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Quantifying and reducing interactions between commercial fishing gear and the seabed in New Zealand

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May 2023

Report

Report for Sustainable Seas National Science Challenge project *Quantifying seafloor contact (Project code 2.18)*

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For more information on this project, visit:

sustainableseaschallenge.co.nz/our-research/quantifying-seafloor-contact

About the Sustainable Seas National Science Challenge

Our vision is for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders. We have 75 research projects that bring together around 250 scientists, social scientists, economists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. We are one of 11 National Science Challenges, funded by the Ministry of Business, Innovation & Employment.

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1 Table of Contents

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Executive Summary

Demersal trawling evokes strong views from a range of stakeholders with differing opinions on how to achieve the balance required to sustainably harvest seafood. Ensuring biological and economic sustainability of fisheries is an important component of supporting a thriving Blue Economy.

Balanced decision making in New Zealand is supported by the monitoring of trends in the extent and intensity of the commercial trawl footprint. Currently a nominal trawl footprint approach is used, reliant on scientific assumptions associated with classifying gear setups and assuming homogeneity of bottom contact across tow tracks.

The purpose of this study is to demonstrate the capability of moving our understanding of trawl footprints away from assumptions associated with nominal trawl footprints to trawl footprints driven by in situ empirical data collection. The objective to improve real-world data streams on benthic interactions from some inshore trawl gear so that we can better understand our interactions with the oceanic environment and manage our interactions. It is anticipated this will support well-informed management of our fishery resources.

Tilt-sensors each with an accelerometer were deployed onboard an inshore demersal trawler in the Hawkes Bay to collected bottom contact data at seven attachment sites across gear components. Camera validation was used to establish clearance values of “ON”, “NEAR” and “OFF”. These classifications were then used to calculate contact adjusted footprints and compare these to nominal trawl footprints.

The results demonstrate that the sensors can record differences in bottom contact of a net compared with the standard assumption and with sufficient accuracy to also distinguish between differences in gear. Results indicate variability associated with the way gear is interacting with the seabed and the environmental or operational influences on the gear overall and at each attachment site. Looking at the data by depth shows the results are consistent with the literature where there is higher variability associated with deeper tows. Comparing trawl footprint methodologies showed a statistically significant difference. There was a 64% reduction in trawl footprint for Gear Setup 1 when using contact adjusted trawl footprints compared to the nominal footprint approach, and a 57% reduction in the trawl footprint for Gear Setup 2.

It is being increasingly recognised that trawl efficiency needs to be improved in response to the pressures on fishers to economically catch sustainable seafood to meet consumer demand in an ever changing regulatory and environmental situation. The study demonstrates fishers can use these sensors to inform decisions regarding gear changes to change their contact profile specific to their vessel to optimise their operations while minimising contact.

Embracing new technology and associated data streams to meet these challenges is consistent with the recommendations from the Future of Aotearoa commercial fisheries report to move to a data driven future. It is anticipated this work aligns with the Industry Transformation Plan to support operators who are innovating to improve trawl efficiency and mitigate environmental effects.

This study represents the start of a development pathway. As the technology is developed and there is broader uptake the opportunities presented by empirical data collection are broad. Potential shortcomings of the method are discussed and areas where further research is required are identified. Further research is required to expand the placement of sensors in terms of the number deployed on gear, the number of gear set ups investigated and the number of vessels involved.

2 Background

Globally, trawling is one of the most commonly used fishing methods and catches more than two-thirds of commercially harvested tonnage in New Zealand[1]. Trawling as a harvesting method has, however, become increasingly controversial as a result of an increased focus on the environmental impacts of trawling (Guijarro et al., 2017; Neill et al., 2018). Trawling is recognised to interact with the seabed, causing disturbance and changes to the benthic environment (Diesing et al., 2013).

Jennings & Revill (2007) recognise that, whilst any fishing activity affects the ecosystem, fishery managers need to identify and mitigate effects. Fisheries managers are required to balance socio-economic activity with sustainable practices that ensure the long-term health of fisheries (Hilborn et al., 2020). In New Zealand this balancing act is specified in the purpose of the Fisheries Act to support sustainable utilisation and mitigate adverse effects.

To support management decisions, it is imperative we improve our understanding of the nature and extent of bottom-contacting fishing activity within New Zealand waters. Improved understanding of the variability associated with seabed contact will better enable managers to meet the requirements of the Fisheries Act to manage effects on the benthic environment.

2.1 The need to improve our knowledge

Globally, the fishing industry is cognisant of the significant data gaps that need addressing to support sustainable fisheries in a dynamic changing global environment (Kaiser et al., 2016).

Kaiser et al. (2016) identified key knowledge needs for achieving best practices for trawling including: exploring the spatial and temporal extent and variation in intensity of trawling, exploring gear configurations to mitigate impacts and quantifying these effects, and identifying the role that each component of fishing gear plays in habitat disturbance.

Quantifying interactions between fishing gear and the seabed is necessary to ensure that management decisions and/or gear adaptations are based on the best available empirical data at the finest resolution possible.

Measuring benthic interactions supports the sustainable use of fishery resources for economic returns and improved social outcomes while conserving the health of New Zealand's marine ecosystem. Ensuring the biological and economic sustainability of fisheries is critical to industry and important for providing work and seafood for New Zealanders, for which the social and cultural ramifications are significant.

Understanding our interactions with the seabed will help feed into objectives of ecosystem-based management, using a more holistic approach to understand commercial fisheries' interactions with the environment. Better understanding of benthic interactions will benefit New Zealand by supporting long term food security in a manner that reflects the need to minimise environmental impacts while harvesting seafood.

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[1] In the 2020/2021 fishing year, 68% of all fish caught commercially in New Zealand were caught using either bottom trawl gear or mid-water trawl gear within 1 metre of the seabed (https://www.mpi.govt.nz/fishing-aquaculture/sustainable-fisheries/strengthening-fisheries-management/bottom-trawling/)

2.2 Underlying assumptions that inform our understanding of our trawl footprint

Depestele et al. (2015) states that understanding the effects and interactions of demersal fishing gears with the benthic habitats includes the need to understand physical effects.

Physical interactions and the associated effects on the seabed are considered extremely complex (O'Neill and Ivanović, 2016; Rijnsdrop et al., 2015). Physical interactions are dependent on the type of trawl doors and ground gear used, the way the gear is rigged, the oceanographic conditions (current strength and/or direction, sea state, etc.), and the physical characteristics of the seabed and its associated biota.

The scientific literature on physical effects of trawling is focussed on deterministic methodologies and meta-analyses that are based on indirect data and modelling assumptions to improve broad-scale level knowledge associated with changes to the ecosystem functions as a result of fishing effort (Neill, 2015).

'Nominal swept area' is a term used to describe an estimated/assumed/modelled/calculated area of contact. This is typically informed by expert knowledge of gear specifications such as door spread and assumes this is the maximum possible contact during a fishing event (100% contact between maximum door spread from beginning to end of a tow). 'Contact-adjusted swept area' takes into account variability of contact within a fishing event, either also informed by expert industry knowledge, or empirically informed.

Domestically the current approach to quantifying seabed contact uses a nominal trawl footprint approach (Baird & Mules, 2021). The nominal swept area methodology used in New Zealand is to calculate the area derived from the tow distance as a presumed straight-line measurement between start and end positions[2] and the estimated door spread (noting that sometimes this is measured). This is used to determine trends in the annual aggregate swept area and the associated trawl footprint is the area (square kilometres) represents the seabed area estimated to have been contacted by trawl gear (Baird & Mules, 2021).

Our understanding of baseline benthic contact is based on the model assumptions of door spreads and 100% contact between doors spatially and temporally during a fishing event and are not based on empirical observations. Using this assumption, the Aquatic Environment Biodiversity Report (AEBR) 2020-21 records that *'between 2008 and 2018 bottom trawl fisheries contacted 7.2% (annual average of 2.2%) of the seabed in the NZ Territorial Sea (TS) and Exclusive Economic Zone (EEZ)'* (Fisheries New Zealand, 2022).

The combined 30-year period dataset (1990–2019) used by Baird & Mules (2021) using the same assumption estimated *11% of the seafloor within New Zealand Territorial Sea (TS) and EEZ and 33% of the area shallower than 1600 m (fishable depths) and open to trawling (termed the fishable area)*.

When the nominal footprint assumptions are applied to inshore trawl vessels, the trawl footprint estimations for inshore trawl fisheries within the fishable areas between 2008 (2007-08 fishing year) and 2019 (2018-19 fishing year) was 10.7%. When applied to the EEZ and TS the estimated percentage of bottom contact was 3.6 % (Baird & Mules, 2021). Of note is that the annual inshore footprint has decreased from a peak in 2019 (47 220 km^2) to 38,131 km^2 in 2019, noting that inshore trawl effort has dropped from 76,000 events in 2002-03 to 42,000 events in 2019-20 (Fisheries New Zealand, 2022).

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[2] Baird & Mules (2021) define the start and end of trawling as when the net reaches fishing depths (start of tow) and when the net leaves the fishing depth (end of tow).

2.3 Moving from assumptions to empirical data

Trawling is a key method that has been deployed for more than 100 years in New Zealand and is the method that catches most of our finfish in tonnage terms. Trawling is highly efficient but faces increasing pressure from those concerned about the effects of its impact on the organisms living on the seabed, as well as abiotic habitat features.

The trawling debate is multi-faceted with strong views from a range of stakeholders, whose positions can be informed by international scientific literature and / or reports of New Zealand's trawl footprint and its associated effects.

Due to a lack of resources and affordably ubiquitous technology, current estimates of New Zealand's trawl footprint are based primarily on a few important assumptions. The use of nominal trawl footprint[3] is recognised to provide a conservative measure of swept area. Important underlying assumptions are used when calculating the trawl footprint using nominal trawl footprints. Examples of these as described by Baird & Mules (2021) are:

- The gear is in contact with the seabed for the duration of the tow.
- Gear used by similar sized vessels fishing for the same target species has the same door spread, and that there are no differences in the way in which skippers operate or rig their gear.
- Ignoring the irregular nature of the seabed and assuming that within each cell, the seabed is homogeneous.[4]
- The use of ERS data; the tow path is not well understood and has to date been treated in these analyses as being a straight line between shoot and haul positions rather than one that may follow contours or include turns of varying degree. For the latter, a more accurate endpoint will not help to better describe the tow path or the swept area (Baird & Mules, 2021).

Diesing et al.'s research (2011) demonstrated that continual research is needed to test our underlying assumptions. The literature demonstrates observations of bottom contact associated with demersal trawling have been associated with either acoustic (e.g. Depestele et al., 2016) or optical methods (e.g. O'Neill et al., 2009). There are less studies that use sensors to record bottom contact at a fine scale level across different gear components.

This study directly addresses Neill's (2015) observation that there is insufficient information associated directly with the bottom contact of gear components and that increased data collection and recognition of the effect of gear components is required to quantify the environmental and ecological effect of demersal fishing requires (Ivanovic, 2015).

Developing an improved data-driven approach would support getting much finer vessel-specific seabed-contact information that recognises differences in gear set up and use, operators and the different conditions vessels are working in. An improved data-driven approach would also directly address Amoroso et al's (2018) commentary that trawl footprints are 'often contested but poorly described.'

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[3] Defined as - the width of the trawl doors multiplied by the distance of the tow. (Baird & Mules, 2021)

[4] As per Baird & Mules (2021) *'To aid in the categorisation and analysis of the data, a grid of approximately 25 km2 cells was created as a database table and joined to the TCER, TCEPR, and ERS effort table. This 5x5 km cell size has been used in previous work and is considered reasonable, by successive Aquatic Environment Working Group meetings, as the unit of analysis for trawl swept areas on a broad scale such as the EEZ+TS.'*

Gear modification is recognized as an effective way to reduce contact with the seabed, while maintaining economic efficiency and productivity (Eayrs et al., 2020). Achieving this requires consideration of the impact at the gear component level (Neill, 2015). For example Ryer et al (2010) found that sweeps could be elevated but it reduced trawl efficiency, noting that these results were specific to the flatfish studied. The literature highlights the importance to understand the effects of mobile bottom fishing on benthic habitats by having detailed knowledge on the amount of interaction by the gear and its components (e.g., sweeps) and the extent to which mobile bottom fishing methods are used in various habitats.

If modifications are to be made, we first need to empirically measure contact by both typical fishing gear and the modified gear during normal fishing event conditions.

Informed appropriately, effective gear modification will meet the goals of the Blue Economy (finding marine activities that create economic value and contribute positively to social, cultural and ecological well-being in Aotearoa New Zealand).

2.4 Strategic vision for the research

Improving our understanding of the actual trawl footprint in physical terms and moving away from assumptions to fine scale empirical data has a dual strategic purpose to:

(1) improve trawl efficiencies and
(2) improve fine scale understanding of trawl footprints to support management.

This project is focussed on end-user outcomes in terms of both direct and indirect economic benefits. Direct benefits to be realised by reducing gear interaction with the seabed, include reduced fuel usage, and reduces the risk of wear and damage to gear reducing maintenance and replacement. Indirect benefits from reducing interactions with the seabed include maintaining the health of the benthic environment and supporting the environmental and economic sustainability of fisheries that are reliant on this habitat.

These same benefits have other direct environmental outcomes as well. More efficient fuel usage reduces the overall carbon footprint of the fleet provided catch rates are maintained. Minimising the risk of lost or damaged gear lowers the risk of derelict gear remaining in the oceanic environment.

This work recognises that fishers can be empowered to engage in and further embrace a data driven future. This research directly addresses:

- Recommendations from *'The future of commercial fishing in Aotearoa New Zealand'* report to empower innovation to improve environmental outcomes as well as collaborating to fill data gaps to support informed commercial and environmental decision-making, and
- Fisheries New Zealand's position that they want to refine 'methods to estimate the extent and effect of bottom fishing'

We anticipate that this work will enable fishers to make empirically informed operational and gear modifications as appropriate to meet the changing social, cultural and economic demands on their businesses. The potential utility of continued sensor data collection will depend on the user but in a general sense there is the potential to:

- **Support fishers to determine practicable, appropriate and reasonable operational changes** that will reduce the seabed friction and drag of the gear. This has the potential to improve trawl efficiency and result in associated improved environmental outcomes – for example less interactions with benthos as well as reduced energy use resulting in lower CO_2 emissions (provided catch rates are not overly reduced). It is anticipated that any changes would be supported by a cost/benefit analysis recognising the specific individual nature of these decisions.
- **Broaden data collection that supports the development of contact and clearance profiles across a range of trawl types, species and fisheries.** Existing models developed overseas can do this but they are informed by fisher estimates of bottom contact and not empirically collected data. To achieve this, representative coverage of a fishery would be needed and could then be applied to support risk assessments and contact impact profiles across a fishery or defined fishing grounds.
- **Reduce operational costs.** Given the soaring operational costs in the current environment, measuring how small gear changes can change vessel contact profiles could be used to optimise operations to reduce operational costs.

2.5 Project aim and objectives

Our project aims to demonstrate the ability of sensors to obtain empirically derived baselines for bottom contact and detect differences between different gear set ups for the purpose of changing the amount of contact between gear and the seabed.

The project objectives are to demonstrate:

- The utility of empirically derived contact data to establish baseline footprint information
- Data from sensors can assist decision making when fishers make gear modifications to minimise bottom contact

Out of scope for this research project is assessing the impact of bottom trawling on the benthic environment, making recommendations on gear setups or fleet wide assumptions, and making any policy recommendations.

3 Methods

3.1 Instrumentation

Previous attempts to create gear-specific estimates of seabed contact have involved expert perceptions provided by fishing industry personnel (e.g. Smeltz et al., 2018); low-tech or proxy measurements of contact, such as counting the number of polished links on a dropper, pressure sensors, recommended wire length to water depth ratios (“scope”) or tilt-sensors (Rose et al., 2016; King et al,2019; Weinberg and Somerton., 2006).

This project advances the methodology used by King et al. (2019) to use tilt-sensors with an accelerometer to measure angles based on the offset from gravitational force. The angle measured by the sensor is converted into an estimate of height above the seabed (hereafter called ‘clearance’) based on the length of the sensor, either by a quadratic equation (Weinberg and Kotwicki, 2015) or trigonometric equation (Rose et al., 2016).

Previous studies have used tilt sensors on demersal trawl nets placed in the centre of the footrope (Von Szalay and Somerton, 2005), other footrope locations and middle of the bridle (Weinberg and Somerton., 2006), whilst King (2019) placed sensors on various locations of a large pelagic trawl footrope. Given that the gear this project used was smaller than those used in other studies, and that the main focus of a difference in treatment was creating lift in the sweeps, we decided to have sensors placed at the centre of the footrope, the wingends (near bridles), and the sweeps. The tilt sensors (defined as the tilt sensors and its associated housing) used are bespoke designs by ZebraTech, a New Zealand based company, who develop technical solutions to assist commercial fisheries with data collection for research and sustainability projects. Prior to deployment all sensors underwent a validation process conducted by ZebraTech.

3.2 Vessel, gear, and trawling procedure

FV *Nancy Glen* is an inshore 12 m stern trawler , constructed in 1985, with a beam of 3 m, and engine power of 130 kW.

For the purposes of this study two gear configurations were used. Table 1 summarises the two gear specifications and how the two gear set ups differ. Gear Setup 1 was selected for this project as this gear set up is normally used by the fisher and vessel involved, whilst Gear Setup 2 represented gear more closely aligned with that used by other fishers in the area. Gear set up 1 and 2 both have the same lengthener and cod end specifications.

Gear Setup 1 used lighter sweep materials and discs to create lift in the sweeps, whereas the Gear Setup 2 used heavier sweep materials without discs (a setup used by some fishers in NZ).

Figure 1 FV *Nancy Glen*

Table 1 Comparison between the two tested gear set ups specifications

		Gear Setup 1	Gear Setup 2
Sweeps (weights of sweeps and bridles combined)	Length (m) (1 sweep)	134	80
	Dry weight (1 sweep, 1 bridle) (kg)	125	163
	Volume of water displaced (1 sweep, 1 bridle) (L)	165	156
	Weight in seawater (2 sweeps, 2 bridles) (kg)	93*	102*
	Material	Dynex	Steel with rope rounding
	Diameter (cm)	1.15	3
Bridle (bottom bridle) – includes a length of chain (links 13cm x 7.8cm)	Length (1 bridle) (m)	22.9	20*
	Material	Dynex	Steel with rope rounding
	Diameter of material (cm)	1.4	3
Discs	Number per 1 sweep	7	0
	Spacing (m)	Variable	NA
Footrope, net, and ground gear (including net and floats)	Length (m)	34	
	Dry weight (kg)	211	
	Volume of water displaced (L)	235	
	Weight in seawater (kg)	183*	
	Material	Dynex with rubber cookies	

* These data are calculated

3.2.1 Sensor placement and attachment

An iterative process was conducted to review the sensor plate model and attachment method prior to data collection. Figure 2 shows the original two sensor housing and attachment approaches.

Improvements to the sensors were made to add weight and decrease the surface area to reduce hydrodynamic impacts on the sensors and to make sure it does not interfere with the interaction of the gear with the seabed. We also used D-shackles to standardise attachment method to speed up the attachment and detachment process during fishing operations, as the sensor cannot be rolled on the net drum if attached on the wingend or sweeps (Figure 3).

Figure 2 Type A housing & Type B housing (Left) and updated housing (Right)

Figure 3 Photo demonstrating the reduced surface area of the plate attached to the sensor to minimize any hydrodynamic lift, as well as added weight

For data collection seven sensors were deployed on the gear with sensors labelled based on their placement on the footrope (Figure 4 and Figure 5).

It should be noted that on Voyage 4 attachment methods for the sweeps (positions 1, 2, 6 and 7) were slightly different than for Voyages 2, 3, and 5. While in the other voyages the D-shackles for the sensors were tied on with Dyneema line, on Voyage 4 they were attached with hose clamps. This was thought to better protect the sensors as there was some concern that the Dyneema line could potentially break. On review of the Voyage 4 data, however, it was determined that this could potentially change the behaviour of the sensors enough that the data may not be comparable. Upon review of the Voyage 5 data, Voyage 4 data was determined to be comparable for the purposes of this report. For the remainder of the voyages, the sensors on the sweeps used the D-shackles as attachment methods.

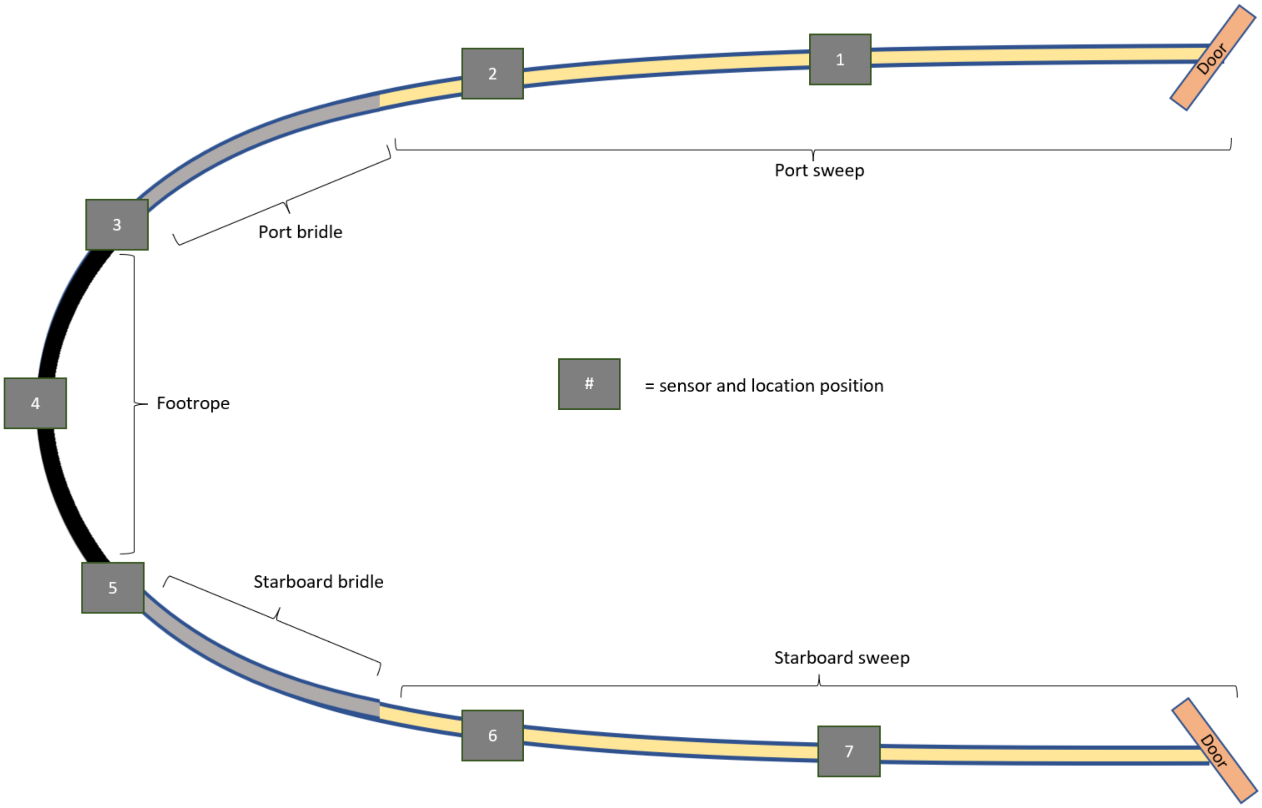


Figure 4 Diagram showing the placement of the sensors on the sweeps, wingends, and footrope

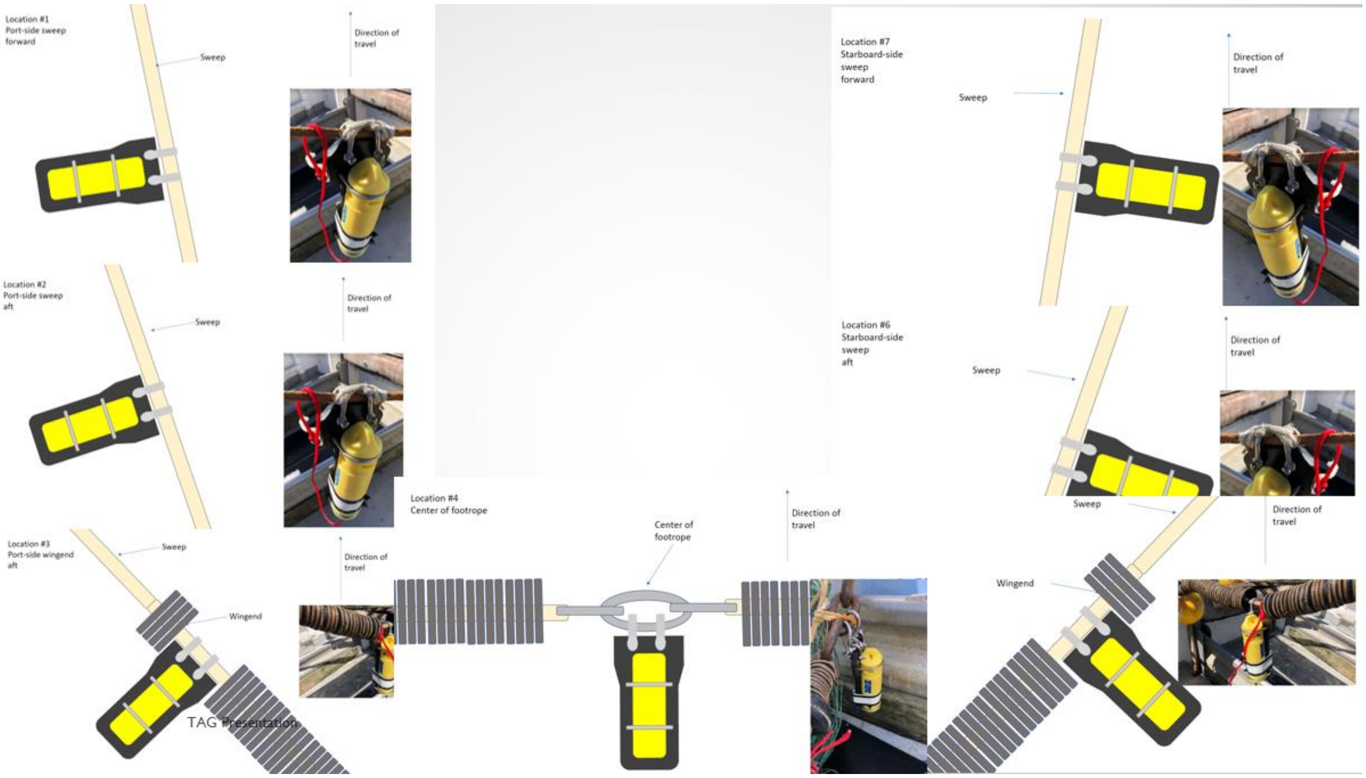


Figure 5 Detailed diagram showing how the sensors were attached to the fishing gear at each location

3.3 Survey area, design, and gear performance

The location for collecting data was the Hawke Bay given the vessel is domiciled in Napier.

Tow stations were selected to reflect the operational capabilities of the vessel and to limit the impact of weather on the research operations. 30m was selected as the shallow strata and 100m for the deep strata tows in order to provide a distinction between the stratum. The deep stratum were selected so that the work could be done within Hawkes Bay in order to limit the impact of inclement weather on the research operations.

All tows were undertaken in daylight, and four to six tows a day were planned, with the number achieved dependent on the time of year. For each tow the vessel steamed to the station position and the gear was set as close to the station start location as possible. Research tows were standardised to an hour duration at a speed over the ground of between 2 - 3 knots dependent on the weather conditions. Once set the gear was towed in a manner to maintain the depth. The direction of the tow was influenced by a combination of factors including weather conditions, tides, bottom contours, and the location of the next tow but was usually in the direction towards the next station.

Data recorded from each tow included:

- Tow details (e.g., gear type, date, time, location, duration, etc.);
- Standard environmental parameters – such as including swell/wave height and direction, wind force and direction, cloud cover and sea state;
- Estimated catch weights – recorded for all species in kilograms;
- Video footage was also collected of the sensors themselves to validate the data collected while towing was underway.

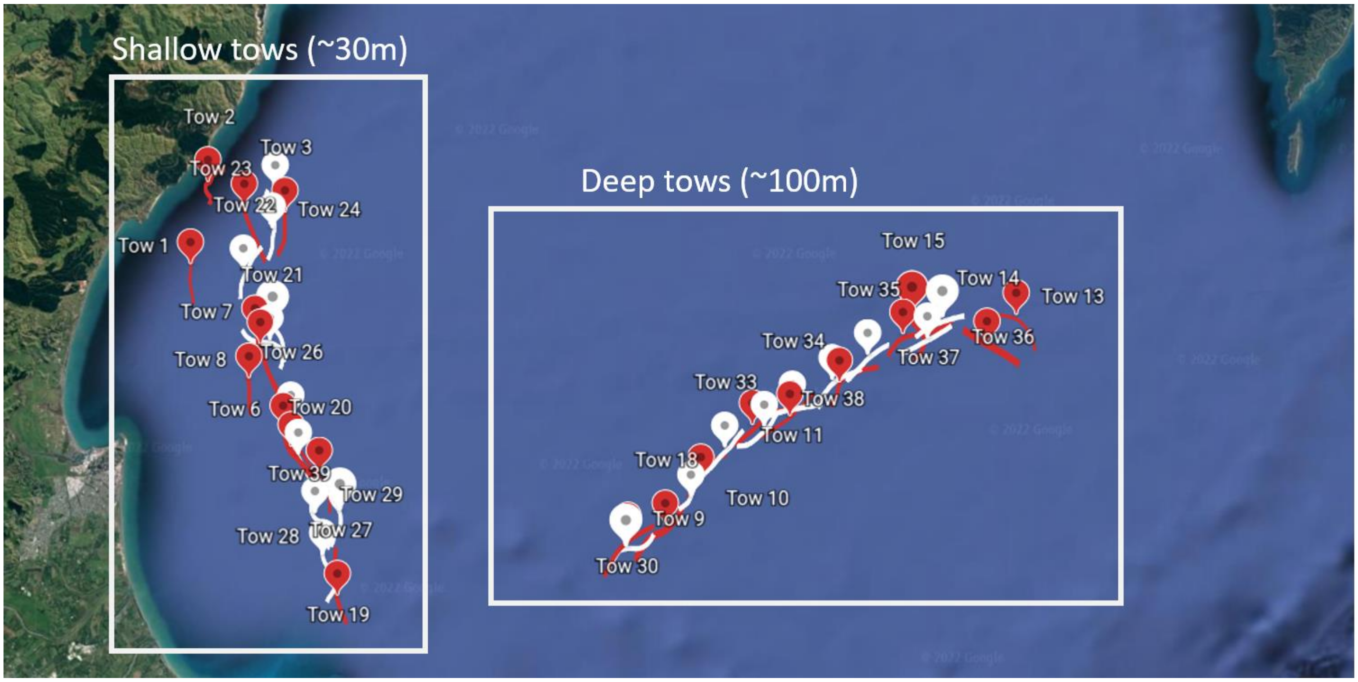


Figure 6 Tow station locations. Red stations denote where Gear Setup 1 was used; white denotes where Gear Setup 2 was used.

3.4 Data analysis

3.4.1 Video footage validation process

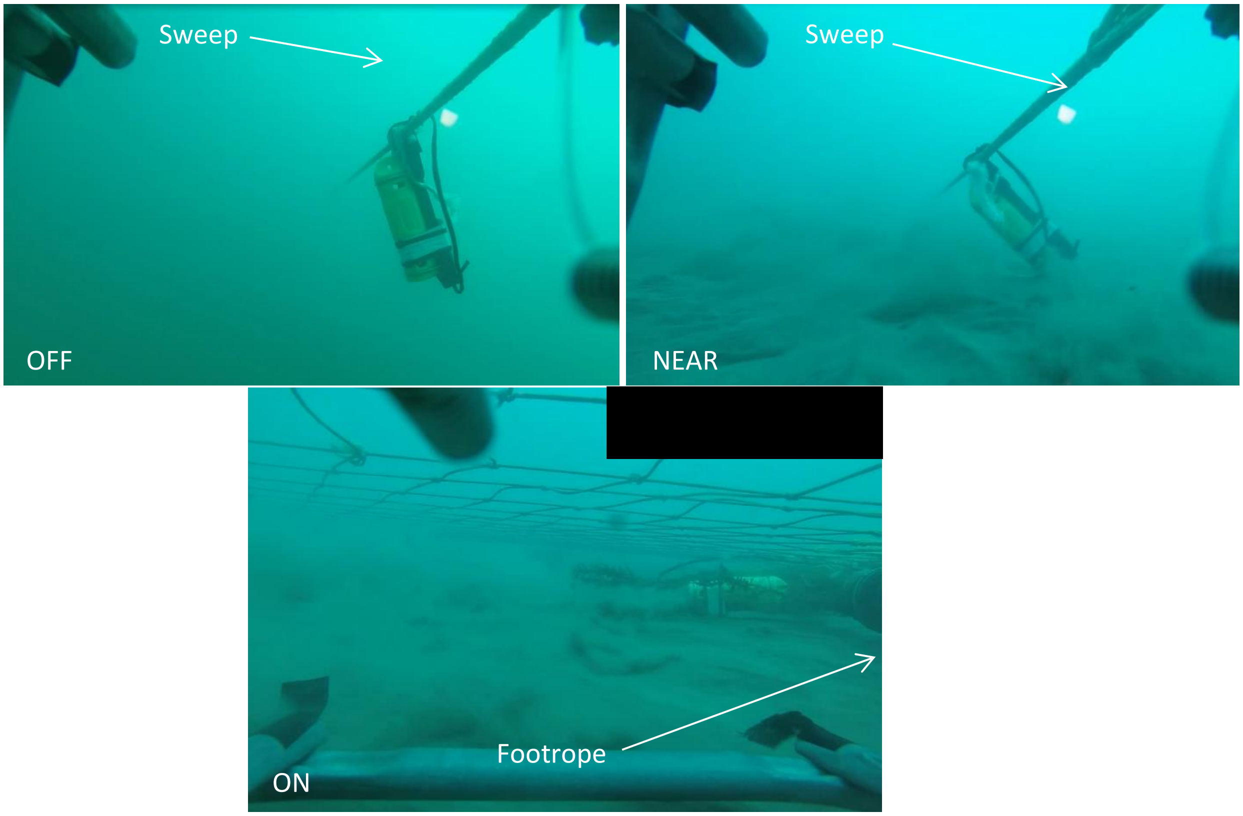
A camera was deployed on tows where possible and would be positioned to have a field of vision to assess the sensor attachment and how the sensor performs during a tow. Camera deployments were moved between sensor attachment sites to cover three locations: footrope, wingend and sweep.

In support of the sensor data collection, video footage of the sensors was collected to validate the range of tilt values that correspond to different ‘contact states’ (

Figure 7).

- “ON” is when the gear is contacting the seabed
- “NEAR” is when the gear is not in contact with the seabed, but the trailing end of the sensor is still in contact. This range of a values is a measurable distance above the seabed
- “OFF” is when both the gear and the sensor are no longer in contact with the seabed

Following King’s (2019) methodology footage clear enough was used to compare sensor clearance values to video review observations of the sensor being on or off the seabed. The respective corresponding time stamps from the sensors and video review were then used to align the two data sets and provide a validation of the sensor readings.



[redacted]

Figure 7. Video footage still examples demonstrating how video footage validation was used to determine different ‘contact states’. Top left panel shows the “OFF” contact state, top right panel shows “NEAR” and the bottom panel shows “ON”.

3.4.2 Multi-nominal regression analysis

Tilt angles measured by the sensors were used to calculate the estimated height above the seabed using trigonometric equations. Once the height above seabed was established, the values were assigned a 'clearance class' ("ON", "NEAR", OR "OFF") based on the cross-validation with the video footage.

Based on these data with height above seabed categorized by clearance class, a multinomial logistic regression model was used to establish a set of probabilities for "ON", "NEAR", and "OFF" bottom contact corresponding to specific tilt sensor readings.

Multinomial regression is a robust statistical technique for modelling a categorical dependent variable with multiple levels or classes. It is widely used in various fields to analyse data with multiple categorical outcomes (Agresti, 2013) and, is based on the principle of maximum likelihood estimation, which estimates the set of parameters that maximizes the likelihood of the observed data (Long, 1997).

The model structure used the video-reviewed sensor data to generate a model that uses sensor readings to predict levels of seabed contact. A simple model structure was used:

bottom contact class ~ vertical clearance

For each tow based on the model's predictions the raw values from each attachment site were converted into bottom contact classifications for the whole tow. The model outputs were then analysed to compare the bottom contact clearance profiles provided by the contact sensors on the two gear set ups for both the shallow and deep depth strata.

The predictor variable (vertical clearance) is the y-axis component of the sensor, obtained by taking the sine function of the sensor readings; and the response variable (bottom contact class) is the categorical designation of the tilt sensors' contact with the seabed.

3.4.3 Conversion to trawl footprint

In this study, because we had multiple sensors, each sensor measured a percentage of the overall nominal area Figure 8. The sweeps, wingends, and footrope were modelled as a catenary curve. Based on the assumed door spread, the length of the curve, and the positions of the sensors on the curve, 7 individual 'tracks' within a tow were attributed to each sensor.

The halfway point between sensors along the catenary curve was designated as the boundary between 'tracks'. (Figure 8). The proportion of these tracks compared to the overall assumed door spread was the percentage of the swept area that the sensor accounted for. These percentages were then used to weight the estimates of contact within a tow.

For each tow, nominal and contacted adjusted trawl footprints were calculated:

- Nominal swept area of a fishing event is typically the nominal width of the gear (in this case, the assumed width between the trawl doors) multiplied by the length of the tow. This trawl footprint approach was completed consistent with Baird & Mules (2021).
- Contact adjusted trawl footprint was calculated by multiplying nominal swept area times the weighted proportion of bottom contact (e.g. 'ON' observations) at each track location.

Aggregate trawl footprints were calculated by summing the 'ON' observations from all tows and dividing by the total number of observations from all tows, whilst overall percentages of contact by the different gear components (sweeps, wingends and footrope) were calculated as a sum across all tows by gear component, and divided by the total number of observations collected for that gear component across tows.

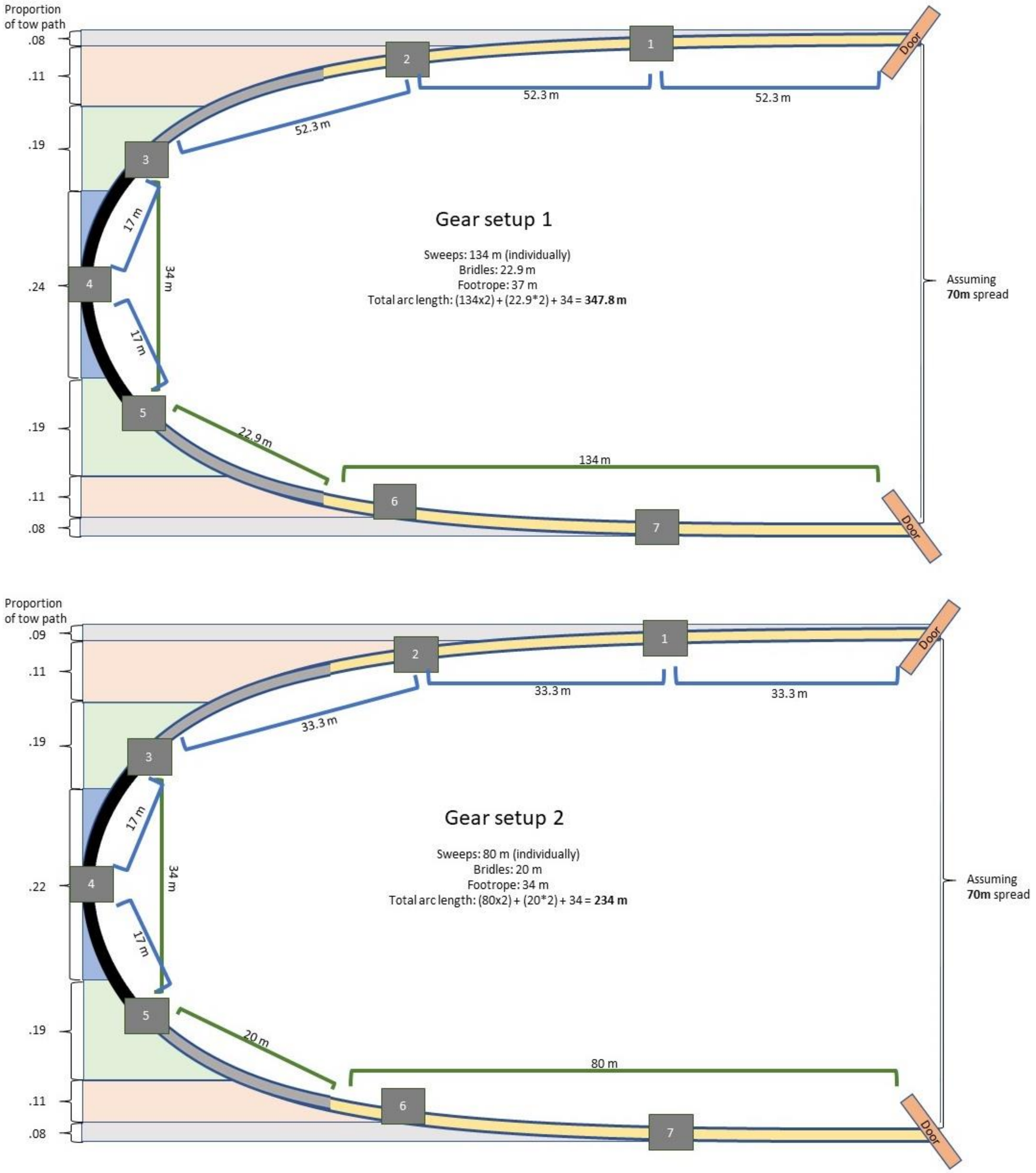


Figure 8. Representation of the modelled sweeps/bridles/footrope (as a catenary curve) associated with defining the boundaries between 'tracks' associated with each attachment site.

4 Results

The purpose of Voyage 1 (December 2021) was to assess the in-situ performance of the sensors to determine the most effective sensor attachments using a camera validation process. The collection of video footage is intended to validate the sensor data received. The detail associated with this voyage is provided in Section 3.

- In situ observations, video review and data analysis from the first voyage determined the best method of attachment and placement of sensors to ensure consistency between all subsequent tows.
- A review of the camera placement and associated video observations identified that video observations should be used where possible but that is should not detract from the focus of the project. This position was emphasised by the Technical Advisory Group (TAG) that noted that even if the camera cage is lifting the gear (creating artificial lift at the position in which the camera is attached), provided it is showing the true clearance it can still be used to support the functional measurement.

During the project four voyages were completed to develop the comparisons between bottom contact profiles using two different Gear Setups in two different depth strata. A summary of the objectives of each of the voyages is as follows:

- **Voyage 2:** This was the first data collection voyage to collect data using Gear Setup 1 conducted in May 2022. During this voyage a camera was used to continue to collect video footage and produce associated data to validate sensor data. The objective of this trip was to complete shallow water stations using Gear Setup 1. Grab samples were also taken at each station to provide ancillary data as a point sample to provide an indication on the substrate at each station.
- **Voyage 3**: This was the second data collection voyage to collect data for Gear Setup 1 in May 2022. The objective of this trip was to complete deep water stations using Gear Setup 1. During this voyage a camera was used to continue to collect video footage to validate sensor data. Grab samples were also taken at each station to provide ancillary data as a point sample to provide an indication on the substrate at each station.
- **Voyage 4:** This was the first of two voyages collecting data using Gear Setup 2in May 2022. This voyage focused on shallow water stations using Gear Setup 2. During this voyage Gear Setup 2 was used and the stations from Voyage 2 were repeated. Grab samples were taken, where possible, at each station to provide ancillary data as a point sample to provide an indication on the substrate at each station.
- **Voyage 5:** This objective of this voyage was to collect deep-water data on Gear Setup 2 in June 2022. Stations from Voyage 3 were repeated. During this voyage a camera was used, where possible, to continue to collect video footage to validate sensor data. Grab samples were taken, where possible, at each station to provide ancillary data as a point sample to provide an indication on the substrate at each station.

Table 2 provides the descriptive information from the Voyages (2 – 5) outlining the information for each Voyage and associated data collected. Voyages 2 – 5, completed for the purposes of data collection, collected 986,023 sensor readings (collected at a rate of 1 tilt measurement per second). Each sensor collected 14% of the total sensor readings (Table 3).

Table 2 Descriptive information for all data collection voyages used to develop the comparisons between bottom contact profiles using two different Gear Setups in two different depth strata

Voyage #[5]	Date start	Date end	# days	# tows	Gear Setup	Strata		# sensors used	# of records	Video used (Yes/No)	Grab sample taken (Yes / No)
						Shallow	Deep				
2	8 May 2022	9 May 2022	2	8	1	Yes	No	7	173478	Yes	Yes
3	13 May 2022	15 May 2022	3	12	1	Yes	Yes	7	294894	Yes	Yes
4	24 May 2022	25 May 2022	2	8	2	Yes	No	7	204181	No*	Yes
5	17 June 2022	19 June 2022	3	10	2	Yes	Yes	7	280701	Yes	Yes

* Using a camera was attempted but the camera housing broke during the trip and camera use could not be attempted for the remainder of the trip.

** There was one station completed in the shallow strata during this trip. This was conducted on the way back to port and in response to avoiding inclement weather conditions.

Table 3 Summary statistics for all data collection voyages used to develop the comparisons between bottom contact profiles using two different Gear Setups in two different depth strata

	# of records per sensor attachment site						
Voyage #6	Port sweep forward (1)	Port sweep aft (2)	Port wingend (3)	Footrope (4)	Starboard wingend (5)	Starboard sweep aft (6)	Starboard sweep forward (7)
2	28,268	28,448	28,448	28,448	28,448	28,401	28,224
3	42,120	42,132	42,132	42,132	42,132	42,132	42,114
4	30,249	30,249	30,249	30,249	30,249	30,249	30,249
5	39,958	40,195	40,085	40,234	40,191	40,078	39,960

4.1 Raw data analysis

Appendix 1 provides the full dataset, with examples of the data outputs from the bottom contact sensors deployed on Gear Setup 1 and 2 shown in

Figure 9 and Figure 10.

Intra tow variability[7] is apparent in the sensor height (cm) at each attachment site with sensor readings ranging from -0.5cm[8] to 25cm within a tow. The broad distribution of the histograms in the raw data figures emphasises the variation in the sensor readings within a tow. Each tow attachment site has a broad range of values that cover all vertical clearance classes demonstrating the extent of intra tow variability.

Intra tow variability appears more prominent associated with Gear Setup 2 compared to Gear Setup 1. Whilst for both Gear Setups the intra tow variability is higher for tows conducted in the deep depth strata compared to those in the shallow strata.

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[5] Voyage 1 has been omitted because this was a validation trip and did not contribute to the data analysis

[6] Voyage 1 has been omitted because this was a validation trip and did not contribute to the data analysis

[7] Intra tow variability refers to variability within a tow, meaning the amount of contact that takes place within a tow is not consistent and can change due to, for example, location of the sensor, behaviour of the fisher, benthic type and oceanic conditions. Inter refers to variability between individual tow events, i.e. one tow may have a lot of contact vs the next tow may have very little.

[8] A negative reading means that the sensor was slightly upside down.

Inter tow variability[9] is evident by the difference in contact profiles between tows demonstrated by Figure 9, Figure 10 and Appendix 1.

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[9] Inter refers to variability between individual tow events, i.e. one tow may have a lot of contact vs the next tow may have very little.

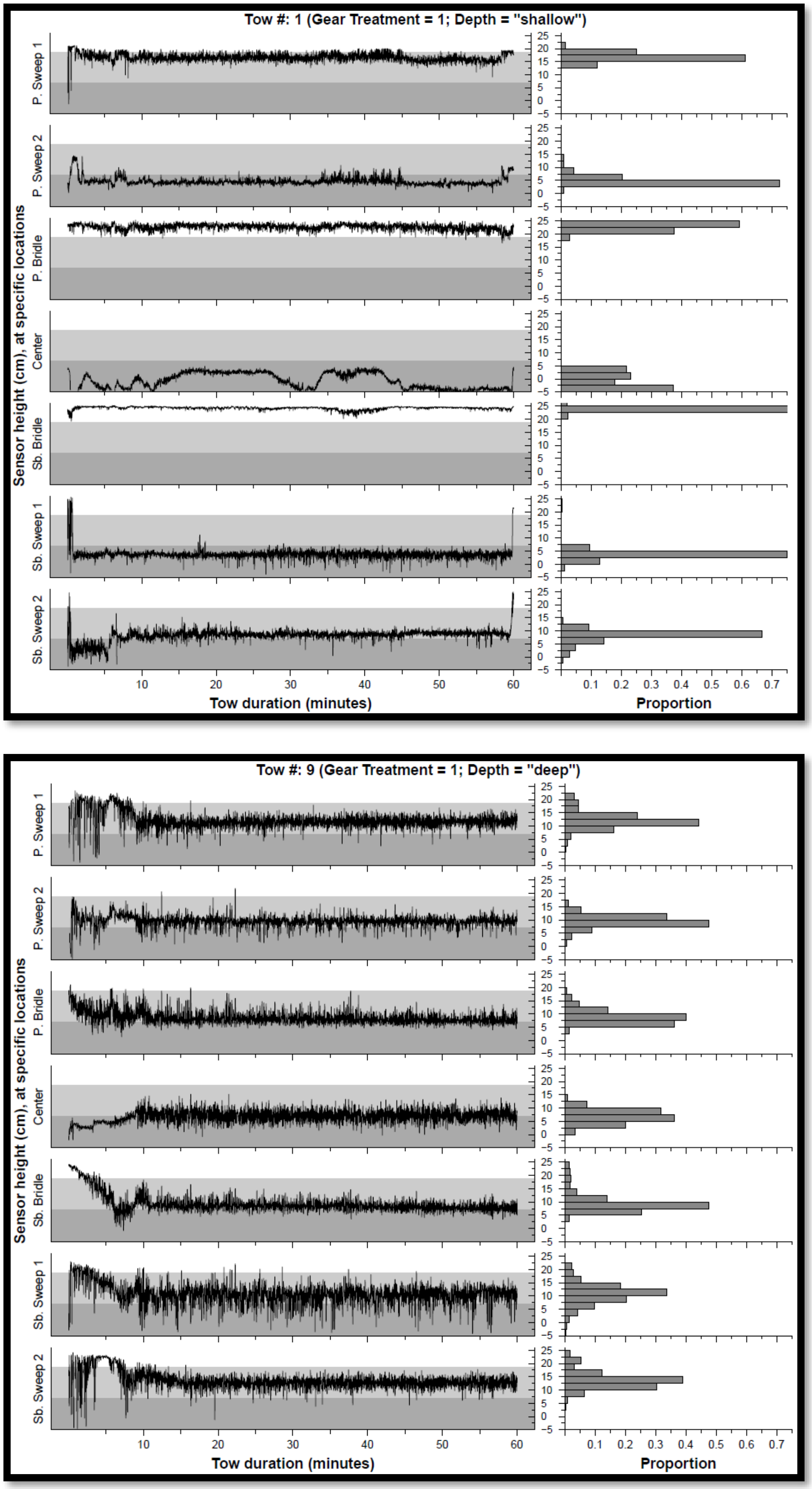

Figure 9. Example data output from bottom contact sensor deployed on Gear Setup 1. The top image is from a shallow stratum tow and the bottom image from a deep stratum tow. The left hand panel shows sensor readings at 1 minute intervals across the duration of the tow by sensor attachment site. The dark grey band indicates when a sensor is “ON” bottom, light grey is “NEAR” bottom and white is “OFF” bottom. The right hand panel shows a histrogram of the proportion of observations at a certain clearance value for the duration of the tow.

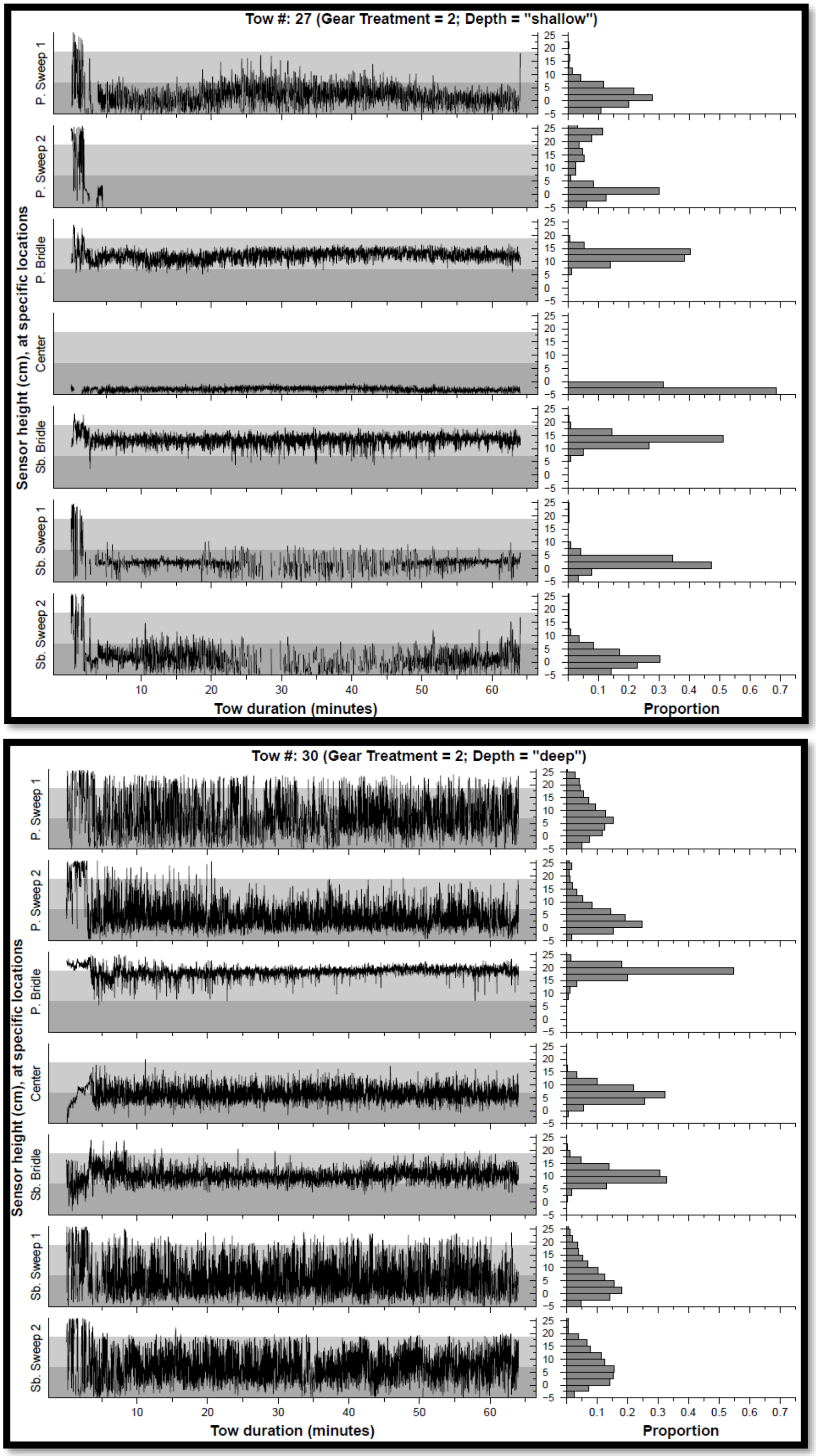

Figure 10 Example data output from bottom contact sensor deployed on Gear Setup 2. The top image is from a shallow stratum tow and the bottom image from a deep stratum tow. The left hand panel shows sensor readings at 1 minute intervals across the duration of the tow by sensor attachment site. The dark grey band indicates when a sensor is "ON" bottom, light grey is "NEAR" bottom and white is "OFF" bottom. The right hand panel shows a histrogram of the proportion of observations at a certain clearance value for the duration of the tow.

4.2 Validation of sensor data from video footage

Of the seven tows with a camera deployment only three tows were identified as tows with useable video footage for video validation analysis. This was due to issues with visibility (primarily stirred up sediment) and whether the camera was positioned well during the tow.

Figure 11 shows the aggregated video-reviewed sensor readings, where the raw tilt sensor readings have been converted into vertical clearances. The classification distributions demonstrate an overlap with each other demonstrating sensor reading variability within a classification. There is minimal overlap between the “ON” and “OFF” classifications but the “NEAR” classification has a broad bimodal range that overlaps with both the other two classifications. The results show the “ON” class has a bell curve distribution, whilst the “NEAR” and “OFF” values have a broader distribution of vertical clearance.

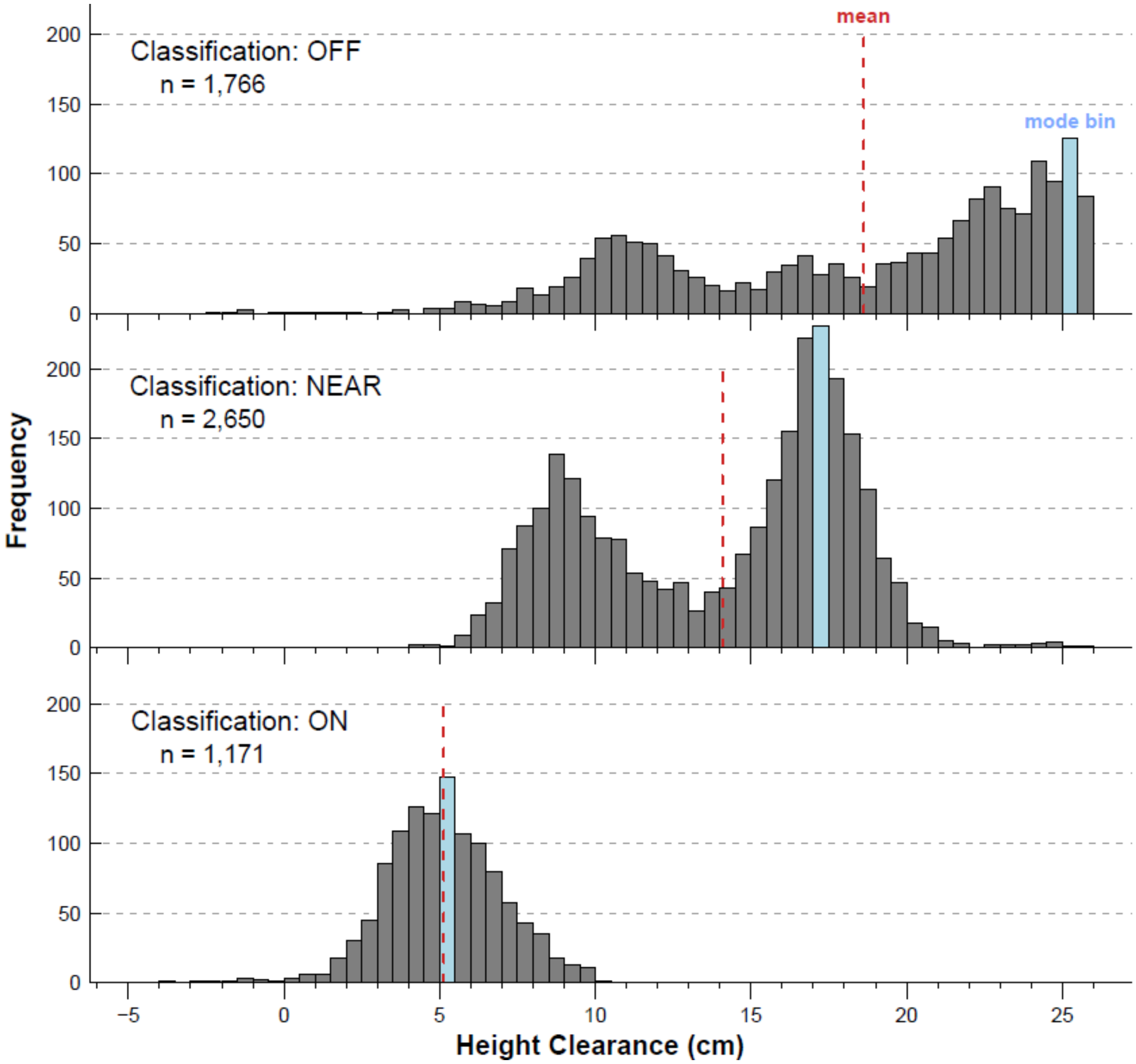

Figure 11 Video - reviewed sensor readings. Raw tilt sensor reading values have been translated to a height above the seabed.

4.3 Multinomial logistic regression analysis

Aggregated data was used instead of tow-by-tow data given the extent of intra tow variability which impacts the ability to conduct a multinominal regression analysis comparing bottom contact at the individual tow scale.

The multinominal logistic regression analysis was based on 5,587 sensor data readings which is deemed adequate to conduct a multinomial logistic regression analysis, ensuring that the results are generalizable to new values obtained in a similar setting. Model fit was evaluated using the deviance and Akaike's Information Criterion (AIC) values. The deviance of the model was 6,685.567, which represents the sum of the differences between the predicted and observed values of the outcome variable. The lower the deviance, the better the fit of the model. AIC value was calculated as: Deviance + 2 * (number of parameters in the model). As with deviance, low AIC values indicate a good fit of the model. Both residual deviance and AIC values are useful measures in future instances when different models are being compared.

A one-unit increase in the vertical clearance variable is associated with an increase of 1.14 in the log odds of being in the "NEAR" class vs. the "ON" class (SE = 0.04, z = 25.9, p < 0.00001). Similarly, a one-unit increase in the vertical clearance variable is associated with an increase of 1.31 in the log odds of being in the "OFF" class, as opposed to the "ON" class (SE = 0.05, z = 29.5, p < 0.00001).

Figure 12 provides a graphical representation of the conversion of the log odds of being in the "NEAR" class vs. the "ON" class into probabilities. The bottom contact classifications are:

- 5 cm – 7.27 cm as "ON" bottom
- 7.28 cm – 18.65 cm as "NEAR" bottom
- ≥ 18.66 cm as "OFF" bottom

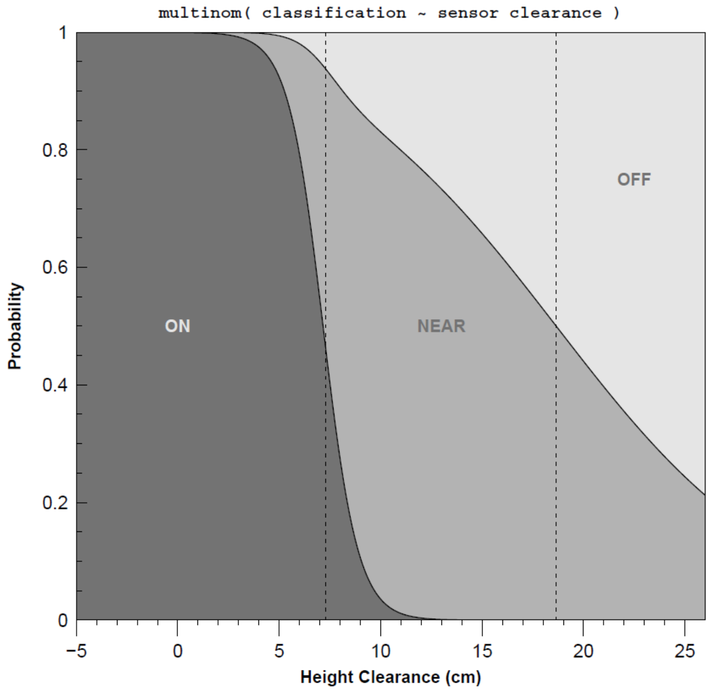

Figure 12 Multinomial logistic regression analysis results showing the (stacked) probabilities of bottom contact based on the video validated sensor readings.

4.4 Comparison of bottom contact clearance profiles between treatments

There were significantly less "ON" bottom contact observed in both the shallow and deep strata for Gear Setup 1 compared to Gear Setup 2 (Table 4 and Figure 13). The largest significant difference was apparent in the "ON" contact classification in the shallow depth strata (p = 0.00016), with the deep depth strata also showing a significant difference (p = 0.00023) (Table 6).

Observations by attachment site showed a demonstrable difference between the proportion of "ON" bottom contact at three attachment sites: Port sweep 1; Starboard sweep 1 and Starboard sweep 2. These were attachment sites where the recorded confidence intervals for each of the gear set ups did not overlap (Figure 14 and Appendix 2).

Statistical analysis showed a significant difference between the two Gear Setups at the following attachment sites:

- **Port sweep** – there is a significant difference in both the shallow and deep depth strata for port sweep 1 whilst for port sweep 2 there was a significant difference in the deep strata only.
- **Starboard sweep** – there is a significant difference in both the shallow and deep depth strata for starboard sweep 2 whilst for starboard sweep 1 there was a significant difference in the deep strata only.

Appendix 2 also shows a significant difference in the footrope contact in the shallow strata.

Figure 13 shows a higher proportion of "NEAR" bottom contact when using the lighter Gear Set up 1 compared to the heavier Gear Set up 2 in the deep strata. This is an artifact of the fact percentages are being compared across individual tows meaning that if "ON" contact is low then proportional either "NEAR" or "OFF" will be high in order to equal 100%.

Table 4 Dunn (1964) Kruskal-Wallis multiple comparison results showing p-values adjusted with the Bonferroni method.

Comparison			
Depth strata	Contact classification	Z	Adjusted p-value
Shallow	ON	-3.779645	0.0001570523*
Shallow	NEAR	1.889822	0.05878172
Shallow	OFF	2.418973	0.01556441
Deep	ON	-3.674235	0.0002385635*
Deep	NEAR	3.674235	0.0002385635*
Deep	OFF	-0.7348469	0.4624327

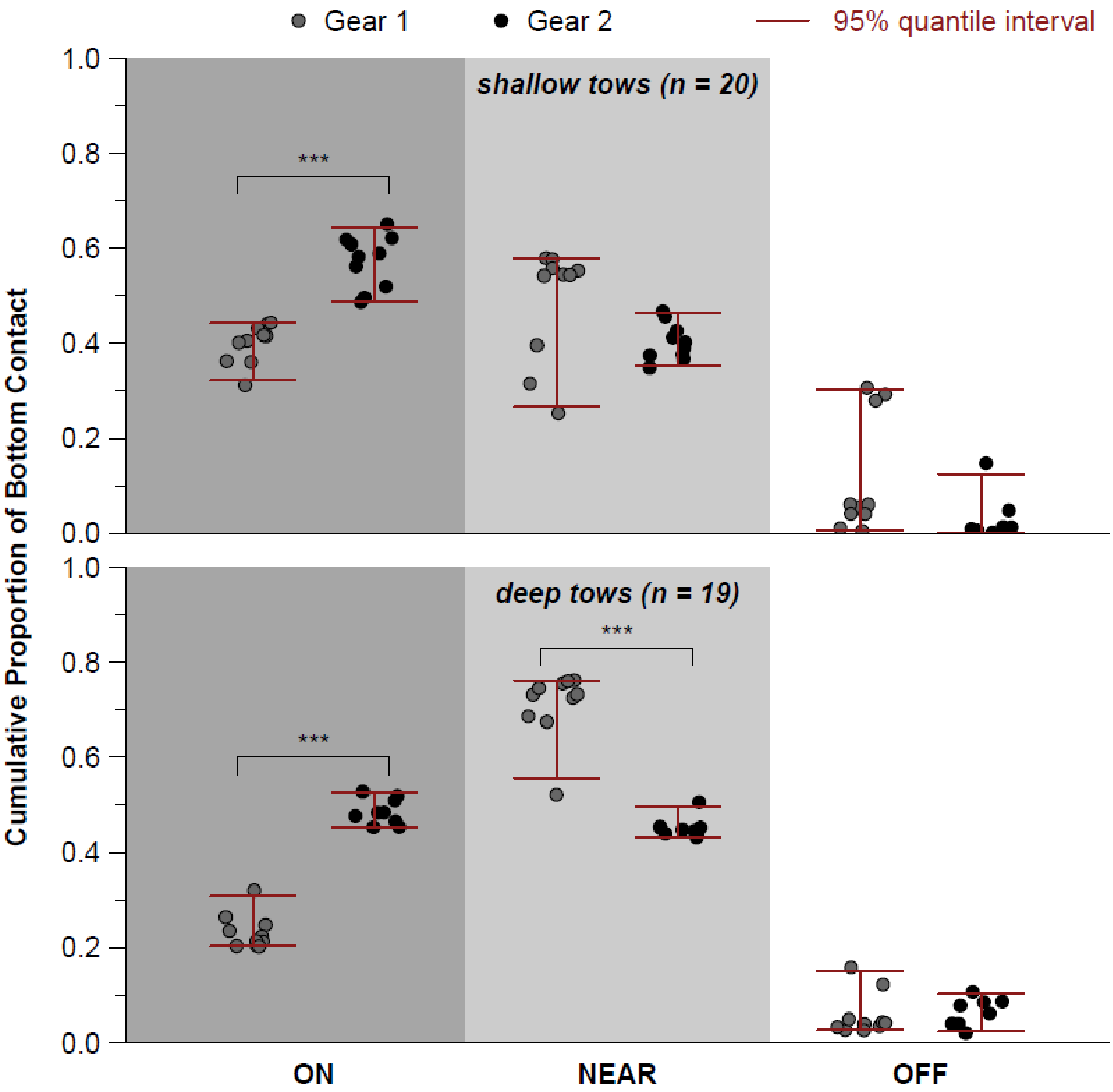

Figure 13 Comparison of the cumulative levels of bottom contact between gear treatments and depth strata. Each data point is a tow representing the cumulative bottom contact across the duration of a tow.

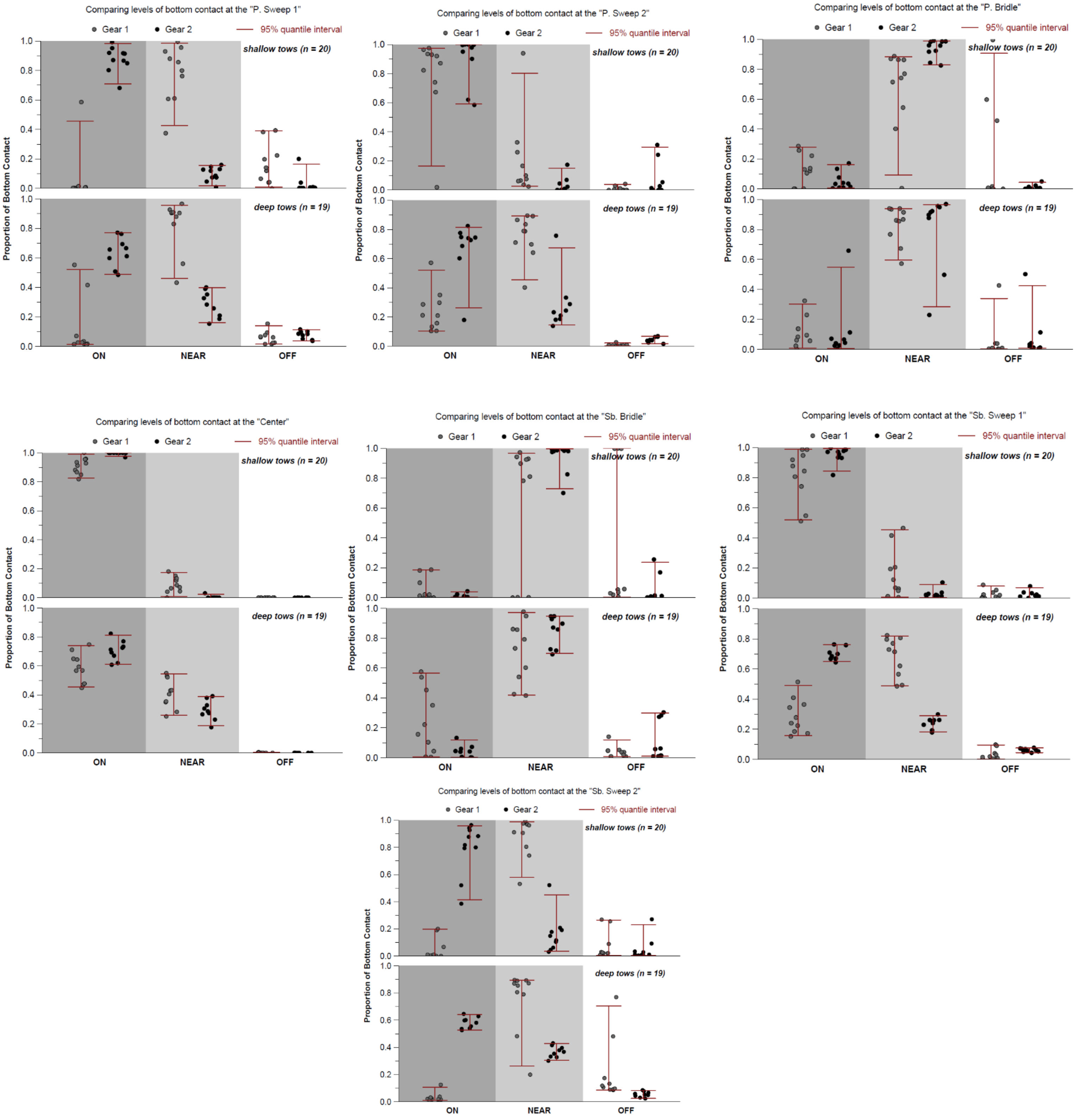

Figure 14 Comparison of the cumulative levels of bottom contact between gear treatments and depth strata. Each data point is a tow representing the cumulative bottom contact across the duration of a tow.

4.5 Trawl footprint comparison

Comparing between trawl footprint methodologies shows there is a demonstrable difference between the currently used nominal approach and the contact adjusted approach used in this study. Figure 15 shows that the "ON" adjusted results have a tight 95% confidence interval with a relatively tight spread between tows, yet the spread of the data for the combined "ON and NEAR" adjusted footprint demonstrates the level of variability associated with the "NEAR" values.

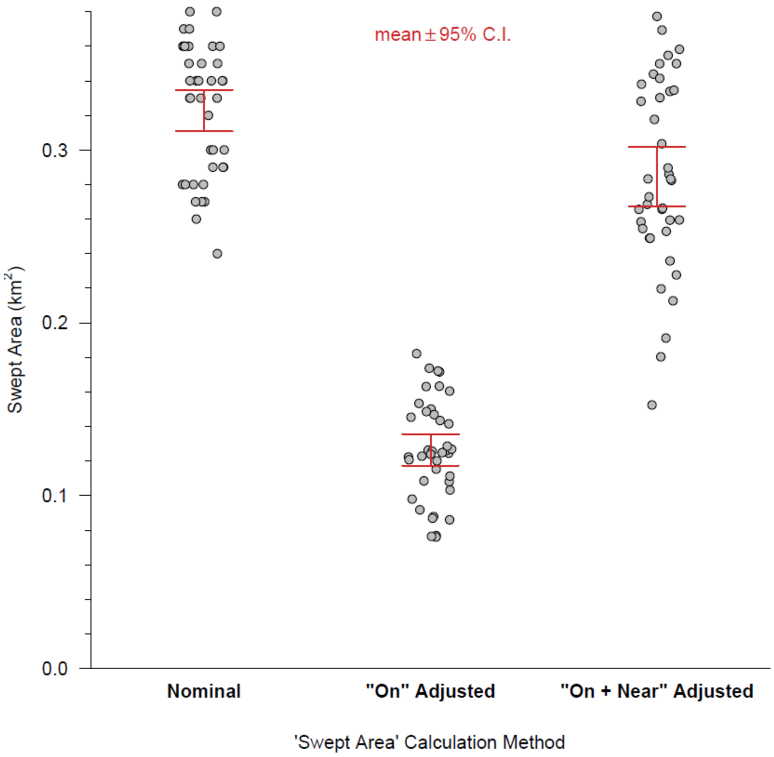

Figure 15 Comparison of the swept area between trawl footprint calculation methodologies.

The average contact adjusted tow footprint for "ON" was 0.122 km^2 and 0.132 km^2 for both Gear Setup 1 and Gear Setup 2 compared to 0.341 km^2 and 0.304 km^2 using the nominal trawl footprint. This equates to a 64% and 57% reduction in bottom contact when using the "ON contacted adjusted" footprint analysis methodology compared to the nominal swept area (Table 5).

For Gear Setup 1, the sweeps were in contact with the seabed 31% of time compared to 54% for gear set up 2, whilst the footropes for both Gear setups were in contact with the seabed for the majority of the time (75% for Gear Setup 1 and 81% for Gear Setup 2) (Table 5).

A significant difference in bottom contact is apparent between the two trawl footprint calculation methods (Table 6). Gear Setup 1 showed a significant difference between the nominal and "ON" contact adjusted trawl footprint methodology in both the shallow and deep strata. Gear Setup 2 shows a significance in the deep strata only.

A conservative sensitivity analysis undertaken by combining the "ON" and "NEAR" bottom contact classifications was consistent with the "ON" contact adjusted analysis results. It showed a decrease in bottom contact for both Gear Setups and depth strata but that the size of this decrease is less (Table 7).

Contact adjusted footprint for Gear Setup 1 resulted in a larger decline in the swept area for deep strata compared to shallow strata, 72% and 56% decline respectively, whilst Gear Setup 2 had comparable reductions for both the shallow and deep strata (57% and 56%).

Table 5 Summary statistics for the two Gear Setup s used during the research voyages. The percentages shown represent the proportion of sensor readings at that attachment site that were "ON".

		Gear Setup 1			Gear Setup 2		
		Aggregate	Shallow	Deep	Aggregate	Shallow	Deep
	Number of tows	20	10	10	19	10	9
Nominal bottom contact[10]	Swept area (km^2)	6.82	3.36	3.46	5.77	3.22	2.55
Contact-adjusted bottom contact	"ON" swept area (km^2)	2.44	1.47	0.97	2.49	1.38	1.11
	% of "ON" seabed contact that took place in the centre of the footrope	75%	46%	29%	81%	45%	36%
	% of "ON" seabed contact that took place in the sweeps	31%	22%	9%	54%	23%	31%
	% of "ON" seabed contact that took place in the wingends	15%	5%	10%	5%	1%	4%

Table 6 Dunn (1964) Kruskal-Wallis multiple comparison results showing p-values adjusted with the Bonferroni method.

Comparison		Z	P-value	
Depth strata	Gear Setup		Unadjusted	Adjusted
Shallow	Gear Setup 1	-3.779645	0.0001570523*	0.0001570523*
Shallow	Gear Setup 2	1.889822	0.05878172	0.05878172
Deep	Gear Setup 1	-3.674235	0.0002385635*	0.0002385635*
Deep	Gear Setup 2	3.674235	0.0002385635*	0.0002385635*

Table 7 Summary statistics for the two Gear Setups used during the research voyages. The percentages shown represent the proportion of sensor readings at that attachment site that were "ON".

		Gear Setup 1			Gear Setup 2		
		Aggregate	Shallow	Deep	Aggregate	Shallow	Deep
	Number of tows	20	10	10	19	10	9
Nominal bottom contact[11]	Swept area (km^2)	6.82	3.36	3.46	5.77	3.22	2.55
Contact-adjusted bottom contact	"ON" and "NEAR" combined swept area (km^2)	6.25	2.96	3.29	4.82	2.52	2.3
	% of "ON" and "NEAR" combined seabed contact that took place in the centre of the footrope	99%	50%	49%	96%	45%	51%
	% of "ON" and "NEAR" combined seabed contact that took place in the sweeps	92%	47%	45%	70%	25%	45%
	% of "ON" and "NEAR" combined seabed contact that took place in the wingends	87%	39%	48%	93%	47%	46%

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[10] Applied a 70m trawl width when calculating the nominal swept area. This is consistent with the methodology and approach as per Baird, S.J.; Mules, R. (2021). Extent of bottom contact by commercial fishing activity in New Zealand waters, for 1989–90 to 2017–18. New Zealand Aquatic Environment and Biodiversity Report No. 259. 143 p.

[11] Ibid

4.6 Validation of sensor accuracy

An additional Voyage was completed with days split across December 2022 – February 2023 due to poor weather conditions. The purpose of the voyage was to deploy 15 sensors on the gear, deploying multiple sensors at each attachment site to collect data to validate the sensor readings. At the sweep and wingend attachment sites two sensors were placed next to each other, whilst three sensors were used on the footrope.

Sensor data validation was conducted to increase the confidence that sensors are providing an accurate and precise reflection of the extent of bottom contact. Figure 16 shows that the sweeps provided the most precise sensor readings and that the footrope had the highest variability in sensor readings.

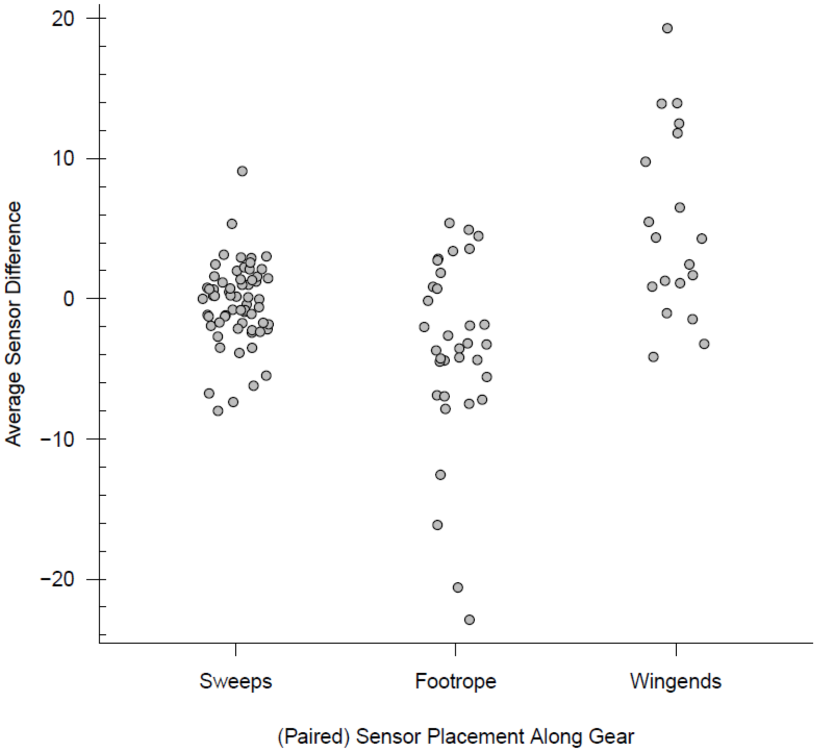

Figure 16 Summary of mean differences between side-by-side sensors placed in three locations along the gear (sweeps, footrope and wingends) (across the sum of 21 tows)

4.7 Catch rates and size composition

The project scope initially intended to analyse the catch composition between the different gear set ups and between depth strata.

As a result of the process to unhook the sensors, the vessel was required to pause hauling whilst the sweep and bridle sensors could be removed. This could result in a positive bias in the catch composition towards slower swimming species and/or catch taken early in the tow and more exhausted as opposed to any faster or stronger fish which could have more ability to escape the net.

The operational observations described above identified that analysis between catch compositions would not provide an accurate representation of the selectivity of the nets or provide an accurate comparison between catch compositions.

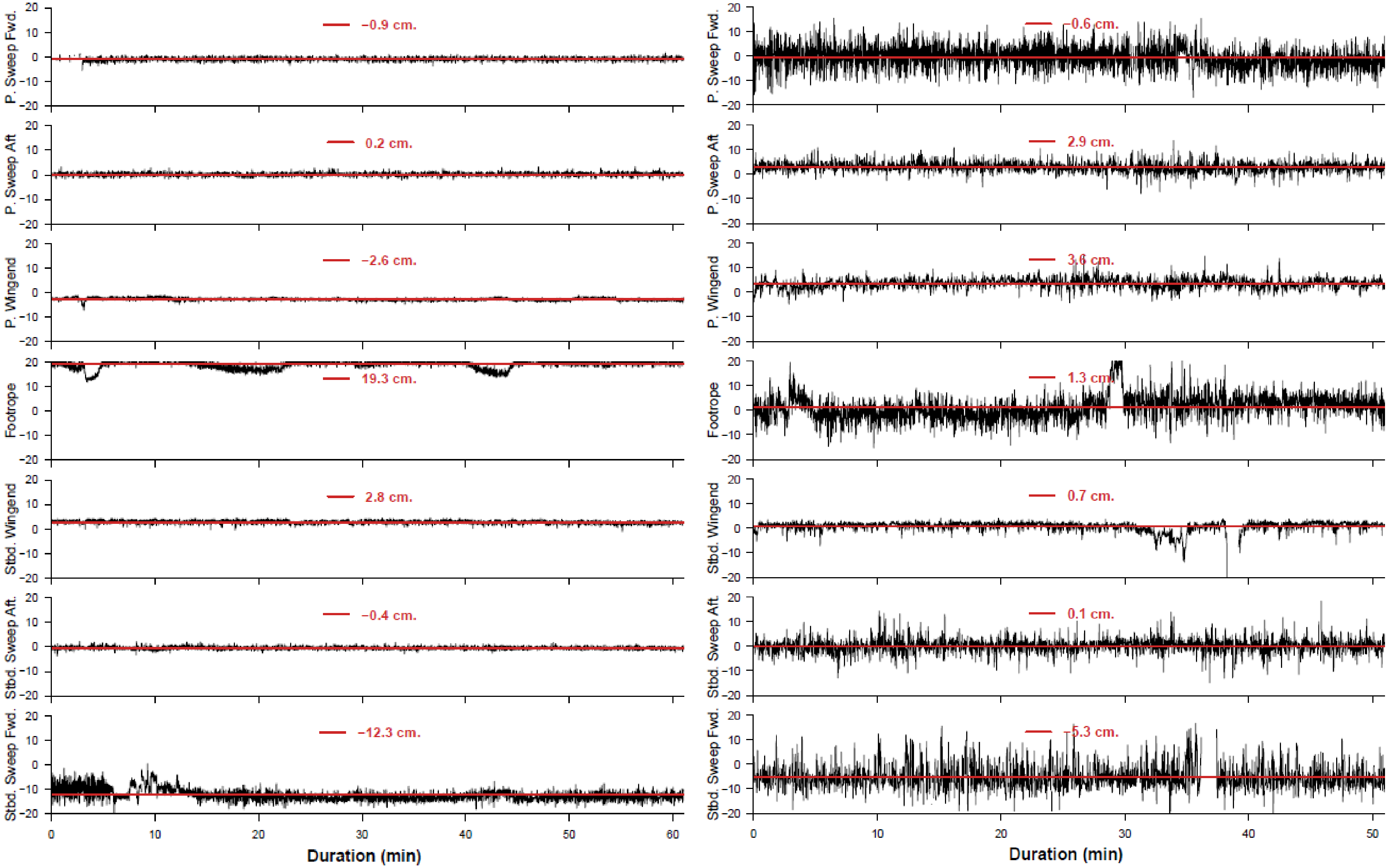

Figure 17 Difference between side-by-side sensor readings at various gear locations

5 Embracing a data driven future

5.1 Creating an empirical baseline

The current study results show that the shallow strata had the largest reduction in swept area when using contacted adjusted data. This is consistent with Ragnarsson & Steingrímsson, (2003) who identified that swept areas based on fixed assumptions *"overestimated the swept area in shallow waters but underestimated the swept area in deeper waters.".*

It is recognised that a number of factors can influence trawl footprints, however to date there is an acceptance that accounting for all these variables such as towing speed, bottom type and bridle lengths are difficult to incorporate (Ragnarsson & Steingrímsson, 2003).

The difficulty of accounting for all the variables is acknowledged, but that only emphasises the need to have robust empirical baseline to inform associated work. It is critically important that we better understand our trawl footprint, considering how this information is used to support fishery assessments and support risk-based management frameworks.

The proportion of bottom contact did not directly record swept area associated with the doors, however as Neill (2015) notes, the hydrodynamic drag of the ground gear and net is 3.5 times that of the doors, thereby justifying the focus on the sensor attachment sites used. The ability to predict the physical impacts at the gear component level will allow the quantitative assessments of gear modifications at the design stage and permit an evaluation of the extent to which physical impacts can be mitigated (Neill & Ivanovic, 2015).

5.1.1 Understanding variability

Higher intra tow variability was apparent for Gear Setup 2 whilst Gear Setup 1 had higher inter tow variability. It is considered this is due to a range of factors that require more investigation to support detailed interpretation of sensor readings.

Heterogeneity in the behaviour of the fishing gear at each attachment both within and between tows is consistent with the scientific literature that emphasises that there is variability associated with the physical effect of demersal trawling (e.g. Amoroso et al., 2018b; Hiddink et al., 2017; Kaiser, 2019; O'Neill et al., 2018; Rijnsdorp et al., 2020).

The intra tow variability at each attachment site and between attachment sites shows that the gear is not uniformly being pulled across the seabed during a tow and different gear components are experiencing different levels of environmental or operational influences. Variability of bottom contact at the different attachment sites is consistent with literature that has recorded jumping otter board tracks or herring bone patterns, demonstrating that there is not consistent contact (Bradshaw et al.,2021; Smith et al. , 2007).

The additional sensor validation process-built confidence that the sensors are providing precise and accurate data with the sensors deployed next to each other behaving in the same manner. The validation process also confirmed the extent of intra and inter variability. For instance where the paired sensors readings diverged, it indicates either the sensors are acting differently as a result of their attachment site or the sensors are impacting each other. Observations were also made whereby paired sensors' readings demonstrably changed during a tow suggesting that the sensors can be affected during tows. It is assumed that these are the result of environmental operational factors such as when the vessel may be turning resulting in a door raising off the seabed which is expected in turn to lift associated gear components (e.g. sweeps and bridles) (Smith et al., 2007).

To truly understand the drivers of this variability both within and between tows, data sources should be correlated to support interpretation of the data using co-variates, which should include vessel operations and environmental data.

Whilst precision can be assessed by looking at the difference between sensor readings, the issue of accuracy is more complex. To provide an assessment of accuracy, in situ cameras are required to provide an independent review of the sensor data. Continued camera use for the purposes of sensor data validation will improve understanding of what causes differences between sensor readings and which sensor is providing the accurate measurement. Additionally, video footage will provide the ability to interpret and understand what dynamics are influencing the difference in values or a divergence in values that occurs part way through a tow.

5.1.2 Interpreting the influence of depth on bottom contact

A higher level of intra variability is apparent for both Gear Setups associated with deep strata compared to shallow strata. The results show a decrease in bottom contact across all components for Gear Set up 1 compared to Gear Setup 2.

The results from the study that depth is influencing the variability in sensor readings within and between tows and is affecting the trawl footprint readings is supported by the scientific literature. Ragnarsson & Steingrímsson (2003) showed applying generic assumptions resulted in larger swept area estimations, with impacts on the swept area dependent on the depth strata. Ragnarsson & Steingrímsson (2003) identified using a fixed door spread approach (compared to varying the door spread estimated on bridle length) impacts swept area estimations with the fixed approach resulting in a higher swept area estimation.

Weinberg and Kotwicki (2015) showed increased variability in bottom contact associated with the deep depth range compared to the shallow depth range. They attributed this to degree of warp catenary, which increases at greater depths, thereby transferring pulling forces from upward to horizontal resulting in increased bottom contact.

Differences in the bottom contact between the depth strata could be attributable to the seabed strata. Ivanovic (2015) records that cohesive sediments (such as mud) result in larger drag forces compared to less cohesive, sandier sediments. Understanding and accounting for these differences is important as demersal trawling is not consistently associated with particular sediment types (Amoroso et al., 2018), meaning there is a need to account for any differences in bottom contact to support decision-making.

Sediment sampling data collected during the studies indicates that this is a plausible hypothesis, but to verify this further video validation and co-variate analysis is required to investigate the extent of the effect of sediment on the sensor readings.

It identifies the need for continued camera validation to quantify the effect environmental and operational factors are having on the sensor readings.

5.2 Supporting risk based management

5.2.1 Why improved understanding is important

Given the importance of our trawl footprint for informing broader management, it is imperative that the best available data is used to support associated decision making related to the effects of trawling for a range of fisheries management decisions (Ragnarsson & Steingrímsson, 2003). Inherent variability in seabed contact and associated affects associated with the performance of different commercial can have strong implications for management, research, and industry (King, 2019).

It is acknowledged that high resolution quantitative information is needed to support these decisions and the scientific literature emphasises the potential of 'advanced remote sensing technology' to support work to improve the decision-making process (Marrs er al., 2022; Ragnarsson & Steingrímsson., 2003).

Oversimplistic assumptions being used to characterise our inshore trawl footprint means that management decisions and the promotion of innovation is undermined, resulting in inaccurate statements and predetermined assumptions to be made on the extent and scale of benthic interactions. AEBR 2020-21 recognises the need for ongoing research to refine 'methods to estimate the extent and effect of bottom fishing' (Baird & Mules, 2021).

Determining the granularity of the data collection needed to support management decisions will enable decisions to be made regarding broader uptake of the technology, future research plans and research and development work in associated research areas. Currently Fisheries New Zealand defines any trawl event using demersal trawl gear or midwater gear within 1m of the seafloor as bottom contact (Baird & Mules, 2021). Policy makers and managers have taken a pragmatic approach to defining and monitoring the trawl footprint based on the availability of data.

Ultimately discussions need to be had to confirm the desire for improved measurement of trawl footprint using fine scale data, and that this information will be used to inform decision making.

Further work is work required but it is advisable to consider broadening uptake of this technology in line with broader strategic planning, research and policy considerations. Accounting for these the following needs to be considered:

- What is the applicability and efficacy of using centimetre measurement instead of metres?
- Do the definitions of bottom contact for the purposes of trawl footprint analysis need to consider whether the 1m rule needs to be reviewed to account for improved knowledge of tow-by-tow bottom contact?
- Is a review of the applicability of the 1m rule for all areas and habitats warranted now that technology can provide higher resolution data?
- Should a generic rule or a more nuanced approach account for habitat and sub-strata differences. Such an approach would require work to be completed to ensure there is good fine-scale habitat information.
- What is the impact of the use of the nominal footprint approach, including the associated assumptions, in overestimating the extent of the trawl footprint?
- Is it practicable to broaden the use of technology sufficiently to provide coverage that can support the current trawl footprint methodologies and augment existing approaches?

Improving the measurable clearance range would be of interest considering that the AEBR fishing footprint models consider gear within 1m of the seabed to be in contact. Understanding the near-seabed interactions with benthic structures would improve understanding of benthic interaction effects.

5.2.2 Importance of high-resolution effort data – moving from assumptions to empirical data

Our research shows that our fine-scale knowledge of demersal trawling bottom contact is still rather rudimentary and that bottom contact associated with demersal trawling is highly variable both within and between tows in an inshore context. Current assumptions associated with calculating the nominal trawl footprint don't account for intra and inter variability in the physical effects of demersal trawling., emphasising the need for fine scale detailed information.

There is a demonstrable difference between the various methods used to calculate trawl footprints and that the contact adjusted approach has a lower proportion of bottom contact compared to the current nominal approach. The results indicate that the coarse level being used at the moment to determine trawl footprints is overestimating and oversimplifying the extent of bottom contact.

Trawl footprints are generally overestimated with the nominal swept area methodology. Given footprints are used as the basis for assessing trawling impacts, it is important that the best available fine-scale data is used to inform trawl footprint estimates (e.g. Eigaard et al., 2016a; O'Neill and Ivanović, 2016; Hiddink et al., 2017).

Fisheries require a data-driven future, supported and built upon robust data and monitoring regimes. The current study shows higher resolution data can be collected and corroborates the view that empirical data collection supports *'higher resolution estimations of area of ocean swept by fishing'* and results in a *'notable decrease in estimated area swept by fishing'* (King et al. 2019; Amoroso et al. 2018).

Fisheries New Zealand continues to refine its established nominal footprint methodology to monitor trends in the extent and intensity of trawl footprints. The accepted footprint approach is iteratively being refined, in order to improve our understanding, as new data becomes available. The introduction of electronic reporting and geospatial position reporting has improved the precision associated with vessel trawls and provide for more realistic trawl tracklines (Baird & Mules, 2021).

The existing trawl footprint studies have identified that the trawl footprint analysis is improved with finer resolution data. Notwithstanding these advancements there has not been a fundamental shift away from the use of the underlying assumptions of 100% contact for a polygon associated with a trawling event even though other research states that to be oversimplistic. This study identifies that more detailed data can be collected to improve the information to support and/ or review the validity of the current policy position of 100% contact across the entire swept area if the net is within 1m of the surface.

5.2.3 Enhancing the current trawl footprint methodology

Striving for a data driven methodology is consistent with the *Future of Aotearoa commercial fisheries report* (Gerrard, J., 2021) and Bradley et al.'s (2019) observations that new approaches to fisheries data systems will *'promote innovation to increase data coverage, accuracy and resolution, while reducing costs and allowing adaptive, responsive, near real-time management decision-making to improve fisheries outcomes'*

The collection of empirical bottom contact data is emblematic of a data-driven future. It represents continued advancement from the current modelling approaches to quantitative assessments of gear component interactions with the seabed (Ivanović and O'Neill,2015; Ivanovic, 2015).

The study demonstrated the capability of the technology and represents that start of a development pathway. Results should not be extrapolated to the broader fishing industry, as this would result in different inaccurate generalisations associated with contact adjusted trawl footprints (Ragnarsson & Steingrímsson, 2003) which would be directly contrary to the vision to move away from generalised assumptions and move to in situ empirical measurements.

Notwithstanding, the study presents the potential to enhance the current trawl methodology by advancing the Baird & Mules (2021). Broadening the study's approach will address the recognised limitations of the current study and should be done in conjunction with the continual improvement of the nominal approach. A collaborative work programme that allows for a comprehensive comparison of the approaches will support decision-makers to determine the most appropriate methodology for calculating the trawl footprint in the future.

It is recognised that the current study had limitations: 1) is of limited scale and focussed on one vessel in one area and (2) as with other studies it does not account for externalities such as sea state conditions, vessel factors such as the impact of changes to the vessel track during a tow.

These limitations would be addressed through broader uptake of these sensors. The collection of empirical covariate data associated with bottom contact should also be considered in order to advance our knowledge of how environmental and operational factors can influence trawl footprints associated with different trawl gear set ups.

5.3 Establishing a data driven framework to support innovation to improve trawl efficiency

This study will not directly improve trawl efficiency but demonstrates there is a methodology available to generate a baseline of physical interaction between gear components and the seabed. This research presents a data collection framework that can be used to quantify the contribution of technological innovations. The availability of that comparative data will assist fishers to choose gear that increases trawl efficiency.

Trawl efficiency is about catching an optimum amount of fish whilst using as little energy, fuel, effort, etc. as possible.

5.3.1 Demonstrating the ability to quantity innovation to improve trawl efficiency

Observations from the current study reinforces the accepted literature that lightening components of the fishing gear can lighten the extent of the bottom contact. It is well recognised that modifications to demersal trawl gear can reduce the extent of the physical interaction with the seabed (McConnaughey et al., 2019). The degree of contact of the trawl with the seabed depends on the design and rigging of the gear, the speed at which the gear is towed, and the characteristics of the seabed (He and Winger, 2010; Buhl-Mortensen et al ., 2014). Existing papers quantifying the change in habitat disturbance that can be achieved through gear modifications such as amending the warp-length-to-depth ratio (Valdemarsen et al., 2007), or adjusting the footrope can reduce habitat disturbance by 24% (Smeltz, Harris, Olson, & Sethi, 2019).

Trawl efficiency improvements have historically focussed on catchability (Poos et al., 2020; Rijnsdorp et al., 2008). However, in reality fishers view trawl efficiency in a broader sense accounting for fuel use, the wear and tear of gear, tow times as well as catchability and associated catch per unit effort returns. McConnaughey et al. (2019) recognises the trade-off required given higher levels of bottom contact can improve capture efficiency but may also increase net abrasion and fuel use.

This study shows that a quantitative baseline can be determined using these sensors and that they can identify and demonstrate differences in bottom contact between different gear set ups. The ability to determine differences specific to gear components directly benefits fishers by informing them about the exact nature of how changes at the gear component level influence catchability, fuel use and gear abrasion.

Supporting fishers to improve their trawl efficiency requires the need to associate the quantification of baseline information and any reductions in bottom contact with a reduced environmental impact. As noted by Jennings & Revill (2007) ‘in developing and introducing gears with reduced environmental impact, a key step is to assess the current and future (with the new gear) impacts of fishing in relation to the status and profitability of the fishery, the state of ecosystem components and attributes, and policy objectives for the fishery and the ecosystem.'

Jennings & Revill (2007) identify the uptake of innovative gear is negatively influenced where fishers see no incentives or disincentives to making changes. To support the broad uptake of sensors to provide the value in getting detailed bottom contact profiles, the value-add proposition for fishers needs to clearly outlined. Suuronen (2022) identifies the need for motivation and readiness to accept change. Suuronen (2022) identifies the presumed incentives range from long-term biological and socio-economic benefits as well as improved social as a result of improved reputation of fisheries. An example of the profitability associated with improved trawl efficiency is shown by Ivanovic (2015) who showed that combined contact and hydrodynamic drag of demersal towed gear can account for up to 80% of fuel consumed while towing. Given volatile fuel prices and increased cost pressures on operators and fishers, it is of interest to reduce cost and increase trawl efficiencies where possible.

Expansion of sensor uptake should emphasise that the sensors provide the data with which fishers can then assess how trawl efficiency improvements can most effectively be made whilst not adversely impacting their catch. The data should also illuminate whether a change to specific gear components (e.g. a lightening of the footrope) could potentially result in increased pressure in other areas of the footrope – thereby undermining the benefit achieved by reducing physical contact in one area if it does not reduce the level of overall drag and associated fuel use (McConnaughey et al., 2019).

5.4 Future vision

Continuing this work and expanding this scope is dependent on clear dissemination of the strong incentives for advancing this work:

- **Fishers demonstrate their provenance** individually by demonstrating their own bottom contact profiles compared to the generic wider industry profiles. Where appropriate it will enable fishers to demonstrate any changes in their bottom contact profiles. Collectively fleets will be able to demonstrate a combined lighter footprint than historically – this will be important with the concerns about the impacts of trawl on the benthos.
- **Continued innovation on gear modifications** by recognising a range of innovations already exist amongst fishers but historically these are poorly recorded. Sensor use is expected to support fishers in recording the success of current innovations and drive further innovations appropriate to their operations.
- **Support operational decisions on locations of fishing** based on finer scale sub-strata data and finer resolution bottom contact data.
- **Development of vessel specific risk assessment** associated with their bottom contact profile and trends in bottom contact, directly aligned with individual gear set and any subsequent changes to their gear.
- **Regulatory framework developments** accounting for empirically derived contact when developing spatial management tools.

Recommendations for further research to achieve this include:

- **Support broader sensor uptake across the commercial fishing fleet** with data collection integrated into normal fishing operations to support the ongoing demonstration of the utility of the sensors and deployment of the sensors on other vessels within the fleet. One way to support broader uptake is to develop reference sheets that indicate the potential bottom contact changes

associated with a range of gear changes. To achieve this it is proposed that the current study is advanced by continuing comparative analysis of different gear types and configurations on one or two vessels and making the results of that known to trawlers throughout the country.
- **Expansion of sensor placements per tow.** The current study extrapolated the bottom contact for a tow from sensor locations across each portion of the gear. But the current sensor placements did not provide information on bottom contact profiles after the mouth of the net. Broadening of sensor deployments and an increase in the number used per tow will strengthen the interpretation of contact adjusted trawl footprints. It will also facilitate an increased understanding of inter and intra variability and support gear technology research directed specifically to address fishers needs relevant to their operations.
- **Camera validation work should be expanded**. The video observations of the sensors in situ are a key component of building confidence in the data being recorded. Due to the placement of the camera and the dimensions of the camera cage, the camera can interfere somewhat with video observations.
- **To support additional sensor placements**
- **Further work is needed to improve the practicality of sensor deployments** to support additional sensor placements.
- **Incorporation of ancillary data** to explore the possible relationships between velocity, current, sensor weight/density and bottom contact.

Incorporation of additional environmental factors should be considered to develop risk assessment models that account for direct and indirect impacts of trawling. Examples of the potential to use the contact profile data are:

- **Fuel sensors** could provide cost efficient data to support fishers to make gear changes and / or decisions on fishing locations to optimise fuel consumption and maximise their catch per unit effort.
- **Load sensors** could support fishers to correlate the impact of catch on their bottom contact profile. Aligned with (1) this could be assessed alongside fuel sensors to optimise catch levels.
- **Commercial catch / effort data** to review the gear set ups and associated bottom contact to determine if gear modifications can be made to optimised catch compositions. The importance of optimising catch compositions is expected to increase following the implementation of the landings and discards policy review.

6 Conclusion

Our analysis successfully proved the methodology of using tilt sensors to collect empirically derived contact data to establish empirically based footprint information based on real world observations enabling the development of contact adjusted trawl footprints. The technology and methodology trialled in this research project successfully determined differences in seabed contact when making modifications to trawl gear.

Using bottom contact sensors is a viable option for providing detailed bottom contact information to support operational and management decisions. Future studies should especially focus to provide for the broader uptake of sensors and develop the long-term utility of using sensors to provide contract adjusted trawl footprints.

Industry, fisheries managers and policy makers should be cognisant of the demonstrable differences between the nominal footprint methodology and the empirical data collection approach used in this study when comparing the ‘on’ reading to the nominal approach.

To most effectively use these sensors to support evidence-based decision-making, it is recommended that these sensors be used in conjunction with other data. The literature acknowledges that the effect of trawling is not constrained to just the physical contact but also sediment plumes associated with trawling. Research should be considered to determine the relationships between the extent of contact adjusted bottom contact, seabed type and associated sediment plumes.

This project is an example of current research meeting the Future of Commercial Fishing in Aotearoa New Zealand recommendation highlighting the need to fill data gaps, take advance of technology advancements and to collaborate to achieve this. Notably the Food and Agriculture Organisation of the United Nations recognises the benefit of gear monitoring instruments and states they can be used to support optimising of trawl gears (Valdemarsen et al., 2007).

A broadening of uptake of these sensors is expected to, in time, improve our trawl footprint knowledge and in line with the Office of the Prime Minister's Chief Science Advisor's report. Furthermore, it opens the potential for New Zealand's commercial fishing vessels to contribute to the Ship Of Opportunity Program (SOOP).[12]

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[12] an international World Meteorological Organization (WMO)-Intergovernmental Oceanographic Commission (IOC) program that addresses both scientific and operational goals to contribute to building a sustained ocean observing system (Goni, 2009)

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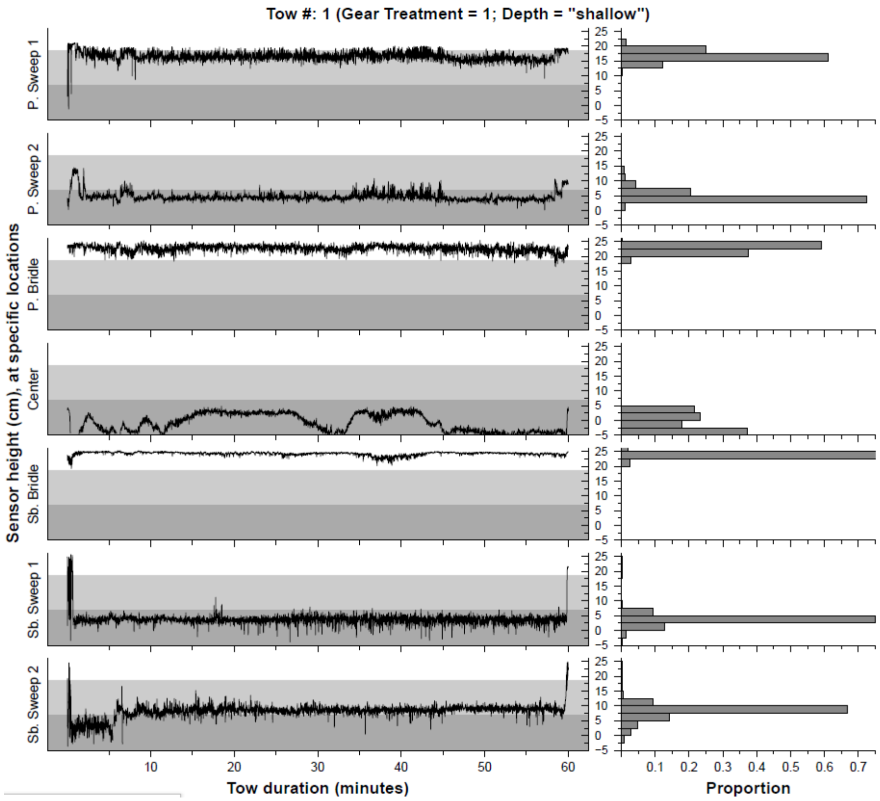
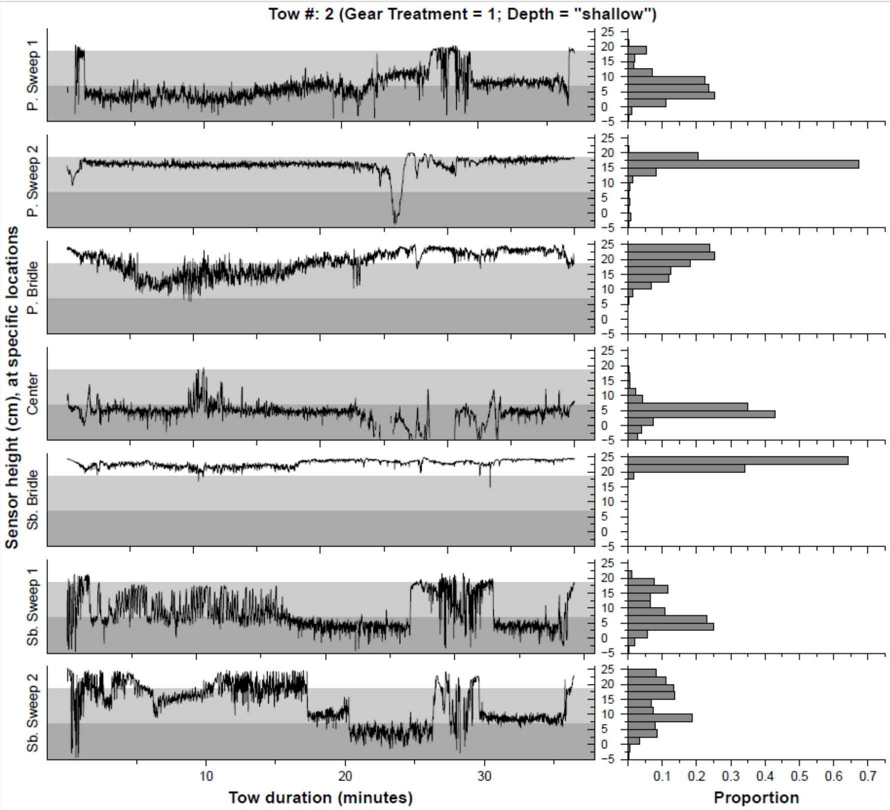
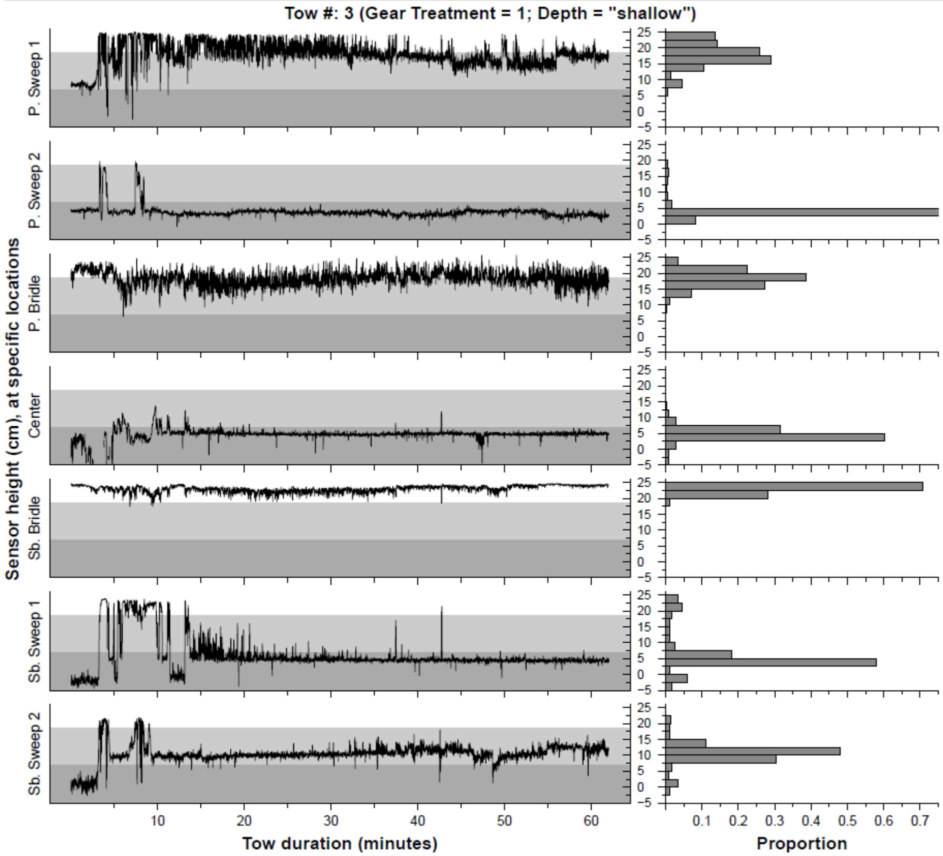
9 Appendices

Appendix 1– tow by tow raw data



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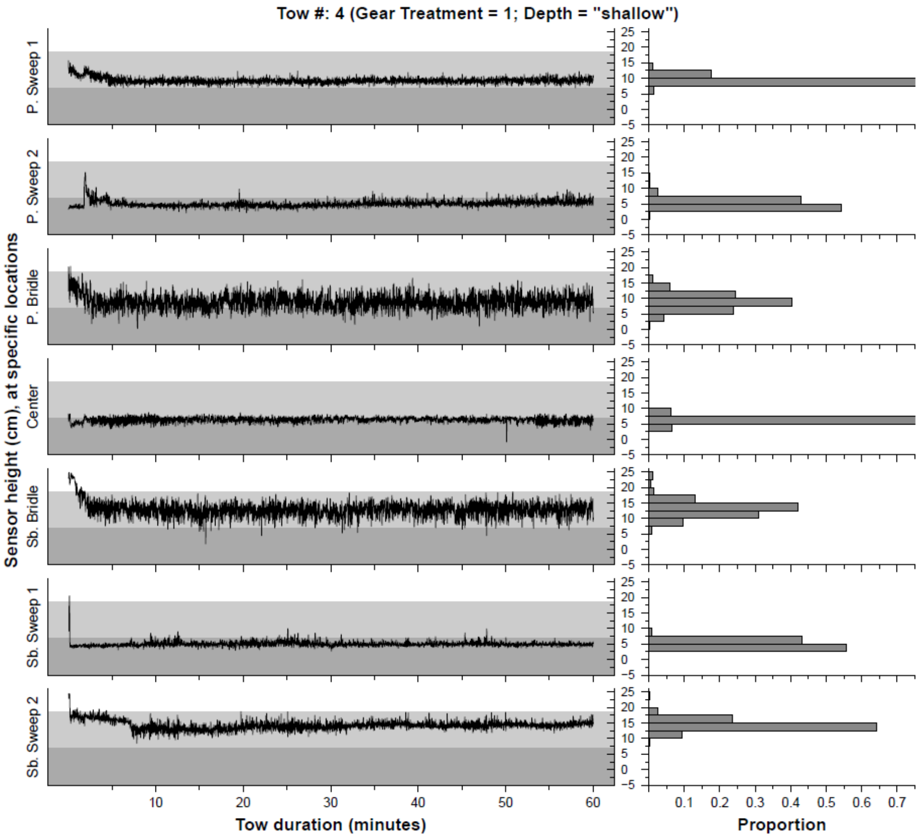
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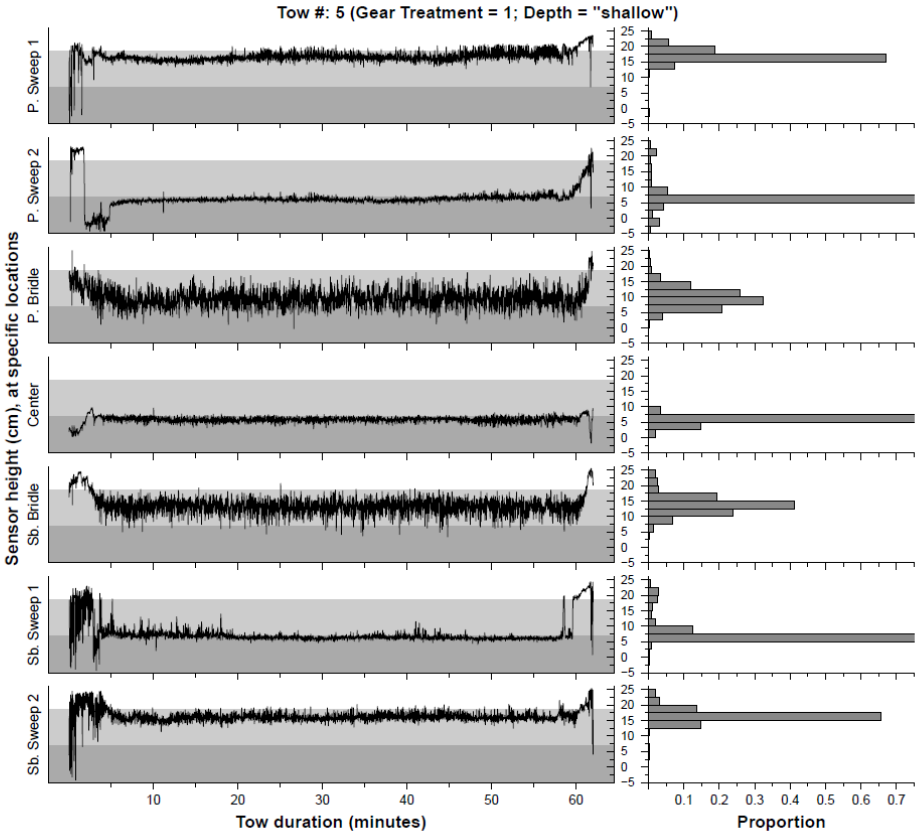
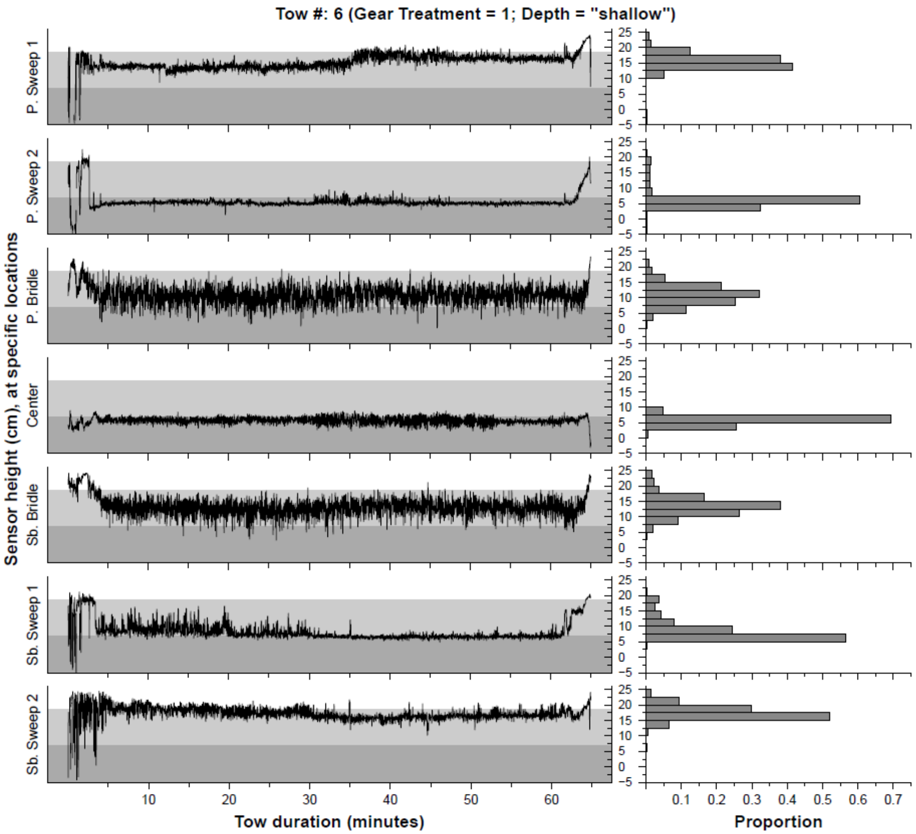
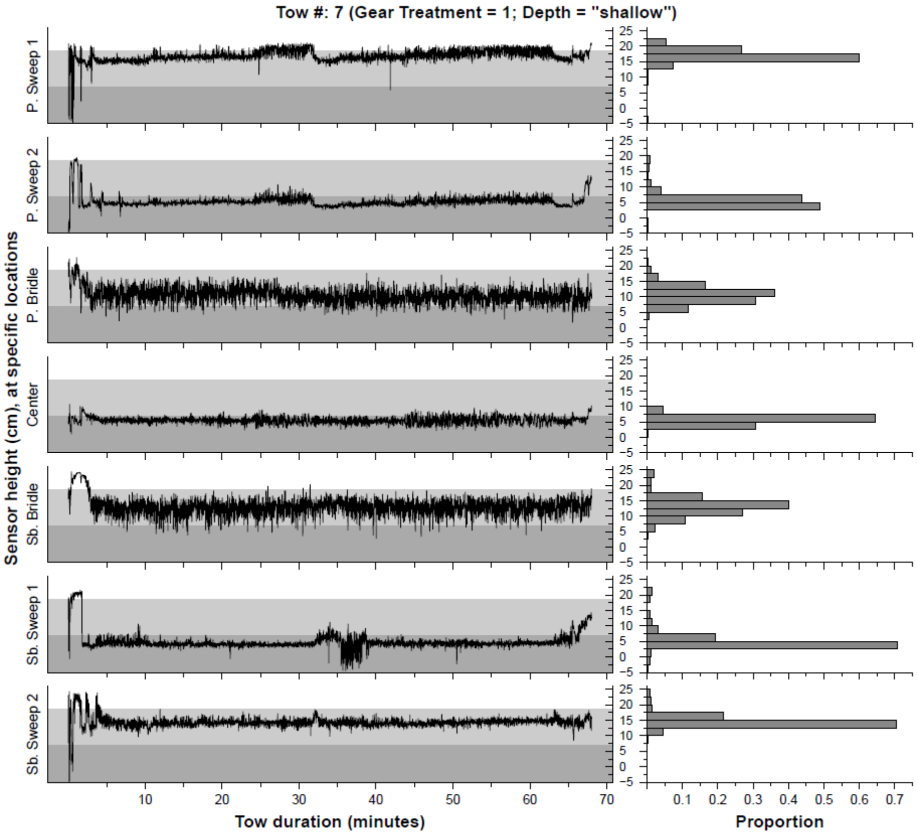
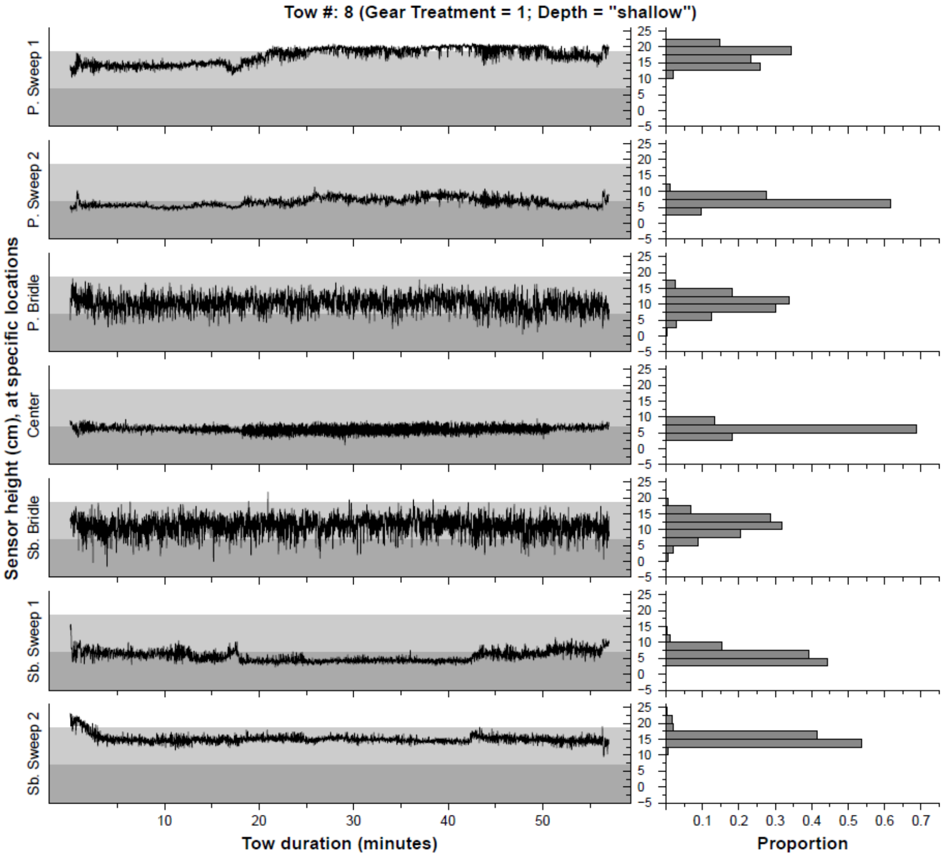
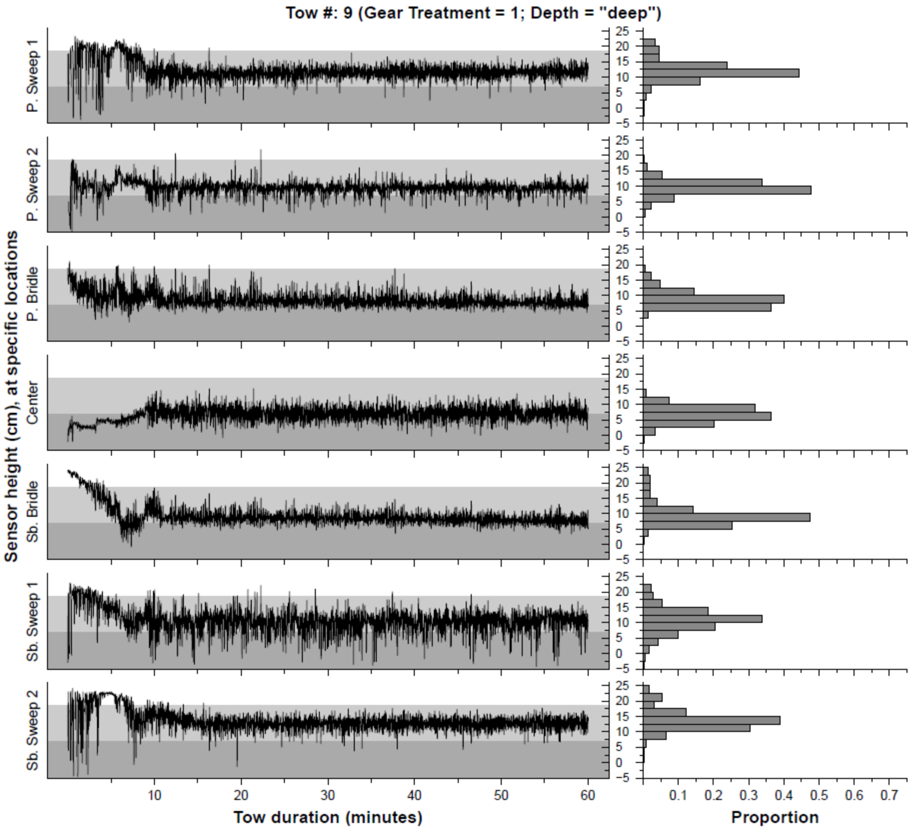
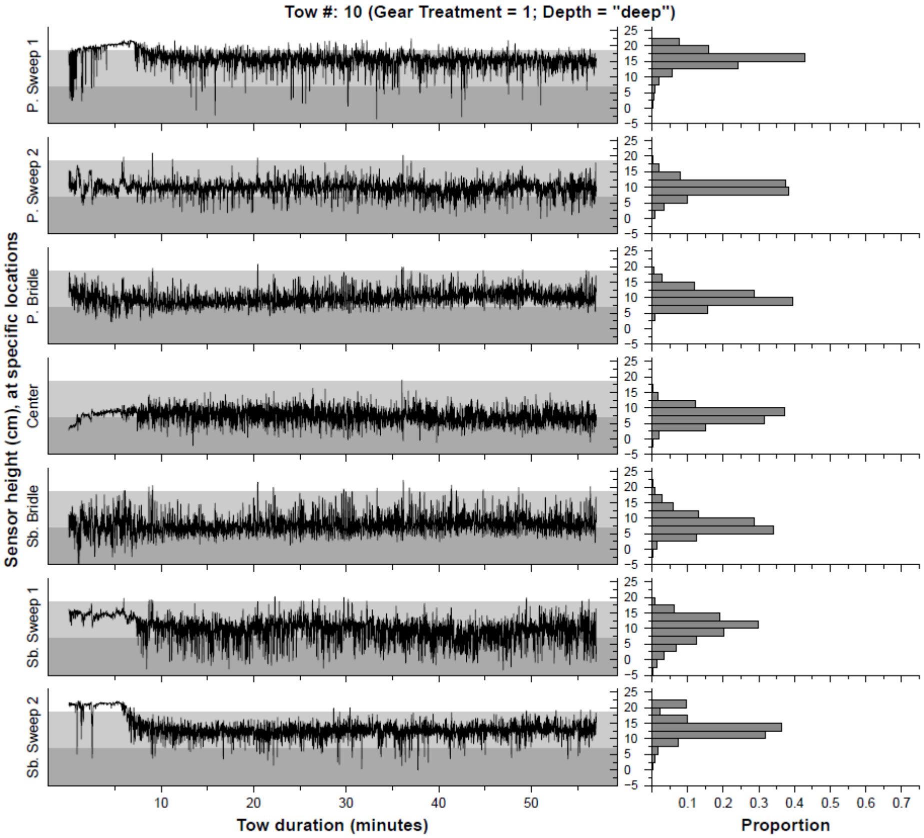

Tow #: 5 (Gear Treatment = 1; Depth = "shallow")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5 0 5 10 15 20 25
10 20 30 40 50 60
Tow duration (minutes)
0.1 0.2 0.3 0.4 0.5 0.6 0.7
Proportion

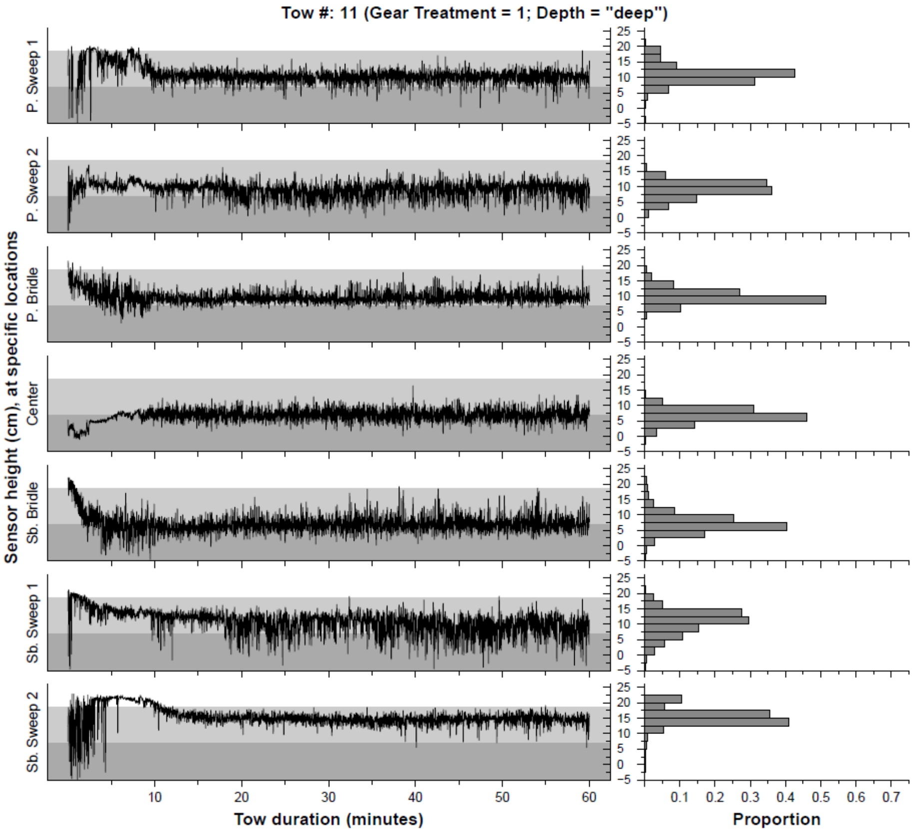

Tow #: 6 (Gear Treatment = 1; Depth = "shallow")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5 0 5 10 15 20 25
10 20 30 40 50 60
Tow duration (minutes)
0.1 0.2 0.3 0.4 0.5 0.6 0.7
Proportion

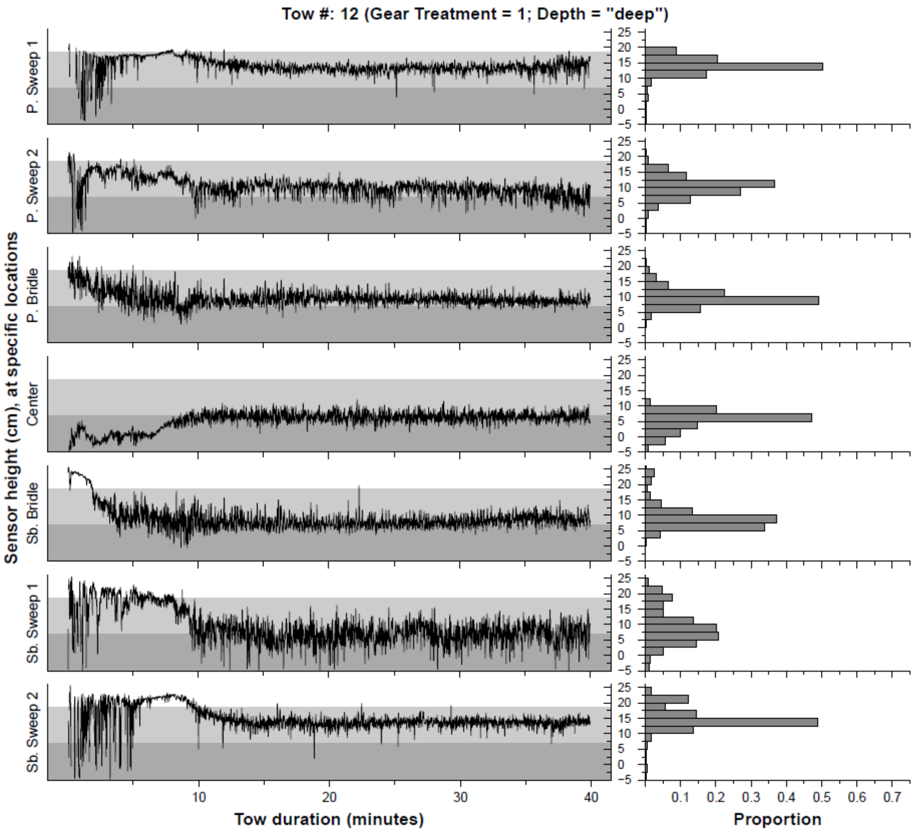

Tow #: 7 (Gear Treatment = 1; Depth = "shallow")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5
0
5
10
15
20
25
10
20
30
40
50
60
70
Tow duration (minutes)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion

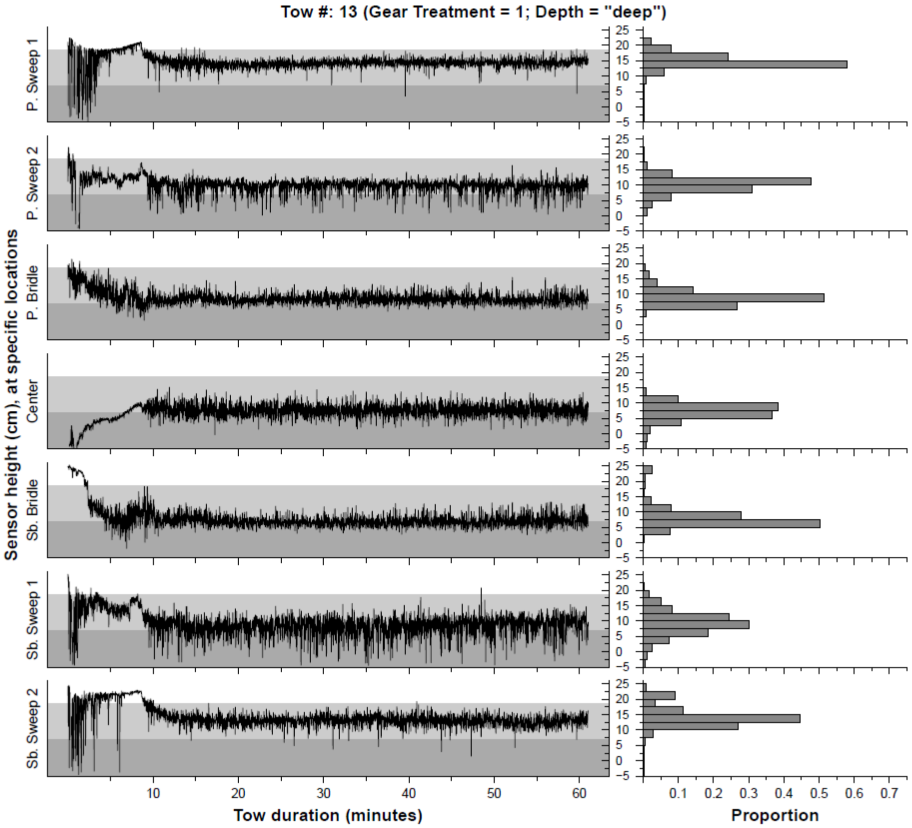

Tow #: 8 (Gear Treatment = 1; Depth = "shallow")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5
0
5
10
15
20
25
10
20
30
40
50
Tow duration (minutes)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion

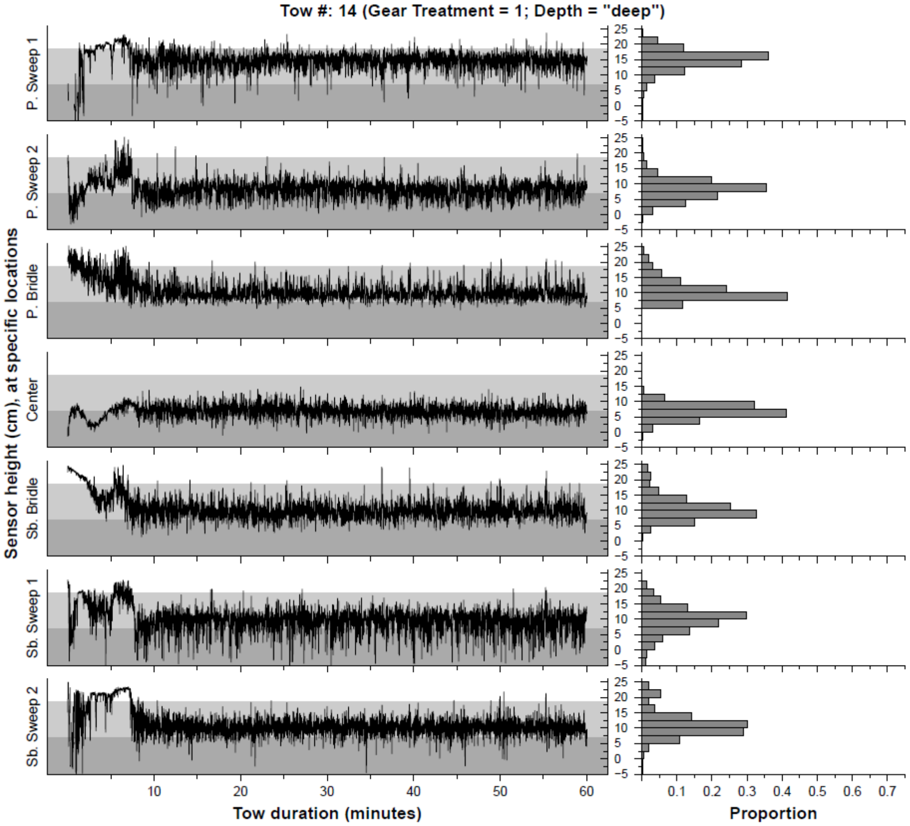

Tow #: 9 (Gear Treatment = 1; Depth = "deep")

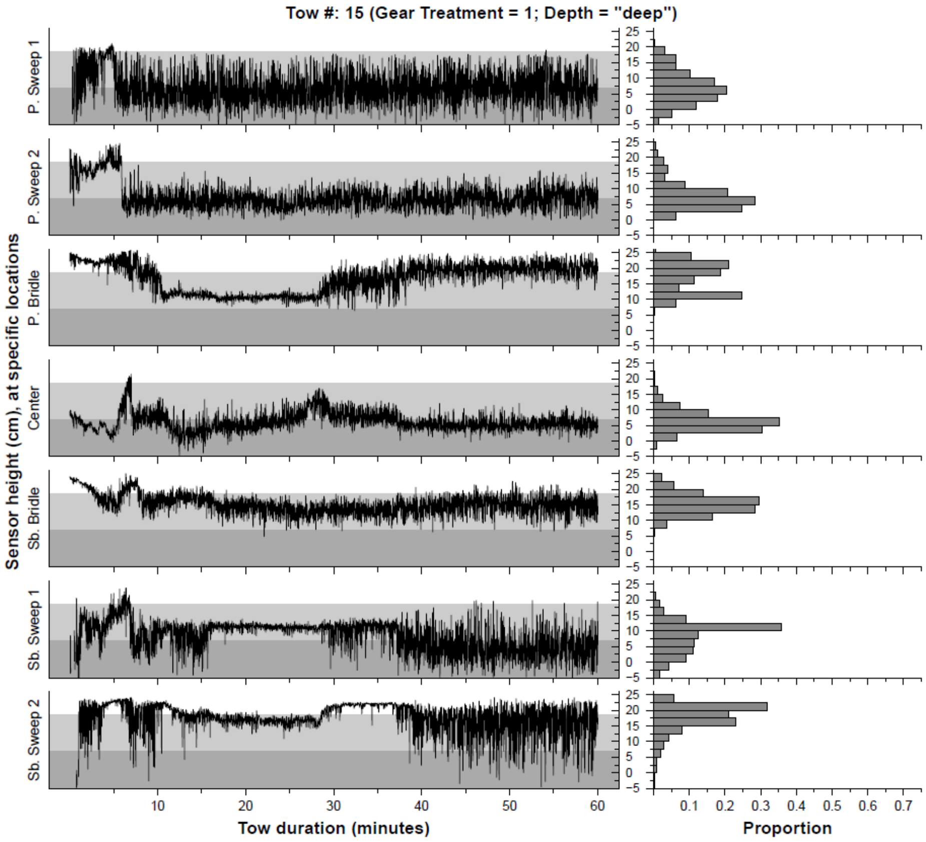

Tow #: 10 (Gear Treatment = 1; Depth = "deep")

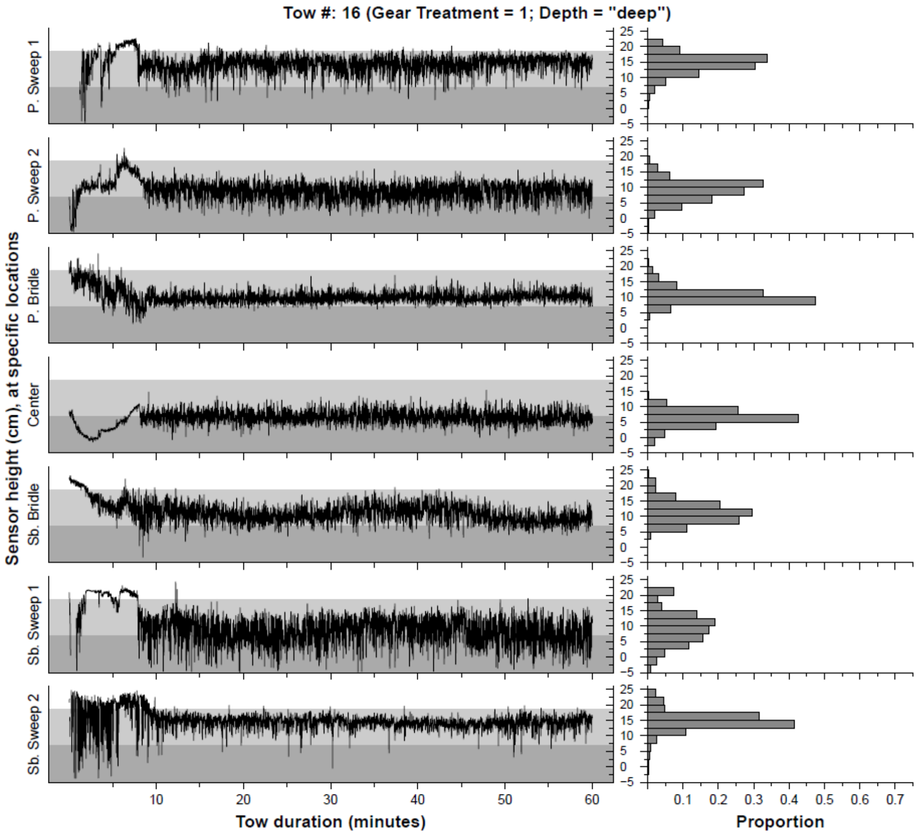

Tow #: 11 (Gear Treatment = 1; Depth = "deep")

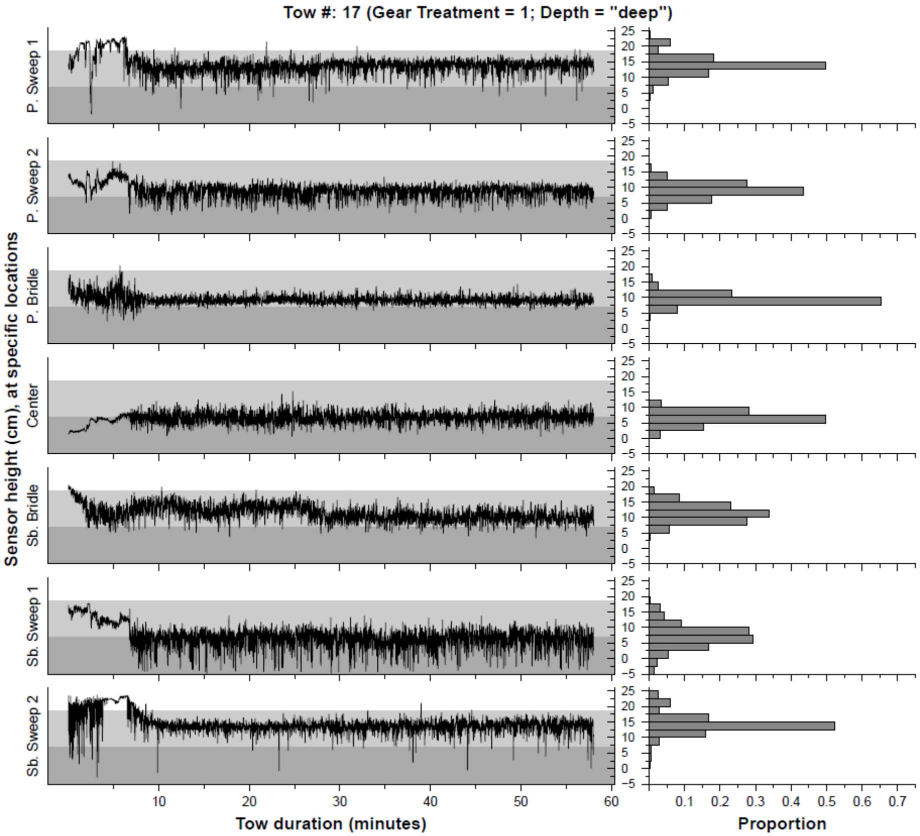

Tow #: 12 (Gear Treatment = 1; Depth = "deep")

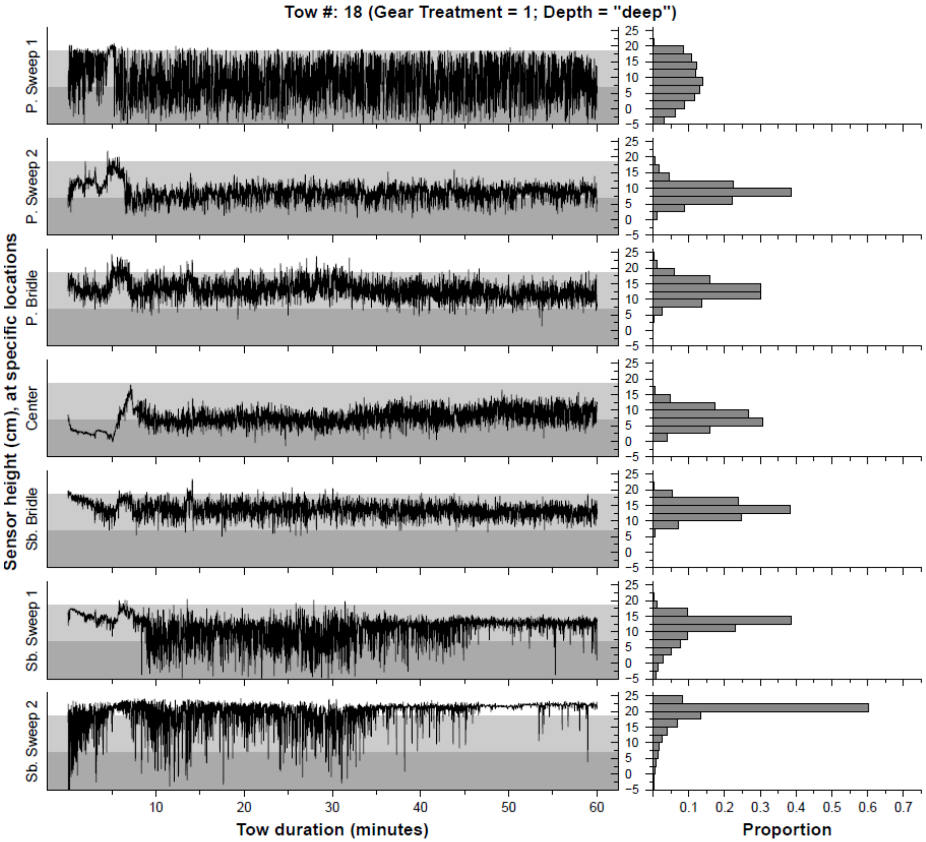

Tow #: 13 (Gear Treatment = 1; Depth = "deep")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
25
20
15
10
5
0
−5
10
20
30
40
50
60
Tow duration (minutes)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion

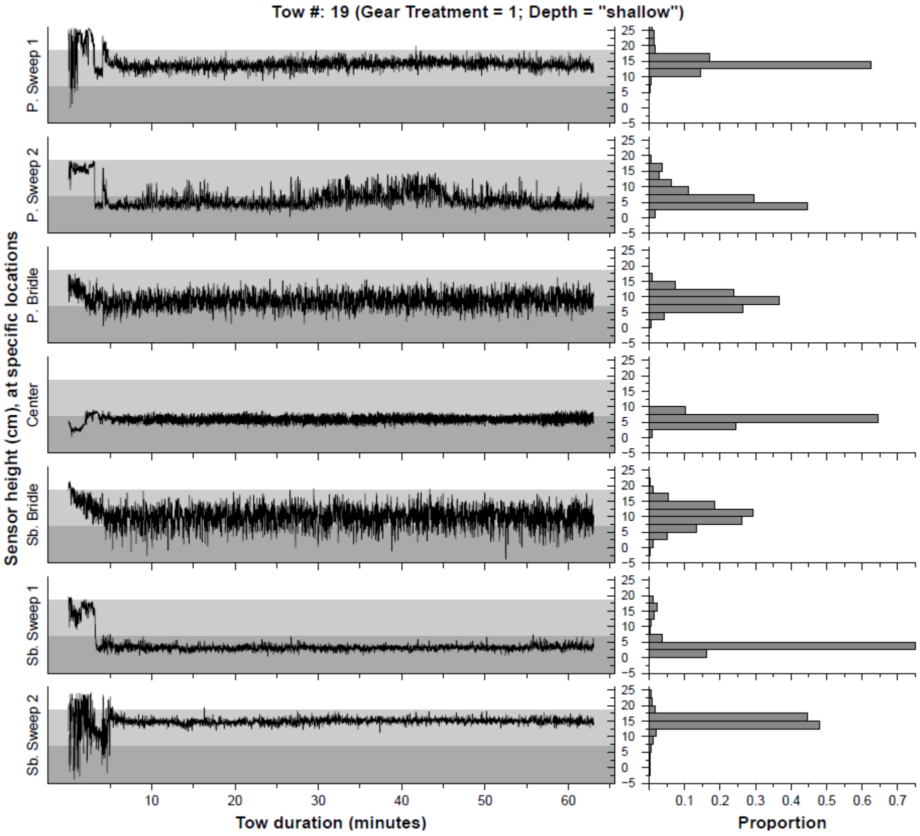

Tow #: 14 (Gear Treatment = 1; Depth = "deep")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
25
20
15
10
5
0
−5
10
20
30
40
50
60
Tow duration (minutes)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion

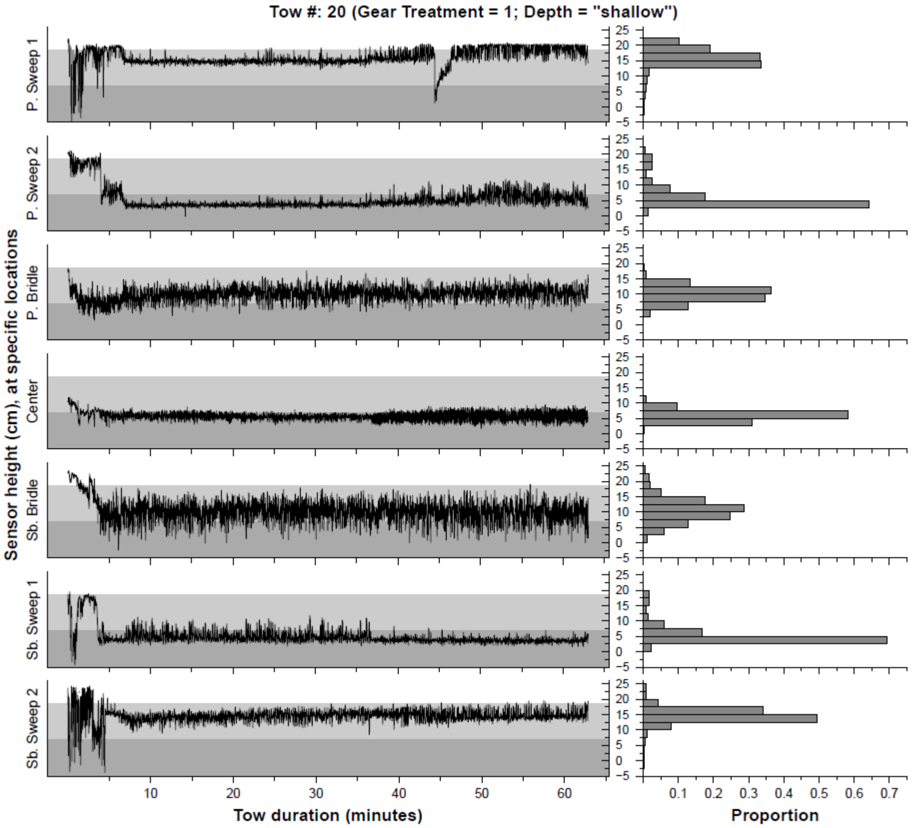

Tow #: 15 (Gear Treatment = 1; Depth = "deep")

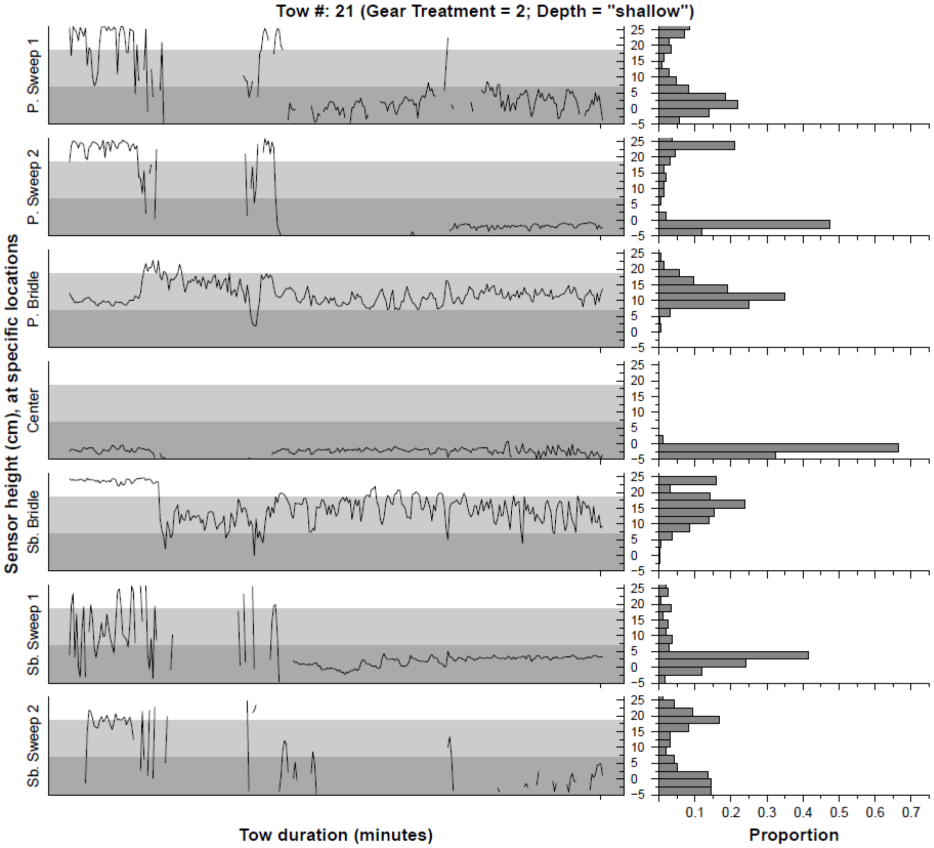

Tow #: 16 (Gear Treatment = 1; Depth = "deep")

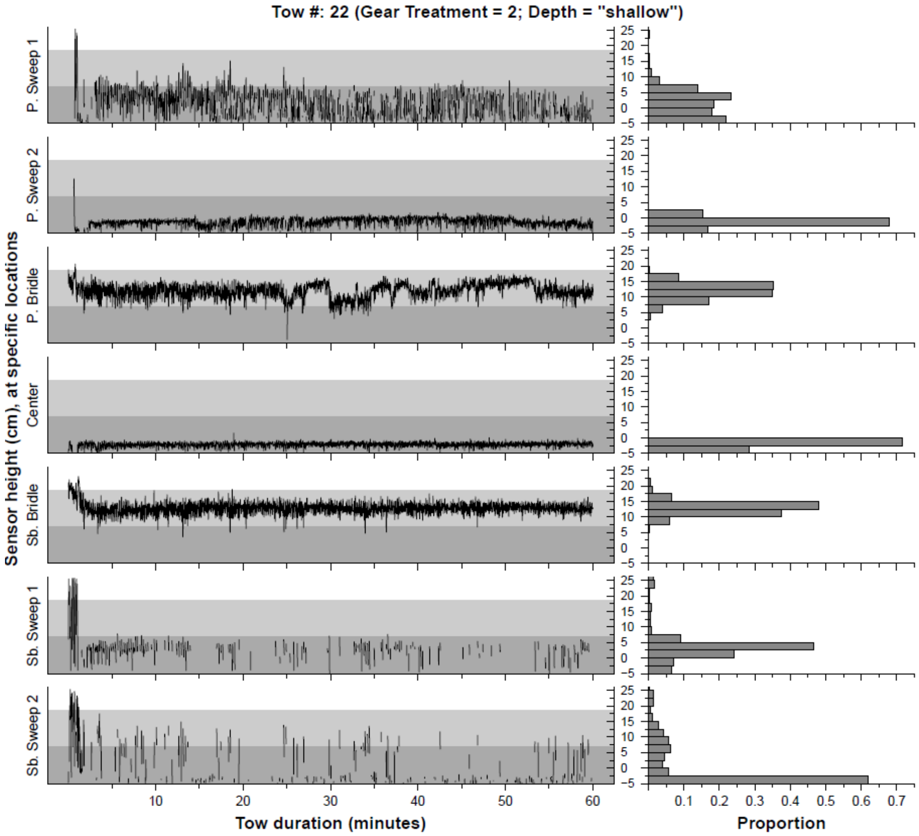

Tow #: 17 (Gear Treatment = 1; Depth = "deep")


Tow #: 18 (Gear Treatment = 1; Depth = "deep")

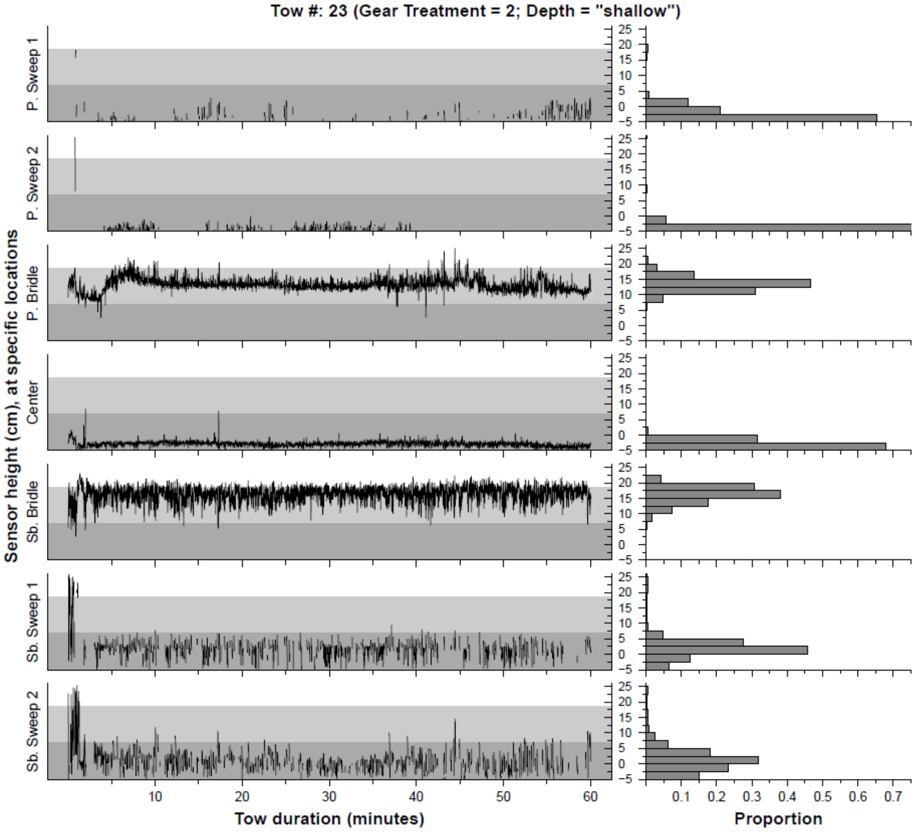

Tow #: 19 (Gear Treatment = 1; Depth = "shallow")

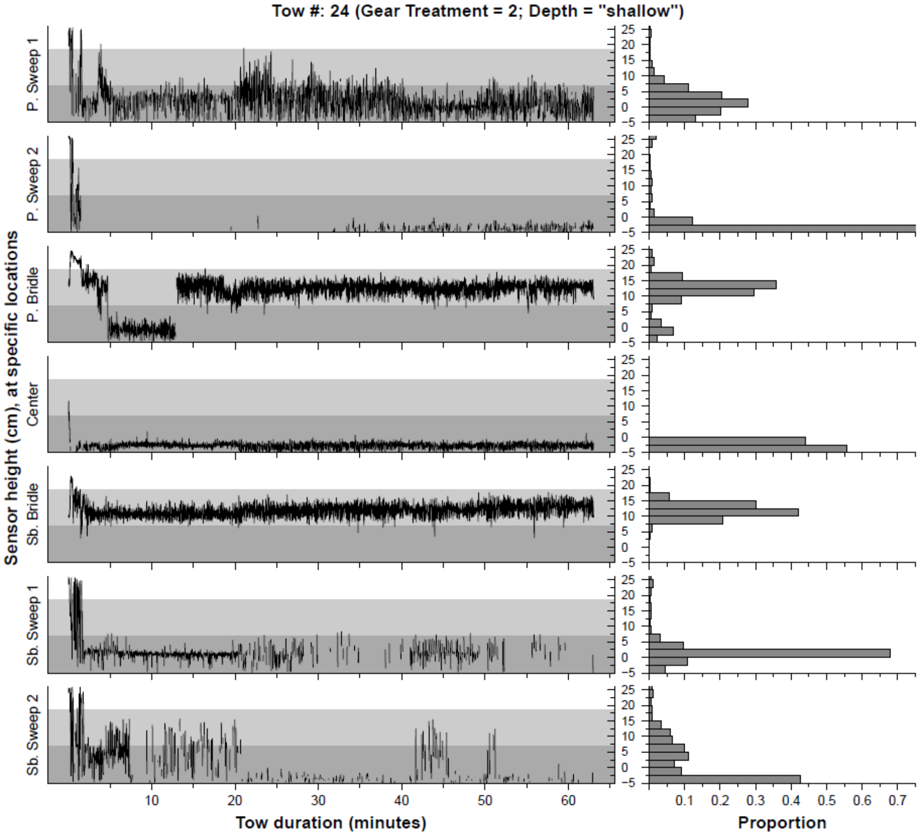

Tow #: 20 (Gear Treatment = 1; Depth = "shallow")

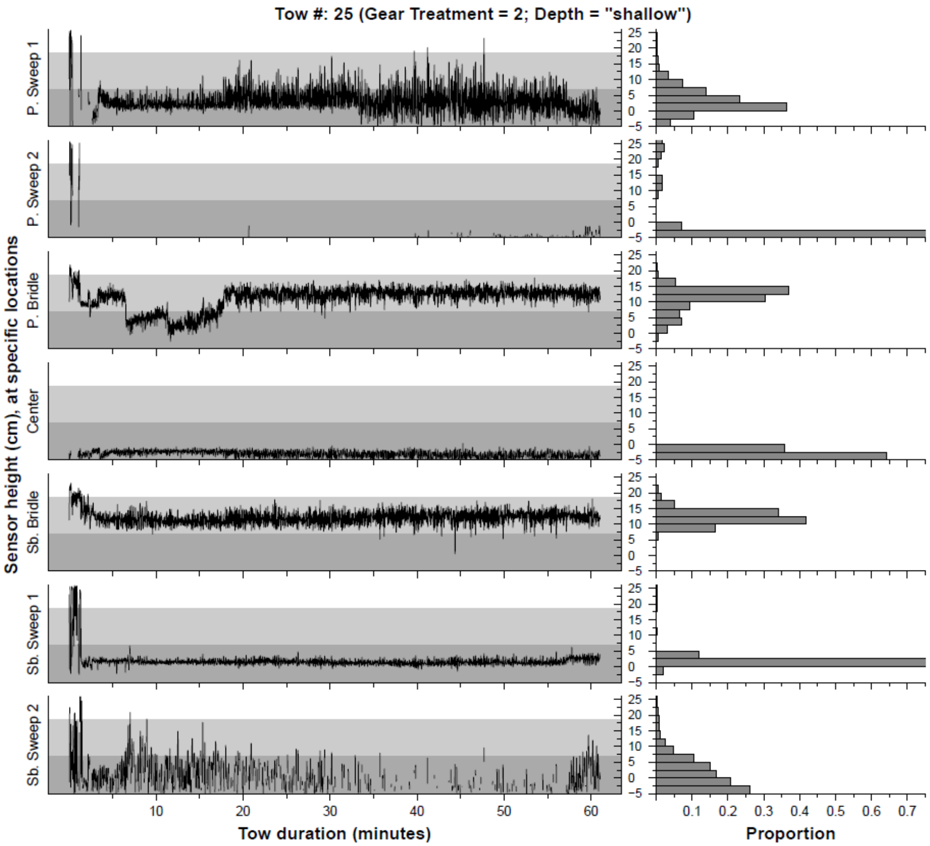


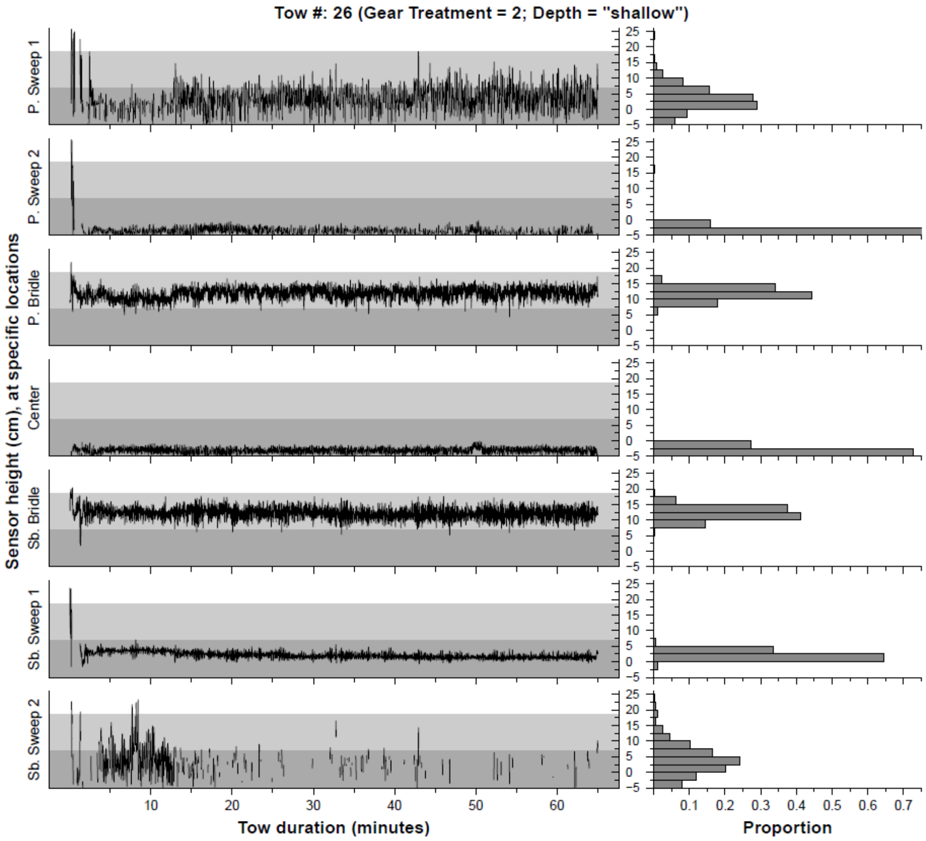


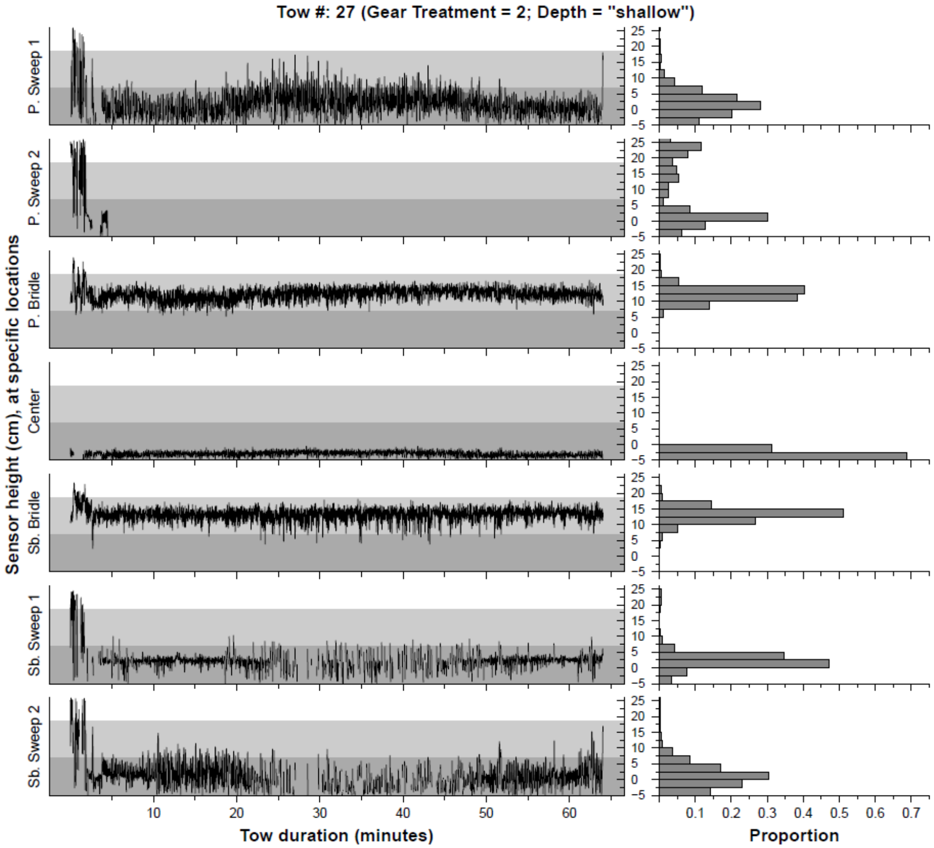
Note: this was a short tow as a result of operational issues. This is why the plots are different to other tows. The tow was just over 5 minutes, noting the marker on the bottom right of the x-axis for the tow duration represents 5 minutes.

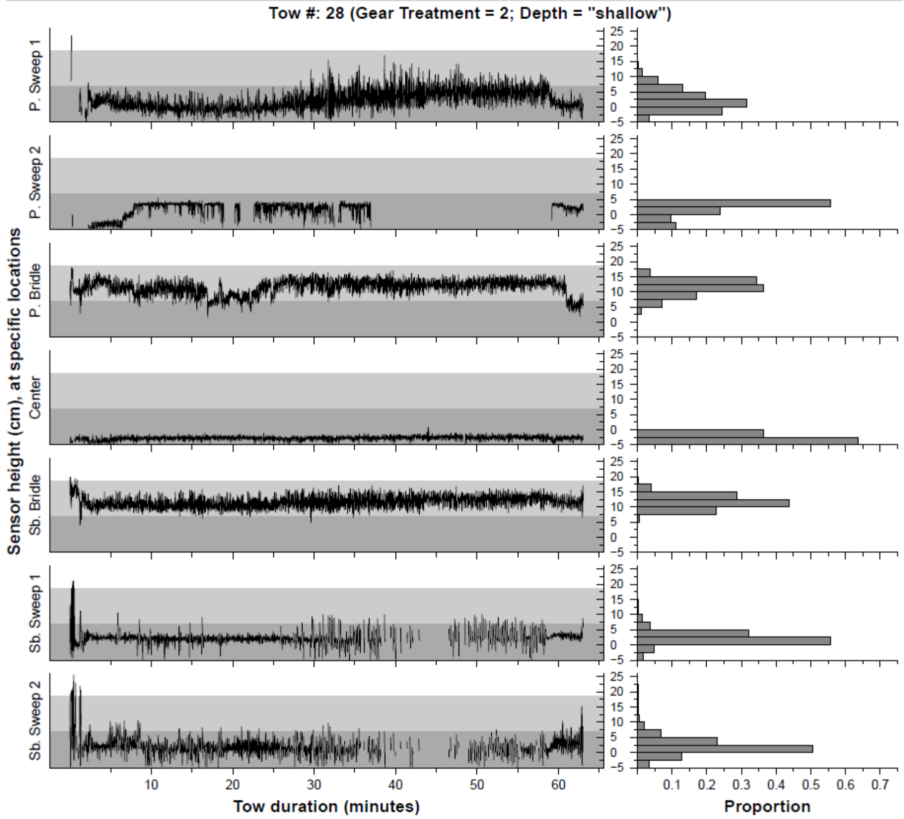

Tow #: 23 (Gear Treatment = 2; Depth = "shallow")

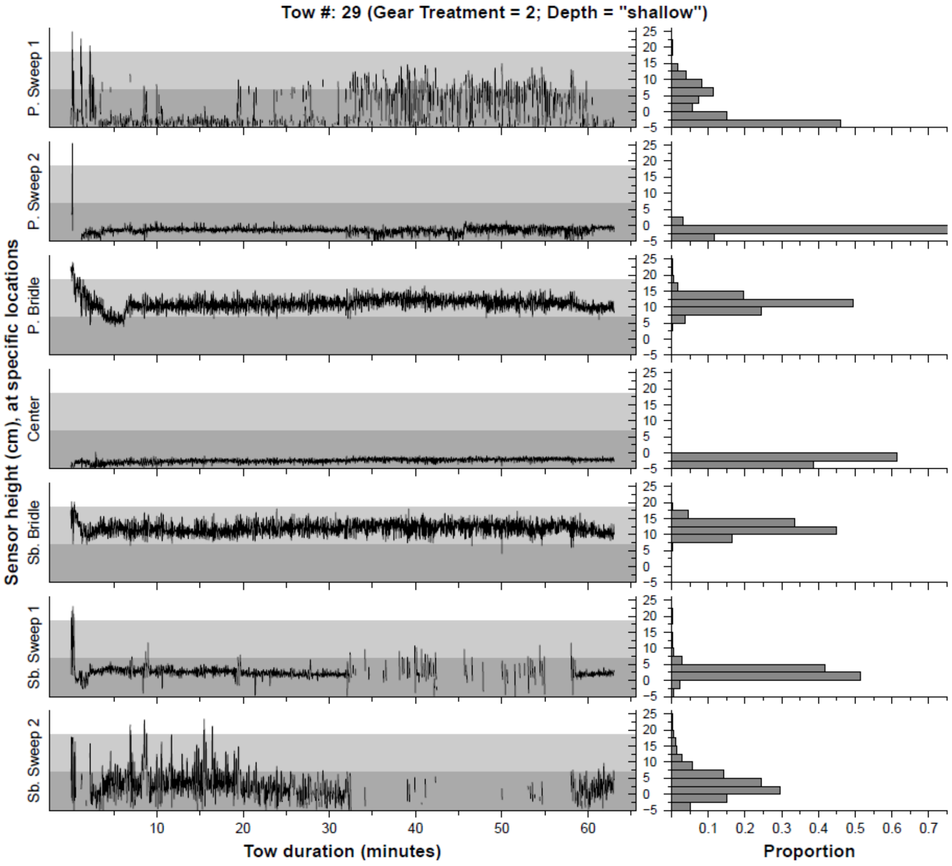

Tow #: 24 (Gear Treatment = 2; Depth = "shallow")

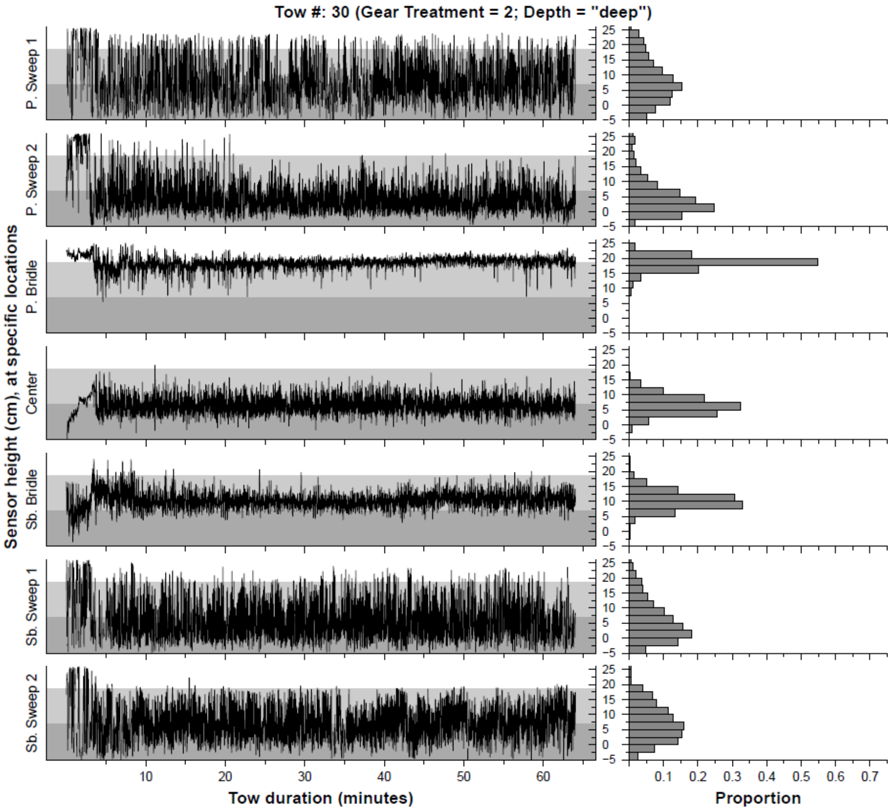

Tow #: 25 (Gear Treatment = 2; Depth = "shallow")

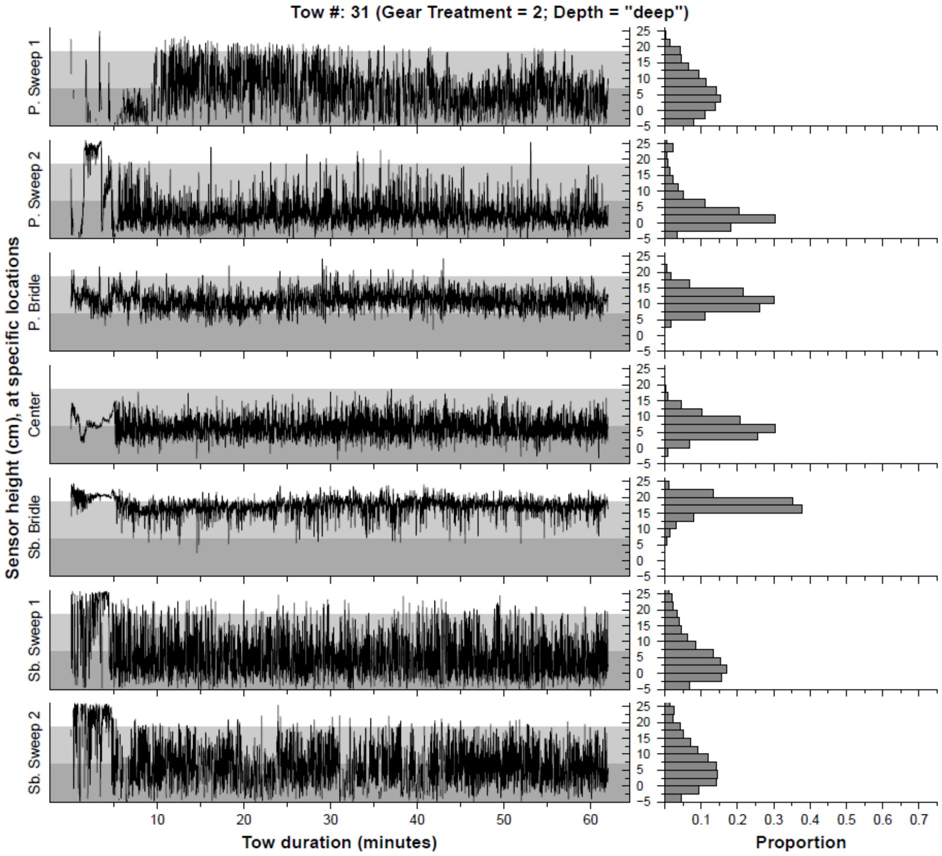

Tow #: 26 (Gear Treatment = 2; Depth = "shallow")


Tow #: 27 (Gear Treatment = 2; Depth = "shallow")

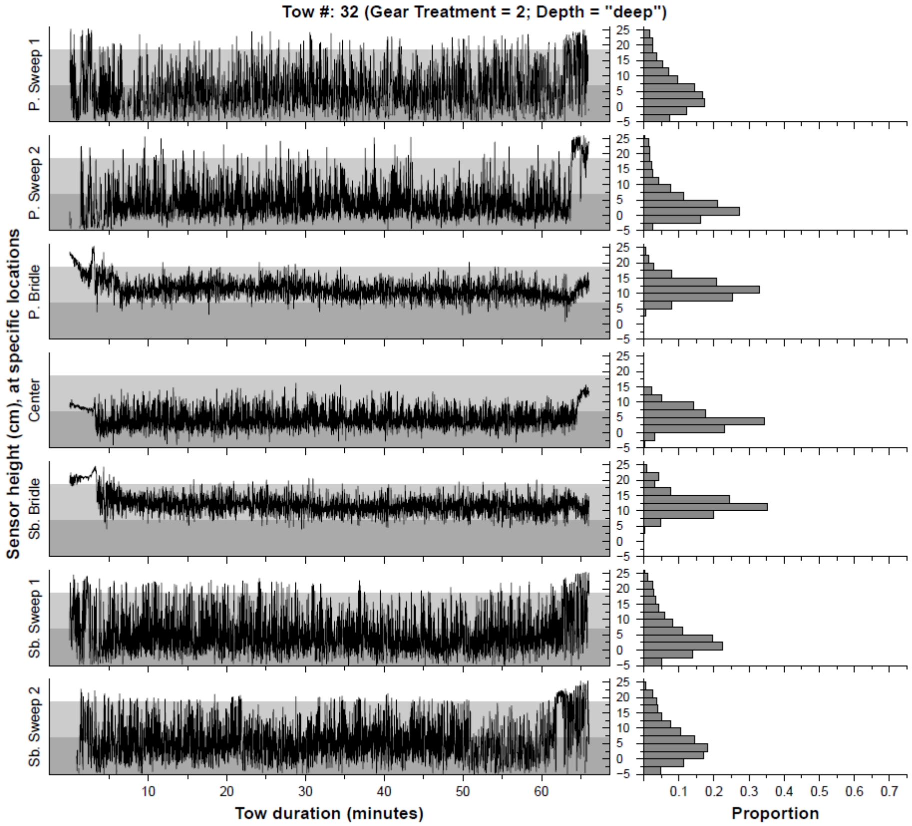

Tow #: 28 (Gear Treatment = 2; Depth = "shallow")


Tow #: 29 (Gear Treatment = 2; Depth = "shallow")

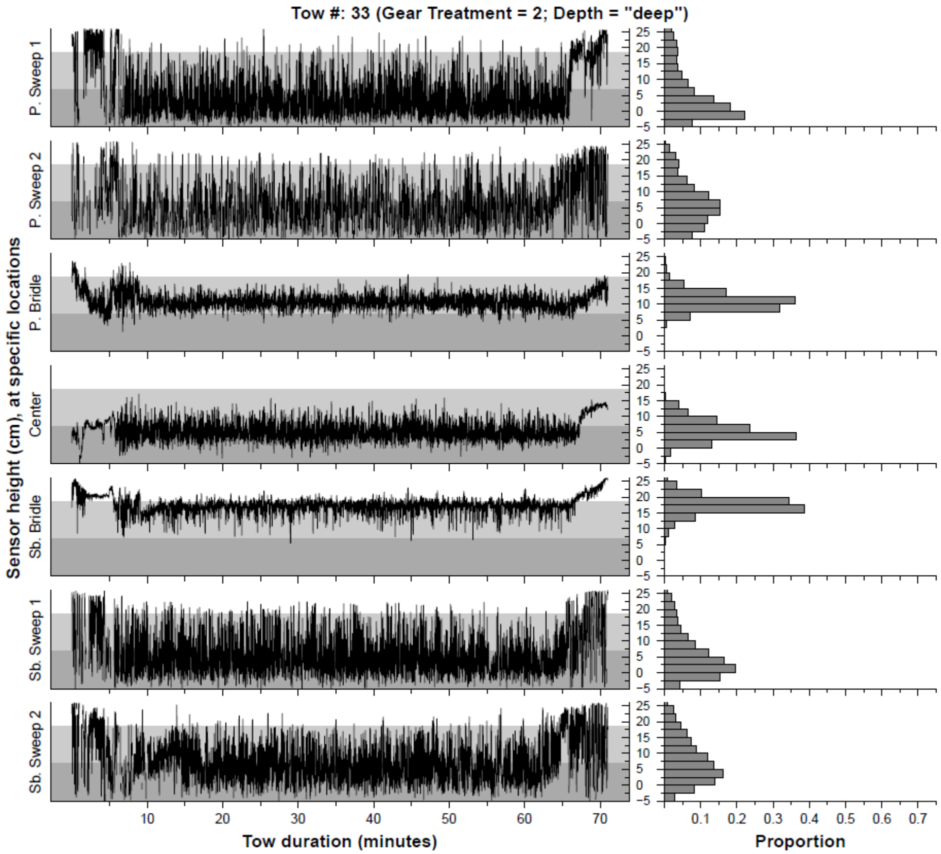

Tow #: 30 (Gear Treatment = 2; Depth = "deep")

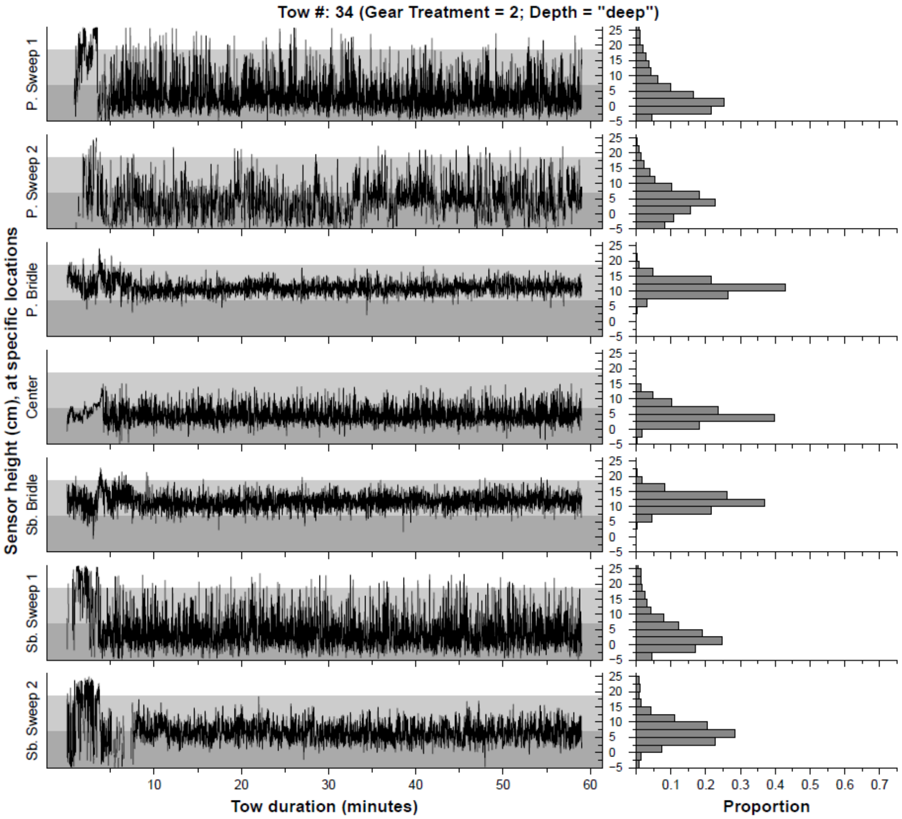


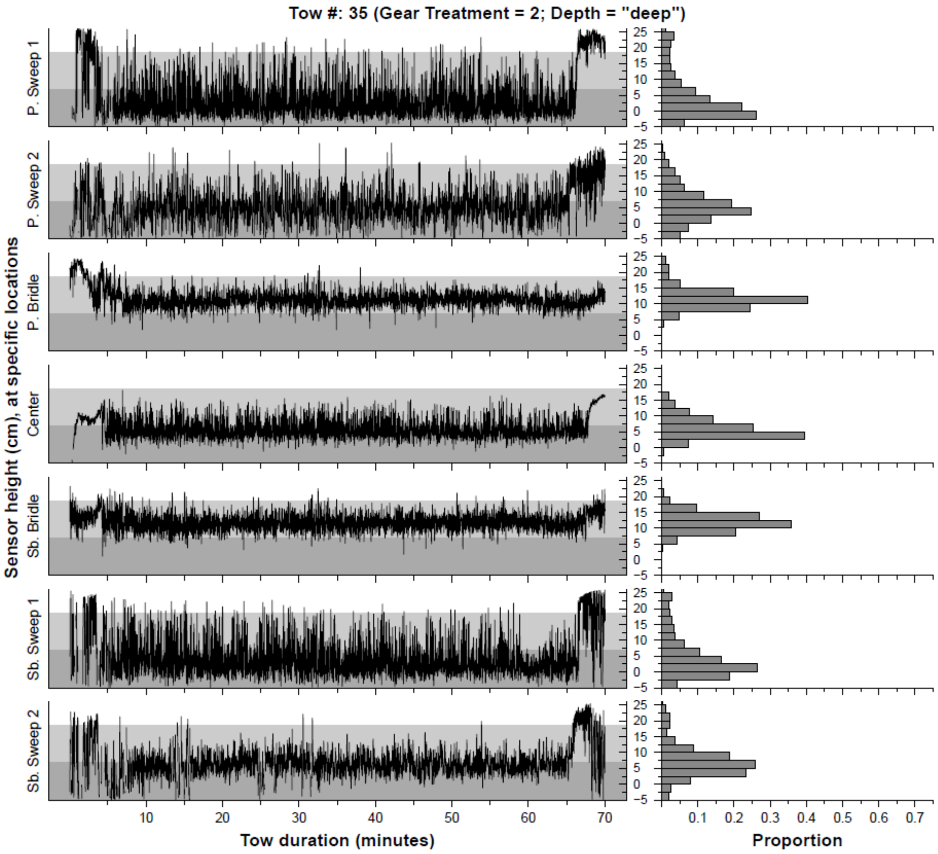
Tow #: 31 (Gear Treatment = 2; Depth = "deep")

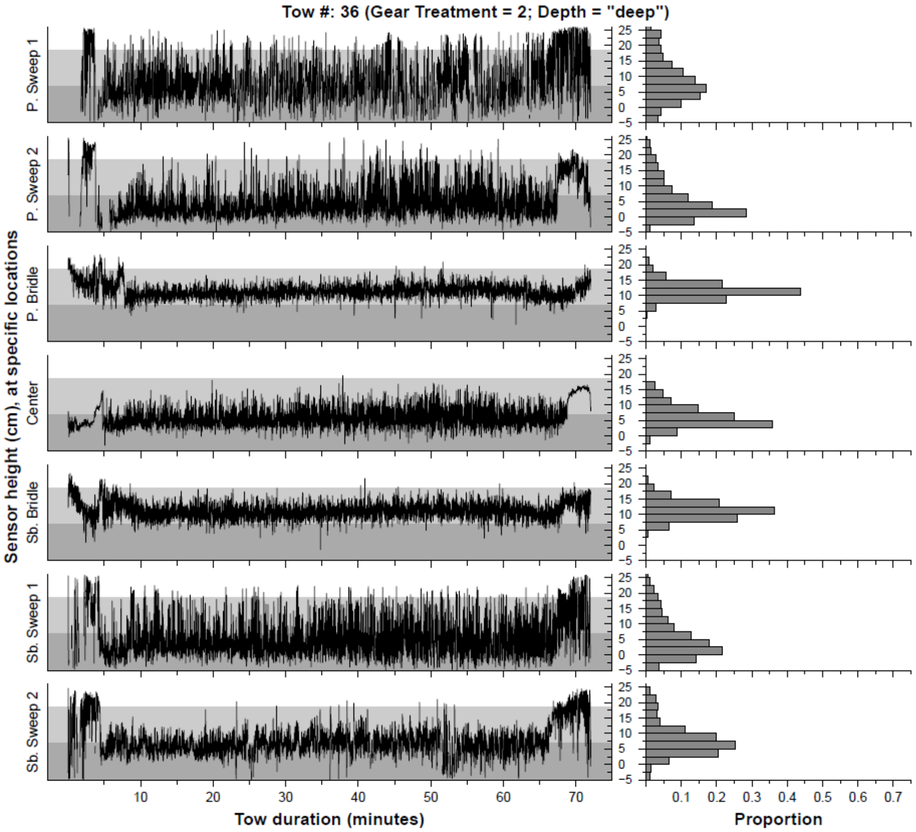


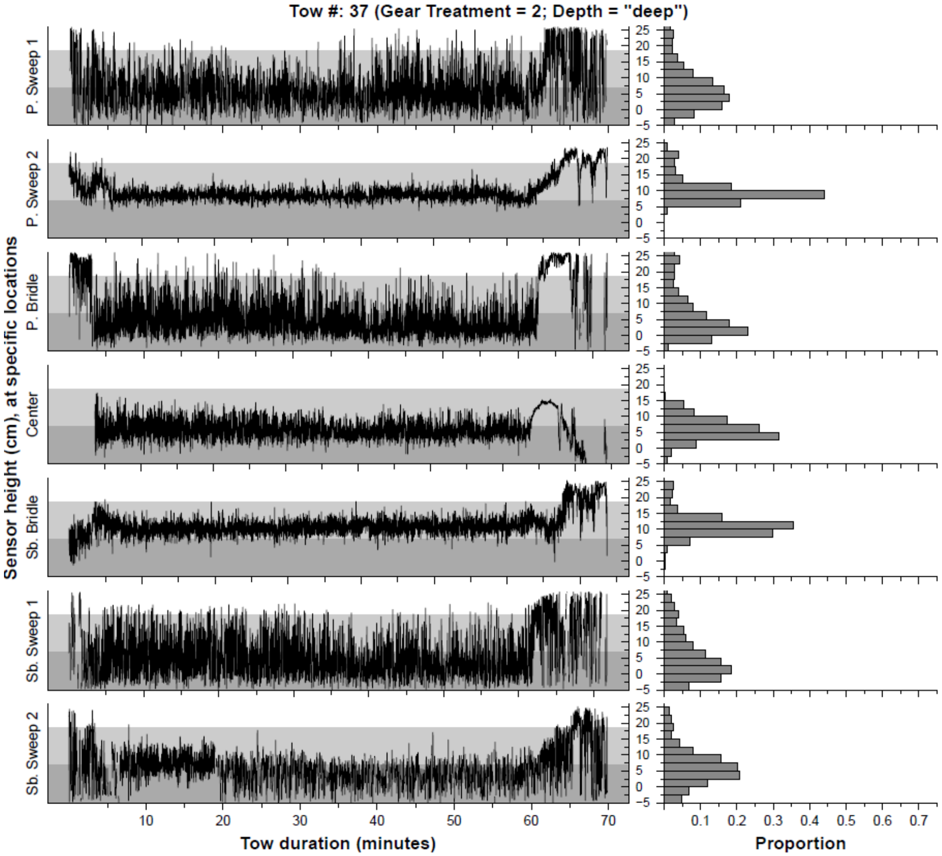
Tow #: 32 (Gear Treatment = 2; Depth = "deep")

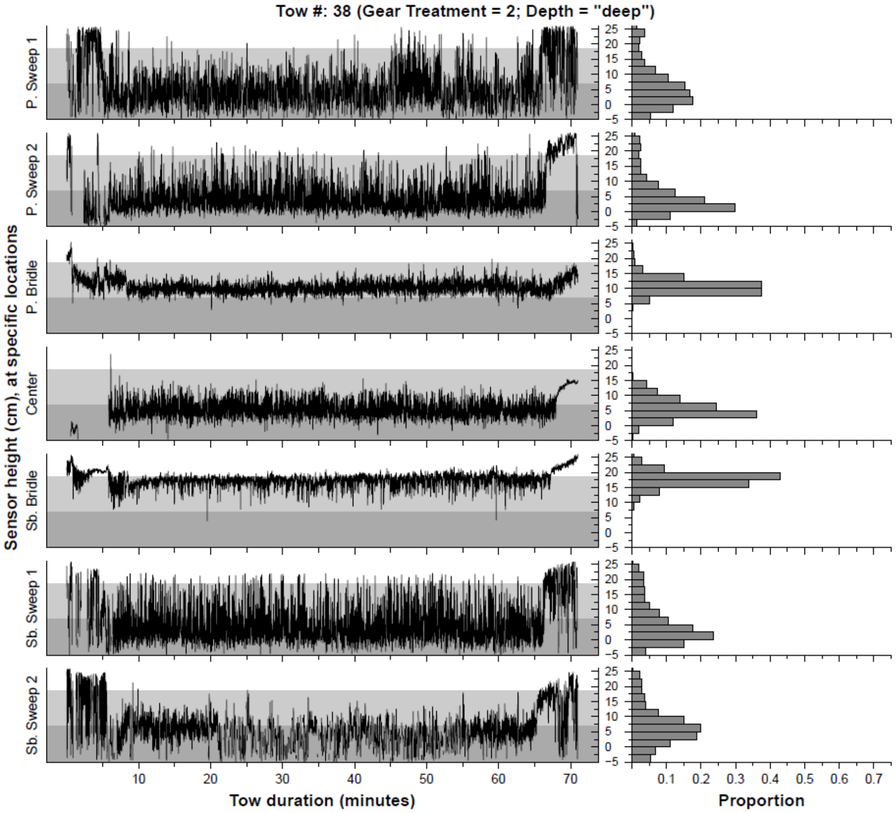

Tow #: 33 (Gear Treatment = 2; Depth = "deep")

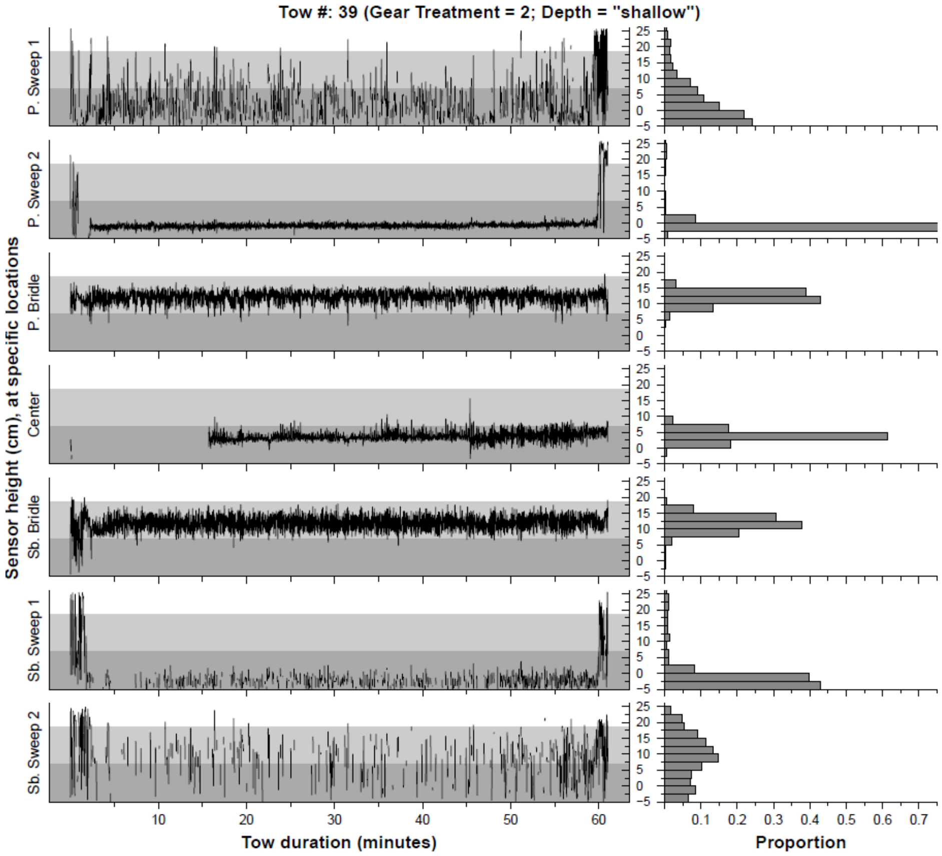

Tow #: 34 (Gear Treatment = 2; Depth = "deep")


Tow #: 35 (Gear Treatment = 2; Depth = "deep")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5 0 5 10 15 20 25
10 20 30 40 50 60 70
Tow duration (minutes)
0.1 0.2 0.3 0.4 0.5 0.6 0.7
Proportion

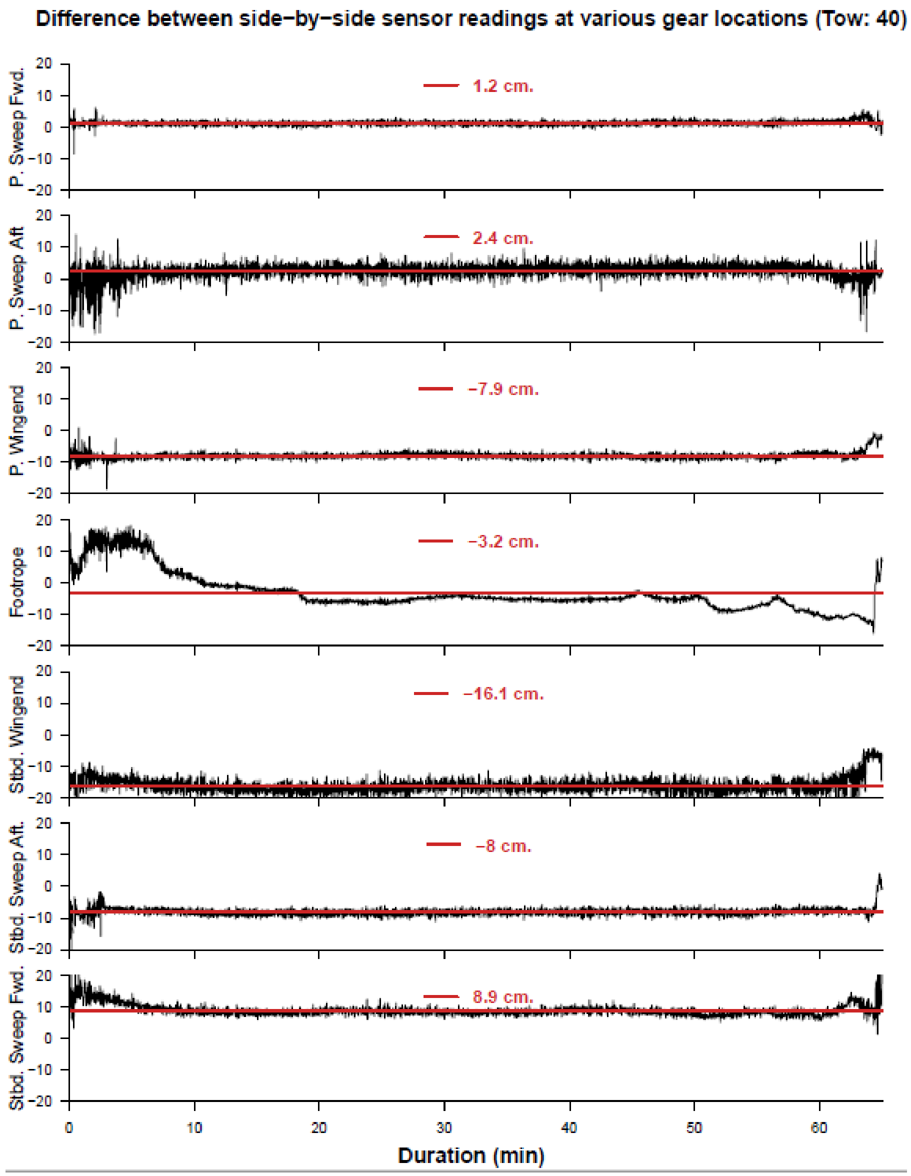

Tow #: 36 (Gear Treatment = 2; Depth = "deep")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
-5 0 5 10 15 20 25
10 20 30 40 50 60 70
Tow duration (minutes)
0.1 0.2 0.3 0.4 0.5 0.6 0.7
Proportion

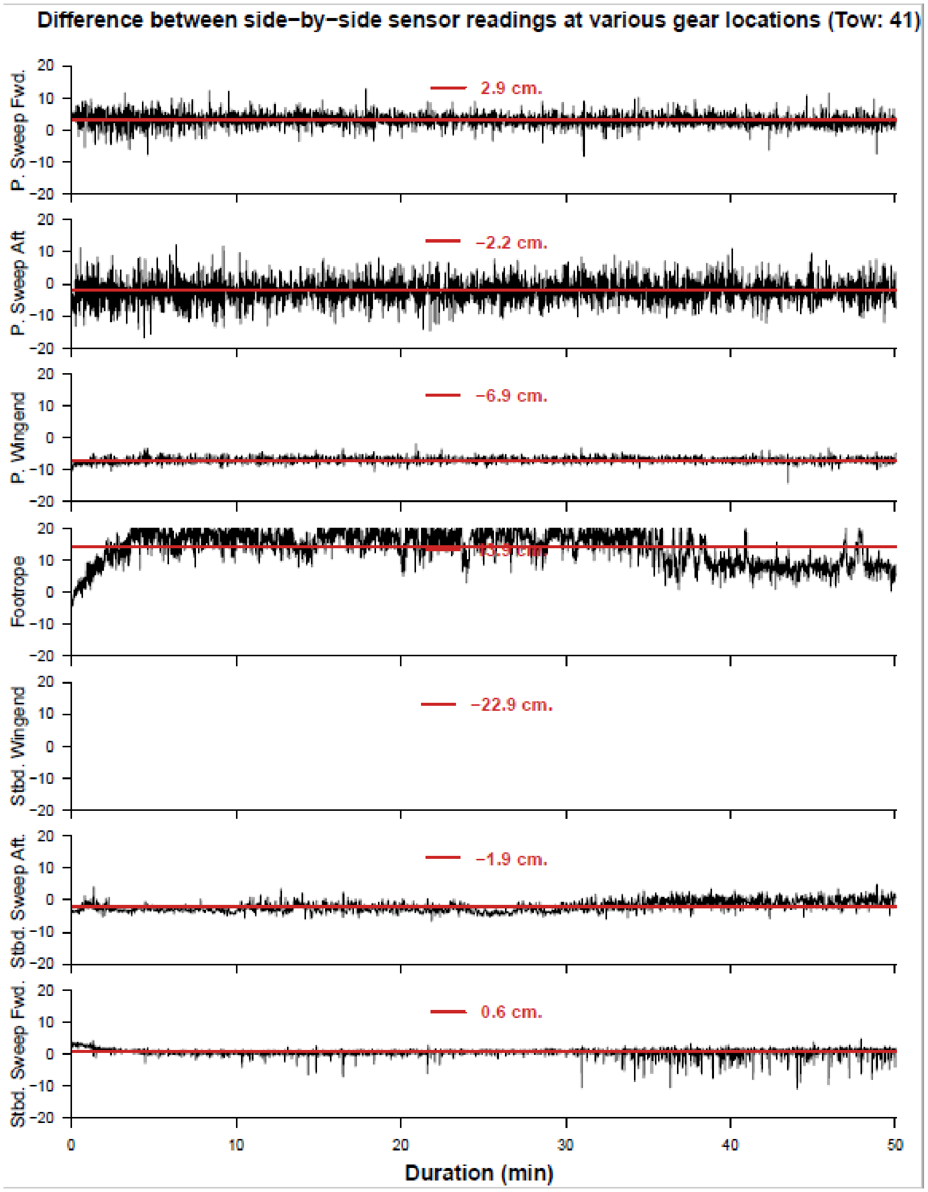

Tow #: 37 (Gear Treatment = 2; Depth = "deep")

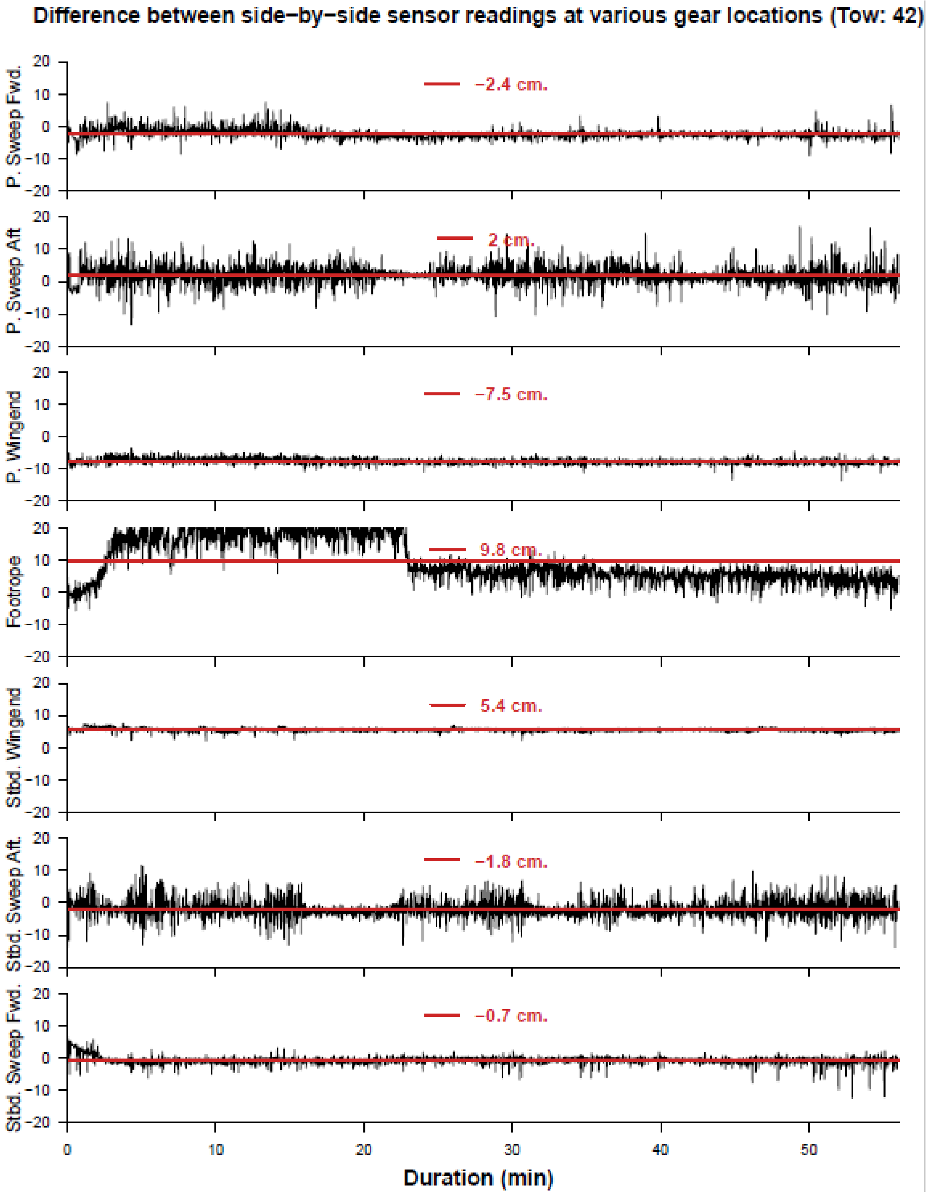

Tow #: 38 (Gear Treatment = 2; Depth = "deep")

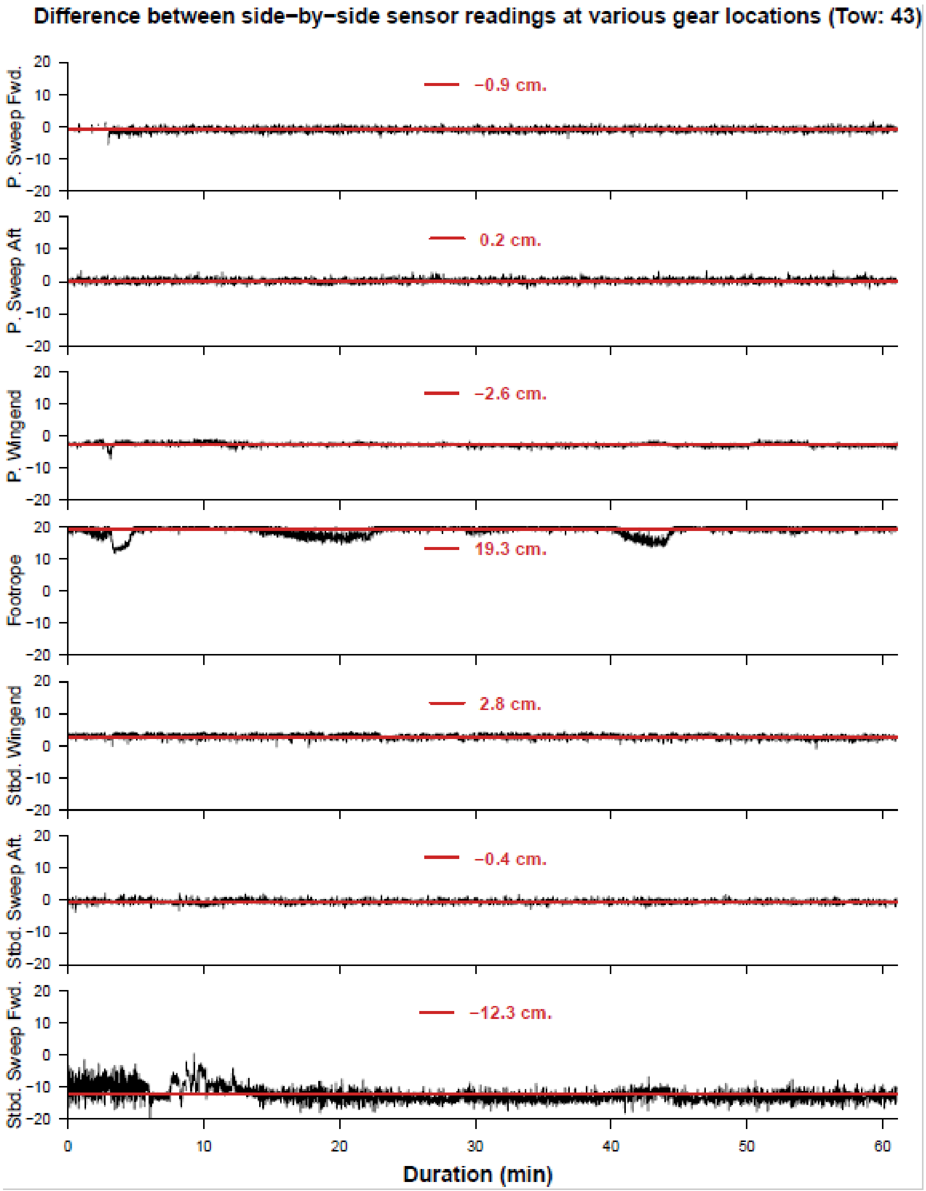

Tow #: 39 (Gear Treatment = 2; Depth = "shallow")
Sensor height (cm), at specific locations
P. Sweep 1
P. Sweep 2
P. Bridle
Center
Sb. Bridle
Sb. Sweep 1
Sb. Sweep 2
25
20
15
10
5
0
-5
10
20
30
40
50
60
Tow duration (minutes)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Proportion

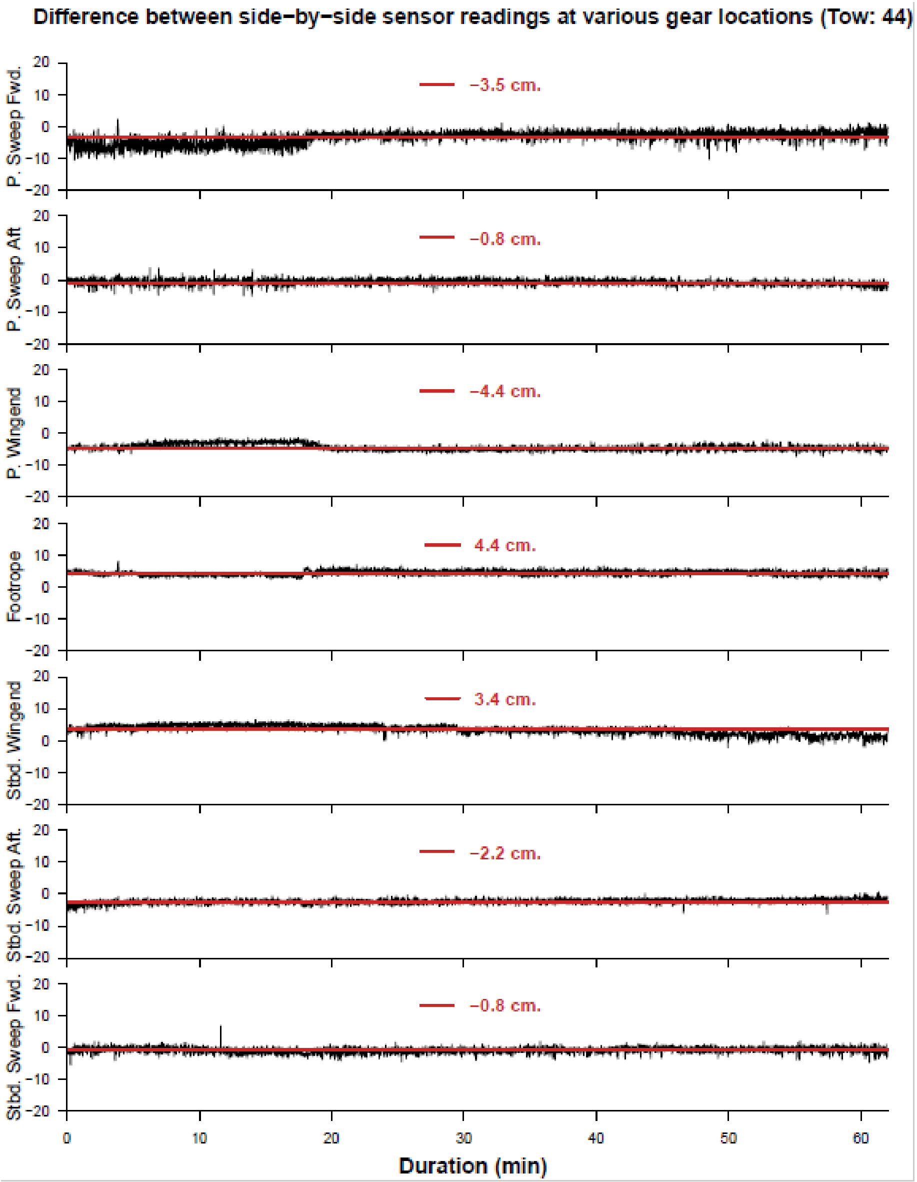
Appendix 2 – difference between multiple sensors readings compared at attachment sites



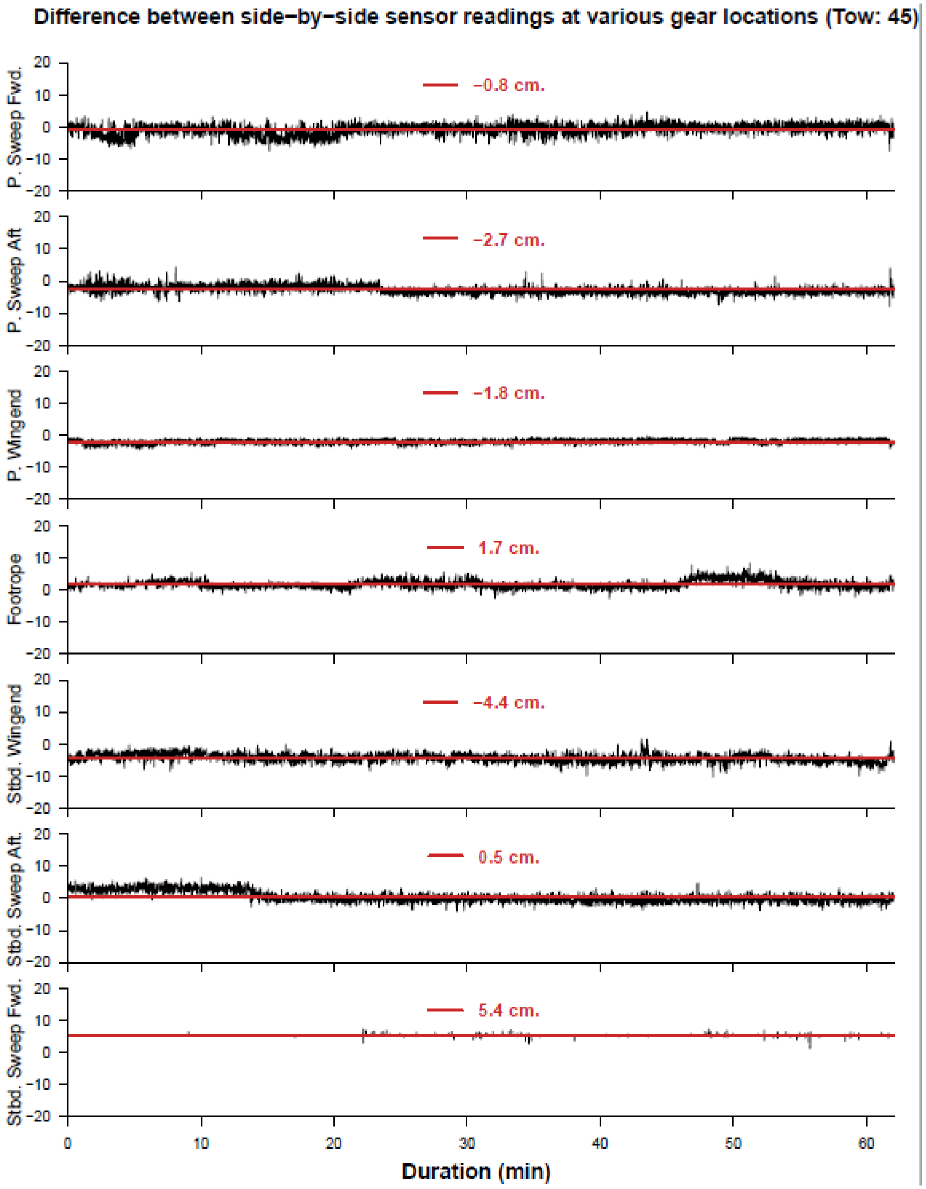



Difference between side−by−side sensor readings at various gear locations (Tow: 42)

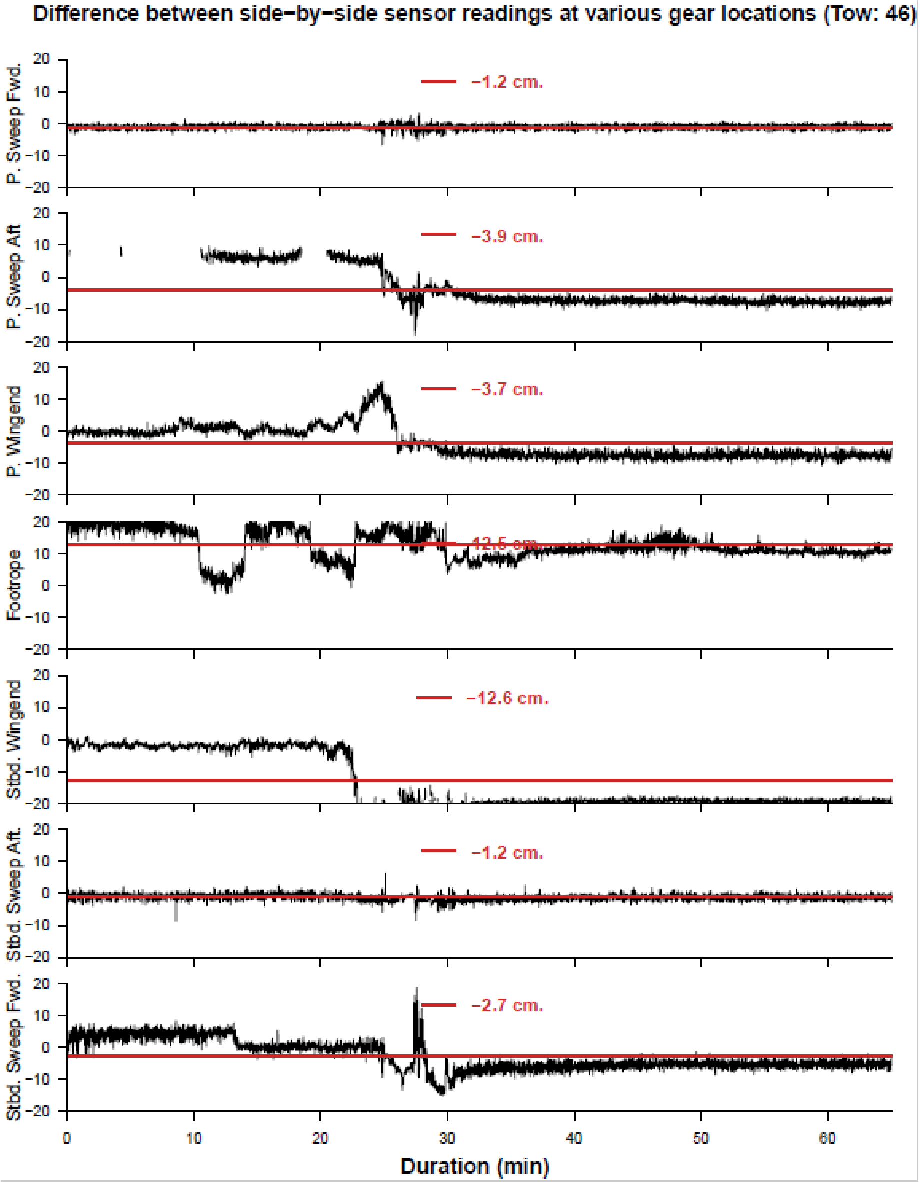

Difference between side−by−side sensor readings at various gear locations (Tow: 43)



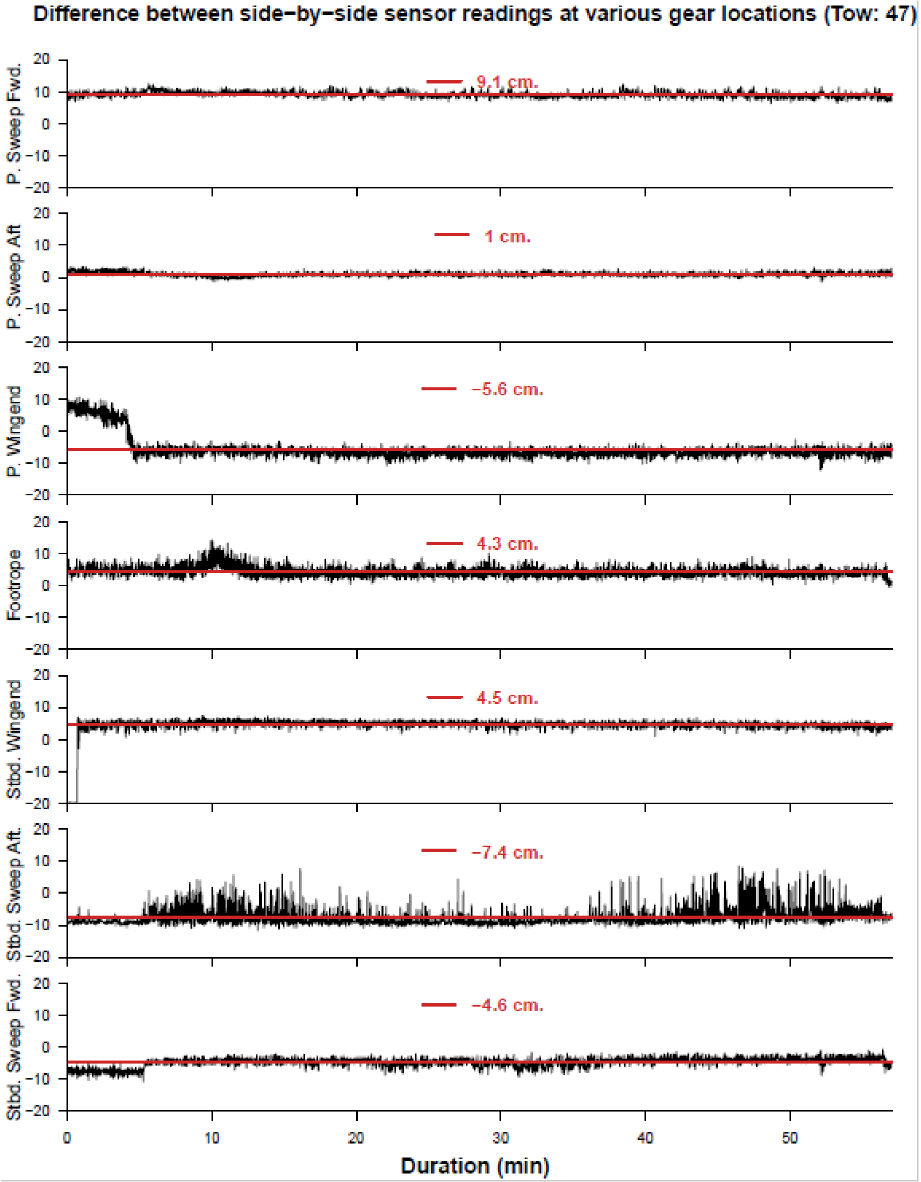
Difference between side−by−side sensor readings at various gear locations (Tow: 44)



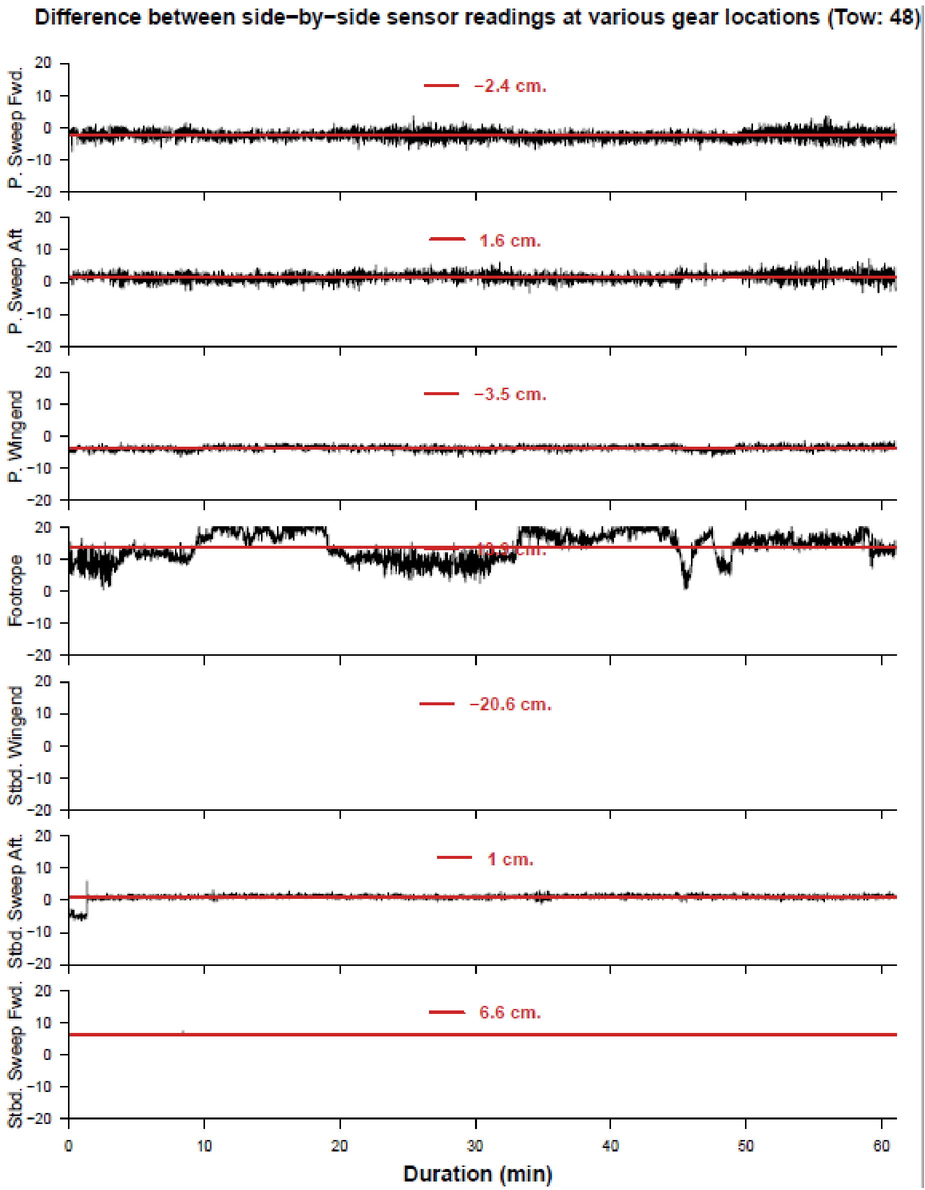
Difference between side−by−side sensor readings at various gear locations (Tow: 45)

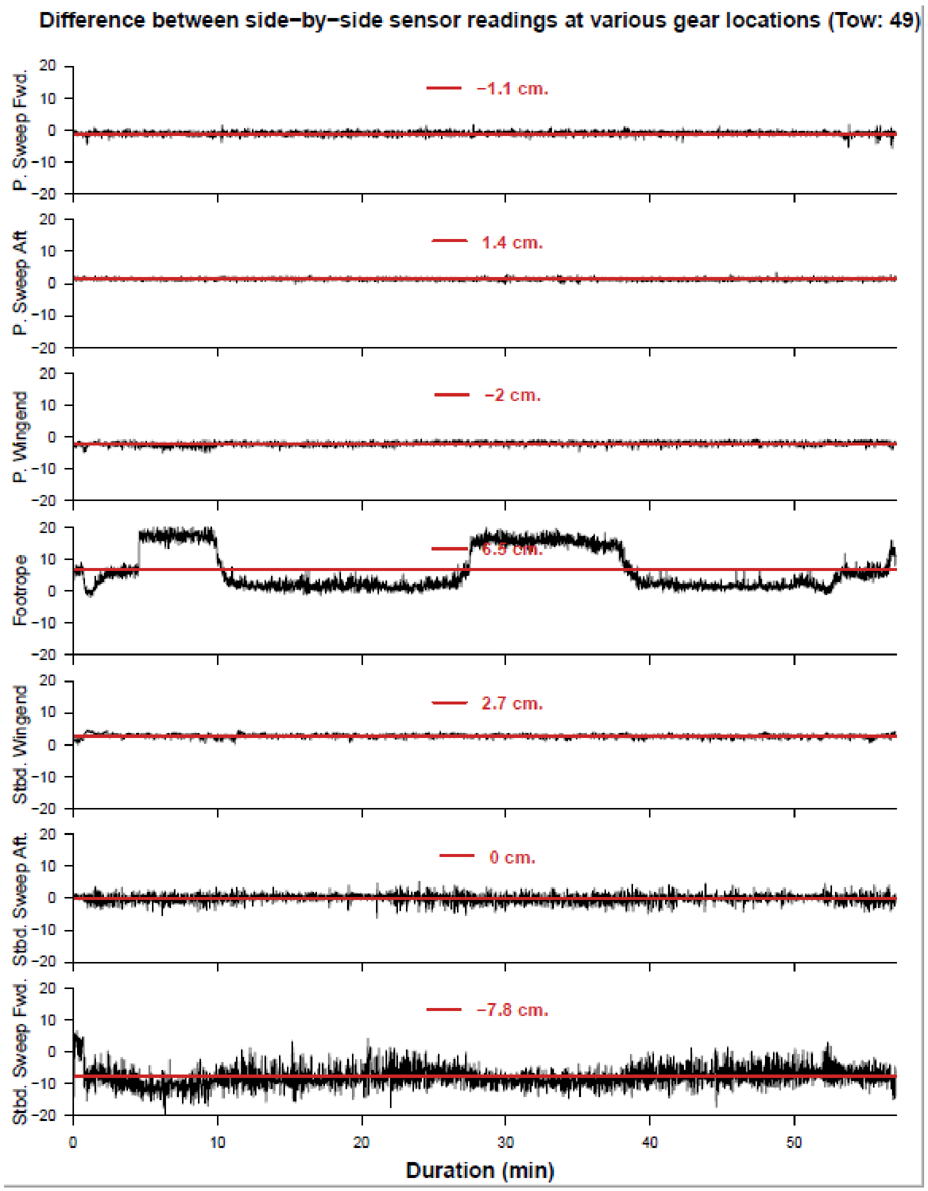


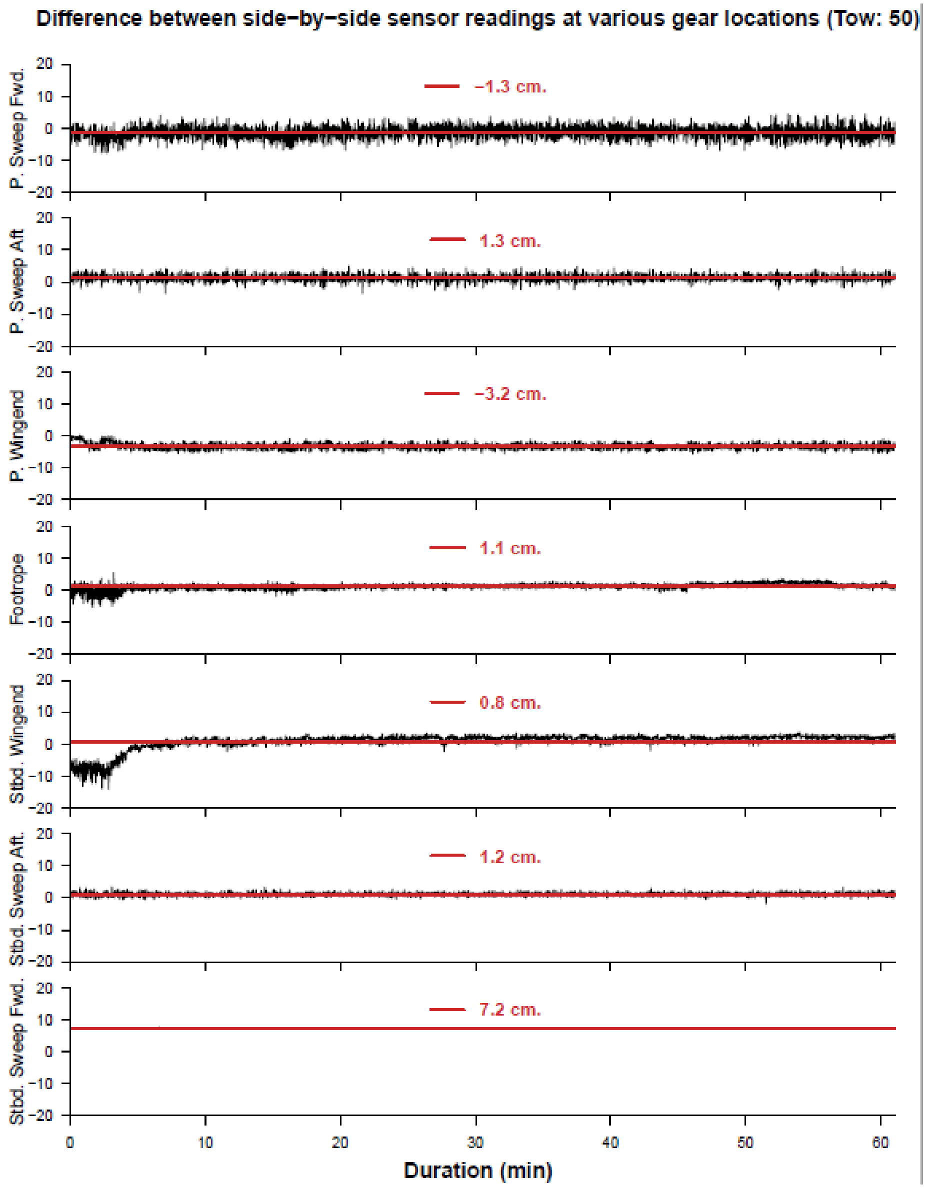
Difference between side–by–side sensor readings at various gear locations (Tow: 46)



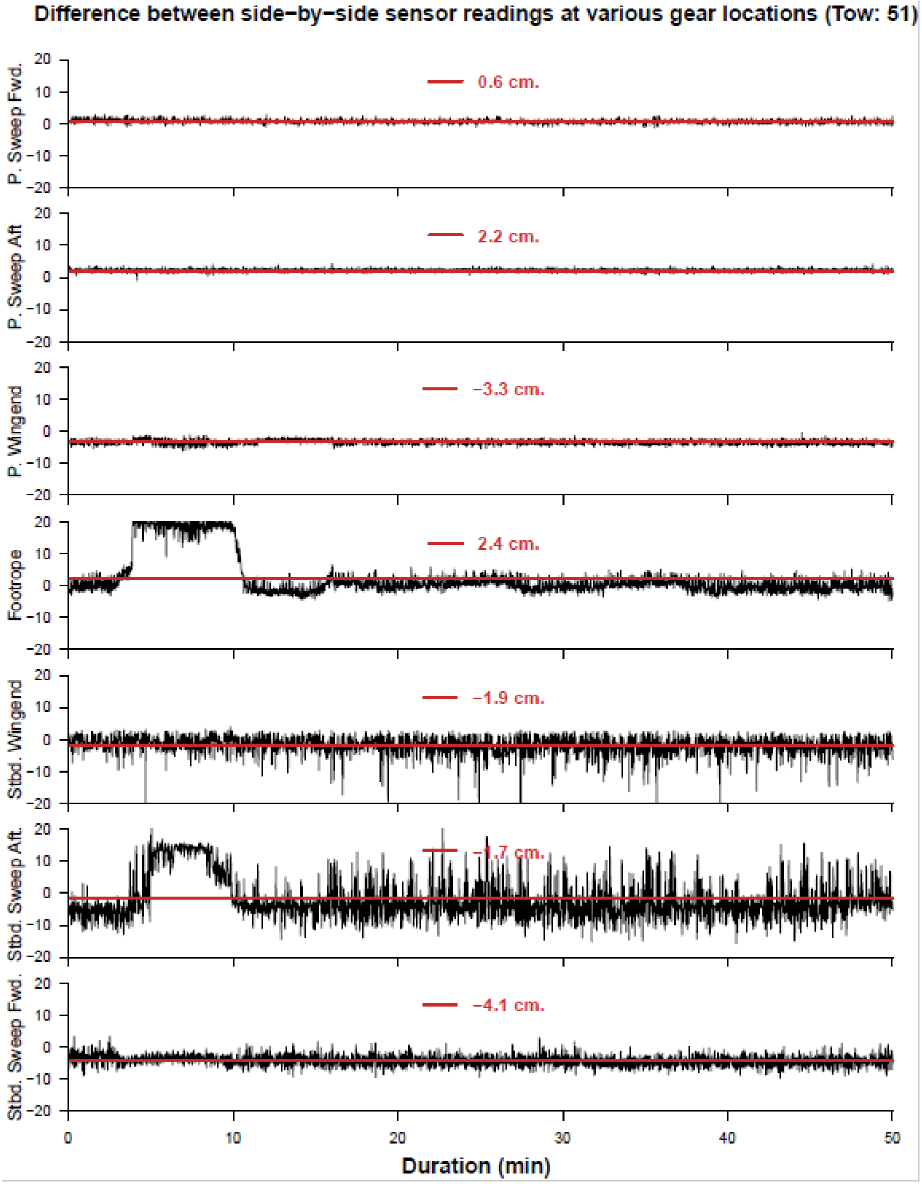
Difference between side–by–side sensor readings at various gear locations (Tow: 47)


Difference between side−by−side sensor readings at various gear locations (Tow: 48)

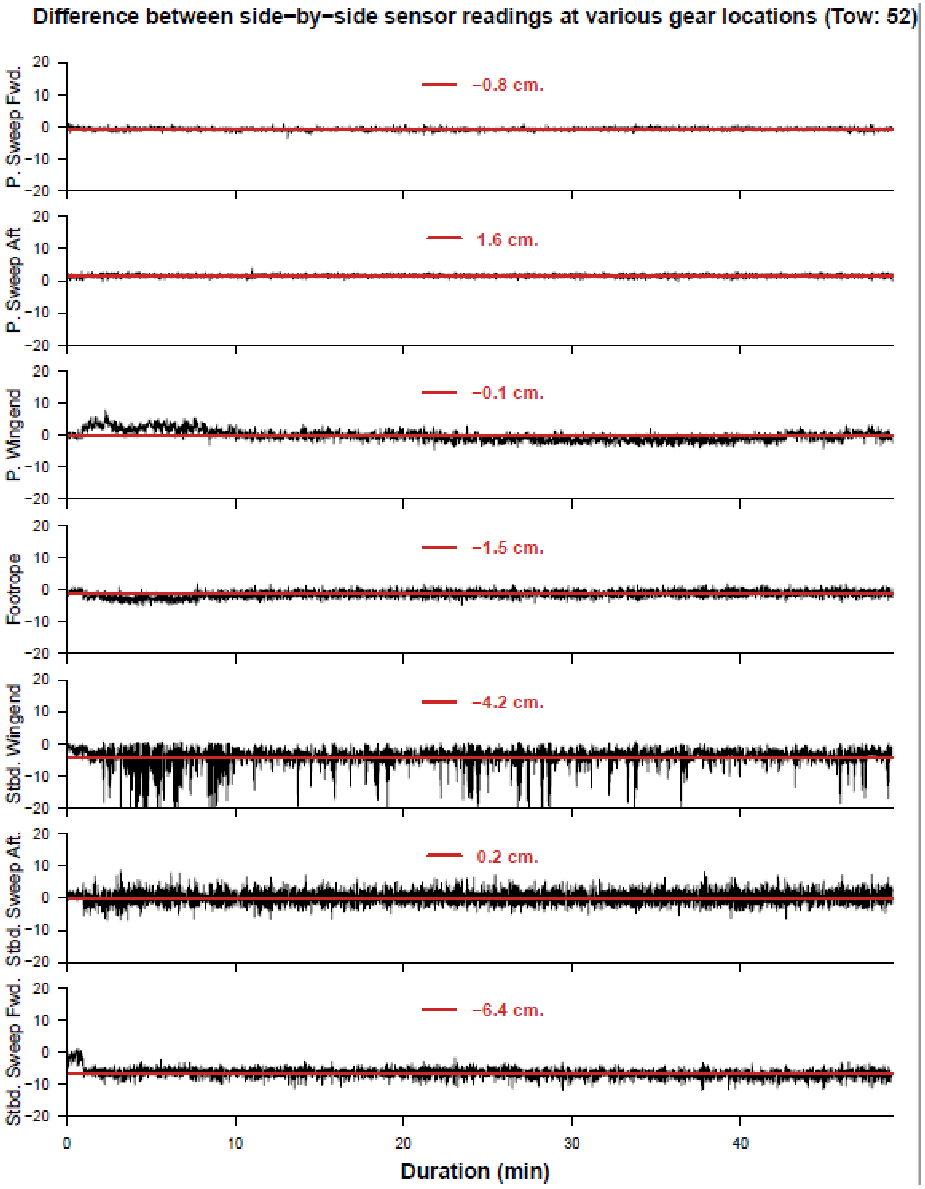

Difference between side−by−side sensor readings at various gear locations (Tow: 49)

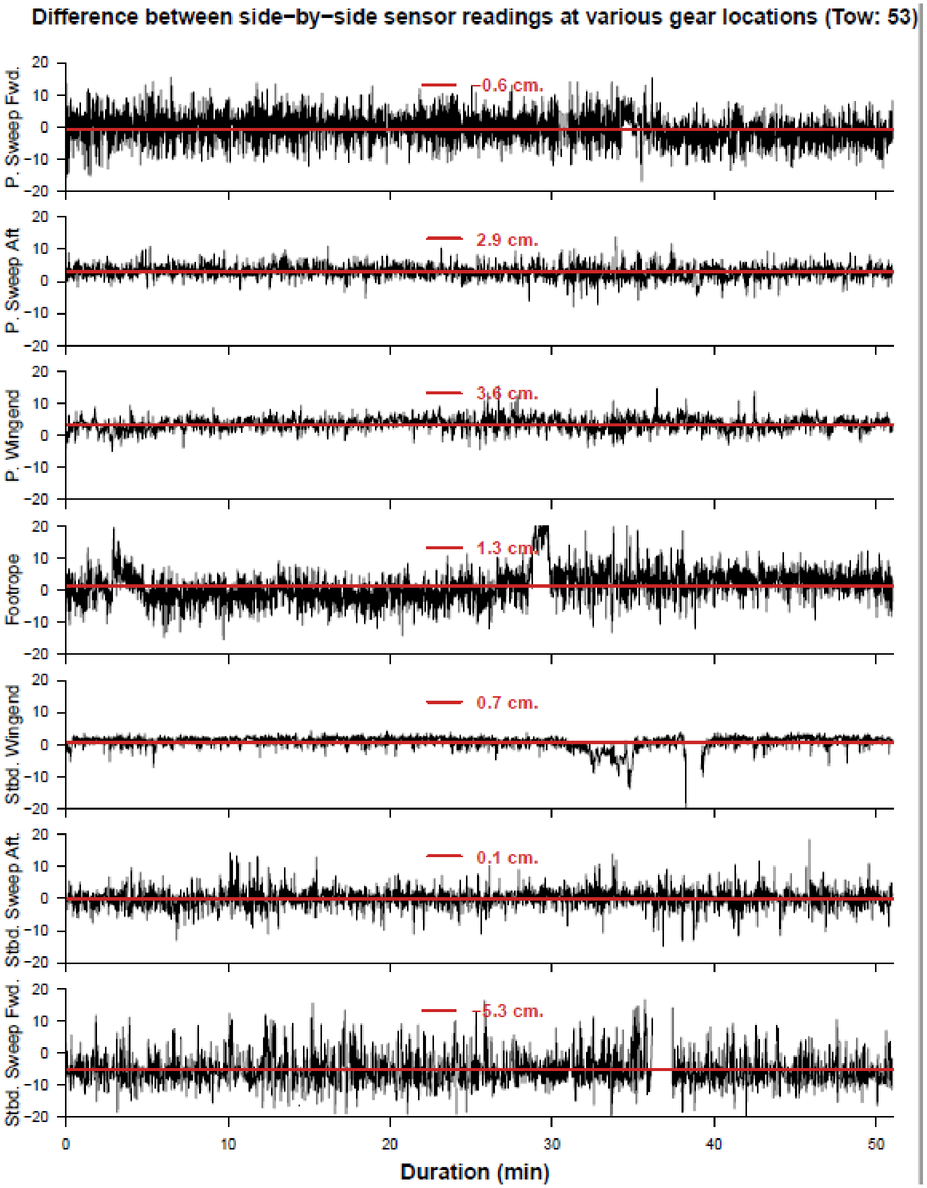


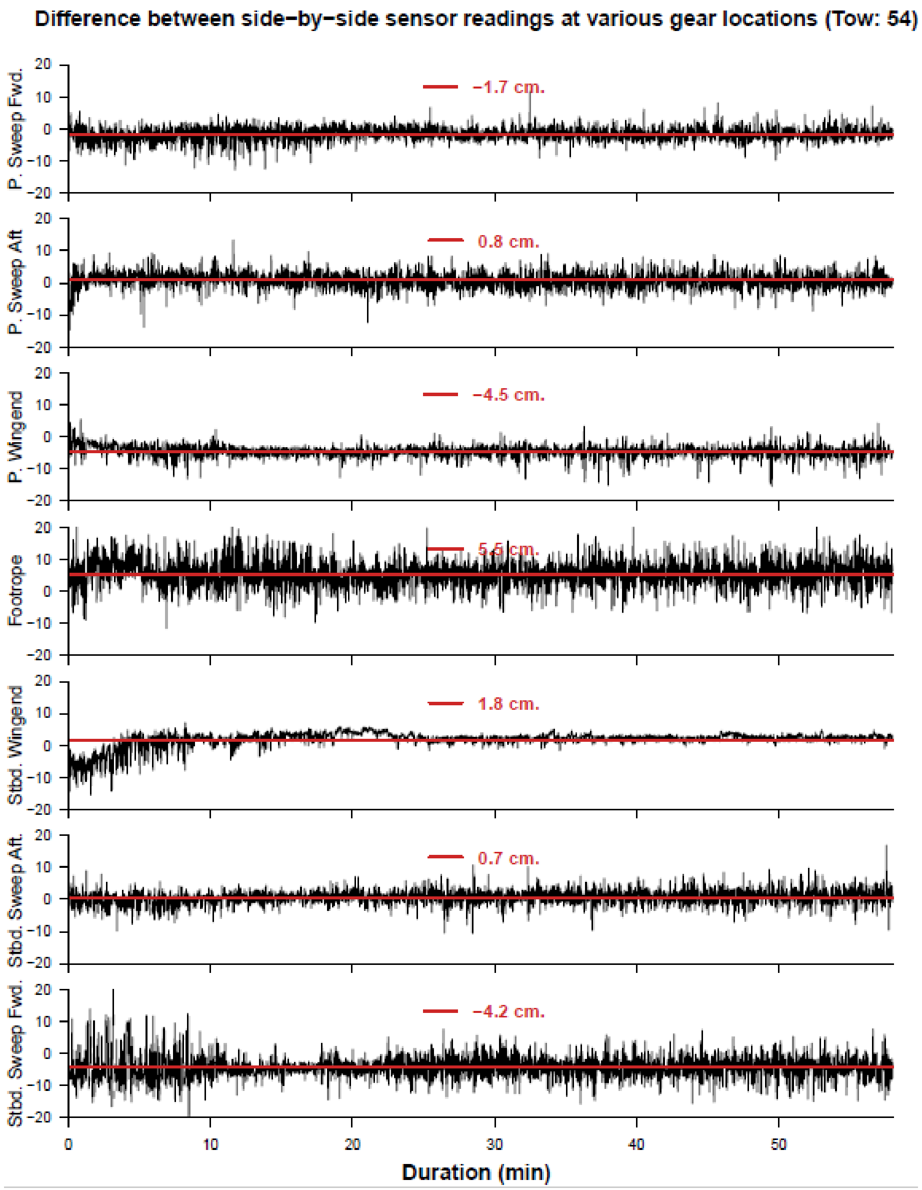
Difference between side–by–side sensor readings at various gear locations (Tow: 50)

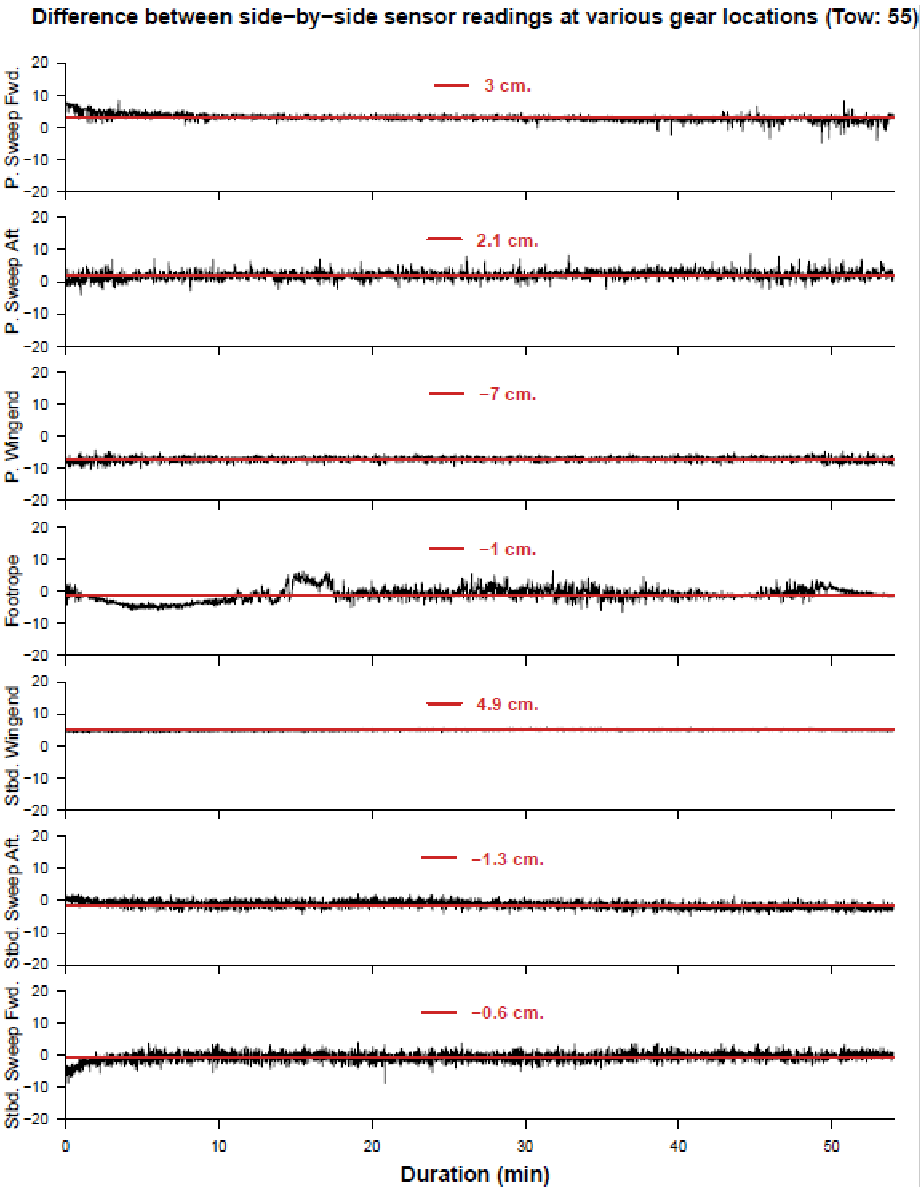


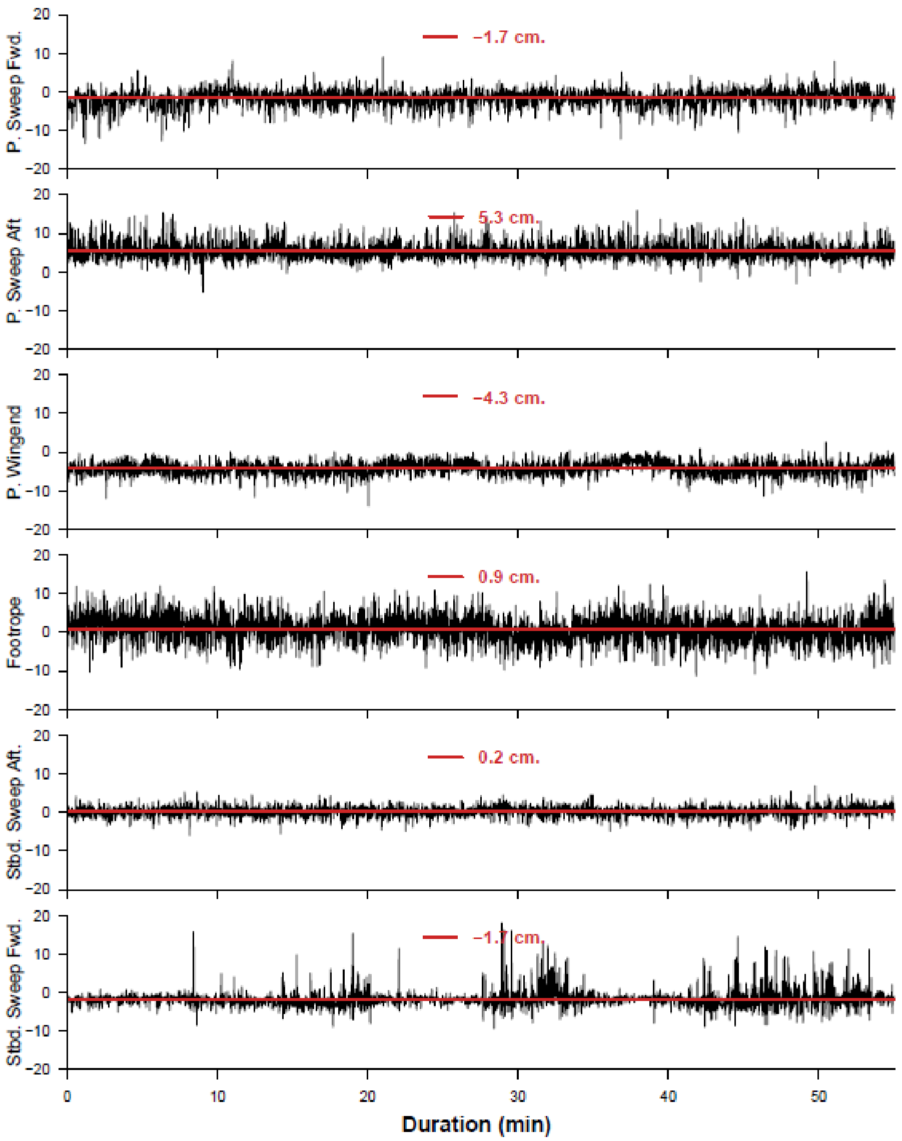
Difference between side–by–side sensor readings at various gear locations (Tow: 51)


Difference between side−by−side sensor readings at various gear locations (Tow: 52)

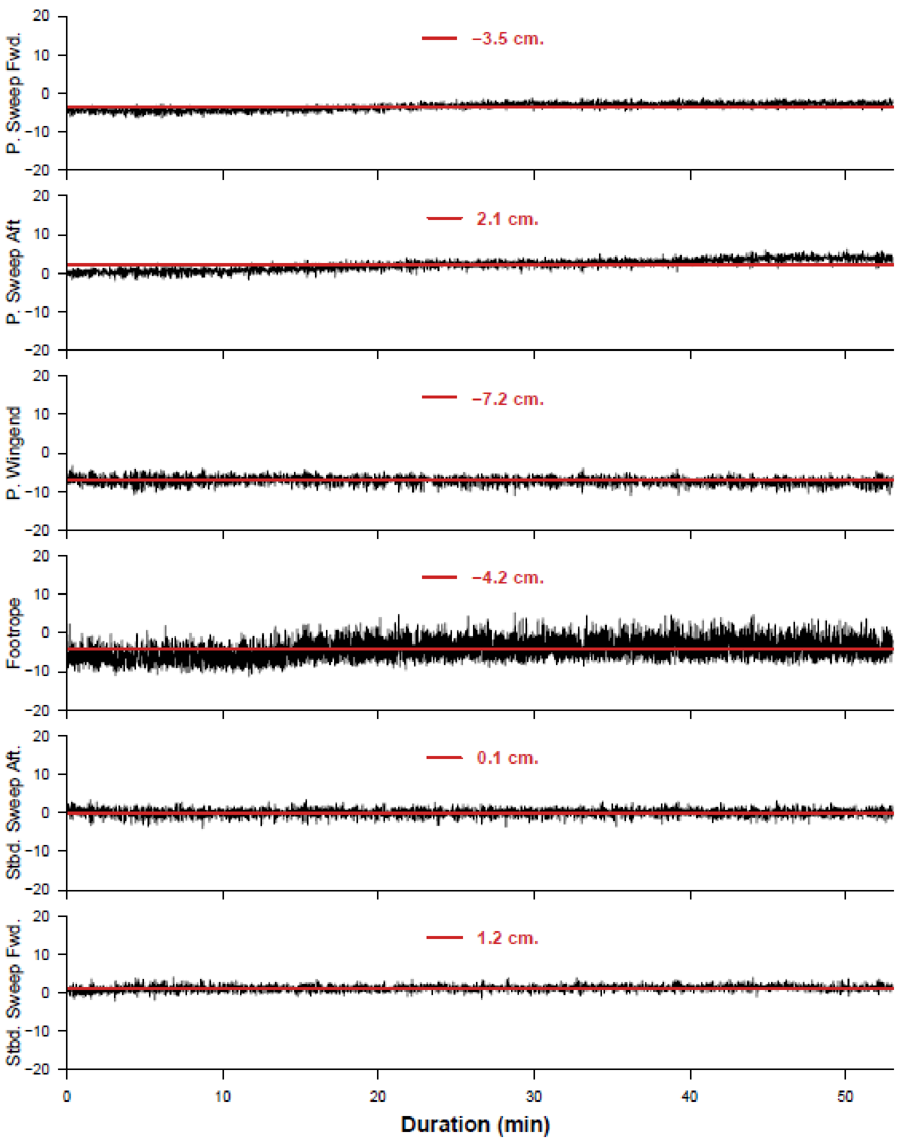

Difference between side−by−side sensor readings at various gear locations (Tow: 53)


Difference between side−by−side sensor readings at various gear locations (Tow: 54)

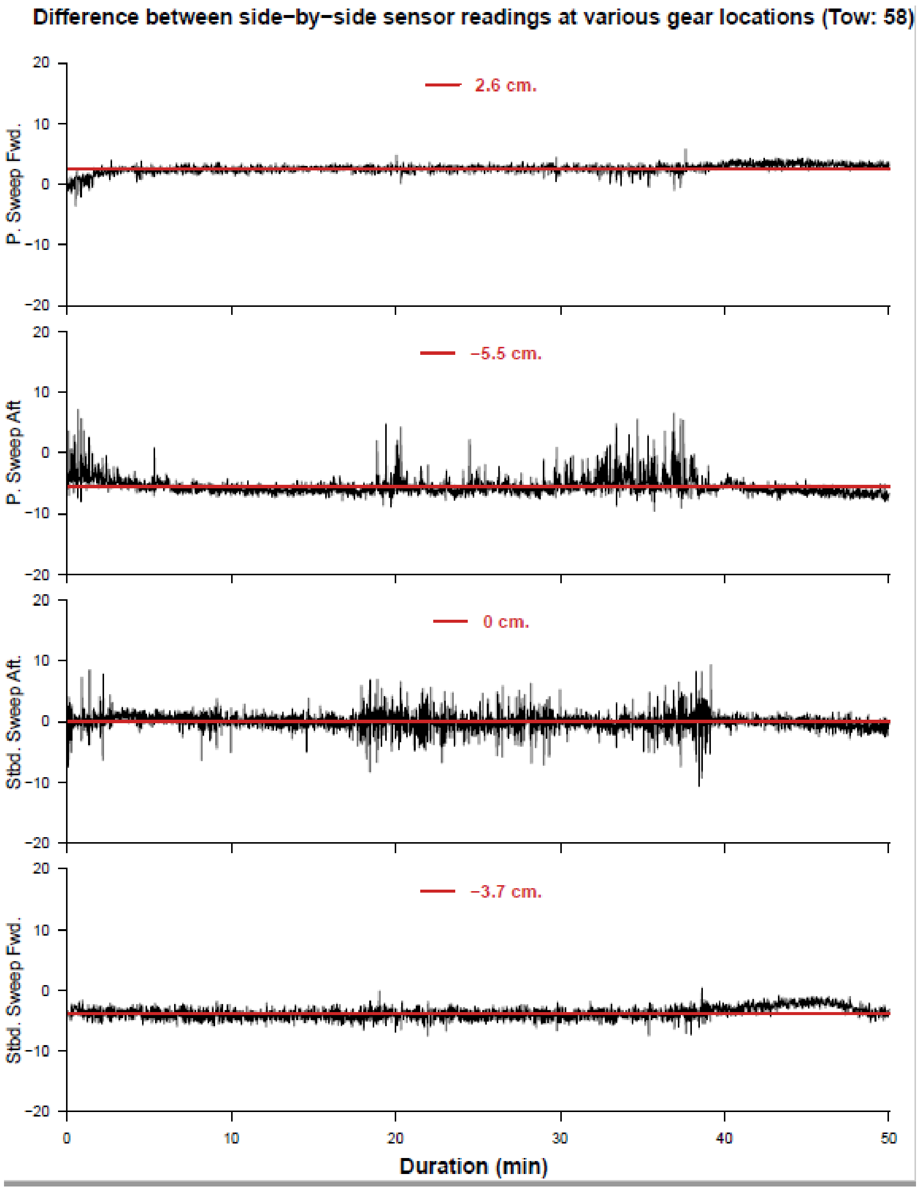

Difference between side−by−side sensor readings at various gear locations (Tow: 55)

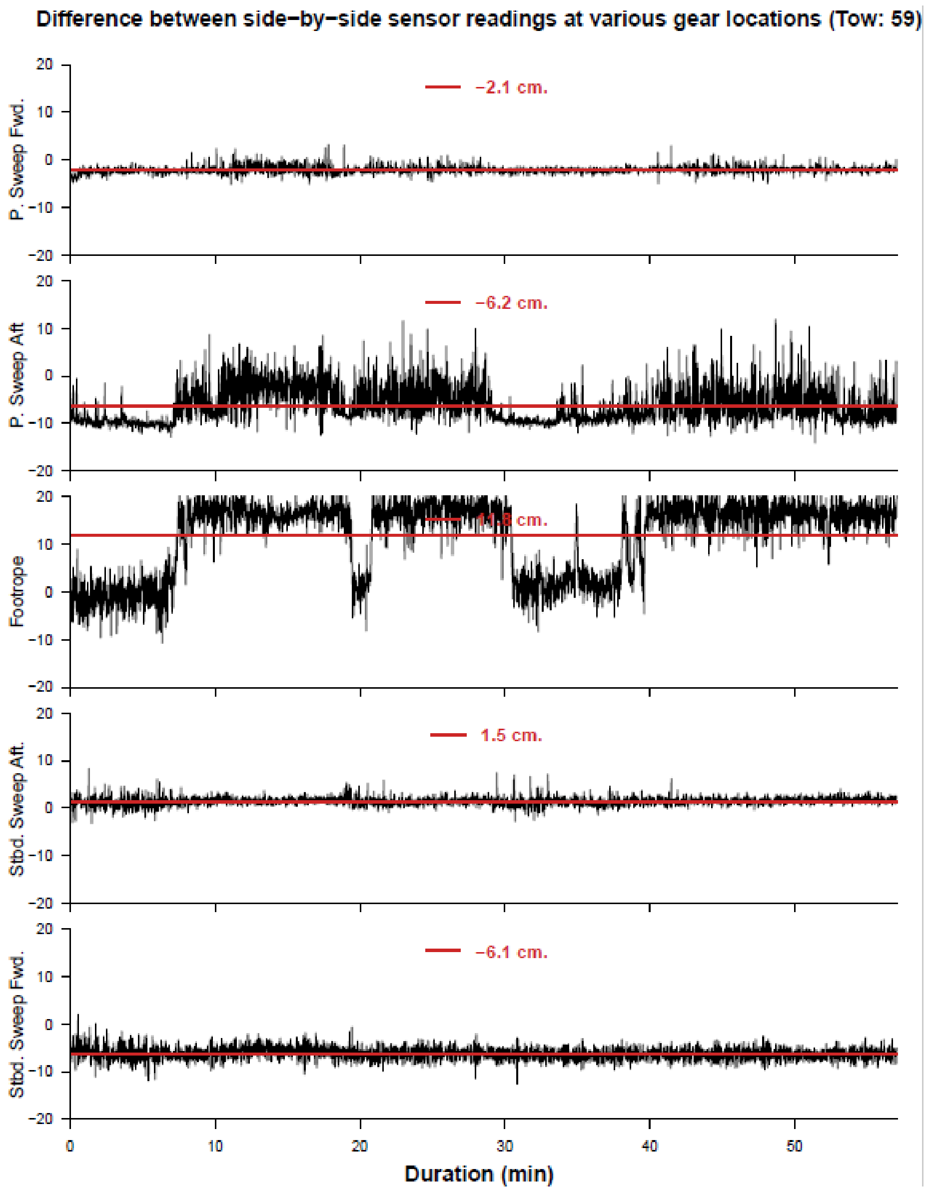


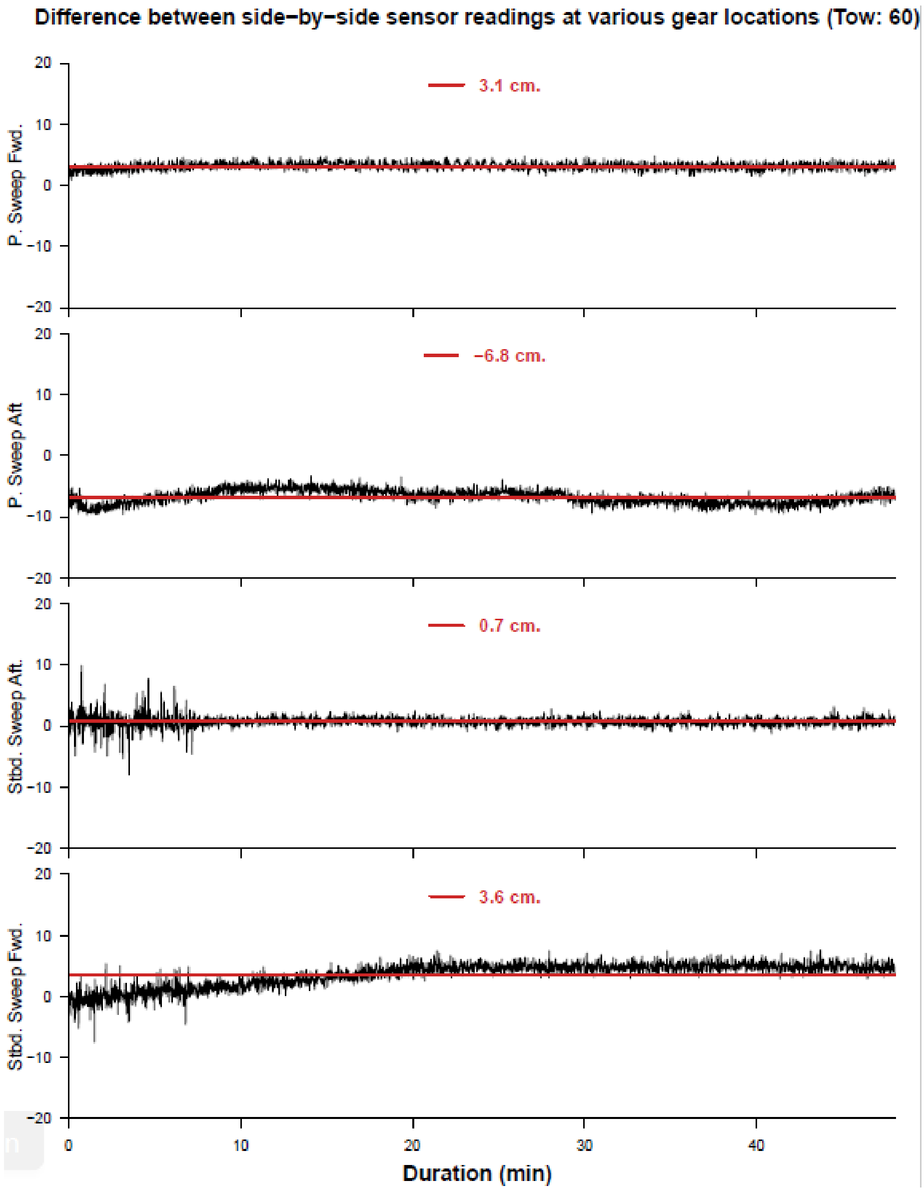
Difference between side–by–side sensor readings at various gear locations (Tow: 56)



Difference between side–by–side sensor readings at various gear locations (Tow: 57)


Difference between side−by−side sensor readings at various gear locations (Tow: 58)
P. Sweep Fwd.
2.6 cm.
P. Sweep Aft
−5.5 cm.
Stbd. Sweep Aft.
0 cm.
Stbd. Sweep Fwd.
−3.7 cm.
20
10
0
−10
−20
0
10
20
30
40
50
Duration (min)


Difference between side−by−side sensor readings at various gear locations (Tow: 59)
P. Sweep Fwd.
−2.1 cm.
P. Sweep Aft
−6.2 cm.
Footrope
11.8 cm.
Stbd. Sweep Aft.
1.5 cm.
Stbd. Sweep Fwd.
−6.1 cm.
20
10
0
−10
−20
0
10
20
30
40
50
Duration (min)


Difference between side−by−side sensor readings at various gear locations (Tow: 60)
P. Sweep Fwd.
3.1 cm.
P. Sweep Aft
−6.8 cm.
Stbd. Sweep Aft.
0.7 cm.
Stbd. Sweep Fwd.
3.6 cm.
20
10
0
−10
−20
0
10
20
30
40
Duration (min)

Appendix 3 Dunn (1964) Kruskal-Wallis multiple comparison results showing p-values adjusted with the Bonferroni method.

	Comparison			P-value
Attachment site	Depth strata	Contact classification	Z	(adjusted)
P. Sweep 1	shallow	ON	-3.77964	0.000157
	shallow	NEAR	3.779645	0.000157
	shallow	OFF	2.608936	0.009082
	deep	ON	-3.51094	0.000447
	deep	NEAR	3.674235	0.000239
	deep	OFF	-1.38804	0.165124
P. Sweep 2	shallow	ON	-1.88982	0.058782
	shallow	NEAR	2.796937	0.005159
	shallow	OFF	-0.9959	0.319299
	deep	ON	-3.18434	0.001451
	deep	NEAR	3.347636	0.000815
	deep	OFF	-3.51248	0.000444
P. Bridle	shallow	ON	0.982708	0.325751
	shallow	NEAR	-3.1749	0.001499
	shallow	OFF	0.56909	0.569295
	deep	ON	1.061446	0.288487
	deep	NEAR	-0.89815	0.369108
	deep	OFF	-1.87794	0.060389
Centre	shallow	ON	-3.39732	0.00068
	shallow	NEAR	3.397325	0.00068
	shallow	OFF	1	0.317311
	deep	ON	-2.44949	0.014306
	deep	NEAR	2.36784	0.017892
	deep	OFF	-0.316	0.752005
Sb. Bridle	shallow	ON	0.833089	0.404794
	shallow	NEAR	-2.87253	0.004072
	shallow	OFF	2.116601	0.034294
	deep	ON	2.204541	0.027486
	deep	NEAR	-1.1431	0.252999
	deep	OFF	-1.22474	0.220671
Sb. Sweep 1	shallow	ON	-1.96542	0.049366
	shallow	NEAR	2.418973	0.015564
	shallow	OFF	-0.15119	0.879829
	deep	ON	-3.67423	0.000239
	deep	NEAR	3.674235	0.000239
	deep	OFF	-2.20454	0.027486
Sb. Sweep 2	shallow	ON	-3.78107	0.000156
	shallow	NEAR	3.779645	0.000157
	shallow	OFF	0.680336	0.496292
	deep	ON	-3.67423	0.000239
	deep	NEAR	2.939388	0.003289
	deep	OFF	3.592585	0.000327