Fisheries New Zealand

Tini a Tangaroa

Net A vs. net B trial for hoki off the North Island east coast

New Zealand Fisheries Assessment Report 2021/51

D. A. J. Middleton

ISSN 1179-5352 (online)
ISBN 978-1-99-100995-1 (online)

September 2021

New Zealand Government

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Middleton, D.A.J.[1] (2021). Net A vs. net B trial for hoki off the North Island east coast.

***New Zealand Fisheries Assessment Report 2021/51*. 47 p.**

An alternate-tow comparison of conventional mesh trawls and the inshore-specification Modular Harvest System (MHS) net was undertaken in the hoki fishery off the east coast of the North Island. Thirty-six tows, in eighteen matched tow pairs, were carried out. Tows within a pair fished the same tow line with the different gears. Alternate tows took place on subsequent days of the trial. Other than date, other effort-related parameters of the tows within the pair were matched as closely as possible. The experimental fishing took place over four trips in May-June 2020.

Length-frequency sampling was carried out for hoki, gemfish, and ling on each tow. When catch volumes were small the entire catch was measured, but larger catches were subsampled with a target sample size of 200 hoki or 100 fish of the other species. Catch data were collected via the vessel's Electronic Reporting (ER) system with catch of all species recorded for experimental tows. The sampling was carried out by a Fisheries New Zealand observer, with data recorded using an electronic device ('YUMA' device) used by the observer programme. ER data were provided daily, and observer data were provided after each trip. This allowed trial progress to be monitored in 'real-time' and an assessment made of when adequate data had been collected. In general, trial logistics were successful, although there were some minor differences in catch data record-keeping and problems with exported data from the observer's YUMA device that could be improved in future trials.

Data were analysed following the approaches developed by Chambers et al. (2021). Specifically, Bayesian generalised linear mixed models were used to fit catches with tow pair as a random effect. Analysis of the length data focused on proportional catch at length ('relative selectivity') with uncertainty in the proportion caught by MHS assessed by bootstrapping. A key difference in the methodology was scaling the sample data to the tow weight, because it was not possible to measure all fish caught.

The MHS1480 was originally engineered for inshore fisheries where a minimum of 125 mm mesh is required. Catch rates of hoki were lower with the MHS than with the 100 mm mesh trawl that is the minimum standard in the fishery, but the difference was not significant at the 95% level. Catch rates of gemfish were significantly lower and there was also evidence that the first tow in a pair had a lower catch rate of gemfish. Catch rates of ling did not differ between the two gears.

The relative selectivity analyses indicated that the MHS caught significantly fewer hoki in the 65 cm to 85 cm range, although the differences in proportional catch at length were generally not significant after accounting for the difference in fishing power. After accounting for the reduced catch rates of gemfish, no differences in size selectivity for gemfish or ling were apparent between the methods.

[1]Pisces Research

1. INTRODUCTION

A variety of fishing gear is currently approved for use in New Zealand fisheries. In some cases the regulations permit a degree of flexibility: for example, trawl mesh size is normally specified as a minimum to allow fishers to use larger mesh sizes if they wish. However, when gear innovations result in designs that are outside the currently permitted specifications, the new gear must be tested and approved as set out (for trawl nets) in regulation 71A of the Fisheries (Commercial Fishing) Regulations 2001.

The Modular Harvest System (MHS) developed by the Precision Seafood Harvesting Limited Partnership (PSH) is currently approved for use in specific fisheries, specified by area and target species (Fisheries New Zealand 2018, 2019). Analyses of a preliminary 'alternate-tow' trial comparing the MHS with traditional mesh trawls in the South Island east coast inshore fishery (Chambers et al. 2021) led to the recommendation that the alternate-tow approach be used for future comparisons of MHS and mesh trawls, with a particular focus on relative selectivity as the information of greatest interest in the approval process.

This report describes the implementation and analyses of an alternate-tow trial in the hoki target fishery off the east coast of the North Island. Although hoki is classified as a deepwater species, and there is an approval for using a 'deepwater MHS' for targeting hoki (Fisheries New Zealand 2018), this particular fishery is undertaken by vessels that are regarded as part of the inshore fleet. The MHS gear used was therefore the current inshore specification MHS (Fisheries New Zealand 2019). The trial was carried out under special permit 743 issued by Fisheries New Zealand.

2. METHODS

The trial was carried out to compare 'Net A', the MHS1480 specification Modular Harvest System gear, with 'Net B', a Milligan 100 mm (4") conventional mesh wing trawl, when targeting hoki. The approach used was the 'alternate-tow' design where the same tow lines were fished twice, once with Net A and once with Net B. Improvements in the alternate-tow methodology, proposed by Chambers et al. (2021) after assessing data from the South Island trial, were implemented.

The experimental fishing was carried out in May–June 2020 by a single vessel over the course of four trips. A number of non-experimental tows were included in the trips to meet the catch requirements of the vessel operator. A Fisheries New Zealand observer was on board for the trial, tasked with carrying out length sampling during the experimental tows.

2.1 Alternate-tow protocols

The alternate-tow process involved changing the gear overnight. Tow lines fished with one gear on the first day were repeated with the other gear on the second day, aiming to fish the lines:

- at approximately the same time of day;
- in the same direction;
- at the same speed; and
- with the same wing spread and headline height.

The skipper was asked to focus on replicating the tow line as closely as possible, adjusting tow speeds if necessary to achieve this due to varying conditions. After the first day of the trial the gears were swapped every second night; this approach had the effect of alternating the gear fished first within the pairs.

2.2 Catch data recording

The trial protocols aimed to capture all catch and effort data using the Electronic Reporting (ER) system. The skipper was asked to use the ER software to record catch estimates for *all* species caught on the tow, even the species for which they would not normally be required to provide catch estimates on a tow by tow basis. In addition, the protocols specified that stickers should be cleared from the meshes and added to the catch from each tow. For the experimental tows, the observer was asked to verify that estimates of all species caught were recorded via the ER software for each tow, rather than making independent estimates of catch quantities.

2.3 Biological sampling

Following a preliminary characterisation of the hoki fishery off the North Island, hoki (HOK), gemfish (SKI), and ling (LIN) were identified as the key species for length sampling, with rubyfish (RBY) and alfonsino (BYX) as secondary targets if catches and sampling time allowed. The sampling targets were 200 fish per tow for hoki, and 100 fish for the other species (if catches allowed). Protocols specified that length samples were to be taken from the ungraded catch (i.e., the catch should have been separated into species but no sorting by size should have been carried out) and ideally to be taken by scoop sampling (scooping fish from the deck into a container), collecting samples of approximately the right number of fish and measuring all fish in the sample. Only length data were collected (total length for hoki and ling, fork length for gemfish, alfonsino, and rubyfish), with lengths recorded to the nearest centimetre under the actual length.

2.4 Data extracts

The Special Permit provided flexibility around the number of tow pairs carried out in the trial, with the intention that the results were monitored and the experimental fishing continued until sufficient data were collected. Electronic catch and effort data were provided daily during the trial, with data exported from the Fishserve system by the vessel operator and finalised landing weights available a few days after each trip was completed. Observer data were also collected electronically, but it was not possible to export these data daily. However, after each trip data were exported to USB storage, processed by the observer programme and supplied electronically approximately one week after the trip was completed. The analyses in this report use these extracts, noting that the data are expected to become available via the normal Fisheries New Zealand reporting databases (i.e., the Enterprise Data Warehouse, EDW, and the Centralised Observer Database, COD) in due course.

The vessel operator also provided access to Vessel Monitoring System data which were added to the tow start and end positions recorded in the ER data to provide finer scale plots of the tow lines.

Observer samples of alfonsino were all of *Beryx splendens* and recorded using observer species code BYS. For the purpose of the analyses presented here, where observer data were matched to the ER catch and effort data, these records were re-coded to the statutory code, BYX (which includes *Beryx splendens* and *Beryx decadactylus*). In post-trial discussions with the observer programme it was also discovered that comments recorded by the observer for four length samples (two species on two tows) indicated that the wrong species code had been entered. These records had not been corrected in the extracts supplied and were fixed as part of the analysis.

2.5 Statistical analyses

Chambers et al. (2021) explored a variety of methods for analysis of data from an alternate-tow trial; the approaches adopted here are the particular methods favoured after review by Fisheries New Zealand's Statistics, Assessments and Methods Working Group.

2.5.1 Catch rate modelling

Catches of key species were modelled using Bayesian generalised linear mixed models (GLMMs) fitted using the `brms` package (Bürkner 2017). The catch taken on a tow was modelled with duration (as an offset term) and gear type as fixed effects, and random effects for tow-pair. An indicator variable indicating which tow was fished first in each tow pair was also included (Equation 1).

$$\text{catch\_kg} \sim \text{gear} + \text{offset(log\_minutes)} + \text{first\_tow} + (1|\text{tow\_pair}). \tag{1}$$

The models were filled using the `brms` default non or weakly informative priors, and 2000 iterations for each of four Markov chains. Models with Gamma or lognormal distributions for the positive observations were fitted and the preferred model selected by comparing their expected predictive accuracy using leave-one-out cross-validation (LOOIC; Vehtari et al. 2017).

For hoki and gemfish, models were fitted to both the full set of tow pairs and various subsets to illustrate the impact of the number of tow pairs included.

2.5.2 Relative catch at length

Confidence intervals for the proportion of fish at a given length caught by the MHS (termed 'relative selectivity') were estimated by bootstrapping. A two-stage bootstrap procedure was implemented, resampling from tow pairs, then resampling from the fish within each tow in a pair. The procedure described by Chambers et al. (2021) was extended to account for the fact that not all fish were measured from each tow.

For each species sampled, the data comprise a set of measurements of fish lengths $\{x_{1jg}, x_{2jg}, ..., x_{ijg}\}$ from tows that are identified by a pair ID, j, and a method label g.

The number of measured fish in length class l in a given tow is N_{ljg} where g is either MHS, m, or conventional trawl c.

2.5.3 All fish measured

For the case where all fish from each tow are measured then, within a tow pair, the proportion of fish in length class l taken by MHS is:

$$p_{lj} = \frac{N_{ljm}}{N_{ljm} + N_{ljc}}. \tag{2}$$

Given k tow pairs, the overall proportion of fish in a length class taken by MHS is:

$$p_l = \frac{\sum_{j=1}^{k} N_{ljm}}{\sum_{j=1}^{k}(N_{ljm} + N_{jc})} \tag{3}$$

To provide a confidence interval for p_l, two-stage bootstrapping is used to construct B replicate sets of measurements $\{x^*_{1jg}, x^*_{2jg}, ..., x^*_{ijg}\}$. Each set is constructed by:

1. sampling a tow pairs, with replacement, from the k available pairs; and then
2. sampling b fish, with replacement, from the i_{jg} fish measurements available on each tow within the pair.

This allows the construction of a set $|B|$ of bootstrap estimates of the population proportion caught by MHS for each length class:

$$p^*_l = \frac{\sum_{j=1}^{k} n^*_{ljm}}{\sum_{j=1}^{k}(n^*_{ljm} + n^*_{ljc})} \tag{4}$$

and the 95% confidence interval for p_l is formed from the 2.5% and 97.5% percentiles of the distribution of p^*_l.

2.5.4 Samples of fish measured

Logistical constraints may mean that not all fish from all tows can be measured. The inverse of the proportion of fish sampled for each tow provides a scaler for upweighting the samples from the tow:

$$w_{jg} = \frac{c_{jg}}{s_{jg}} \tag{5}$$

where c_{jg} is the total catch weight of the species on tow jg and s_{jg} is the sample weight.

These scalers are used directly in the calculation of the proportion at length:

$$p_l = \frac{\sum_{j=1}^{k} w_{jm} n_{ljm}}{\sum_{j=1}^{k} (w_{jm} n_{ljm} + w_{jc} n_{ljc})} \tag{6}$$

and likewise for the bootstrap samples:

$$p_l^* = \frac{\sum_{j=1}^{k} w_{jm}^* n_{ljm}^*}{\sum_{j=1}^{k} (w_{jm}^* n_{ljm}^* + w_{jc}^* n_{ljc}^*)} \tag{7}$$

Note that the scalers vary between bootstrap replicates because the sample weight is calculated as the sum of the fish weights in the particular bootstrap replicate.

For each species, 1000 bootstrap samples were carried out. For each bootstrap sample the default approach is to sample $a = k$ tow pairs and $b = i_{jg}$ fish from each tow; i.e., the sample sizes match those in the original data. The resulting estimates of p_l therefore incorporate differences in catch rates between the gears, as well as differences in size selectivity.

However, a and b can be varied; for example, setting a fixed b number of fish within a pair effectively removes any difference in fishing power between MHS and conventional gear. In this report, the bootstrap analysis was repeated with the target samples sizes of $b = 200$ for hoki and $b = 100$ for gemfish and ling.

Smooth splines were fitted to the bootstrapped proportions. In contrast to the approach taken by Chambers et al. (2021), where mixed model splines were fitted to the bootstrap mean proportions, a cubic smoothing spline was fitted to each bootstrap replicate and uncertainty in the smoothed proportional catch at length was inferred from the distribution of bootstrapped spline fits (see e.g., Hastie et al. 2009, §8.2.1). Fitting the splines at the level of the individual bootstrap samples allowed weighting by the number of fish at length in the individual samples. The resulting distribution of smooth splines was evaluated over the length range defined by the smallest and largest lengths where a minimum of ten fish were present in the raw data.

3. RESULTS

Over the four trips, thirty-six tows, representing eighteen tow pairs with one tow by each gear, were carried out (Table 1). The experimental fishing was carried out in the western Bay of Plenty, north of Tuhua/Mayor Island, and the vessel tracks during towing indicated a good match of tow lines within a tow pair (Figure 1).

Table 1: Summary effort variables, and estimated catches for key species, for experimental tows carried out as part of the trial, listed in order of completion (all dates are 2020) and using the vessel's ER data. The pair number identifies the matching tow for the purposes of the alternate-tow design. Tow bearing is calculated between the start and end points specified in the ER catch and effort data. Tows carried out with the conventional bottom trawl are indicated by the BT method code, and tows that used the Modular Harvest System by the PRB code. Species codes are tabulated in Appendix A.

									Estimated catch (kg)				
Tow	Pair	Method	Tow start	Target	Duration (mins)	Depth (m)	Speed (kn)	Bearing (°)	HOK	SKI	LIN	RBY	BYX
1	1	PRB	23 May 07:35	HOK	180.0	402	3.4	184.6	630	1000	84		
2	2	PRB	23 May 11:36	HOK	171.7	402	3.4	160.9	480	1000	112		
3	3	PRB	23 May 15:31	HOK	181.8	376	3.1	348.8	180	50	56		
4	1	BT	24 May 07:36	HOK	175.3	401	3.4	183.8	840	1250	112		
5	2	BT	24 May 11:45	HOK	165.2	401	3.3	161.5	360	400	308		
6	3	BT	24 May 15:34	HOK	174.2	376	3.3	349.7	180	150			
7	4	BT	26 May 07:19	HOK	189.3	385	3.4	8.1	1200	3500	84		
8	5	BT	26 May 11:52	HOK	174.8	415	3.3	187.6	510	1000	112		
9	6	BT	26 May 15:44	HOK	167.3	360	3.1	9.2	150	280	56		
10	4	PRB	27 May 07:23	HOK	171.1	385	3.4	7.6	240	600		5	
11	5	PRB	27 May 11:34	HOK	184.1	415	3.2	189.4	210	250	224		
12	6	PRB	27 May 15:48	HOK	131.2	365	3.2	12.6	120	100	84		
21	7	PRB	02 Jun 06:45	HOK	180.0	383	3.2	11.1	336	250	120	2	
22	8	PRB	02 Jun 10:56	HOK	182.6	386	3.2	190.0	200	2500	145		
23	9	PRB	02 Jun 15:23	HOK	178.6	411	3.2	6.1	112	25	25		
24	7	BT	05 Jun 06:42	HOK	182.1	383	3.2	10.7	420	2100	50		
25	8	BT	05 Jun 11:02	HOK	179.0	386	3.2	190.7	476	4000	50		
26	9	BT	05 Jun 15:50	HOK	179.0	415	3.2	8.0	170	50	100		
27	10	BT	06 Jun 07:02	HOK	179.5	398	3.2	8.9	616	400	170		
28	11	BT	06 Jun 11:14	HOK	178.1	392	3.3	190.1	532	1100	240		
29	12	BT	06 Jun 15:30	HOK	178.1	433	3.3	6.0	140	30	72		
30	10	PRB	07 Jun 06:40	HOK	180.7	398	3.2	8.9	616	350	144		
31	11	PRB	07 Jun 10:50	HOK	182.5	392	3.3	189.7	588	2405	192		1
32	12	PRB	07 Jun 15:15	HOK	178.9	433	3.3	5.4	224	50	96		
44	13	PRB	13 Jun 07:19	HOK	170.4	415	3.2	191.9	250	100	100		
45	14	PRB	13 Jun 11:17	HOK	174.4	340	3.4	12.9	100	1100	75		1
46	15	PRB	13 Jun 15:10	HOK	177.3	316	3.5	198.6	25	80	25		
47	13	BT	14 Jun 07:22	HOK	170.5	415	3.4	193.9	100	370	75		
48	14	BT	14 Jun 11:15	HOK	178.3	340	3.4	12.3	75	1500	25		
49	15	BT	14 Jun 15:19	HOK	171.9	315	3.4	193.4	100	700	10		
50	16	BT	15 Jun 06:53	HOK	185.8	419	3.4	346.5	125	1100	125		
51	17	BT	15 Jun 11:08	HOK	180.2	420	3.4	349.9	75	1800	250		
52	18	BT	15 Jun 15:14	HOK	149.0	438	3.1	356.3	50	20	100		1
53	16	PRB	16 Jun 06:56	HOK	182.2	419	3.4	346.9	125	1500	350		
54	17	PRB	16 Jun 11:04	HOK	188.8	420	3.3	348.2	100	1200	275		
55	18	PRB	16 Jun 15:12	HOK	151.3	435	3.2	358.1	50	30	75		

3.1 Implementation of the alternate-tow design

Tow durations ranged from 131 min to 189 min with a generally good match between tow pairs, other than pair 6 when the MHS tow was approximately half an hour shorter than the conventional trawl (Figure 2). Tow depths, which were in the range 315 m to 438 m (Figure 3), and tow directions (Figure 4) were also well matched within the pairs.

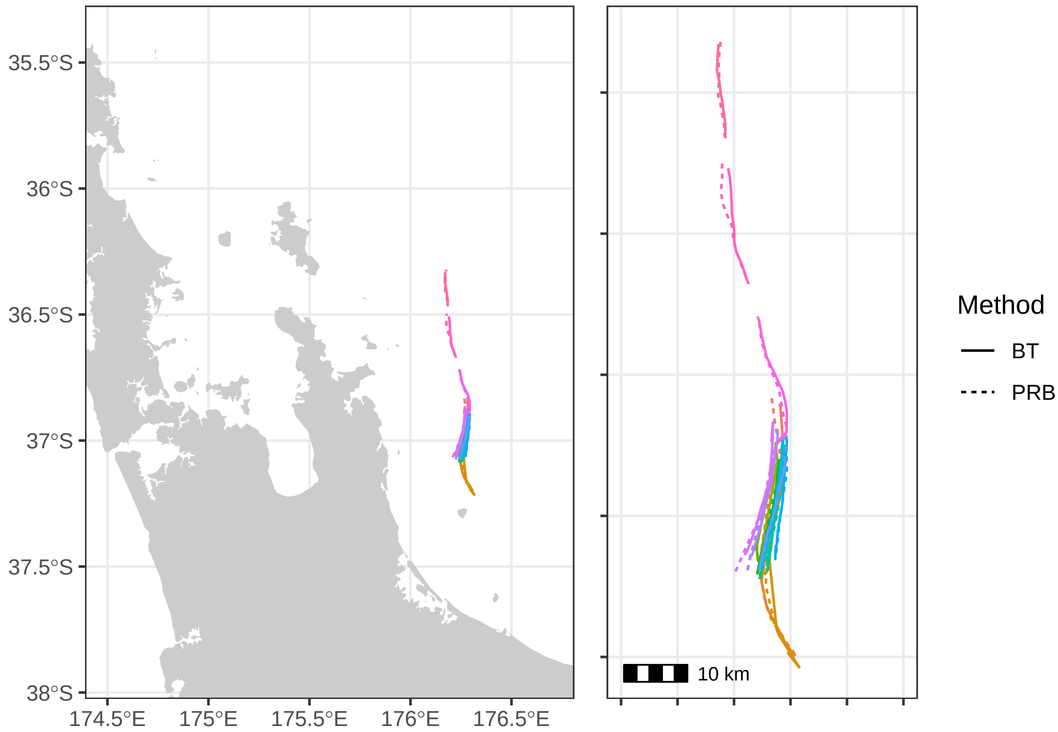

Figure 1: The locations of the experimental tows (vessel tracks during towing). Each tow pair is plotted using a different colour. The conventional mesh trawl is indicated by the BT gear code and the Modular Harvest System by the PRB code.

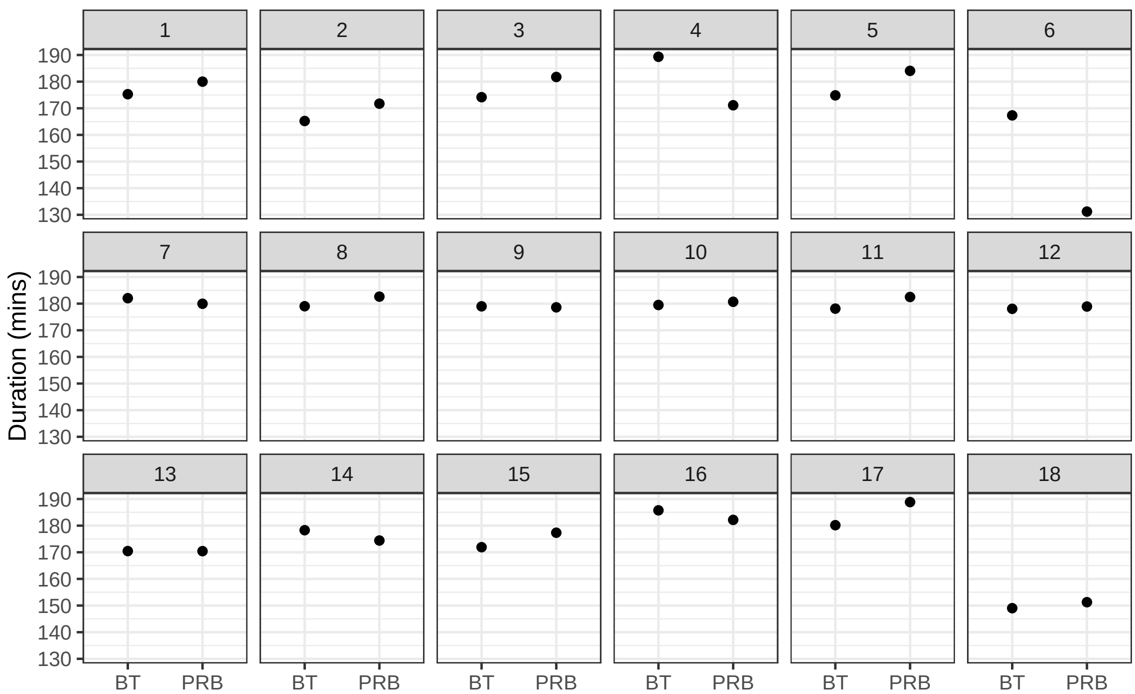

Figure 2: Tow durations (minutes between ER recorded start and end) by pair and gear. The conventional mesh trawl is indicated by the BT gear code and the Modular Harvest System by the PRB code.

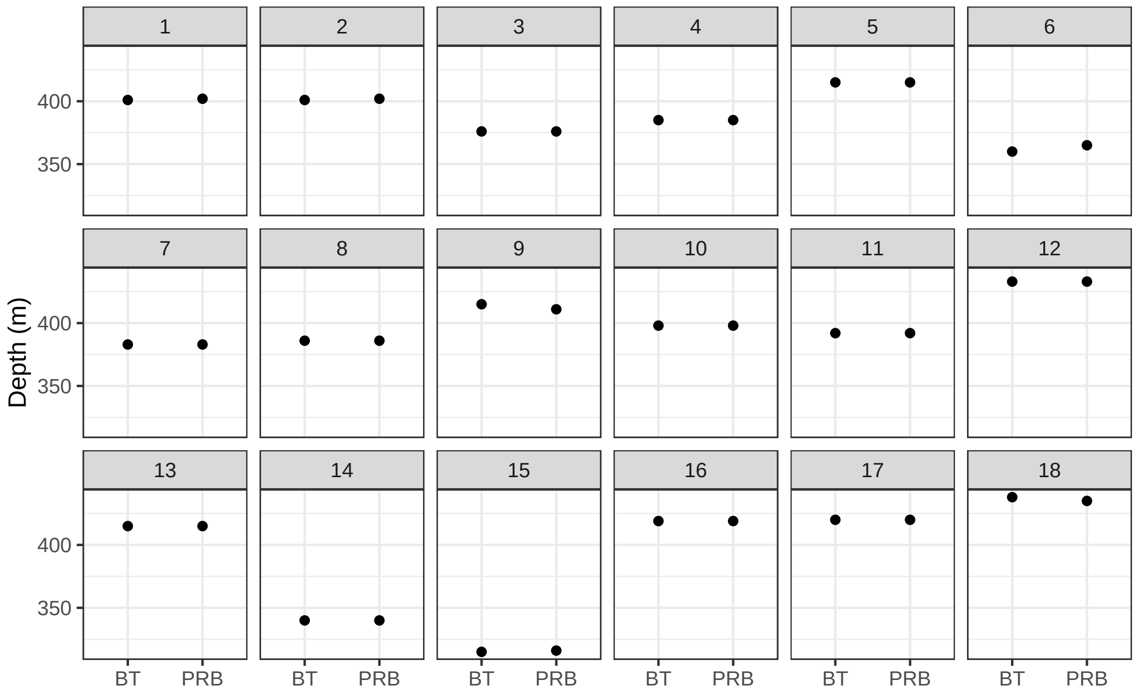

Figure 3: Tow depths (metres) by pair and gear. The conventional mesh trawl is indicated by the BT gear code and the Modular Harvest System by the PRB code.

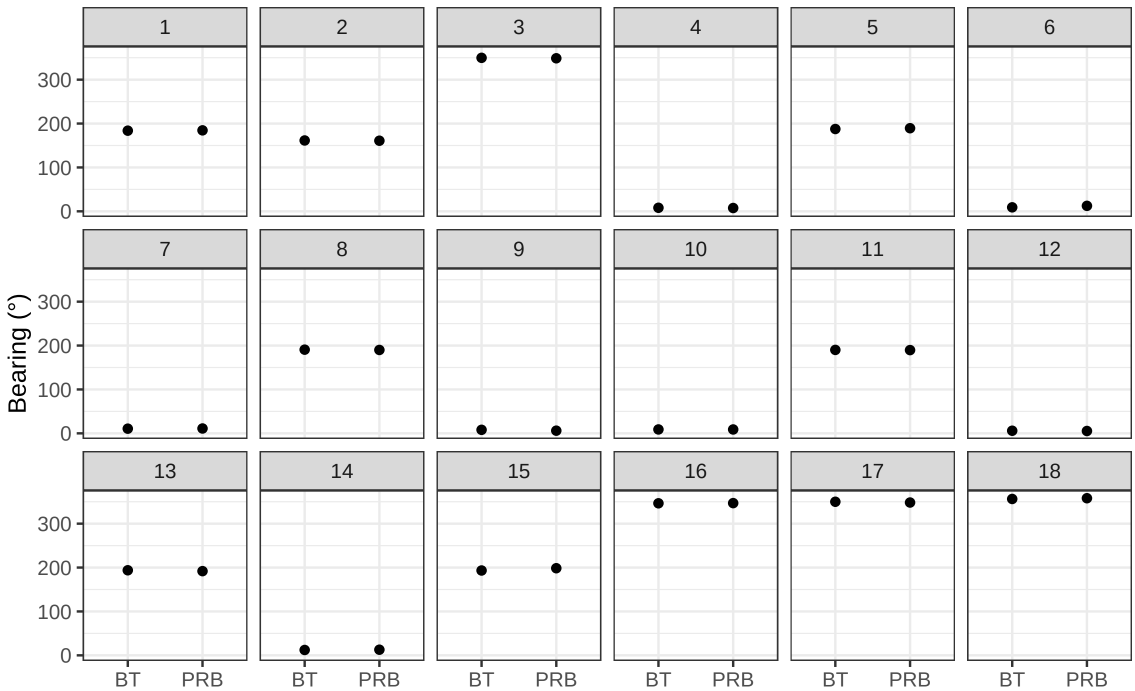

Figure 4: Tow bearings by pair and gear, calculated from the ER recorded start point to the end point. The conventional mesh trawl is indicated by the BT gear code and the Modular Harvest System by the PRB code.

3.2 Non-fish and protected species captures

No non-fish or protected species captures were reported on the experimental tows.

3.3 Catch estimates

Estimated catches (Table 1) from the vessel's ER data indicated that hoki, gemfish, and ling were caught consistently through the trip whereas rubyfish and alfonsino were only caught occasionally and in small quantities.

Catches of ling were not recorded in the ER data for two tows but length samples of ling were provided for every tow (see below). This raises the issue of whether catch estimates were accidentally omitted from the ER data, or whether some fish were accidentally attributed to the wrong tow.

Although the observer did not make independent estimates of the quantity of each species caught on a tow, a separate record was kept by the observer of the vessel's catch estimates. However, although the observer noted an estimate of ling catch for one of the tows (tow 6) where there was a sample but no ER estimate, neither the vessel nor the observer recorded a catch of ling on tow 10 despite length samples being recorded. A comparison of the ER and observer records indicates further discrepancies, some of which are reasonably large (Figure 5). These differences are solely attributable to record-keeping differences, because both records are of the vessel's estimates of catch.

The observer did make separate estimates of sample weights, usually by multiplying the number of fish sampled by an approximate mean weight per fish. For tows where the full catch was measured, these estimates are an independent estimate of the catch weight. The correspondence between these estimates, and the vessel estimates of catch (as recorded by the observer) varies by species (Figure 6): the sample weights are generally lower than the vessel estimates of hoki, but similar for ling. For gemfish, there is evidence that some of the samples that were recorded as 'full catch' samples were actually subsamples.

A separate estimate of sample weights can be made by applying length-weight relationships to the sampled lengths. These estimates (Figure 7) suggest that the observer may have generally underestimated sample weights for hoki and gemfish, and overestimated for ling. However, there is also evidence that some of the sample weights given for hoki and gemfish are actually fish numbers that have not been scaled by an estimated of average fish weight.

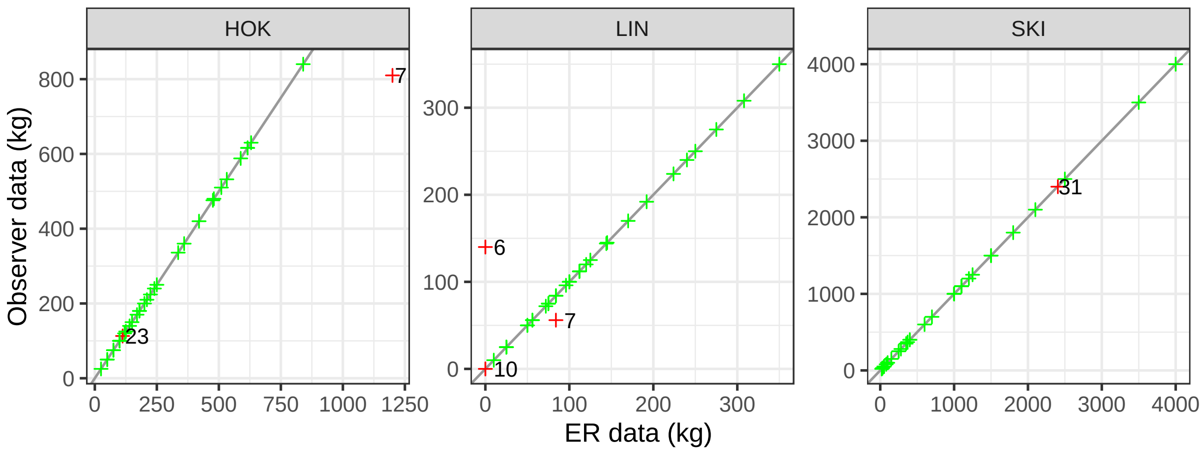

Figure 5: Vessel (ER) and observer records of estimated catch by species. Both records are of the same quantity: the skipper's estimates of species catches per tow. Differences are indicated by red points and labelled by tow number. A record for ling on tow 10 was missing in both sources.

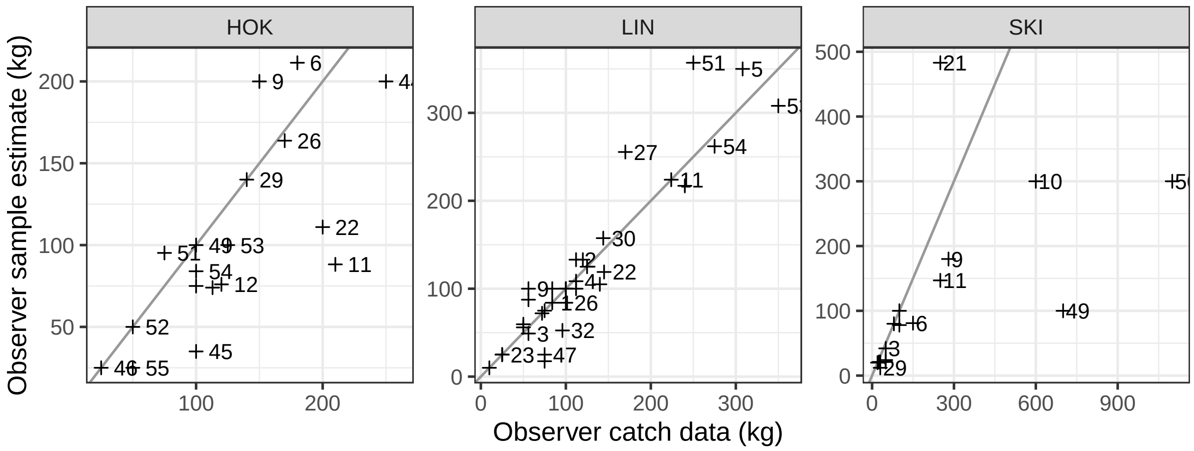

Figure 6: Observer recorded estimated catch by species (from vessel estimates) and estimated sample weights for species and tows where the full catch of a species was measured.

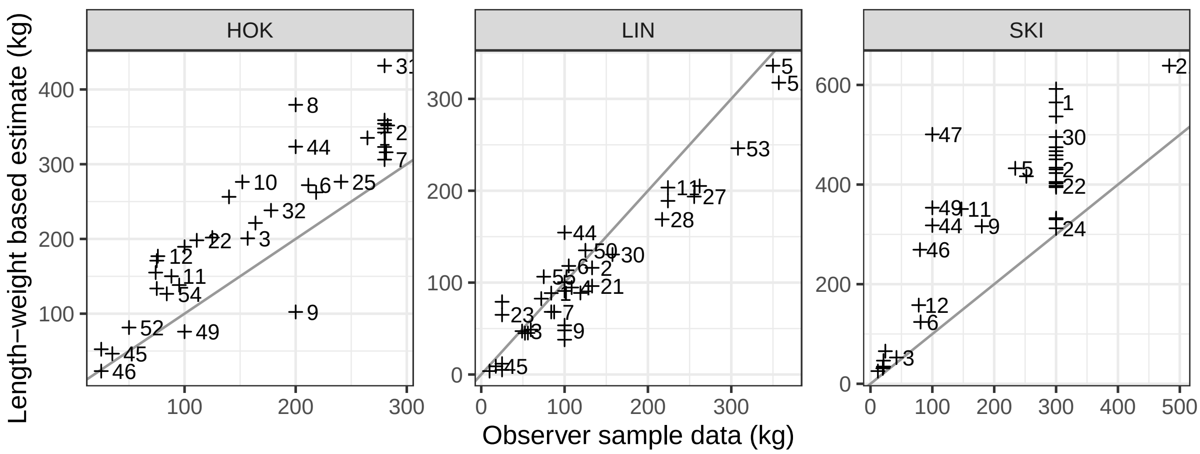

Figure 7: Observer estimated sample weights, with sample weights estimated from recorded lengths and length-weight relationships (from Fisheries New Zealand 2020, using the parameters for HOK 1, SKI 1 females, and LIN 7WC combined).

Because the observer's primary task on the trial was length-frequency sampling, the vessel's ER estimates of hoki, gemfish, and ling were used as the estimated catch per tow as per the trial design. However, because there is evidence that ling may have been caught on tows 6 and 10 but accidentally omitted from the ER data and the observer indicated that all ling from those tows had been sampled, catch estimates based on the application of the length-weight relationships to the length data (Figure 7) were added for ling on these two tows.

3.4 Landings

A comparison of estimated catches (including the additional estimates of ling catch on tows 6 and 10) with landed catches for the four experimental trips (Figure 8) indicates that estimates of all key species other than gemfish were quite consistent with the landings. Gemfish landings were underestimated on all trips, especially the third trip which had the greatest gemfish landings. The issue was raised with the vessel manager who had discussed the issue with the skipper; they suspected that estimated catches were underestimated because they were based on case counts without taking account of the size and condition of gemfish encountered.

Tow catch data were scaled to landings on a trip by trip basis before further analysis.

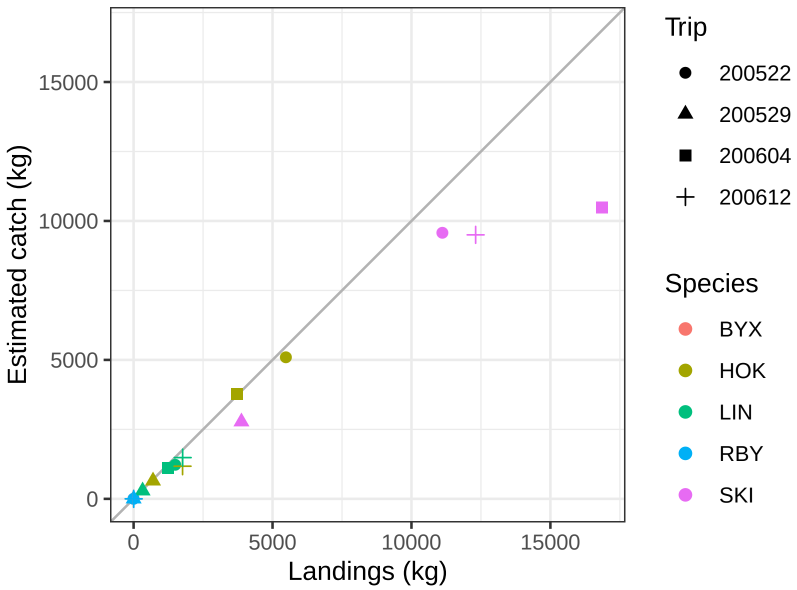

Figure 8: Landed catch and total estimated catch by species and trip. See Appendix A for species codes.

3.5 Sampling

Length-frequency samples of hoki, gemfish, and ling were obtained from each experimental tow (Table 2). The small numbers of rubyfish and alfonsino encountered were also measured. Samples of hoki and gemfish often met the target sample sizes, but ling catches typically did not require subsampling. The round sample numbers (i.e., 200 hoki and 100 gemfish) from many tows suggest that the scoop sampling approach was not implemented entirely as intended, with all fish in the sample measured; rather it appears that sampling ceased when the target numbers of fish were reached.

Over the four trips, good numbers of hoki, gemfish, and ling were measured, with similar numbers of fish from each method (Table 3). Estimated sample weights per species, based on application of length-weight relationships to the measured lengths, indicated sub-sampling was generally required when the catch of a species exceeded 300 kg (Figure 9).

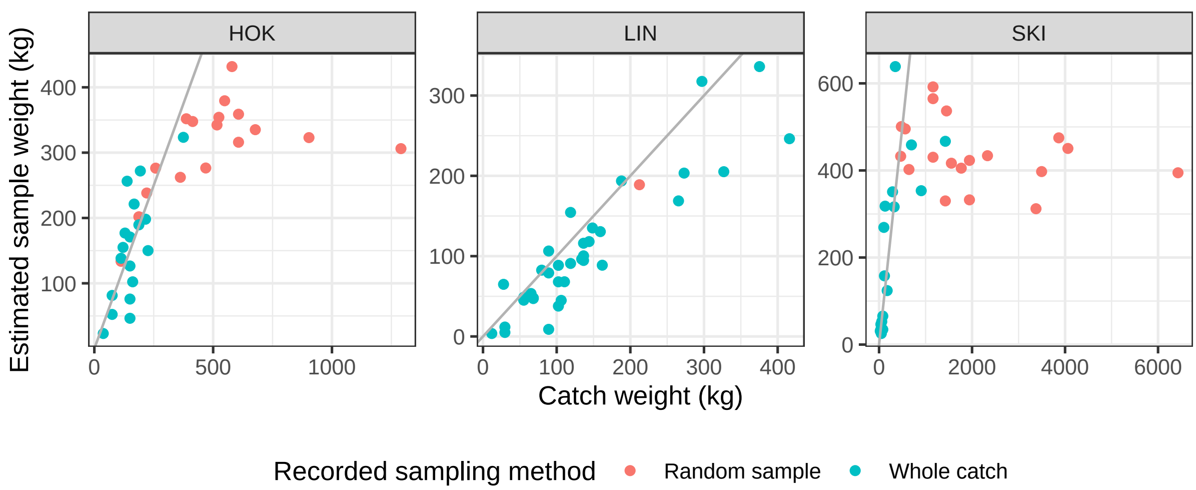

Figure 9: Estimated sample weights, from application of length-weight relationships to fish length measurements (from Fisheries New Zealand 2020, using the parameters for HOK 1, SKI 1 females, and LIN 7WC combined), and catch weights by tow and species coloured according to the sample method recorded by the observer.

Table 2: Number of fish length measurements by species and tow. Species codes are listed in Appendix A.

			Species				
Pair	Tow	Method	HOK	LIN	SKI	RBY	BYX
1	1	PRB	189	29	100		
1	4	BT	200	31	100		
2	2	PRB	200	38	100		
2	5	BT	202	100	78		
3	3	PRB	112	14	14		
3	6	BT	151	30	27		
4	7	BT	200	25	100		
4	10	PRB	152	20	100	2	
5	8	BT	200	35	100		
5	11	PRB	63	67	49		1
6	9	BT	59	17	60		
6	12	PRB	76	17	26		
7	21	PRB	156	38	161	1	
7	24	BT	200	17	100		
8	22	PRB	111	34	100		
8	25	BT	172	16	100		
9	23	PRB	74	24	7		
9	26	BT	117	24	7		
10	27	BT	201	73	100		
10	30	PRB	200	45	100		
11	28	BT	200	62	100		
11	31	PRB	200	64	100		
12	29	BT	137	30	4		
12	32	PRB	127	15	8		
13	44	PRB	190	50	68		
13	47	BT	93	28	100		
14	45	PRB	25	5	100		
14	48	BT	79	11	100		
15	46	PRB	14	3	80		
15	49	BT	46	3	100		
16	50	BT	107	46	100		
16	53	PRB	88	88	100		2
17	51	BT	68	102	100		
17	54	PRB	60	75	84	1	
18	52	BT	36	31	4		1
18	55	PRB	23	41	7		

Table 3: Overall number of fish measured by species and method. Species codes are listed in Appendix A. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

	Method		
Species	BT	PRB	Total
BYX	1	3	4
HOK	2468	2060	4528
LIN	681	667	1348
RBY	0	4	4
SKI	1380	1304	2684

3.6 Catch composition

Aggregate catches of gemfish during the experimental tows substantially exceeded catches of the target species, hoki (Figure 10); this is consistent with the fact that the target gemfish fisheries in SKI 1 historically peaked in May–June (Fisheries New Zealand 2020). Gemfish, hoki, and ling made up 87.1 % of the catch from the experimental tows. Mirror dory (MDO) was the non-QMS species with the greatest overall catch.

Over the course of the trial, 42 fish species were caught. Some species were caught by only one method, such as barracouta (BAR) by MHS and rig (SPO) by conventional trawl (Figure 11). However, for both these species catches were from a single trawl event.

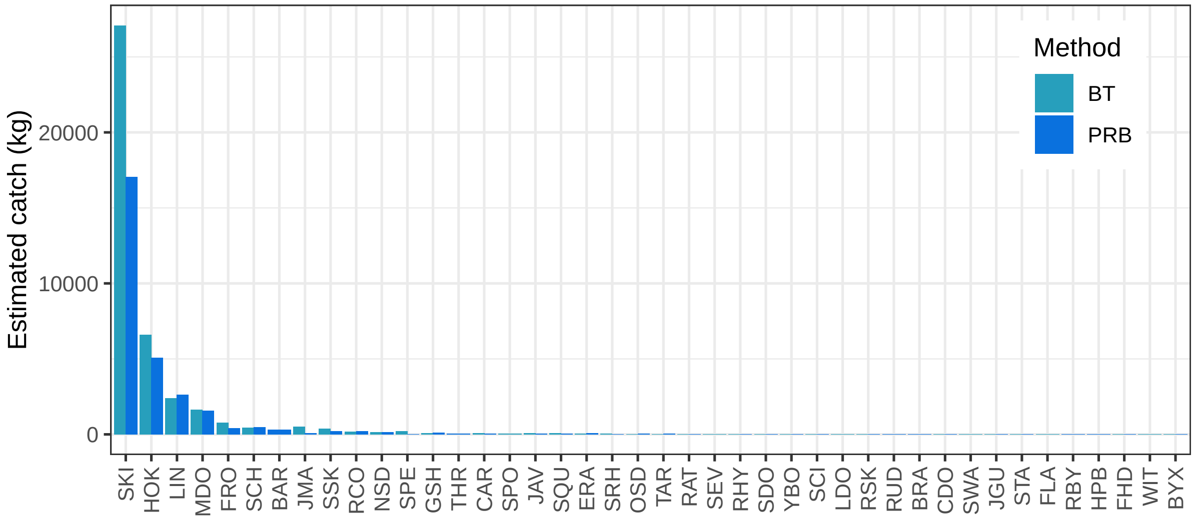

Figure 10: Aggregate catch by species and gear from all experimental tows. Species codes are tabulated in Appendix A. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

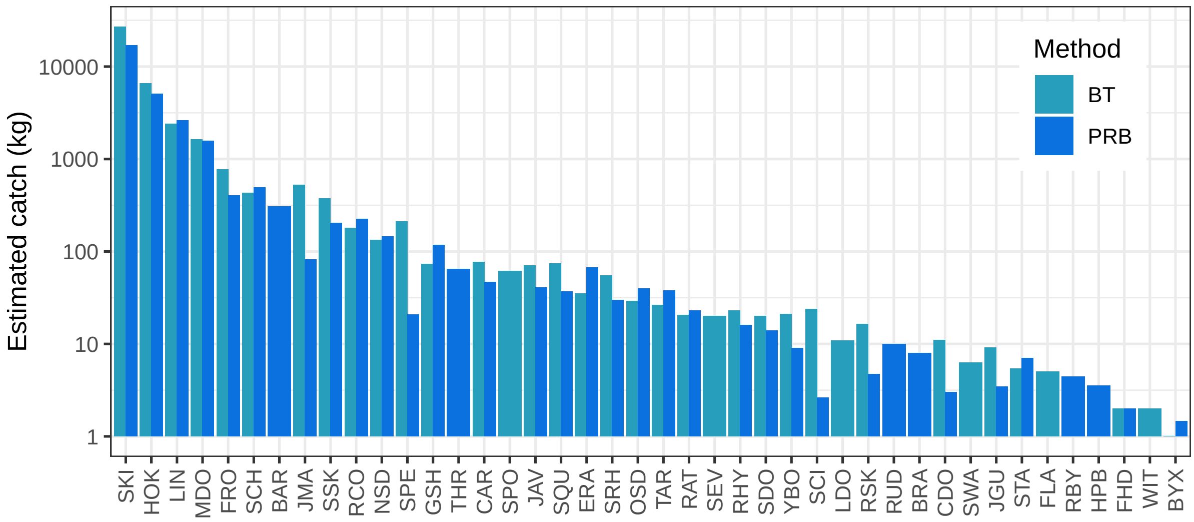

Figure 11: Aggregate catch by species and gear, with catch plotted on a log scale to better illustrate the catches of minor species. Species codes are tabulated in Appendix A. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

3.7 Catch rate modelling

Hoki, gemfish, and ling were caught on all trawls so positive catch models were fitted (i.e., no hurdle component for the probability of a positive catch was required). Models with Gamma and lognormal error distributions showed similar results but, on the basis of LOOIC, the Gamma model was selected for catches of hoki and ling and a lognormal model for gemfish catches. Posterior predictive checks (Appendix B) indicated that the models successfully represented the distributions of observed catches, although there may be a case for using a more constrained prior to limit the upper end of the predicted catch distribution for gemfish in particular.

3.7.1 Hoki

Catches of hoki were variable between and within tow pairs (Figure 12). There was little evidence of an effect of tow order within a pair, but catches were generally lower with the MHS (Figure 13). The gear effect (labelled b_gearPRB in Figure 13) was not quite significant at the 5% level, and between pair effects were substantial. The posterior predictive distribution for hoki catch shows substantial overlap between methods (Figure 14).

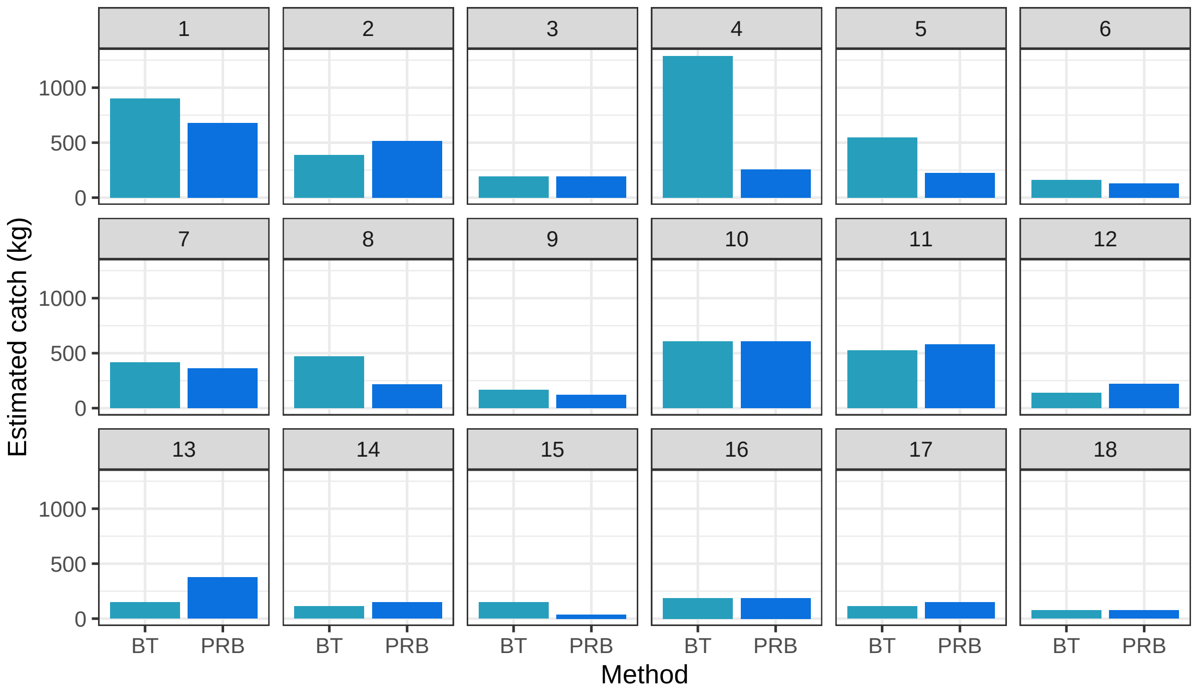

Figure 12: Catch of hoki by tow pair and method. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

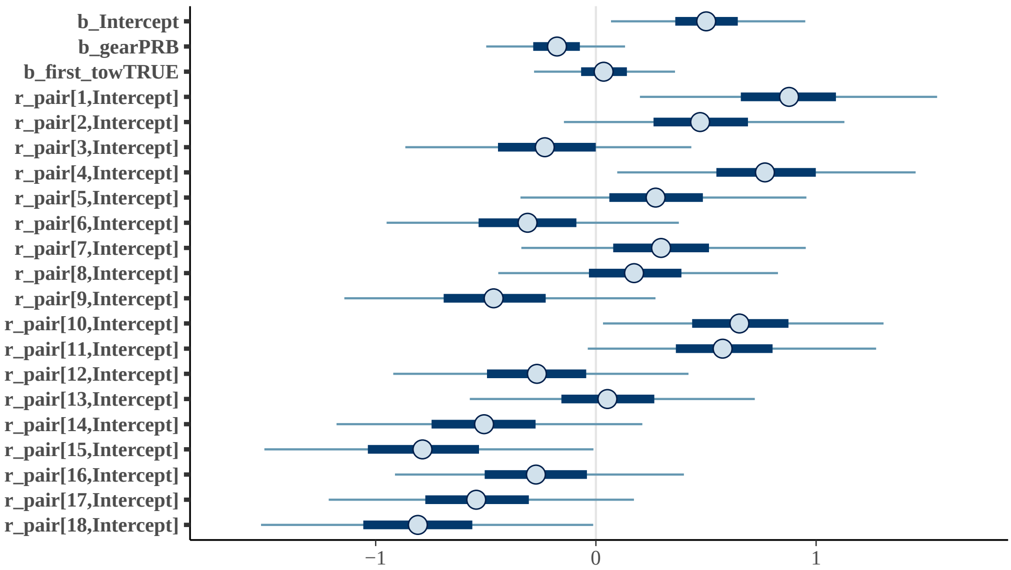

Figure 13: Fixed and random effects for catches of hoki (Gamma model) with plots indicating the median (point) and 50% and 95% intervals of the posterior estimate.

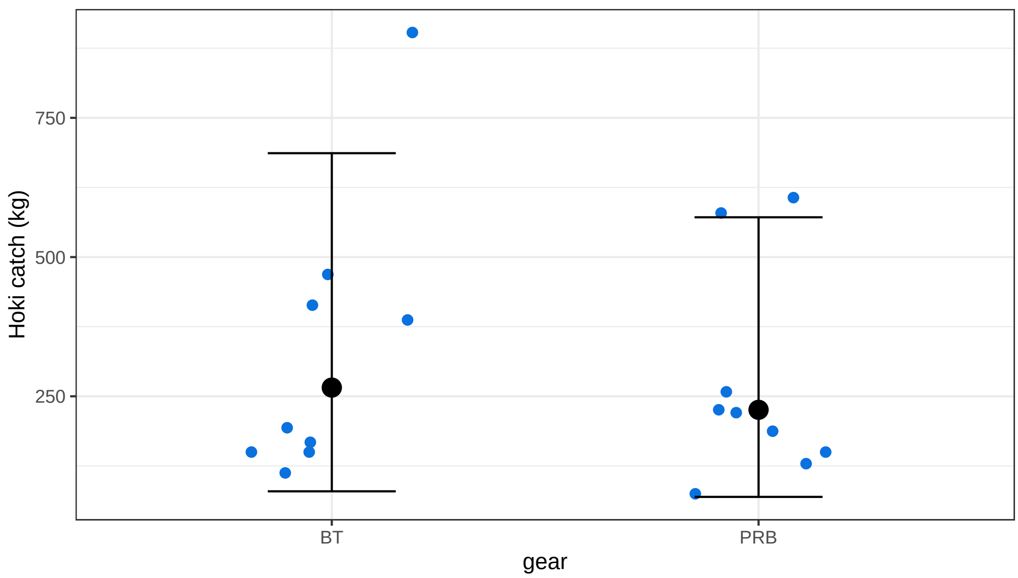

Figure 14: The conditional effect of gear on the posterior predictive distribution for catches of hoki (Gamma model), evaluated for `first_tow = FALSE`; the realised catches for tows meeting this criterion are shown as points. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

3.7.2 Gemfish

Catches of gemfish were also variable between and within tow pairs (Figure 15). In contrast to hoki, there was more evidence of an effect of tow order within a pair (with the first tow of a pair having a lower catch), and catches were also lower with the MHS (Figure 16). Although the gear effect was significant at the 5% level, between pair effects were substantial. As a result, the posterior predictive distribution for gemfish catch also shows substantial overlap between methods (Figure 17), although the distribution of catch weights is wider for bottom trawl.

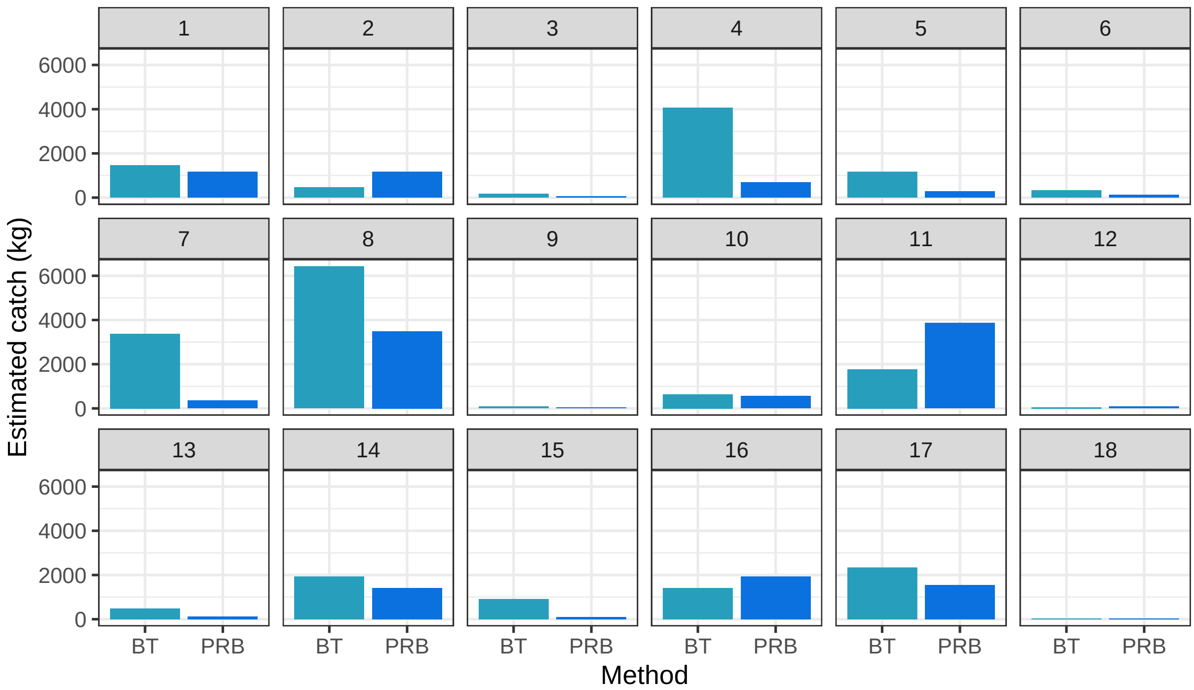

Figure 15: Catches of gemfish by tow pair and method. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

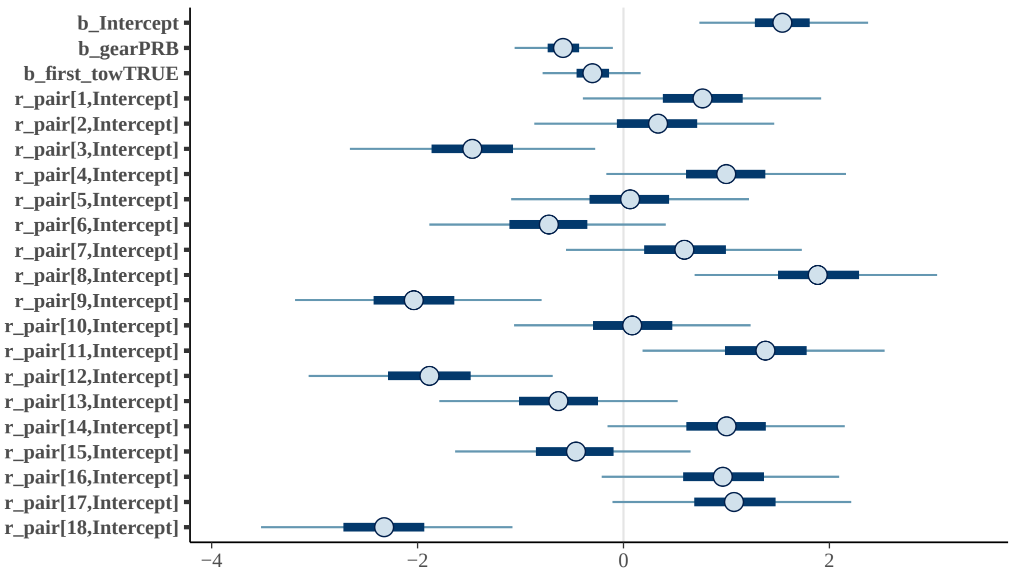

Figure 16: Fixed and random effects for catches of gemfish (lognormal model) with plots indicating the median (point) and 50% and 95% intervals of the posterior estimate.

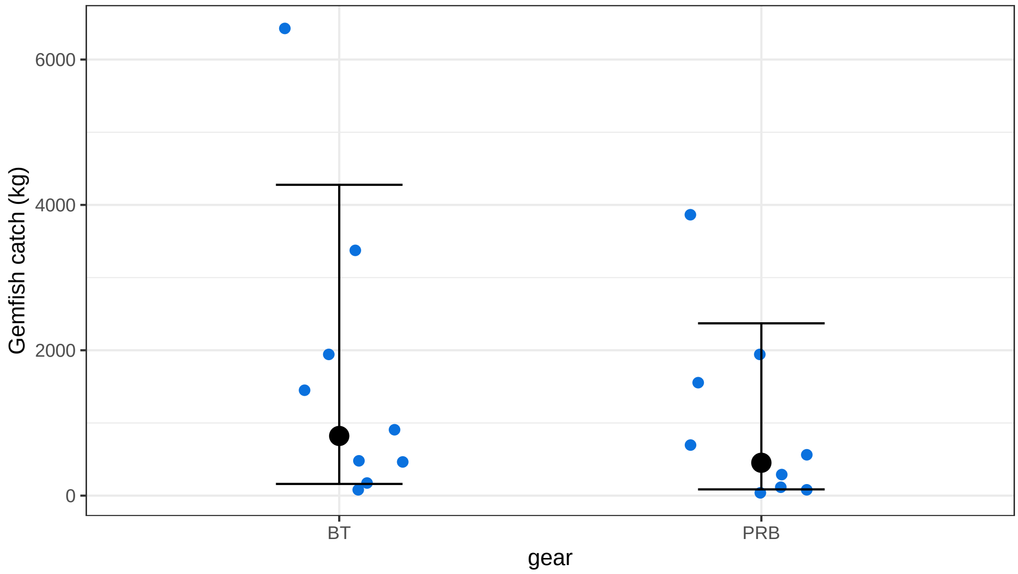

Figure 17: The conditional effect of gear on the posterior predictive distribution for catches of gemfish (lognormal model), evaluated for `first_tow = FALSE`; the realised catches for tows meeting this criterion are shown as points. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

3.7.3 Ling

Catches of ling were somewhat more consistent between and within tow pairs (Figure 18) than for hoki and gemfish. There was little evidence of an effect of tow order within a pair, nor of differing catches by MHS and conventional trawl (Figure 19). Between pair effects were less variable (Figure 19), and the posterior predictive distribution for ling catch is very similar for the two methods (Figure 20).

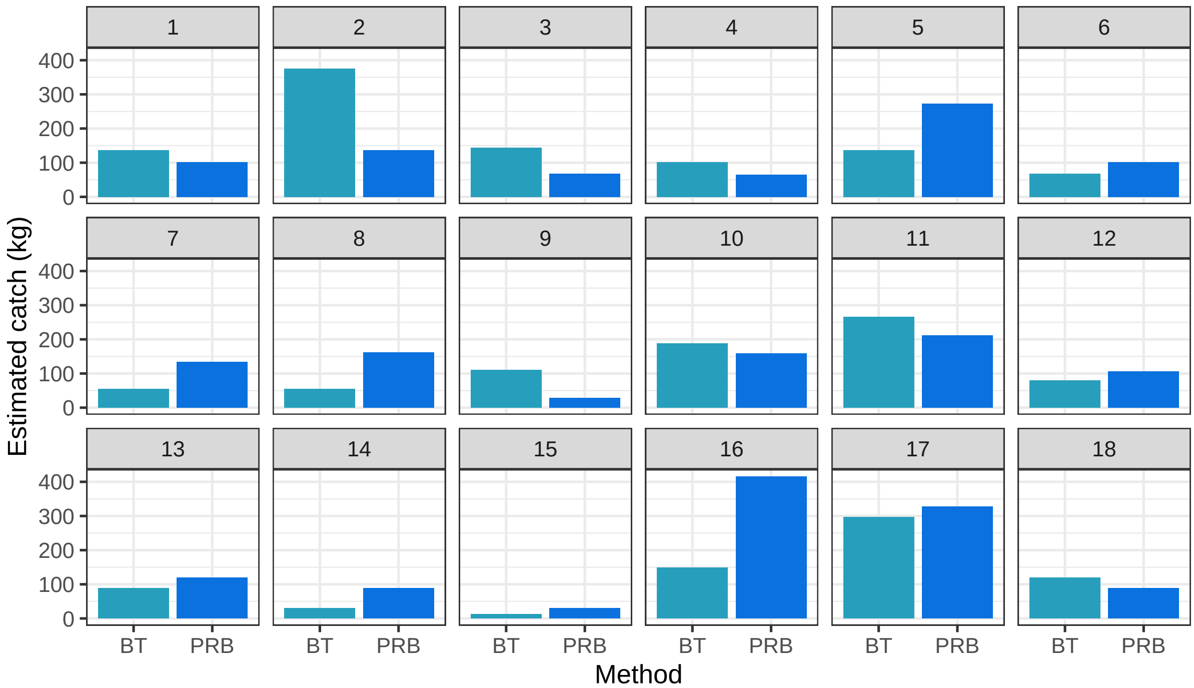

Figure 18: Catches of ling by tow pair and method. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

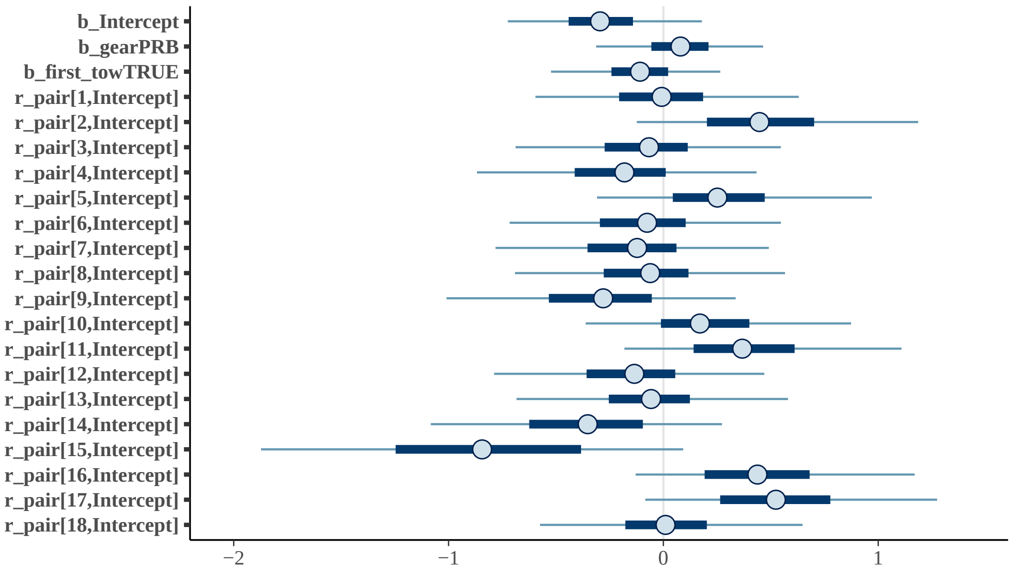

Figure 19: Fixed and random effects for catches of ling (Gamma model) with plots indicating the median (point) and 50% and 95% intervals of the posterior estimate.

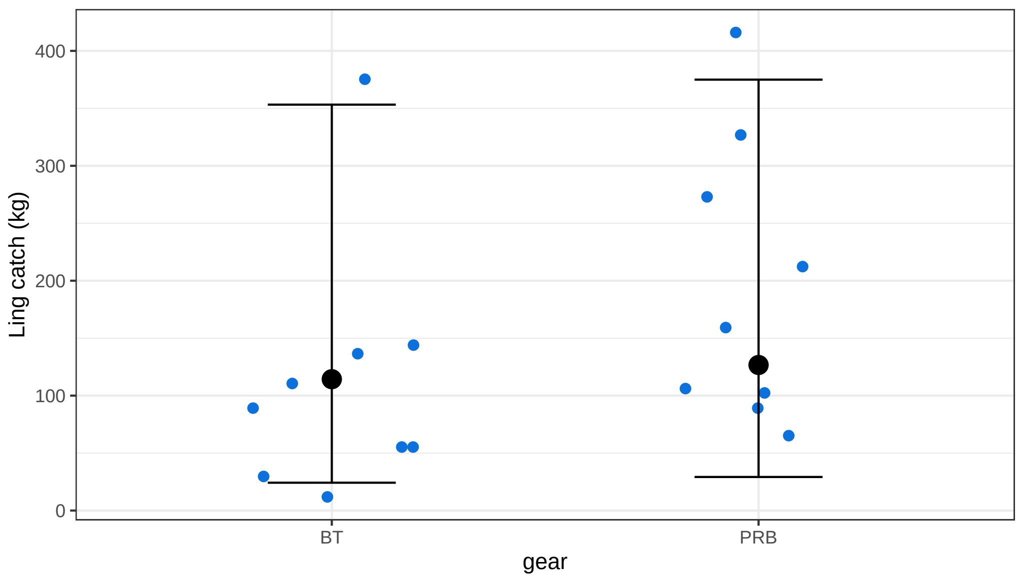

Figure 20: The conditional effect of gear on the posterior predictive distribution for catches of ling (Gamma model), evaluated for `first_tow = FALSE`; the realised catches for tows meeting this criterion are shown as points. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

3.7.4 Impact of the number of tow pairs on catch rate estimates

For hoki and gemfish, where the full dataset provides evidence of lower catch rates when using the MHS, the impact of the number of tow pairs included in the dataset was investigated. Two approaches were implemented; first the catch rate models were refitted as the number of tow pairs in the dataset was increased from six to eighteen, at intervals of three pairs. Secondly models were refitted to blocks of data representing the first, second, and third group of six tow pairs.

For both hoki (Figure 21) and gemfish (Figure 22), the posterior for the tow effect narrows as the number of tow pairs increases. However, whereas for gemfish there was little change in the median estimate of the gear effect as the experiment progressed, the median estimated gear effect on hoki catches reduced in magnitude as the experiment progressed. This is particularly apparent in the estimates from fitting to the three blocks of six tows, with the first block producing the greatest difference between catch rates of hoki by MHS and conventional trawl (Figure 23) whereas gear effects on gemfish catches were similar from all three blocks (Figure 24). Catches of hoki were higher at the start of the trial period (Table 4) and it is possible that the difference in catch rates between gears is influenced by catch volumes, although this was not apparent for gemfish.

Table 4: Mean catch per tow (kg) of hoki (HOK) and gemfish (SKI) for the first, second, and third group (block) of six tow pairs.

	Species	
block	HOK	SKI
1	457.0	926.4
2	368.6	1727.6
3	146.8	1025.7

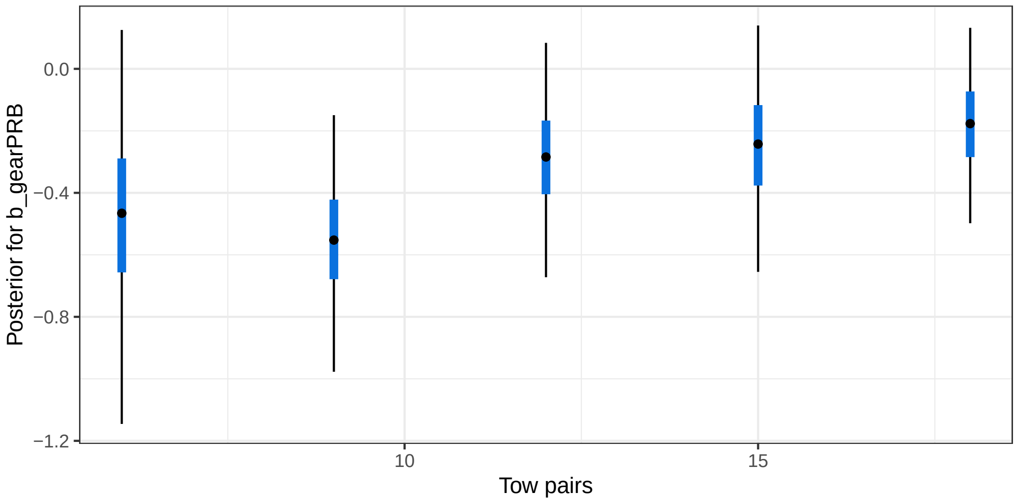

Figure 21: Posterior distributions for the gear effect on hoki catch (Equation 1, Gamma model) as the number of tow pairs in the data set increased.

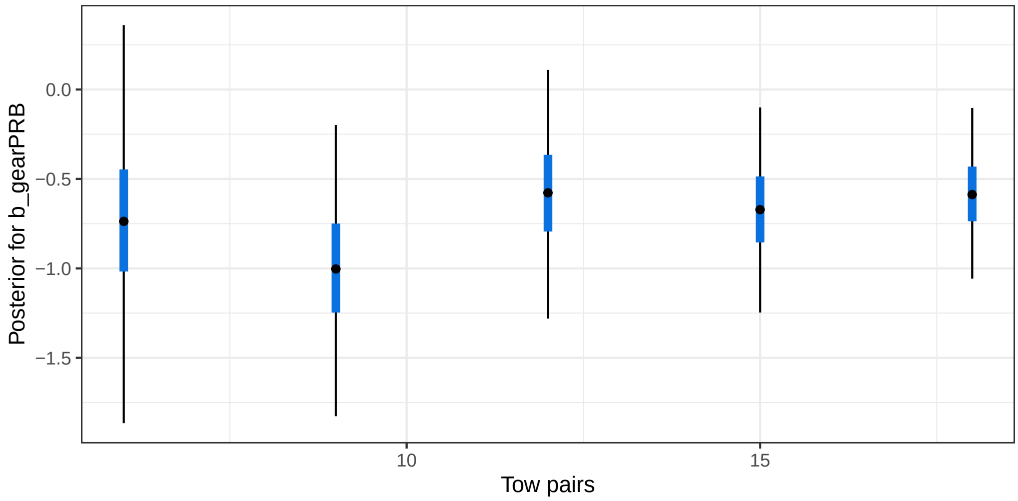

Figure 22: Posterior distributions for the gear effect on gemfish catch (Equation 1, lognormal model) as the number of tow pairs in the data set increased.

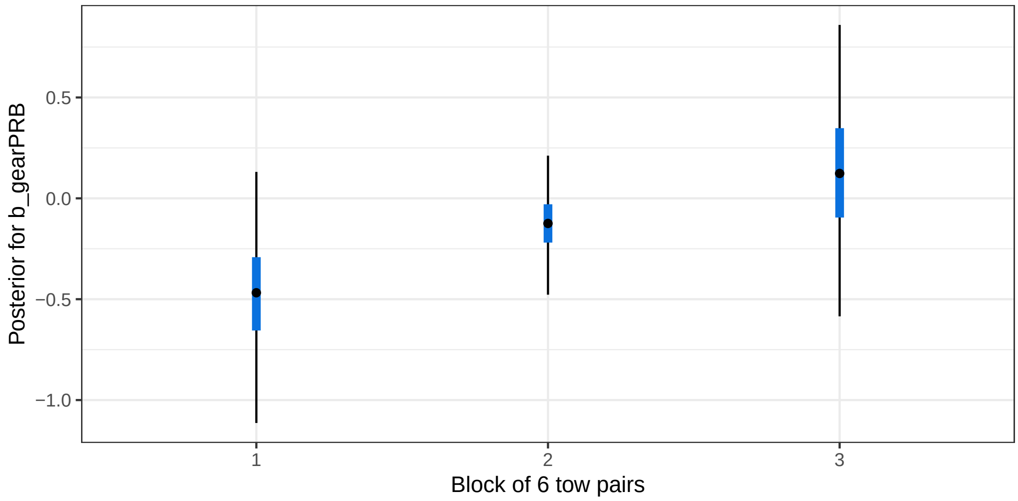

Figure 23: Posterior distributions for the gear effect on hoki catch (Equation 1, Gamma model) for the three sequential blocks of six tows in the data set.

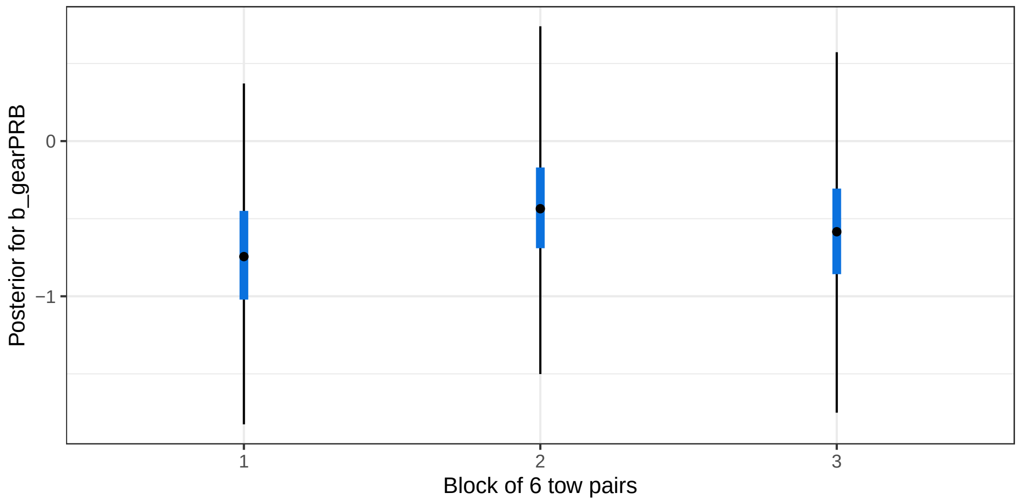

Figure 24: Posterior distributions for the gear effect on gemfish catch (Equation 1, lognormal model) for the three sequential blocks of six tows in the data set.

3.8 Size composition

The overall mean size of hoki, gemfish, and ling caught during the trial was similar for the two gears (Table 5; tow pair comparisons are provided in Appendix C).

Table 5: Mean lengths (cm, with the standard deviation in parenthesis) of fish by species and method, with samples upweighted to tow weights. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code. Species codes are detailed in Appendix A.

	Method	
Species	BT	PRB
HOK	81.5 (8.3)	84.7 (9)
LIN	85.4 (13.1)	84.1 (11.6)
SKI	75.9 (9)	77.8 (8.6)

3.8.1 Hoki

The length frequency distributions for hoki show a similar size range for catches by MHS and conventional mesh trawl (Figure 25), but there are indications of a steeper left tail and lower modal size for conventional trawl. Summaries of the raw sampling data indicate that the proportion of fish taken by MHS is lower for 70 cm to 80 cm hoki, and that this is consistent across the tow pairs (Figure 26). This pattern was confirmed by the bootstrap analysis, with the proportion of hoki taken by MHS being significantly lower than 0.5 for 65 cm to 85 cm hoki (Figure 27). When the bootstrapping was repeated with the same number of fish sampled from each tow (Figure 28), the pattern in relative selectivity persists but the confidence intervals for most proportions at length include 0.5.

Repeating the bootstrap analyses for reduced numbers of tow pairs (Appendix D) indicates that the pattern in relative selectivity of hoki evident in the full dataset (Figure 27) was clearly established from data collected during the first six pairs (Figure D-1) and changed little as further data were added. However, the final six tow pairs had lower catches of hoki, with a smaller size range, and the trend in relative selectivity with length is not evident when the dataset is restricted to just these six tow pairs (Figure D-7).

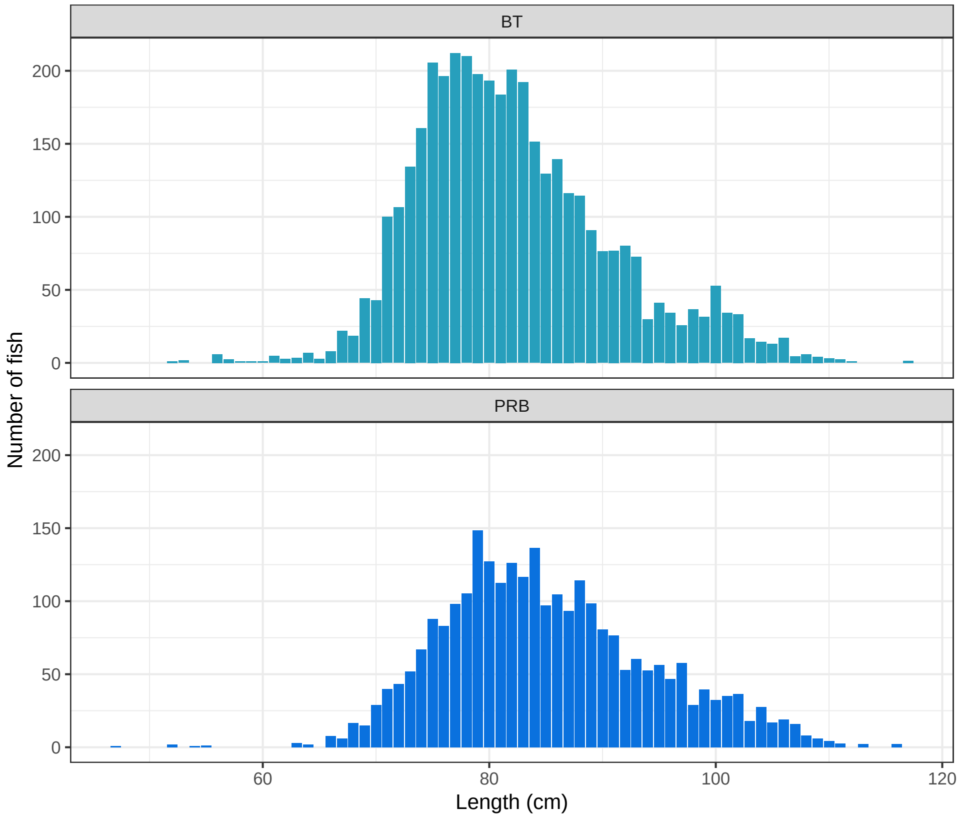

Figure 25: Length frequency distributions for hoki by method, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

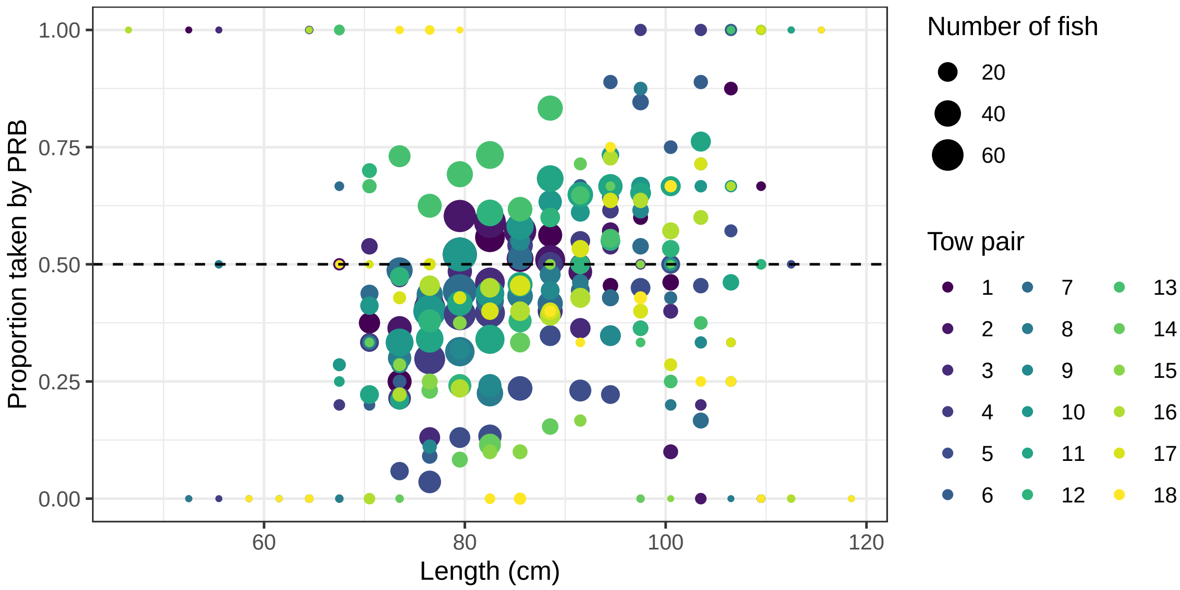

Figure 26: The raw proportion of hoki taken by MHS by length (3 cm length bins); colours indicate tow pairs.

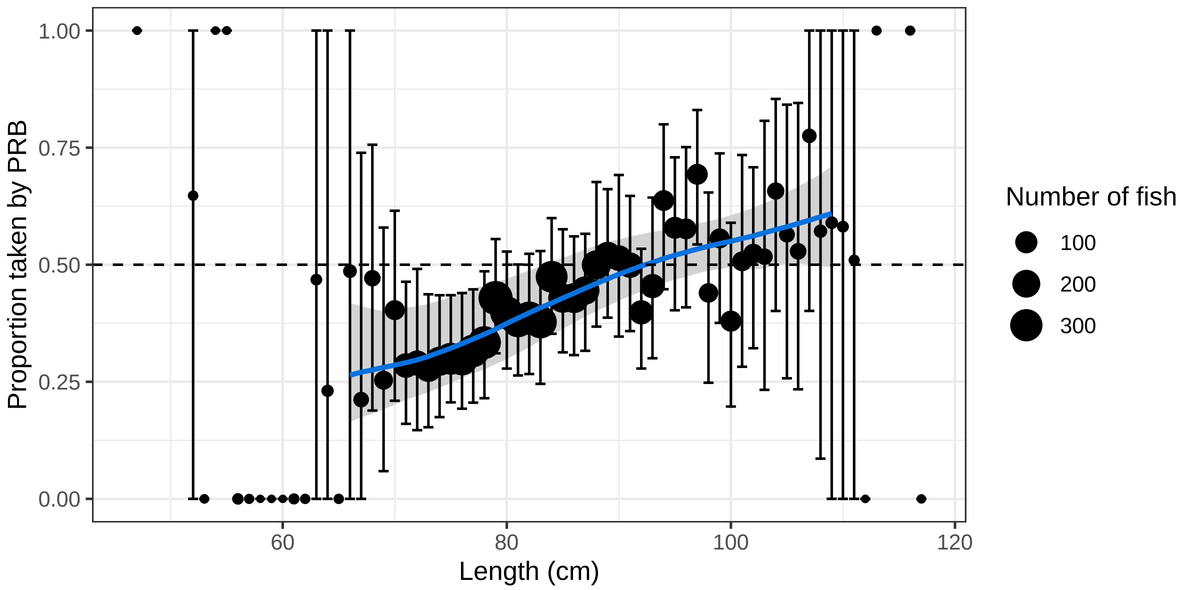

Figure 27: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and distributions of smooth spline fits to the bootstrap samples of proportion at length for samples upweighted to tow weight. All 18 tow pairs are included.

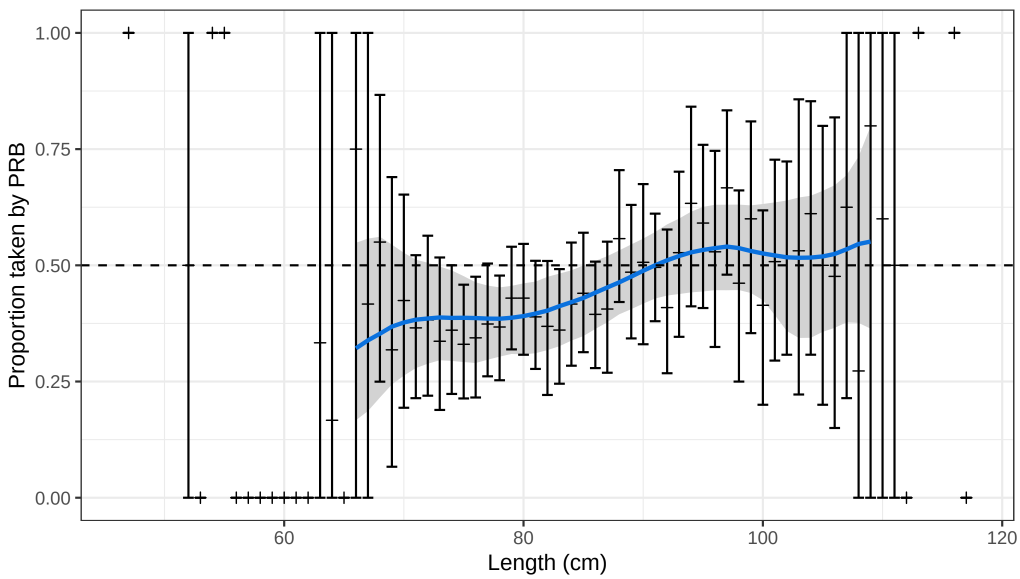

Figure 28: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, with 200 fish sampled with replacement from each tow.

3.8.2 Gemfish

The length frequency distributions for gemfish are similar for MHS and conventional mesh trawl (Figure 29). Summaries of the raw data show no clear trends in proportion taken by MHS with size (Figure 30). When scaled to account for differences in catch, the bootstrap analysis indicates that the proportion of fish taken by MHS is lower overall, and with some indication that this proportion is lower for smaller fish (Figure 31). However, when the bootstrapping was repeated with the same number of fish sampled from each tow (Figure 32) there was little indication of differential selection between the gears.

Repeating the bootstrap analyses for the three blocks of six tow pairs (Appendix D) indicates that the a trend in the proportion taken by MHS with length is only evident for the middle block of six tows (Figure D-13).

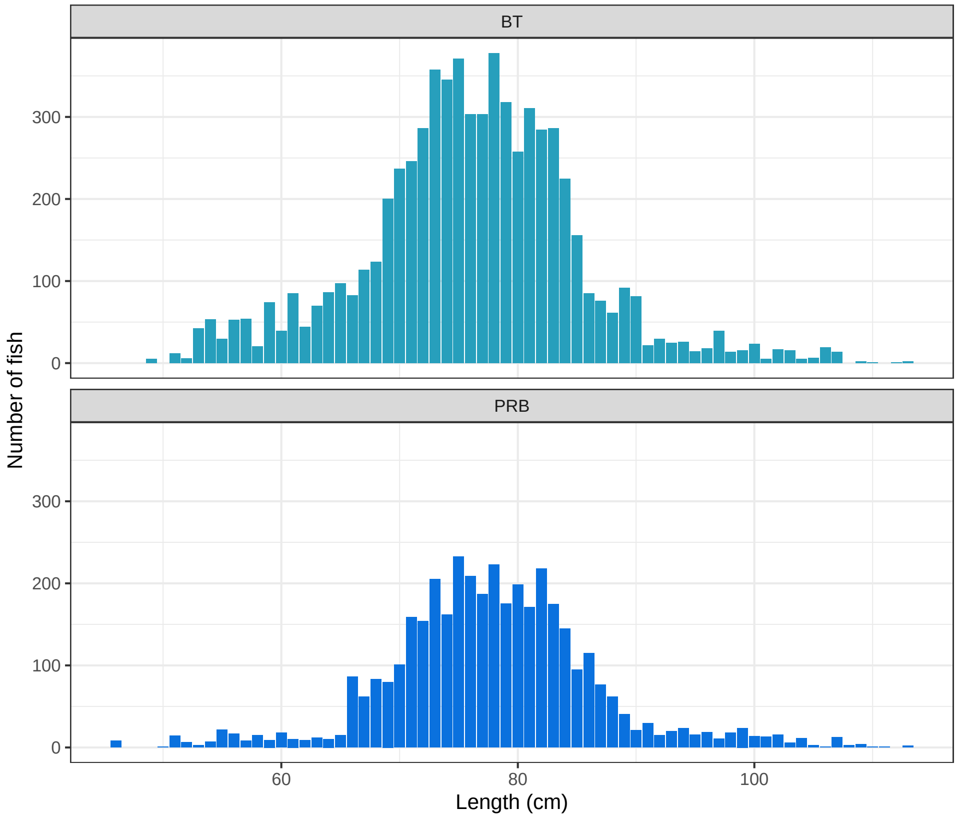

Figure 29: Length frequency distributions for gemfish by method, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

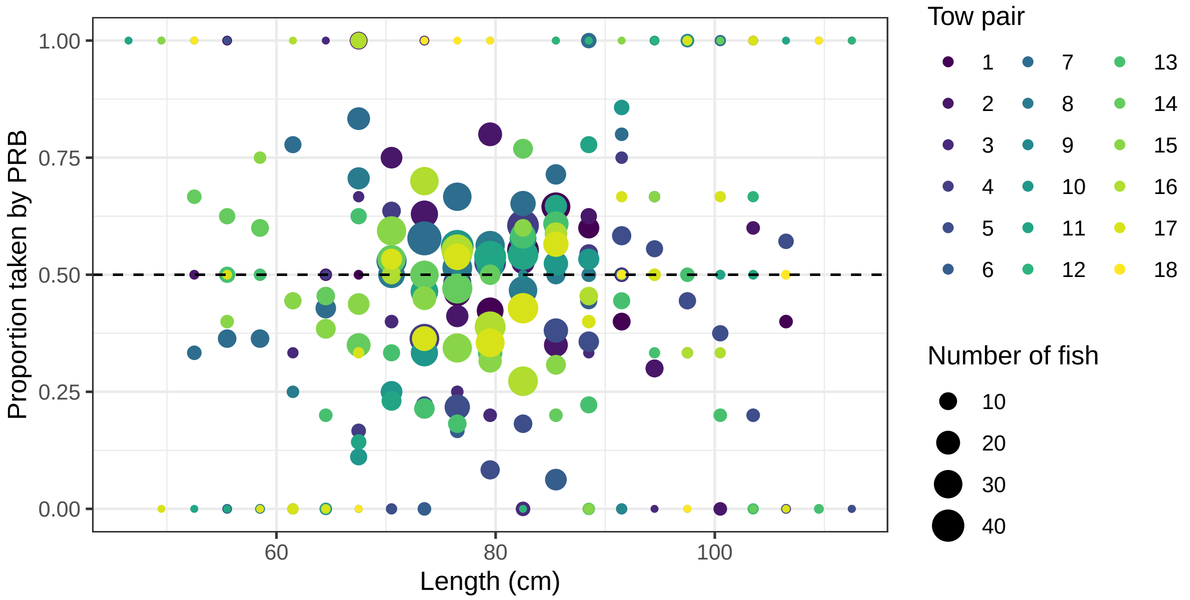

Figure 30: The raw proportion of gemfish taken by MHS by length (3 cm length bins); colours indicate tow pairs.

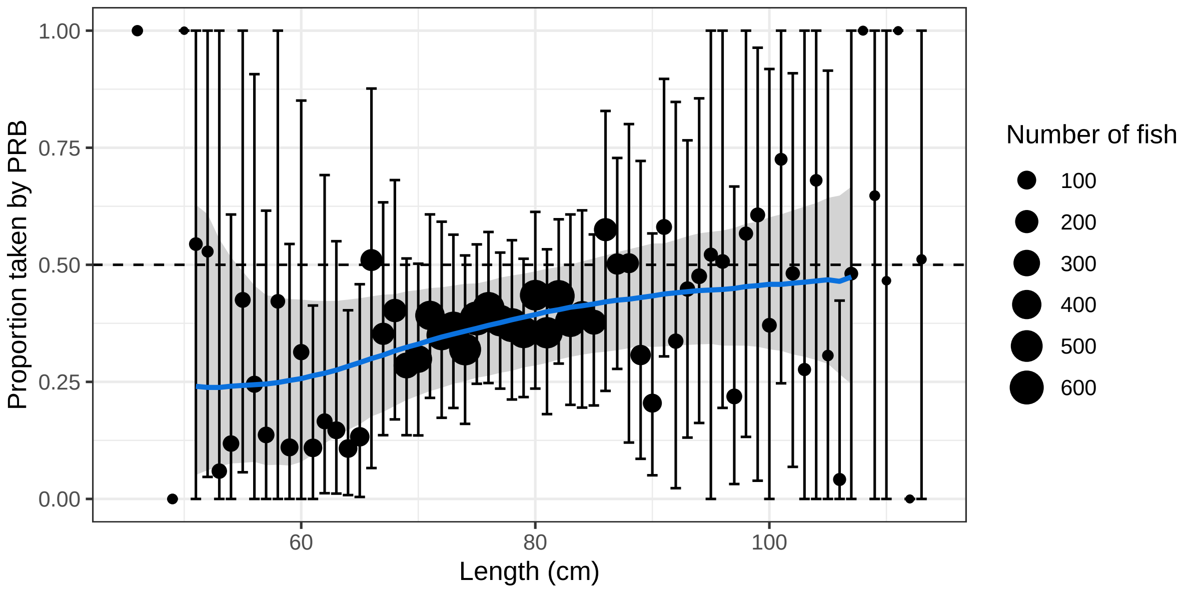

Figure 31: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and distributions of smooth spline fits to the bootstrap samples of proportion at length for samples upweighted to tow weight. All 18 tow pairs are included.

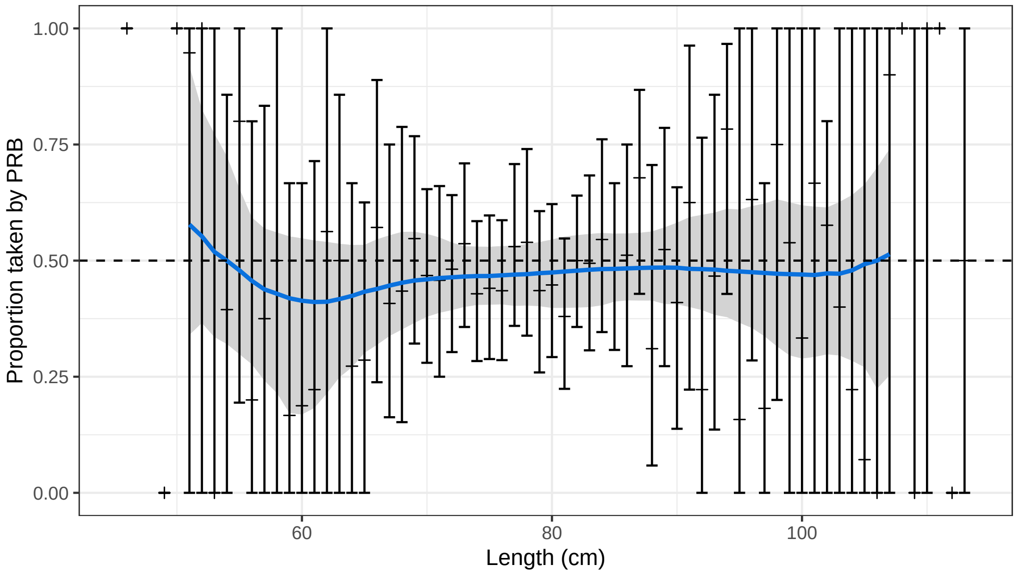

Figure 32: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, with 100 fish sampled with replacement from each tow.

3.8.3 Ling

Length frequency distributions for ling are similar for MHS and conventional mesh trawl (Figure 33), although a few larger ling were sampled from conventional trawl. Summaries of the raw sampling data show no clear trends in proportion taken by MHS with size (Figure 34), and the bootstrap analysis shows little indication of a trend in the proportion taken by MHS with length (Figure 35). This lack of trend persists when the bootstrapping is carried out with equal numbers of fish sampled from each gear type (Figure 36).

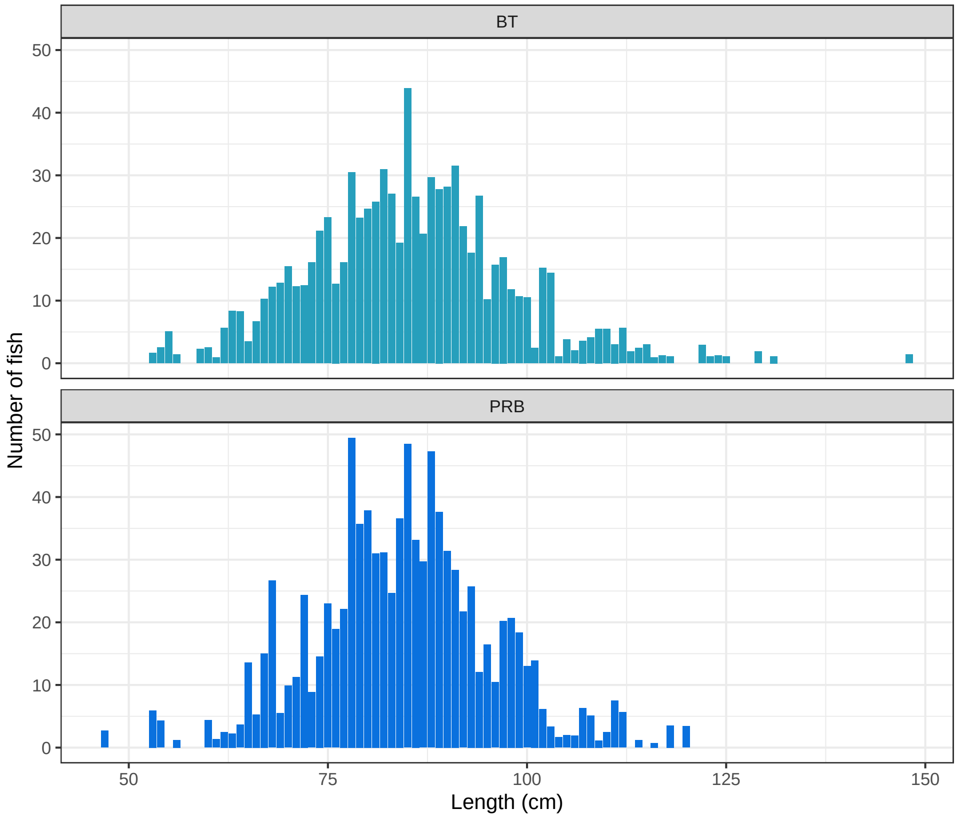

Figure 33: Length frequency distributions for ling by method, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

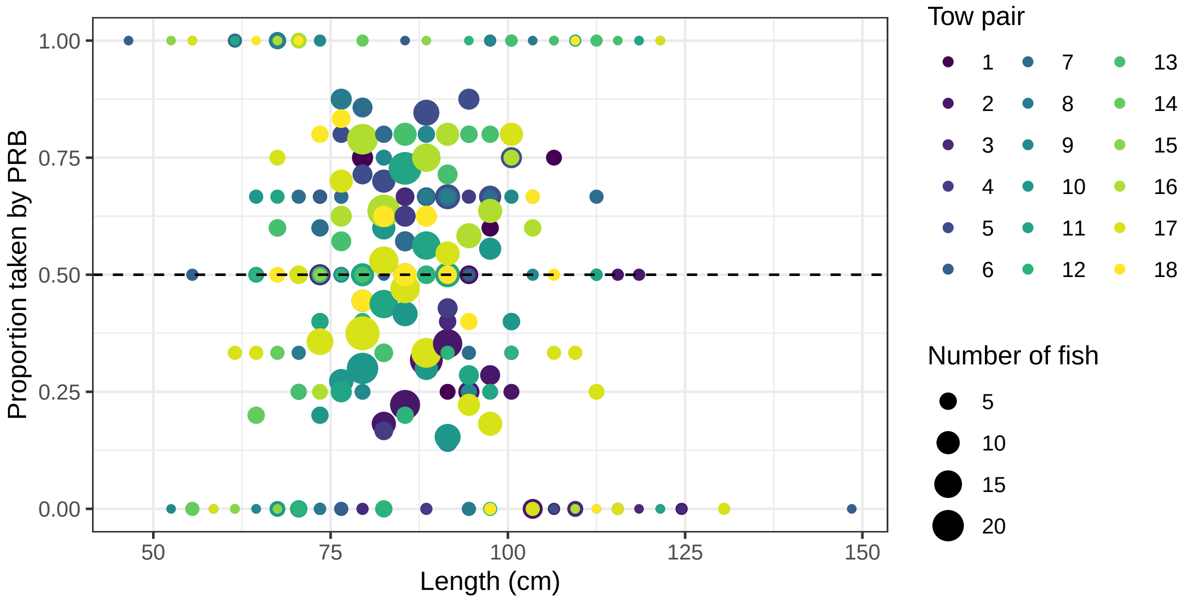

Figure 34: The raw proportion of ling taken by MHS by length (3 cm length bins); colours indicate tow pairs.

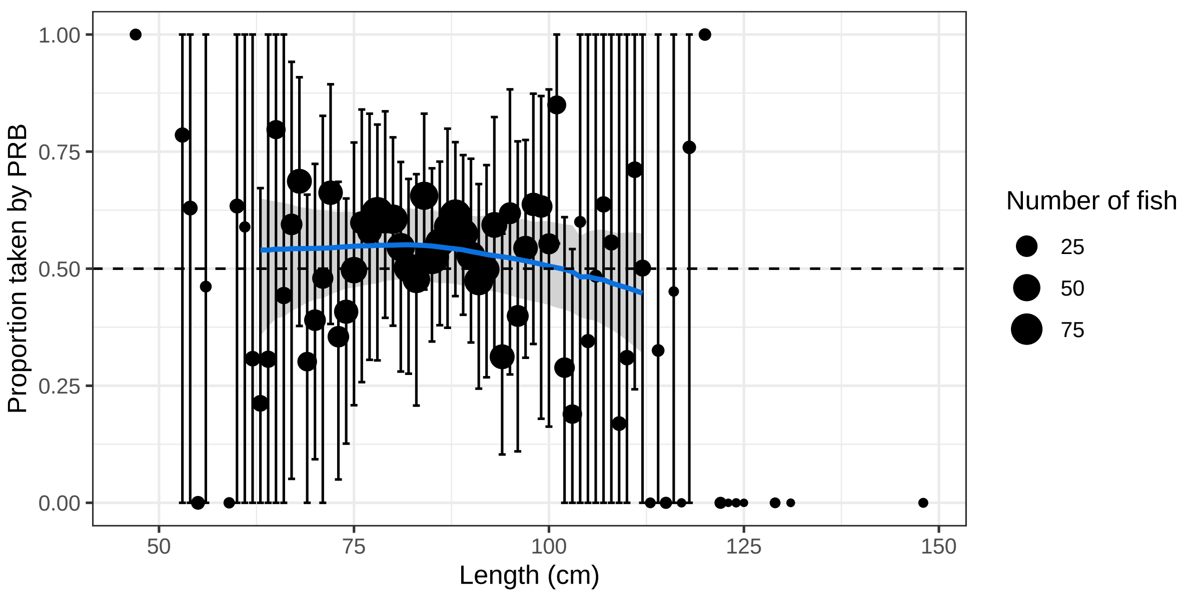

Figure 35: The proportion of ling taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and distributions of smooth spline fits to the bootstrap samples of proportion at length for samples upweighted to tow weight.

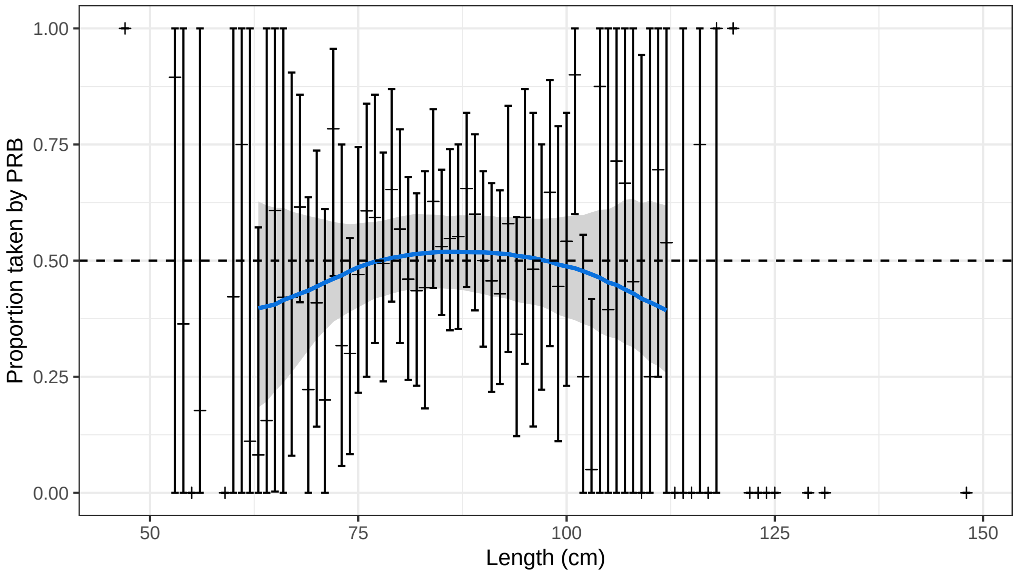

Figure 36: The proportion of ling taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, with 100 fish sampled with replacement from each tow.

4. DISCUSSION

The alternate-tow approach was successfully implemented for a comparison of the 'inshore' MHS1480 specification Modular Harvest System gear (Net A), with a Milligan 100 mm (4") conventional mesh wing trawl (Net B), when targeting hoki in the inshore fishery off the North Island. Tow parameters within a pair were generally well matched.

Collecting catch data via the vessel's Electronic Reporting software was successful, especially because it allowed daily updating of preliminary analyses from the trial. There were some minor differences in catch data record-keeping between the vessel's crew and the Fisheries New Zealand observer, with catches of ling omitted for two tows when fish were sampled. There were some problems with exported data from the observer's YUMA device that could usefully be improved in future trials. It was not possible for the observer to correct records where fish had been logged under the wrong code. Sample weight recording seemed particularly problematic: initial sample weights recorded by the observer were actually numbers of fish; these estimates were subsequently updated using estimates of average fish weights, previously recorded as comments, but it proved difficult to identify 'final' species-sample header records. As a result, sample weights were estimated for the analyses by applying length-weight regressions to the sampled lengths.

Bayesian generalised linear mixed models were used to fit catches with tow pair as a random effect. Catch rates of hoki were lower with the MHS than with the 100 mm mesh trawl, but the difference was not significant at the 95% level. Catch rates of gemfish with the MHS were significantly lower and there was also evidence that the first tow in a pair had a lower catch rate of gemfish. Catch rates of ling did not differ between the two gears. The MHS1480 was originally engineered for inshore fisheries where 125 mm mesh is required, so slightly reduced catch rates were not unexpected.

Analysis of the length data focused on proportional catch at length ('relative selectivity') with uncertainty in the proportion caught by MHS assessed by bootstrapping. A key difference in the methodology from that used by Chambers et al. (2021) was scaling the sample data to the tow weight, necessitated by the fact that not all fish in all tows could be measured.

Where the measured fish represent the full catch in each tow (either by scaling or where all fish are measured), the resulting proportional catch at length was influenced by overall differences in fishing power between the gears as well as differences in size selectivity. Differences in fishing power can, however, be accounted for by sampling equal numbers of fish from each gear in the bootstrap analysis.

The relative selectivity analyses indicated that the MHS caught significantly fewer hoki in the 65 cm to 85 cm range. Taking into account the lower catch rate of hoki in the MHS reduced the significance of the difference in size selectivity between the MHS and conventional gear, although still indicated a tendency for the MHS to have a lower probability of retaining hoki less than 85 cm.

Previous comparisons of selectivity between the deepwater MHS and a 100 mm conventional mesh trawl (O'Driscoll & Millar 2017) suggested no significant difference in selectivity, with both gears estimated to retain close to 100% of fish greater than 70 cm. The inshore MHS used in this trial was originally designed for fisheries where 125 mm mesh is the minimum and the reduced catch rates of the smaller hoki size classes is therefore not unexpected. It should be noted, however, that the smallest size classes of hoki, encountered on the Chatham Rise, do not appear to be present off the east coast of the North Island. As a result, the practical effect of reduced catches of smaller hoki will be limited in this fishery.

Catches of smaller gemfish (sizes below approximately 70 cm) were also lower with the MHS than in the mesh trawl but, after accounting for the lower overall catch rate of gemfish using the MHS, there is little evidence of a selection differential between the gears over the size ranges of gemfish encountered. No differences in size selectivity or catch rate for ling were apparent between the methods.

Although variation between tow pairs was reasonably large, the eighteen pairs carried out were generally sufficient to assess differences in catch rates and relative selectivity for hoki, gemfish, and ling, with the parameters of the catch rate models and shape of the relative selectivity curve remaining stable as tow pairs are added to the analysis. For hoki, catch rates were low for the final six tow pairs. As a result, the differences in size selectivity are determined by data from the initial 12 tows. However, the low catch rates in the final six tows appear to moderate the estimate of the difference in catch rate of hoki by the two gear types, indicating that further pairs with a greater range in catches would be useful to provide a more precise estimate of the gear effect on hoki catch rate.

Over longer time periods, it is likely that fishing patterns using MHS gear will differ from the patterns observed with conventional gear because fishers will seek to take advantage of the improved fish quality obtained using the MHS. It is also possible that, with larger datasets and a greater range in relevant covariates, other factors that influence the difference in size selectivity and catch rates between the MHS and conventional gears will become apparent. For example, there were differences in subsets of the experimental tow pairs in the catch rates of hoki, and the selectivity patterns of hoki and gemfish (Appendix D), that may be related to catch volumes either by species or overall. These are second-order effects to the main gear effect but will nevertheless influence the realised selectivity of the fishery over the longer term.

For the purposes of making decisions about the introduction of new gears under regulation 71A of the Fisheries (Commercial Fishing) Regulations 2001, Fisheries New Zealand has expressed a preference for direct side-by-side comparisons rather than prolonged studies of realised differences in fishing patterns from different gears. The alternate-tow methodology aims to meet this information need. Comparing the inshore MHS with a 100 mm conventional mesh trawl in the hoki target fishery off the east coast of the North Island, the key differences between gears indicated by this trawl are a slightly reduced catch rate of hoki, particularly for fish in the 65 cm to 85 cm range, and a significantly reduced catch rate of gemfish primarily associated with a reduced tail of large catches when fishing with the MHS.

5. ACKNOWLEDGEMENTS

The skippers and crew of the FV *Tengawai*, and shore-based staff from Sanford Ltd, were instrumental in implementing the trial successfully. Fisheries New Zealand Observer, Monique Watson, carried out a large volume of length measurements during the trial. Caroline Cunningham and Alice Sagar from Fisheries New Zealand worked to ensure the trial logistics were successful, and Martin Cryer (Fisheries New Zealand) contributed to ensuring the protocols for the trial were clear and implemented the knowledge gained from previous trials. Dave Woods and Greg Johansson oversaw the trial for Precision Seafood Harvesting. Pamela Mace (Fisheries New Zealand) chaired the Statistics, Assessments and Methods Working Group and provided scientific review of this draft report, while Suze Baird undertook final editing and managed the publication process for Fisheries New Zealand.

6. REFERENCES

Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software 80 (1)*: 1–28. doi:10.18637/jss.v080.i01.

Chambers, M.S.; Middleton, D.A.J.; Moran, D.; Janssen, G. (2021). An alternate-tow net A vs. net B comparison. *New Zealand Fisheries Assessment Report 2021/52*. 43 p.

Fisheries New Zealand (2018). Approval for the use of a Precision Seafood Harvesting Modular Harvest System Trawl Net under the Fisheries (Commercial Fishing) Regulations 2001. Regulation 71A Approval. Retrieved from https://www.fisheries.govt.nz/dmsdocument/29003-precision-seafood-harvesting-modular-system-trawl-net-deepwater-fisheries-24-may-2018.

Fisheries New Zealand (2019). Approval for the inshore use of a Precision Seafood Harvesting Modular Harvest System trawl net under regulation 71A of the Fisheries (Commercial Fishing) Regulations 2001. Retrieved from https://www.fisheries.govt.nz/dmsdocument/34527-precision-seafood-harvesting-modular-system-trawl-net-north-island-inshore-fisheries-12-april-2019.

Fisheries New Zealand (2020). Fisheries Assessment Plenary, May 2020: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1746 p.

Hastie, T.; Tibshirani, R.; Friedman, J. (2009). The Elements of Statistical Learning: Data Mining, Inference, and Prediction (2nd ed.). Springer Science & Business Media.

O'Driscoll, R.; Millar, R.B. (2017). Hoki fishery PSH selectivity trials: FV *Rehua* (reh1701). NIWA Client Report No: 2017209WN, prepared for Precision Seafood Harvesting. National Institute of Water & Atmospheric Research Ltd.

Vehtari, A.; Gelman, A.; Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing 27*: 1413–1432.

APPENDIX A: SPECIES CODES

Table A-1: Species codes used in this report.

Code	Common name	Scientific name
OSD	Other sharks and dogs	*Selachii*
FLA	Flats	
SDO	Silver dory	*Cyttus novaezealandiae*
FHD	Deepsea flathead	*Hoplichthys haswelli*
JGU	Spotted gurnard	*Pterygotrigla picta*
RHY	Common roughy	*Paratrachichthys trailli*
SRH	Silver roughy	*Hoplostethus mediterraneus*
SWA	Silver warehou	*Seriolella punctata*
YBO	Yellow boarfish	*Pentaceros decacanthus*
BRA	Short-tailed black ray	*Dasyatis brevicaudata*
CAR	Carpet shark	*Cephaloscyllium isabellum*
JAV	Javelin fish	*Lepidorhynchus denticulatus*
LDO	Lookdown dory	*Cyttus traversi*
RAT	Rattails	*Macrouridae*
RUD	Rudderfish	*Centrolophus niger*
THR	Thresher shark	*Alopias vulpinus*
WIT	Witch	*Arnoglossus scapha*
CDO	Capro dory	*Capromimus abbreviatus*
NSD	Northern spiny dogfish	*Squalus griffini*
MDO	Mirror dory	*Zenopsis nebulosa*
BAR	Barracouta	*Thyrsites atun*
BYX	Alfonsino & long-finned beryx	*Beryx splendens & B. decadactylus*
FRO	Frostfish	*Lepidopus caudatus*
GSH	Ghost shark	*Hydrolagus novaezealandiae*
HOK	Hoki	*Macruronus novaezelandiae*
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae*
LIN	Ling	*Genypterus blacodes*
RBY	Rubyfish	*Plagiogeneion rubiginosum*
RCO	Red cod	*Pseudophycis bachus*
RSK	Rough skate	*Zearaja nasuta*
SCH	School shark	*Galeorhinus galeus*
SCI	Scampi	*Metanephrops challengeri*
SKI	Gemfish	*Rexea* spp.
SPE	Sea perch	*Helicolenus* spp.
SPO	Rig	*Mustelus lenticulatus*
SQU	Arrow squid	*Nototodarus sloanii & N. gouldi*
SSK	Smooth skate	*Dipturus innominatus*
STA	Giant stargazer	*Kathetostoma* spp.
TAR	Tarakihi	*Nemadactylus macropterus & N. rex*
HPB	Hapuku & bass	*Polyprion oxygeneios & P americanus*
ERA	Electric ray	*Torpedo fairchildi*
SEV	Broadnose sevengill shark	*Notorynchus cepedianus*

APPENDIX B: CATCH MODEL DIAGNOSTICS

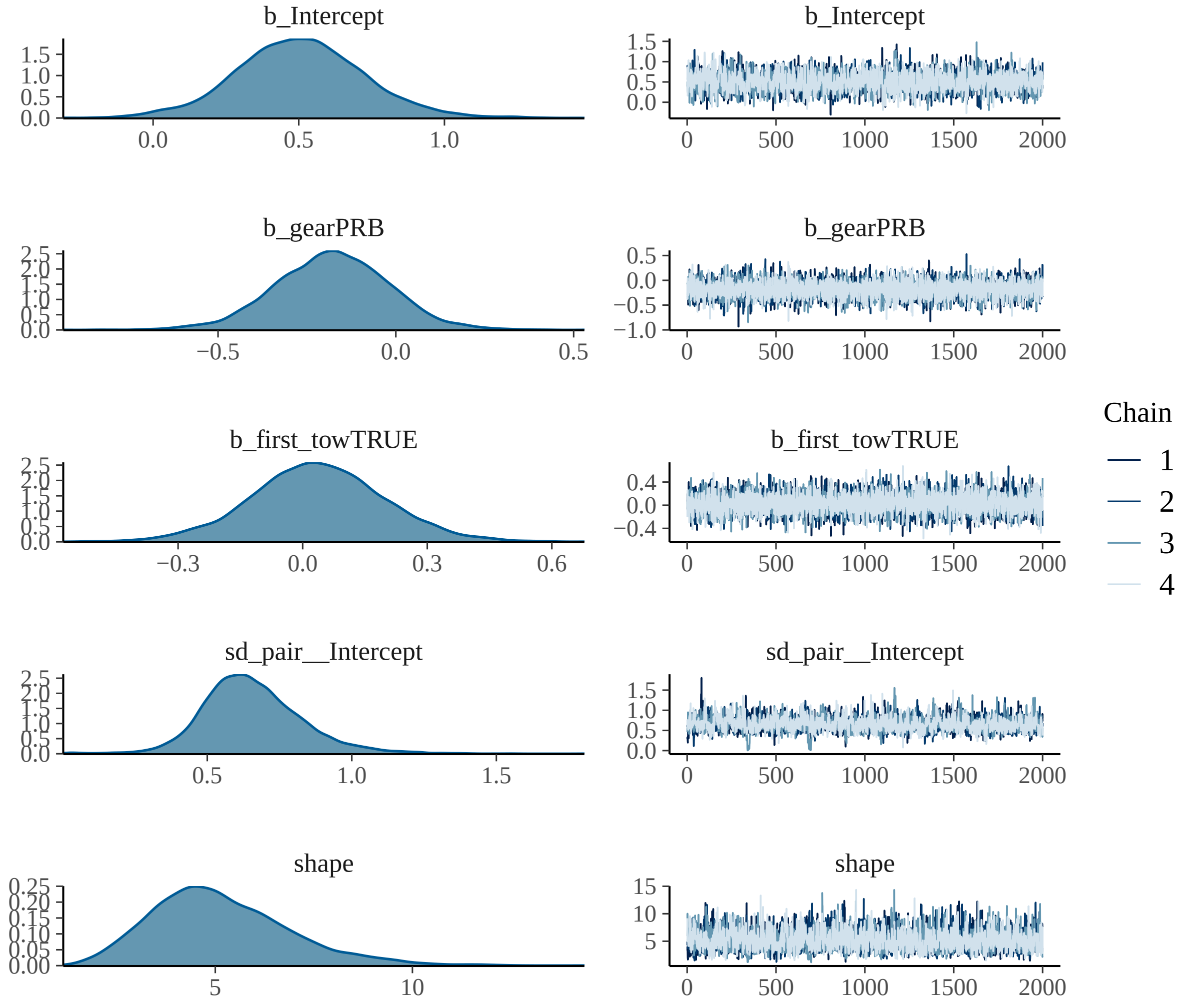

Figure B-1: MCMC traces and posterior densities for fixed effects in a Gamma model for hoki catch.

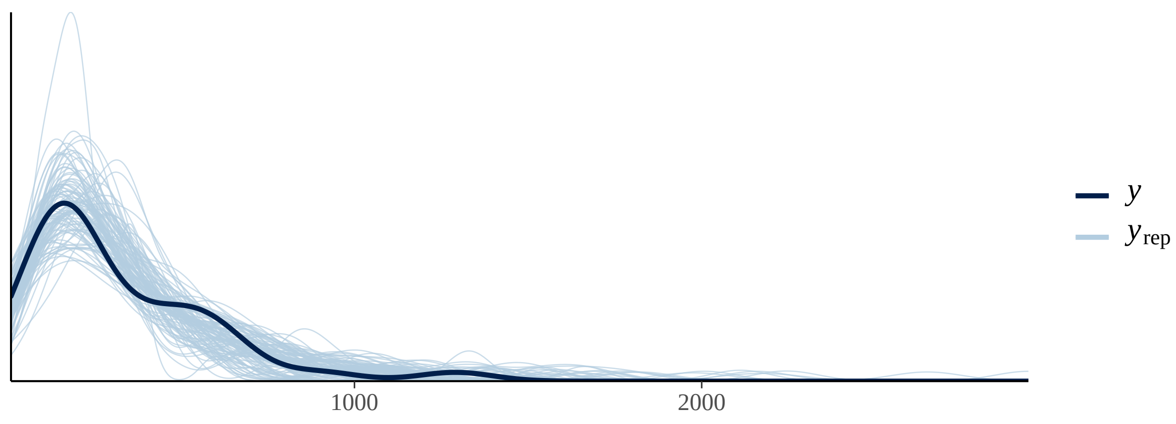

Figure B-2: Posterior predictive check for catch of hoki modelled with a Gamma error distribution, using 100 posterior samples.

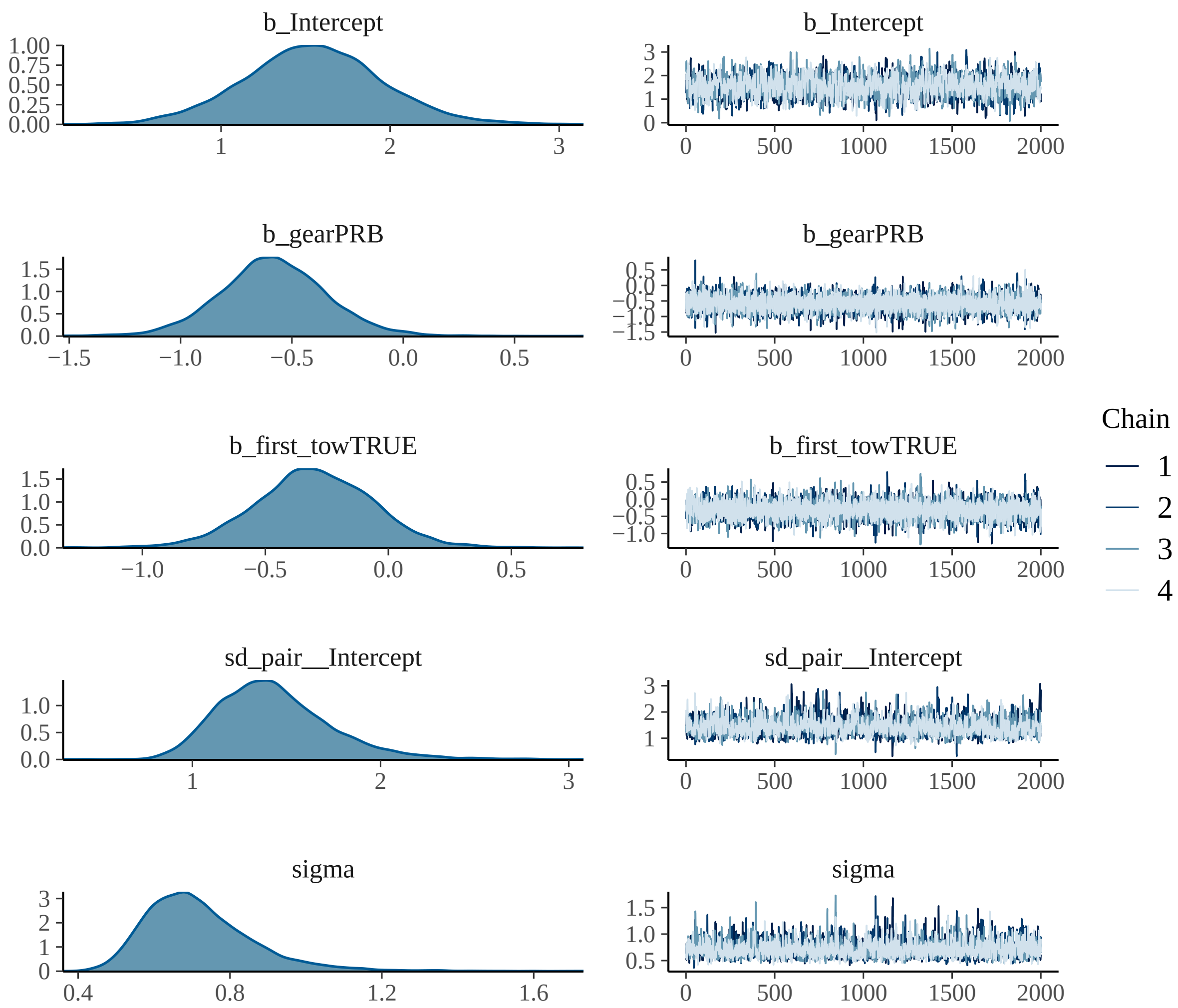

Figure B-3: MCMC traces and posterior densities for fixed effects in a lognormal model for gemfish catch.

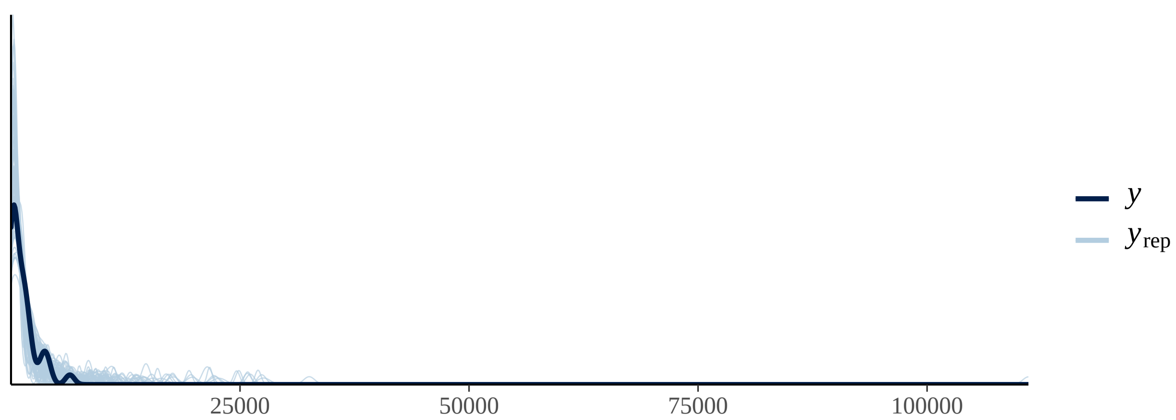

Figure B-4: Posterior predictive check for catch of gemfish modelled with a lognormal error distribution, using 100 posterior samples.

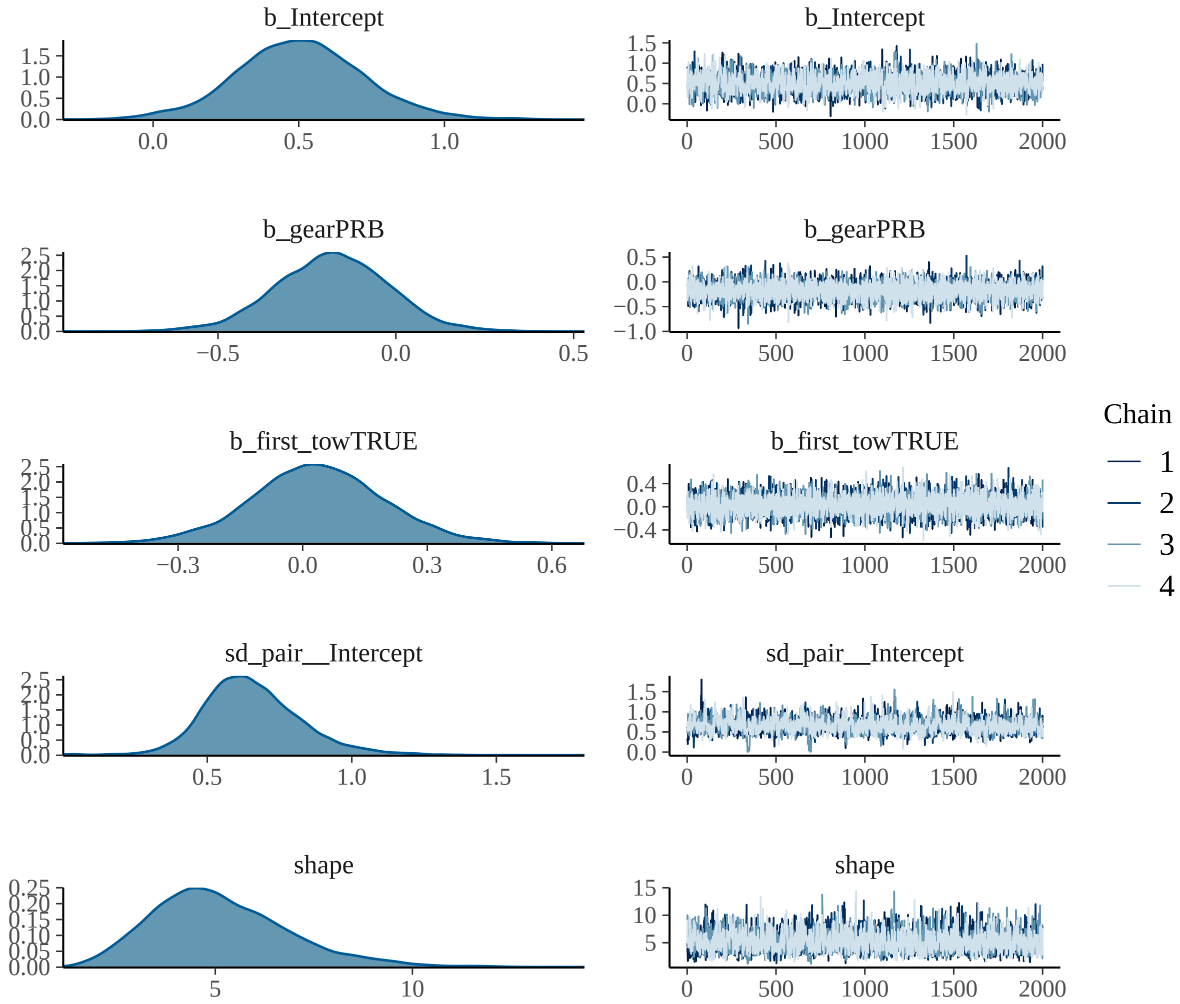

Figure B-5: MCMC traces and posterior densities for fixed effects in a Gamma model for ling catch.

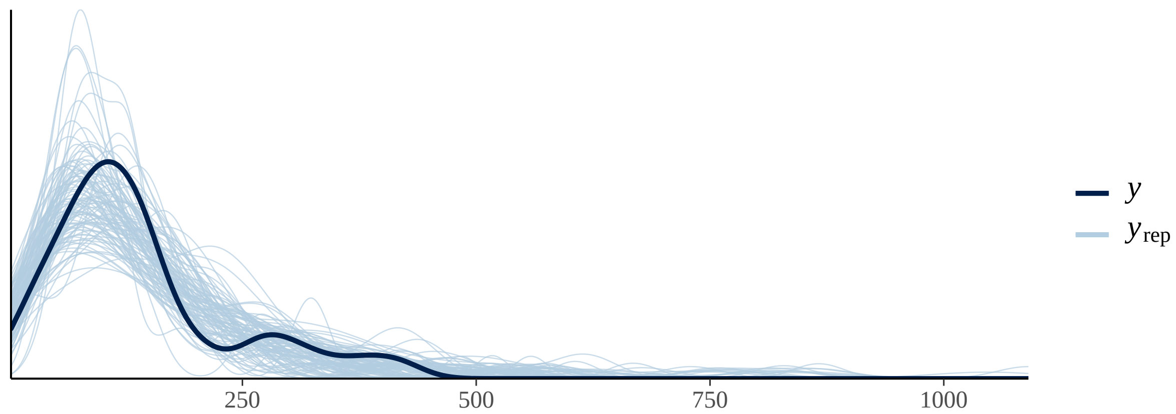

Figure B-6: Posterior predictive check for catch of ling modelled with a Gamma error distribution, using 100 posterior samples.

APPENDIX C: LENGTH FREQUENCY DISTRIBUTIONS BY TOW PAIR

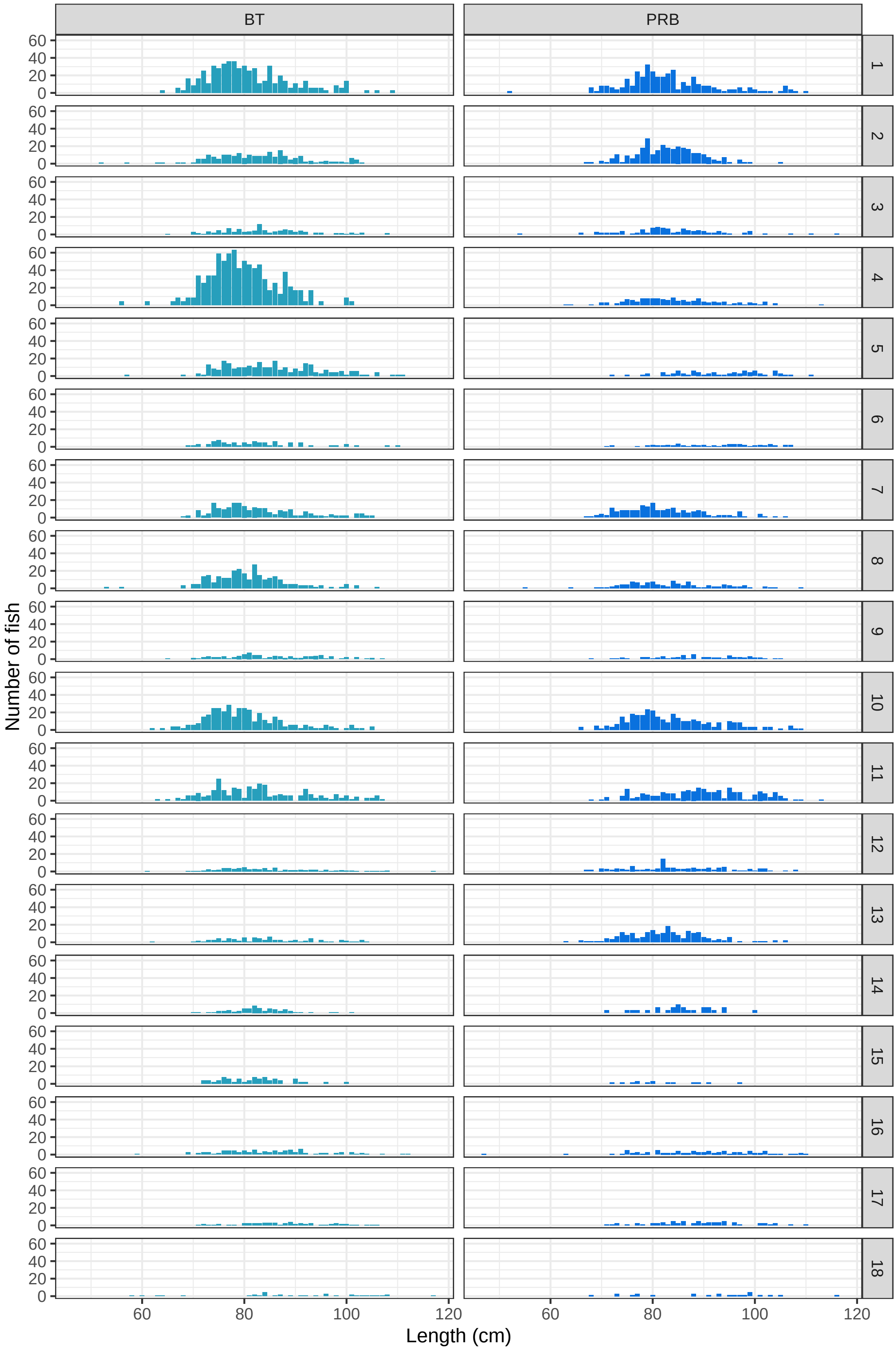

Figure C-1: Length frequency distributions for hoki by tow pair, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

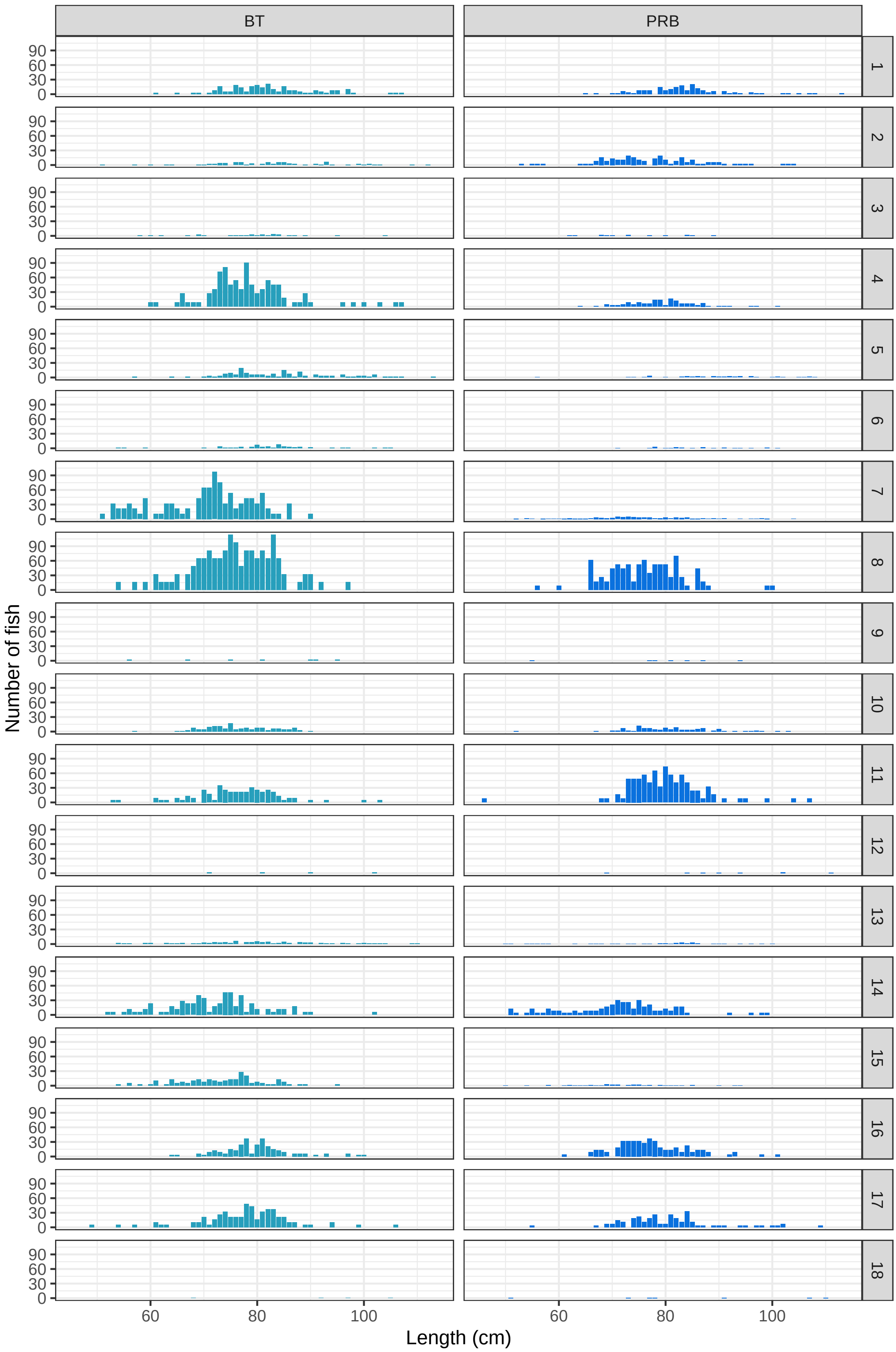

Figure C-2: Length frequency distributions for gemfish by tow pair, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

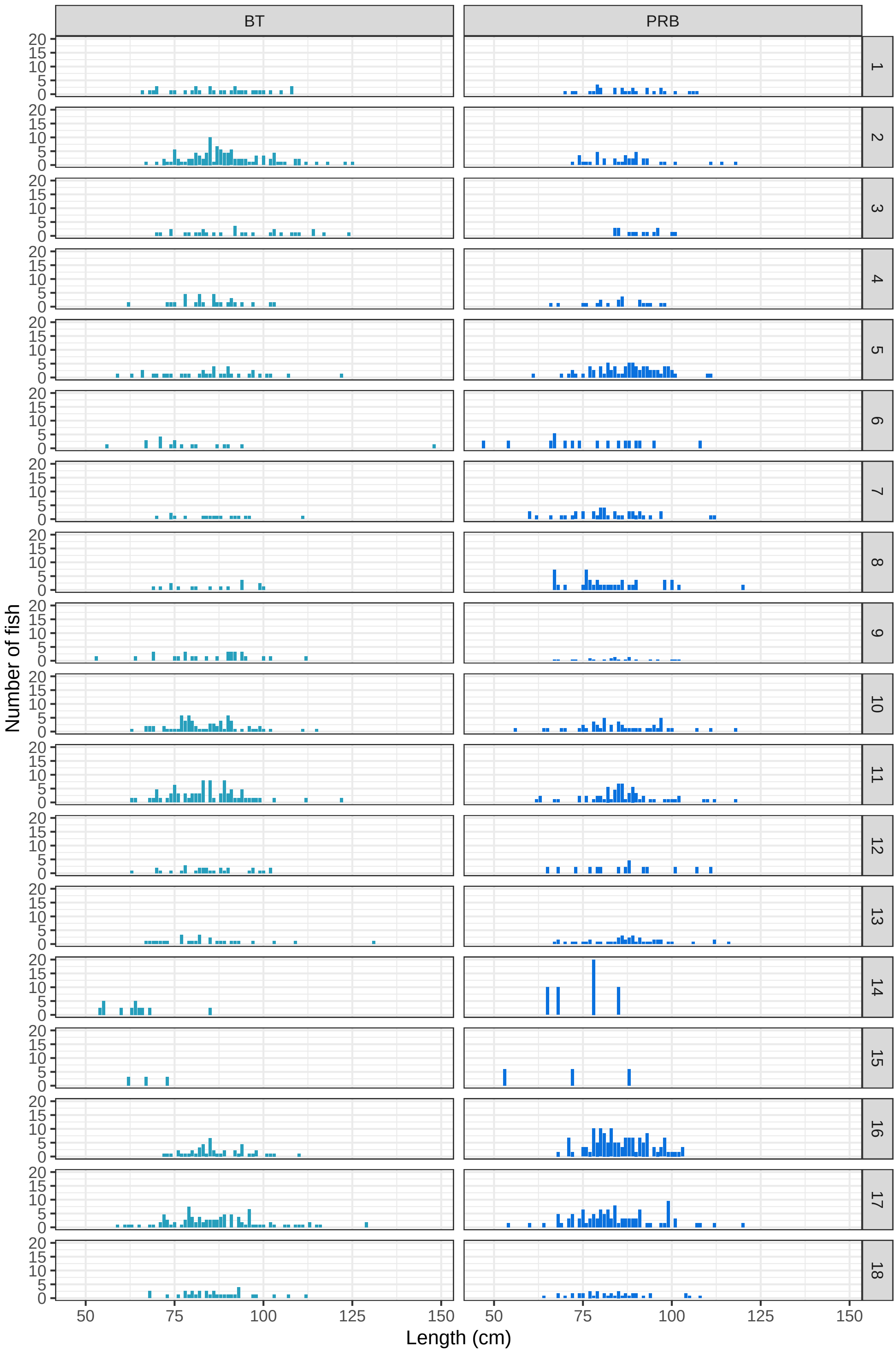

Figure C-3: Length frequency distributions for ling by tow pair, with per tow fish numbers scaled to the full catch. The conventional mesh trawl is indicated by the code BT and the Modular Harvest System by the PRB gear code.

APPENDIX D: IMPACT OF TOW PAIRS ON RELATIVE SELECTIVITY ESTIMATES

D.1 Hoki

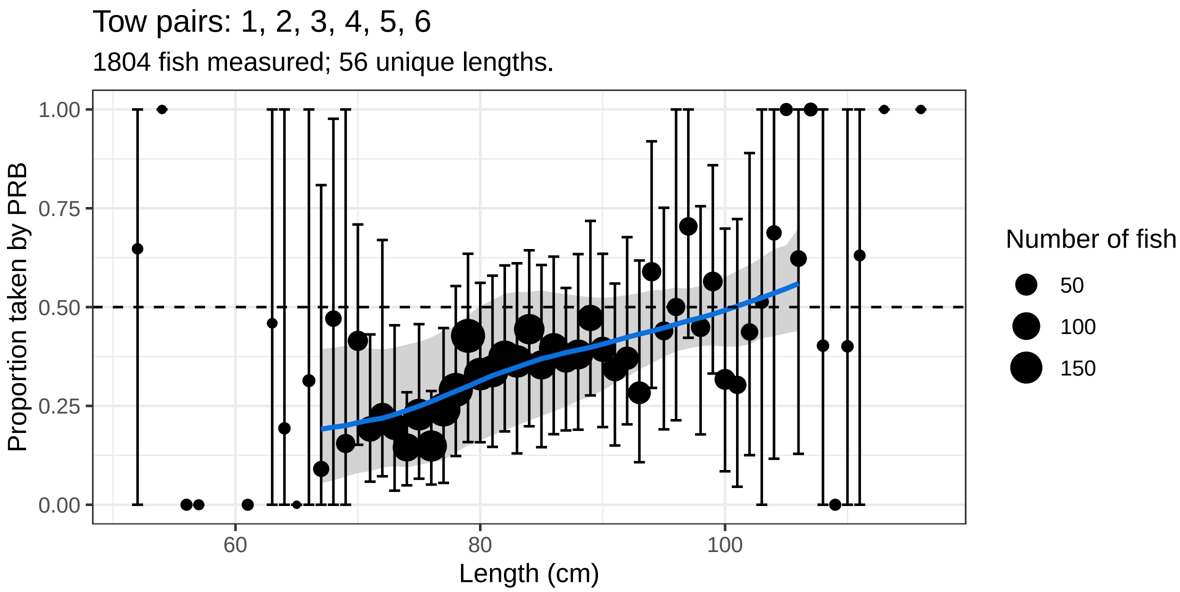

Figure D-1: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first six tow pairs.

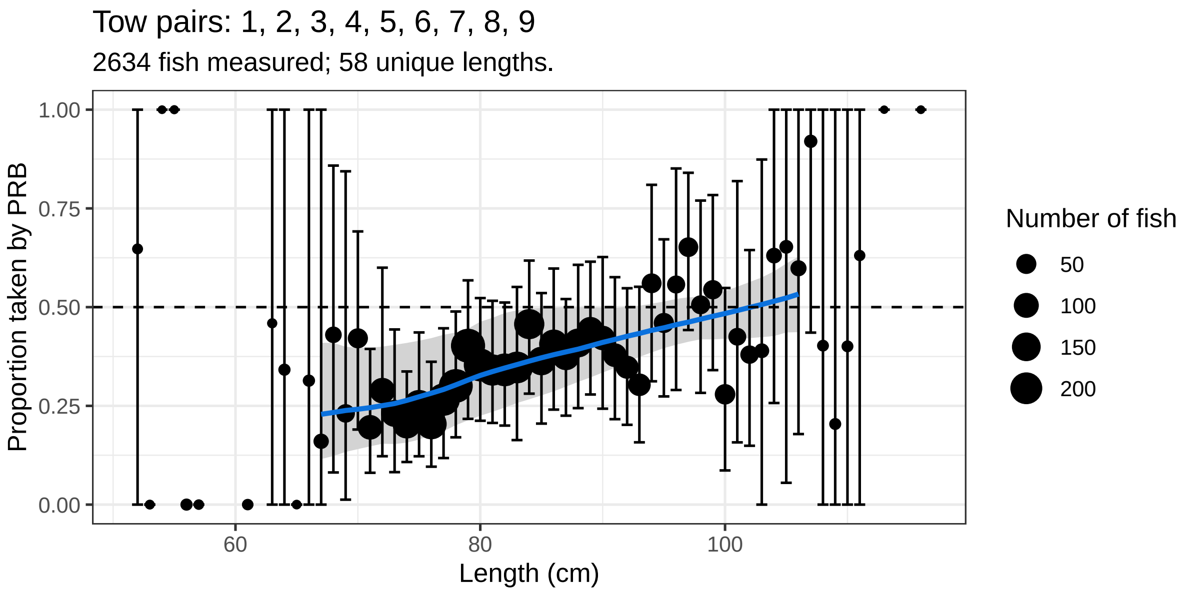

Figure D-2: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first nine tow pairs.

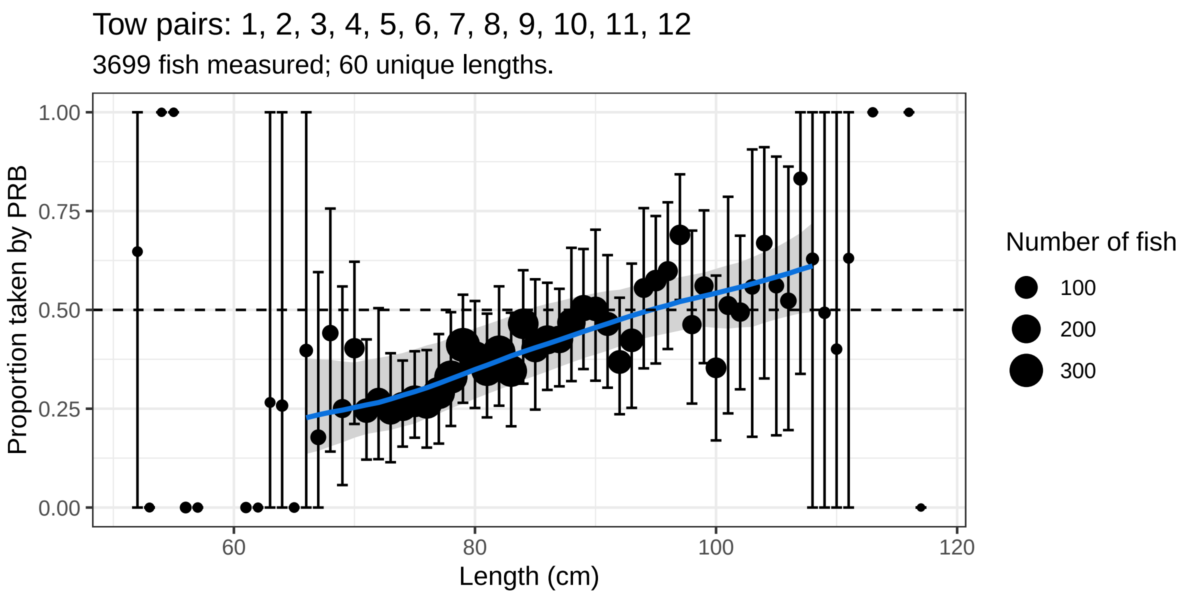

Figure D-3: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first twelve tow pairs.

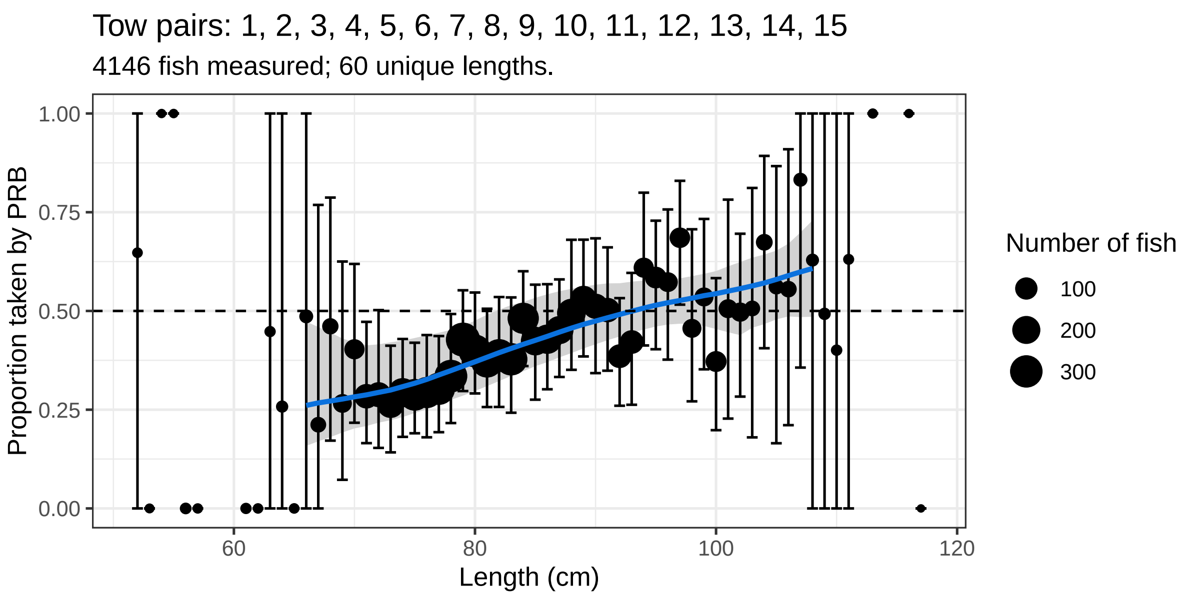

Figure D-4: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first fifteen tow pairs.

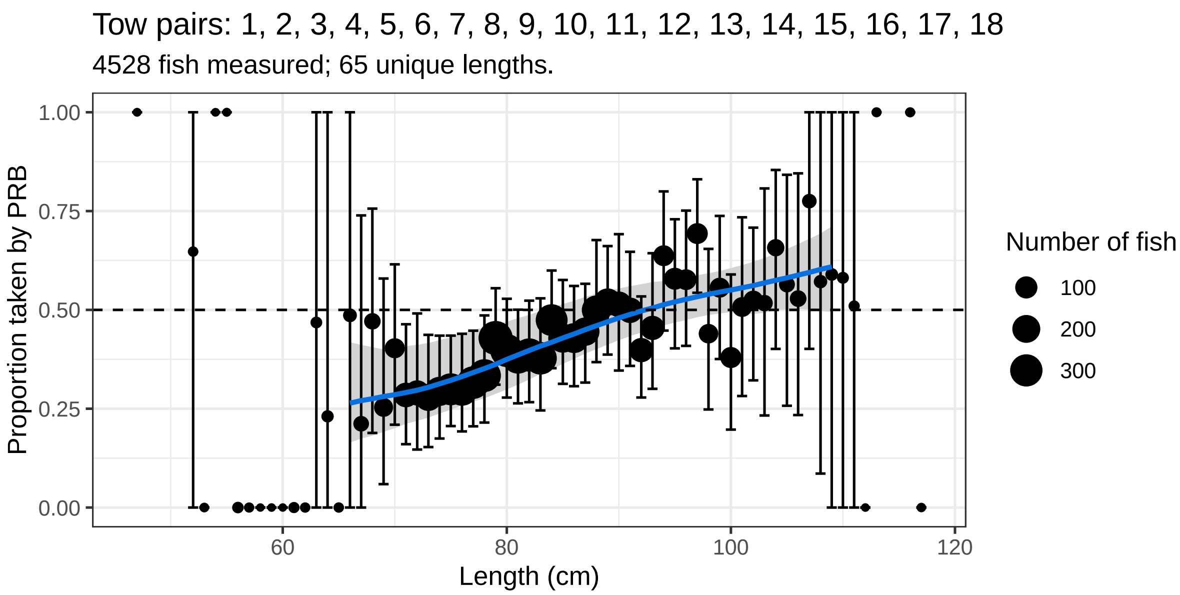

Figure D-5: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and distributions of smooth spline fits to the bootstrap samples of proportion at length for samples upweighted to tow weight. All 18 tow pairs are included.

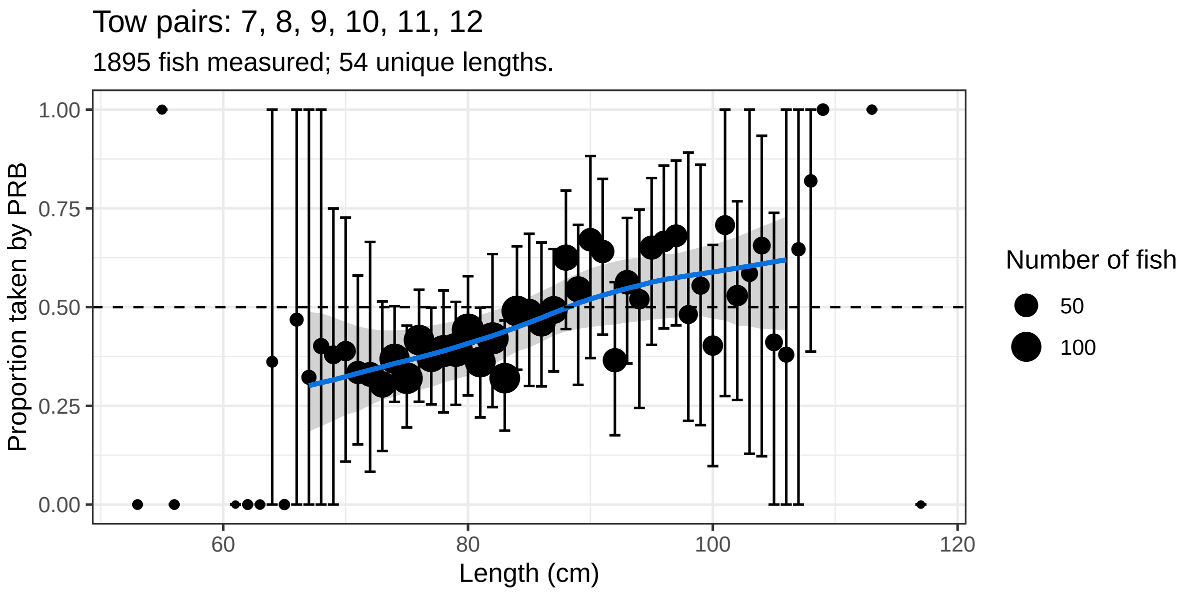

Figure D-6: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the second block of six tow pairs.

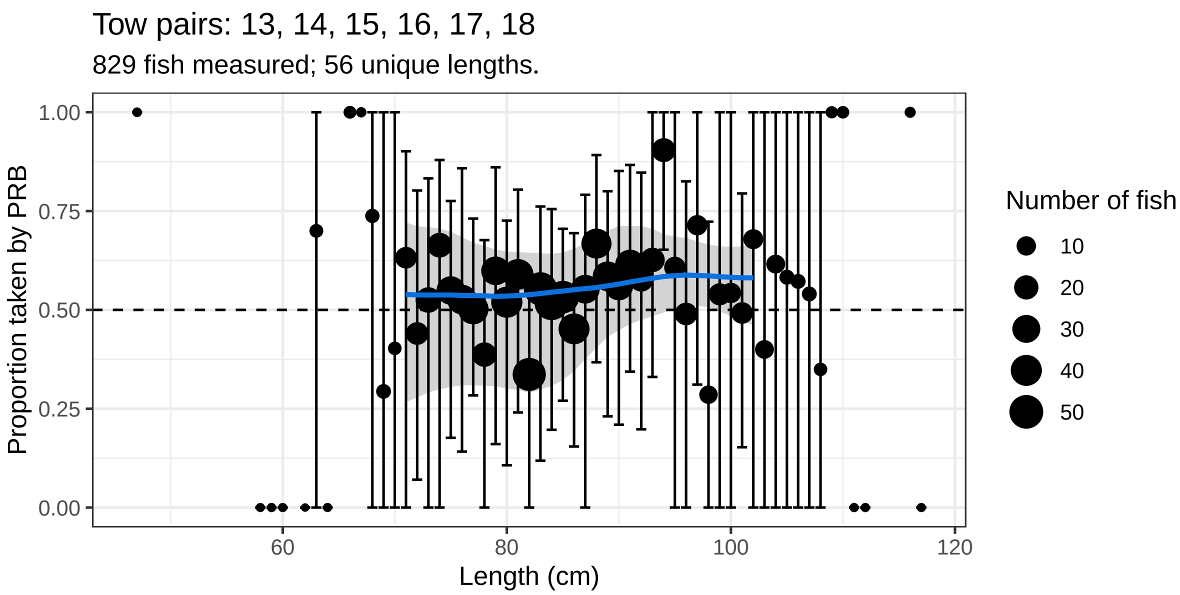

Figure D-7: The proportion of hoki taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the third block of six tow pairs.

D.2 Gemfish

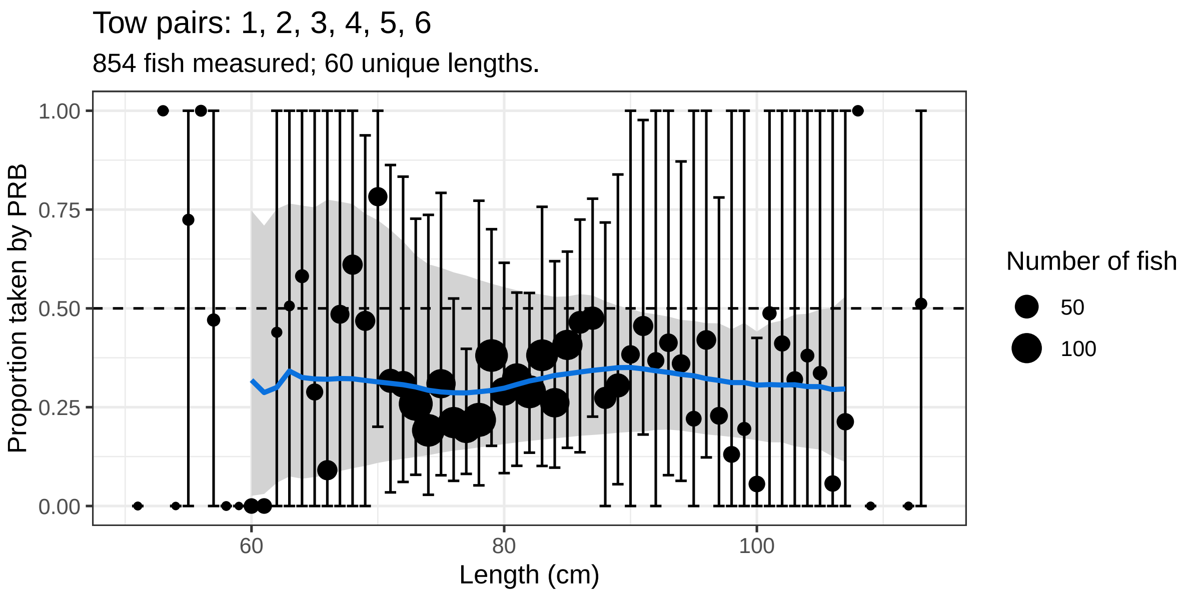

Figure D-8: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first six tow pairs.

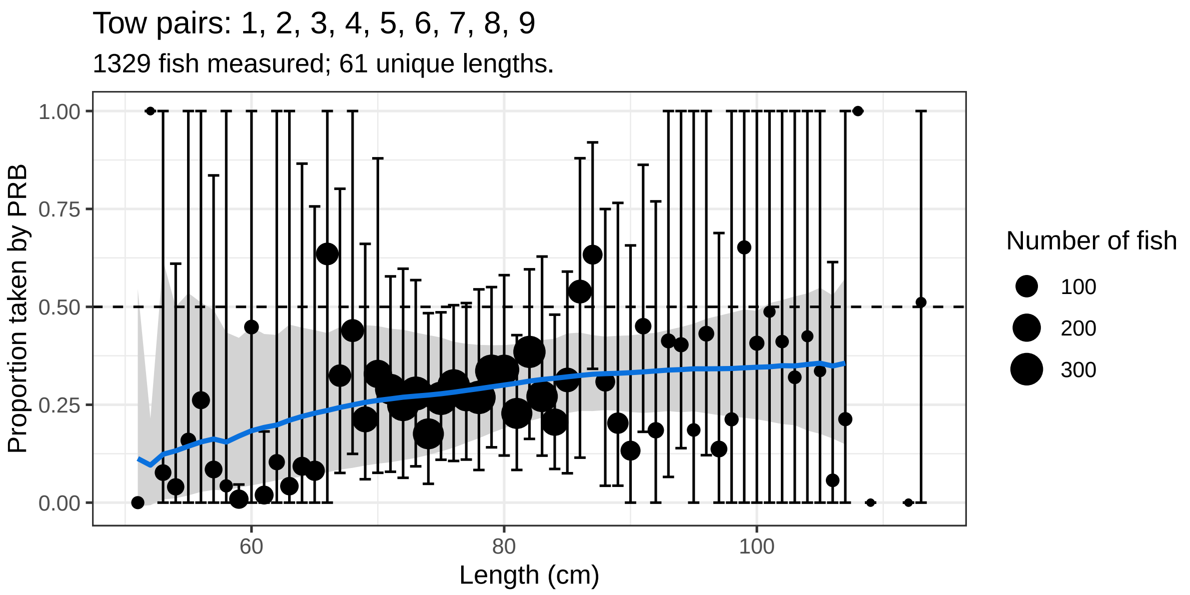

Figure D-9: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first nine tow pairs.

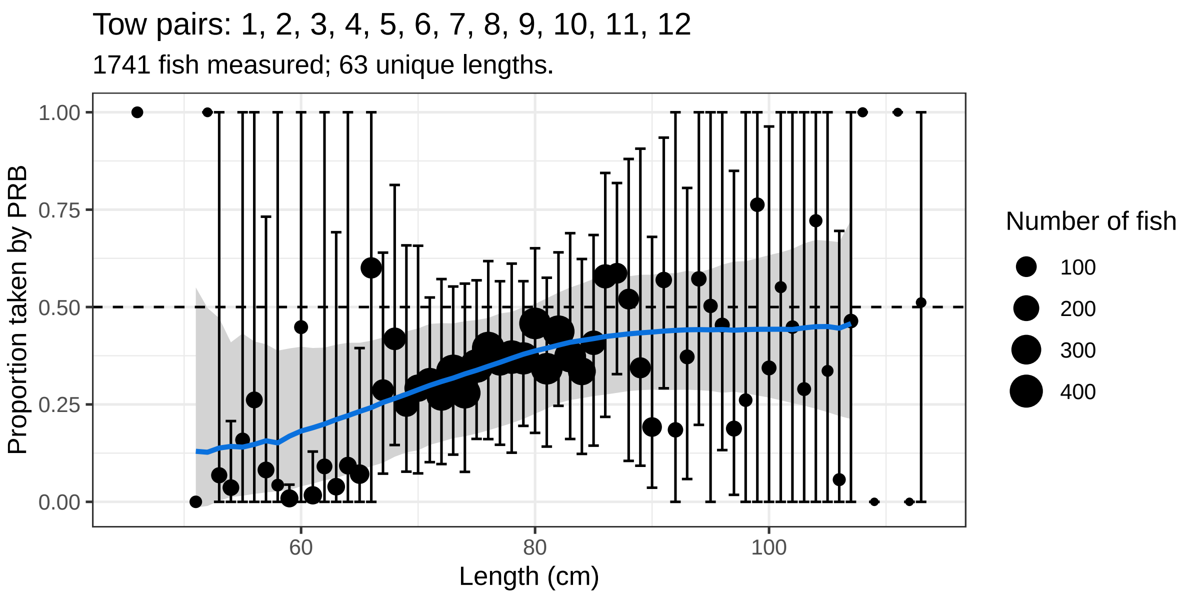

Figure D-10: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first twelve tow pairs.

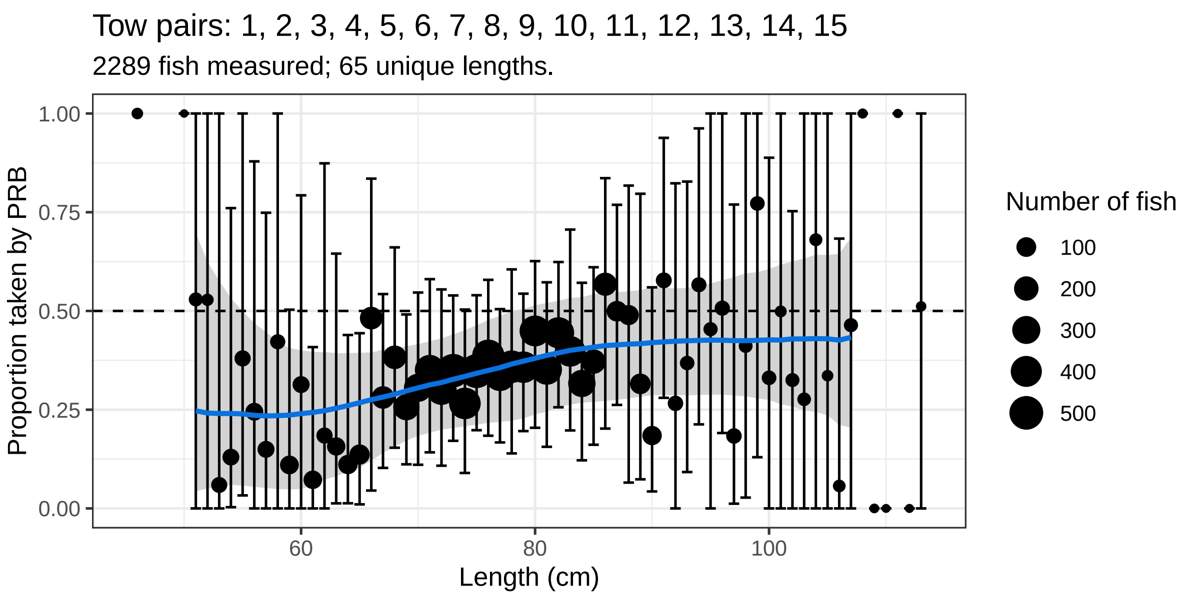

Figure D-11: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the first fifteen tow pairs.

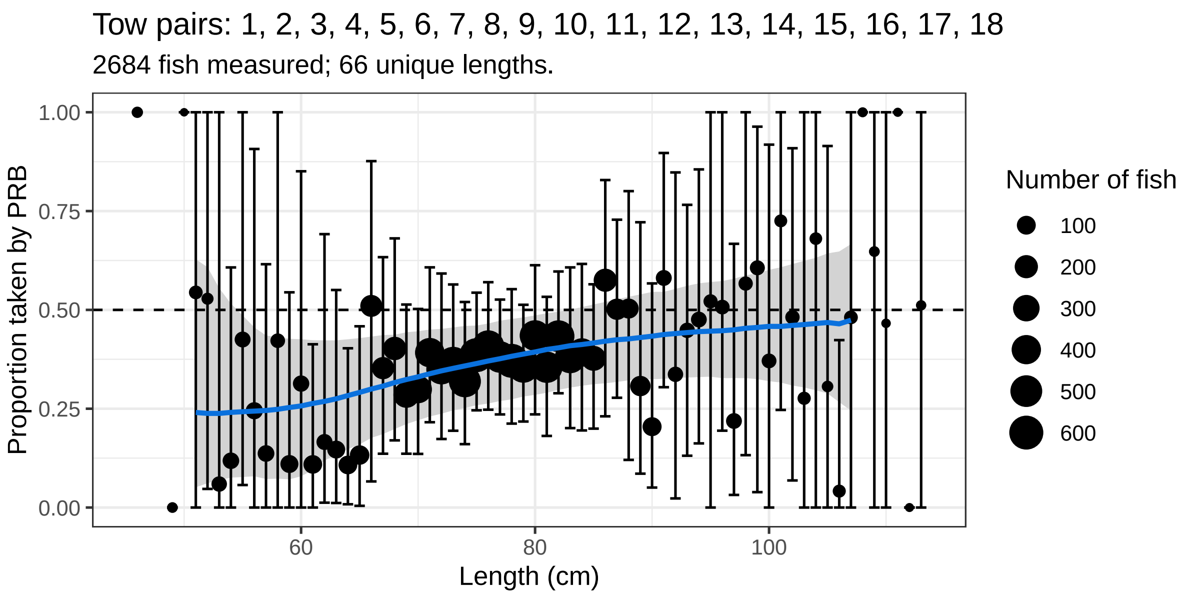

Figure D-12: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and distributions of smooth spline fits to the bootstrap samples of proportion at length for samples upweighted to tow weight. All 18 tow pairs are included.

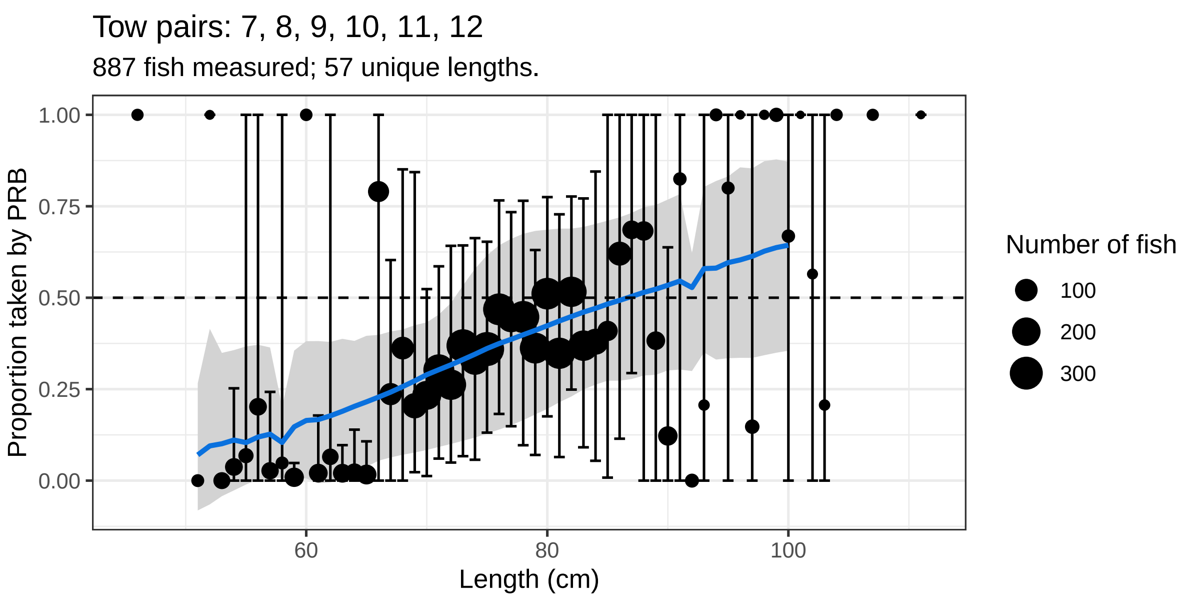

Figure D-13: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the second block of six tow pairs.

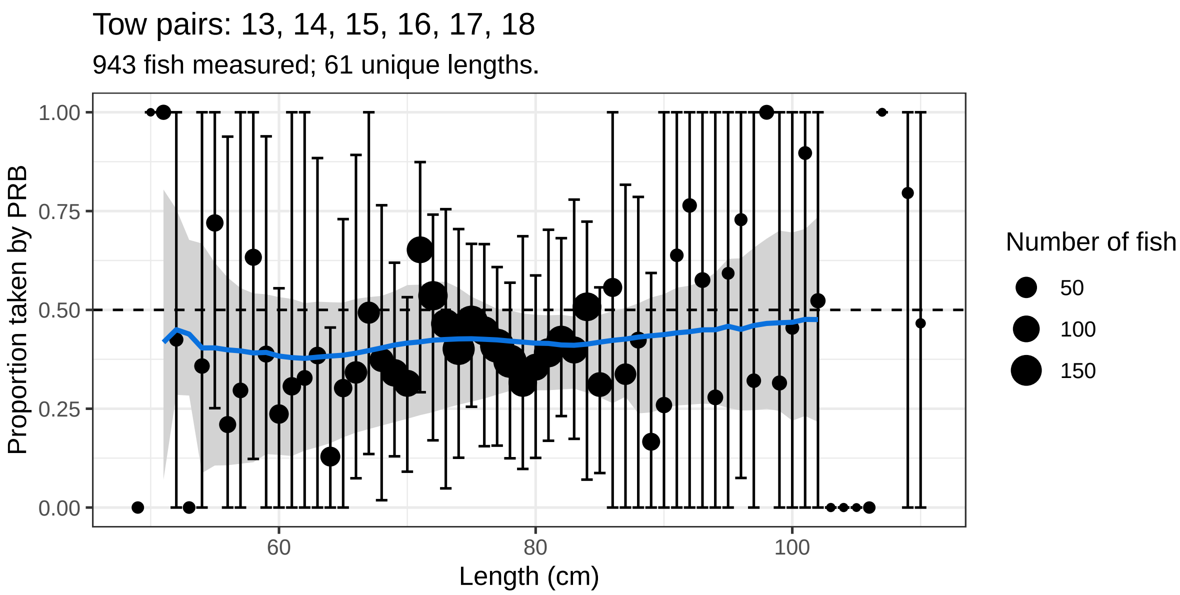

Figure D-14: The proportion of gemfish taken by MHS by length (1 cm length bins) with bootstrap confidence intervals based on 1000 replicates, and the data set limited to the third block of six tow pairs.