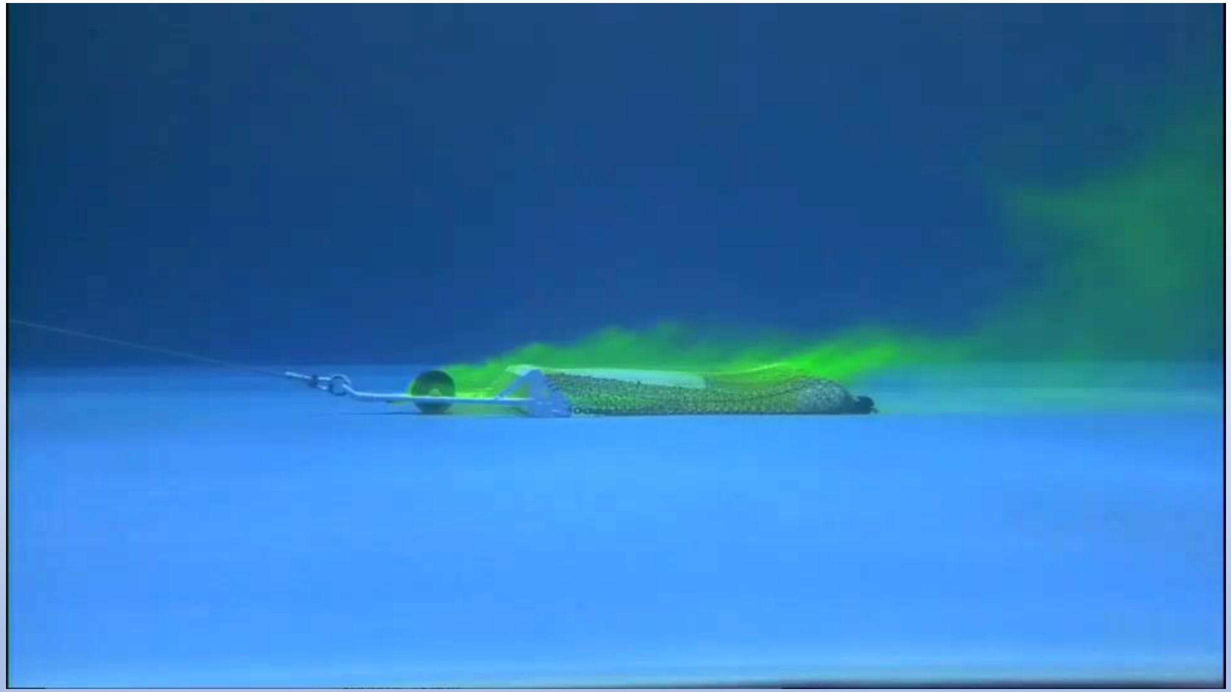
Dredge angle did not difference greatly between the lined and unlined dredge configurations.

Results – Liner vs No Liner

Lined Dredge
3:1 Scope to Depth Ratio, 3.8 kts & 100 BioRings



Unlined Dredge
3:1 Scope to Depth Ratio, 3.8 kts & 100 BioRings

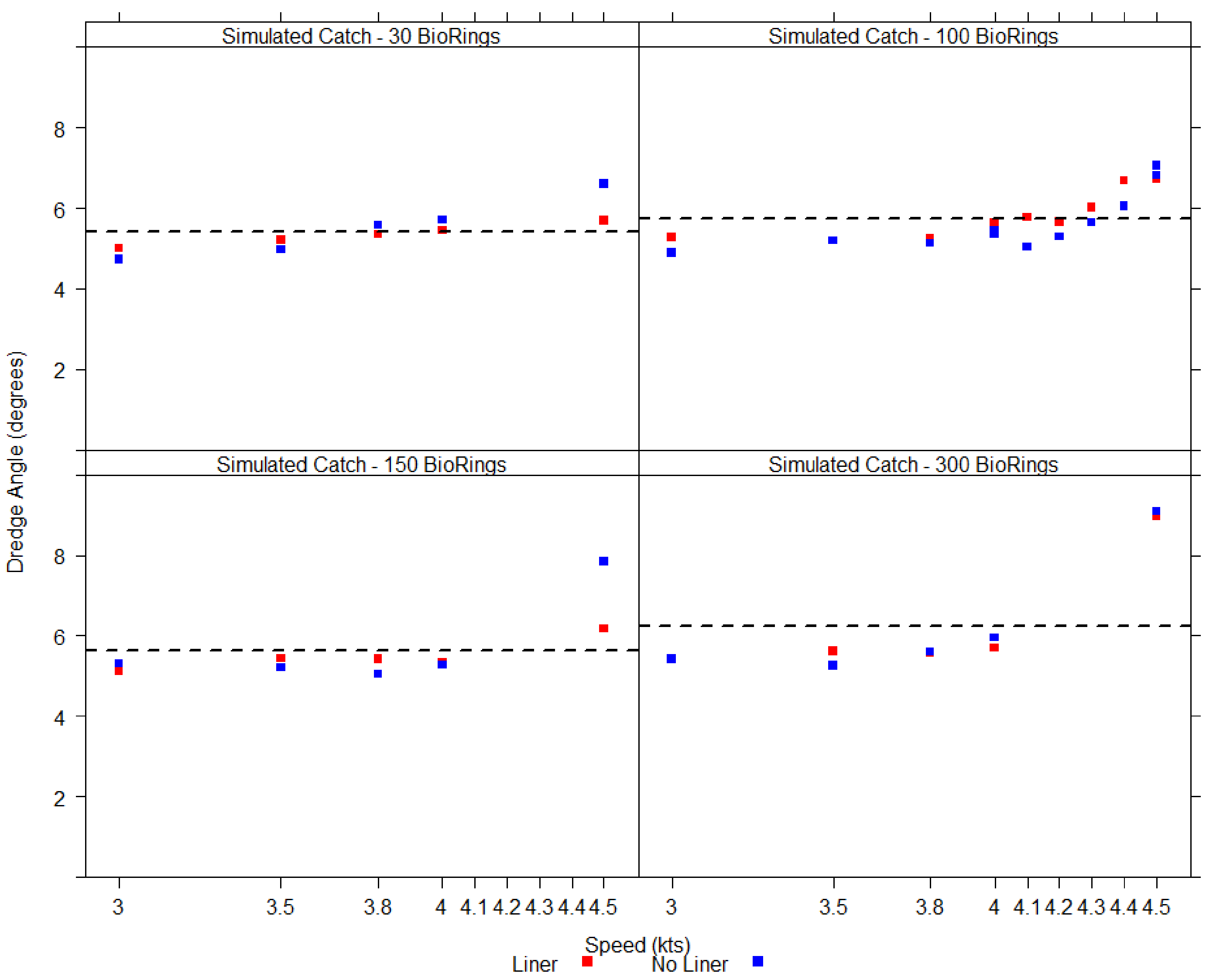


Hydrodynamic flow was also improved when the liner was installed in the dredge.

Results – Simulated Catch

- Catch volume & speed can impact dredge angle
- At 3.8-4 kts dredge angle was similar
- For VIMS survey, dredge angle began to increase at 4.3 kts with 100 BioRings

Dredge Angle

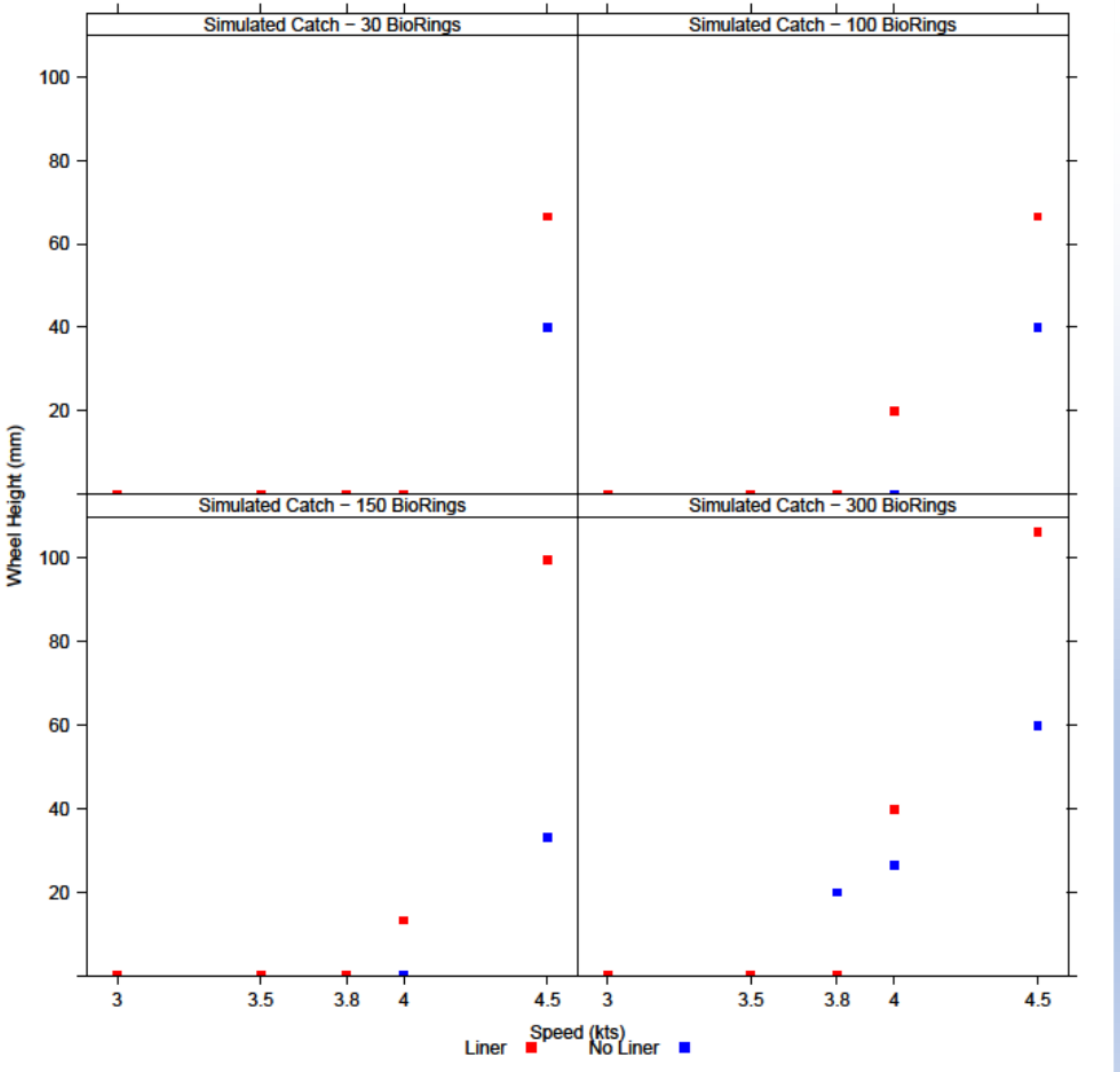


Results – Simulated Catch

- Catch volume & speed increased the height of the wheel off the conveyor belt

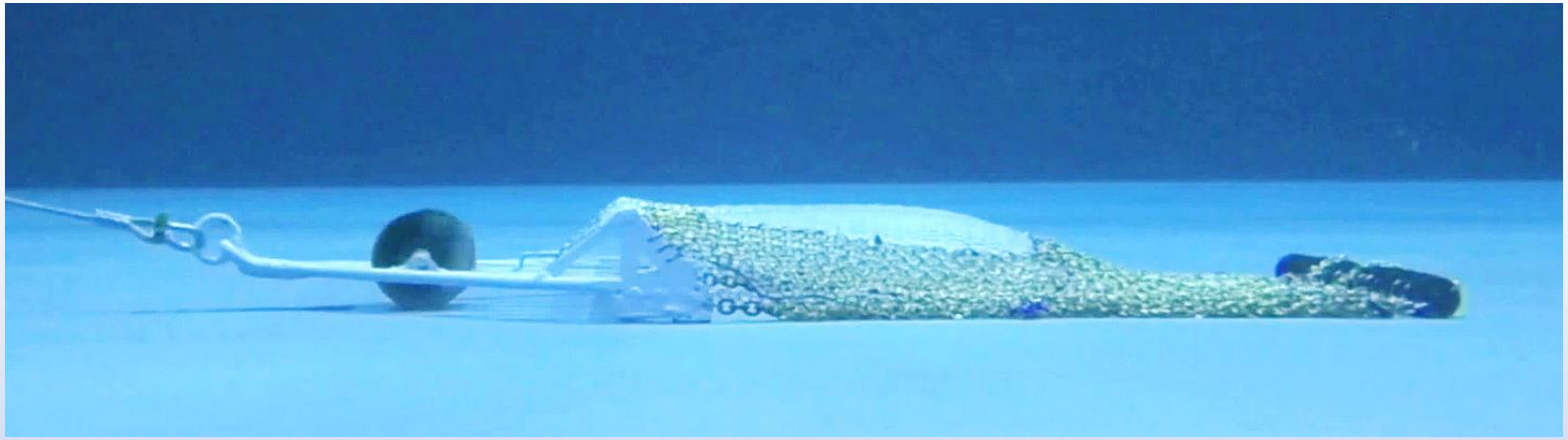
- Wheel height off bottom was greatest at largest catch volume

Wheel Height



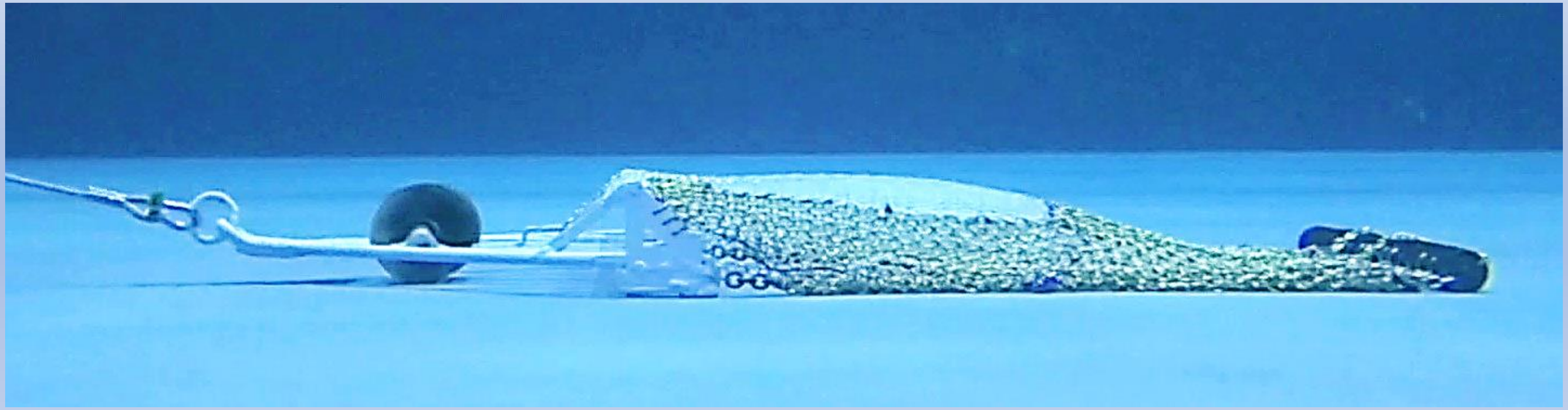
Results – Dredge Angle

Lined dredge, 3:1 Scope to Depth Ratio, 3.8 kts



Dredge angle: 5.4°

Lined dredge, 3:1 Scope to Depth Ratio, 4 kts



Dredge angle: 5.3°

Discussion

- Flume tank project allowed for dredge to be studied under controlled conditions
- Does not account for real world conditions including environmental conditions, substrate type or extreme catch volumes
- Liner does not seem to negatively effect dredge performance
- Catch volume & tow speed can increase dredge angle, wheel height, twine top height and height of dredge bag
- Reduced efficiency may be a combination of gear saturation and decreased dredge performance

Discussion

- Optimal dredge angle/fishing configuration?
  - Unaware of any protocols for optimal dredge angle for survey dredge
- Under current protocols the VIMS dredge shoes & wheel are completely on the conveyor belt
- Should dredge be fished differently?
  - VIMS tow speed could be increased
  - May not be needed for NEFSC survey