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West coast fishery trials of a twin rig *Nephrops* trawl incorporating a large mesh top sheet for reducing commercial gadoid species by-catch

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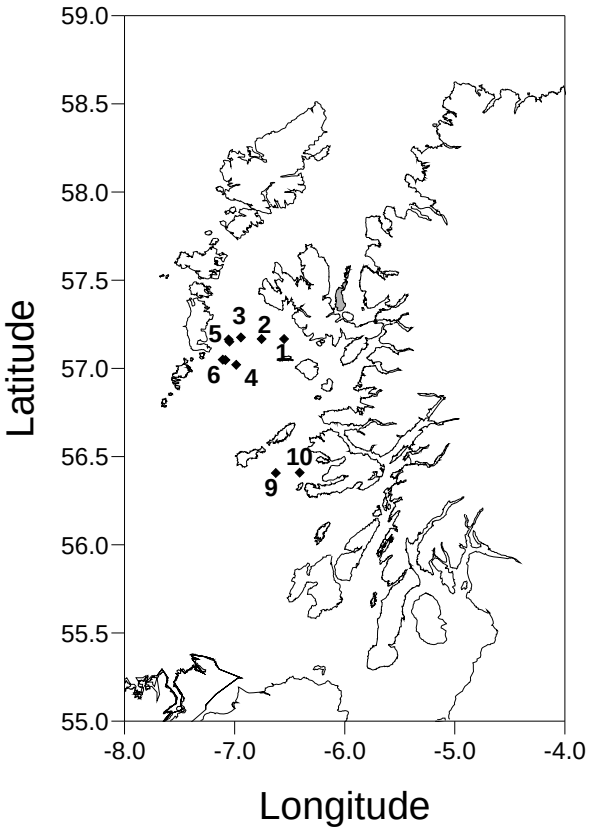
Introduction

In 2009 a local owner and skipper, Mr Willie Burke and Mr Vincent Williams, approached the Scottish Association for Marine Science for scientific help with improving catch selection in their *Nephrops* twin-rig trawl fishery. Because the *Nephrops* fisheries use 80 mm mesh nets, by-catch and discarding is a problem. On the west coast of Scotland by-catch and discarding of gadoids is currently of particular concern in relation to cod re-building but Mr Burke and Mr Williams explained that they are also keen to reduce the amount of discarding of all fish in their catches. An application for financial support was made to the Scottish Industry/Science Partnership in 2009. The original trials were planned for autumn 2009 but the contract was delayed due to internal re-organisation within Marine Scotland with the result that trials could not be conducted until February/March 2010. The proposal from Mr Burke and Mr Williams was to test replacement of the 80 mm mesh in the top-sheet with a large mesh. Following consultation with Marine Scotland it was agreed that 290 mm mesh would be used. The nets were fabricated by Harkess Trawls (12 Whin Park, Cockenzie, Prestonpans, EH32 0JQ).

Vessel and Fishing Grounds

The *Charmel* (OB22) a 17.07 m, 309 hp twin-rig trawler, built in 1980 and registered in Oban was chartered for the trials (Figure 1). Two fishing trips were undertaken, the first ran from 12-16 February and the second from 8-12 March. Grounds at the mouth of the Firth of Lorne and in the southern Minch were targeted (Figures 2a and 2b). Based on previous experience, it was thought that there would be small gadoids on these grounds.

Figure 1: *Charmel* (OB22) at sea



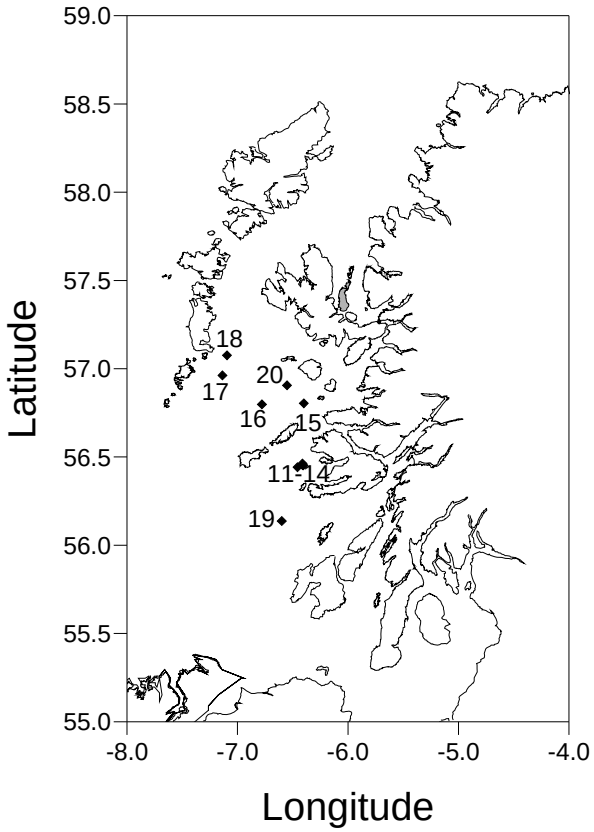


Figure 2a: Positions for first trial (12-16 Feb) **Figure 2b:** Positions for second trial (8-12 Mar)

Fishing Gear – Control Trawl - Sampling

The test and control trawls were new and manufactured by Harkess Trawls based on commercial designs (Figures 3-6). The two trawls were identical except that the top-sheet of the modified trawl was replaced with 290 mm mesh. At the start and end of each trip, mesh sizes were determined using an Omega electronic measuring gauge. Measurements were made of 20 meshes for each area of the net (Table 1). The gear was fished using a three warp tow with a 360 kg chain clump and 230 kg Thyborn doors. The doors and trawl wing-ends were connected by 54 m sweeps. No tickler chain was used.

The twin trawl technique was used to assess the relative catch rates of the test gear against the control. On both trials the test and control nets were swapped across half-way through the trip. Notus net monitoring gear was used to measure the door spread. A headline sensor was, unfortunately, not available. All tows were around three hours in duration. Towing speed was 2.2 knots and the start and end of the tow was determined from the door spread monitored by the Notus system. Tows were made with or against any tide as far as practical. Tow tracks were recorded using the vessel GPS plotter. A full tow summary is given in Table 2.

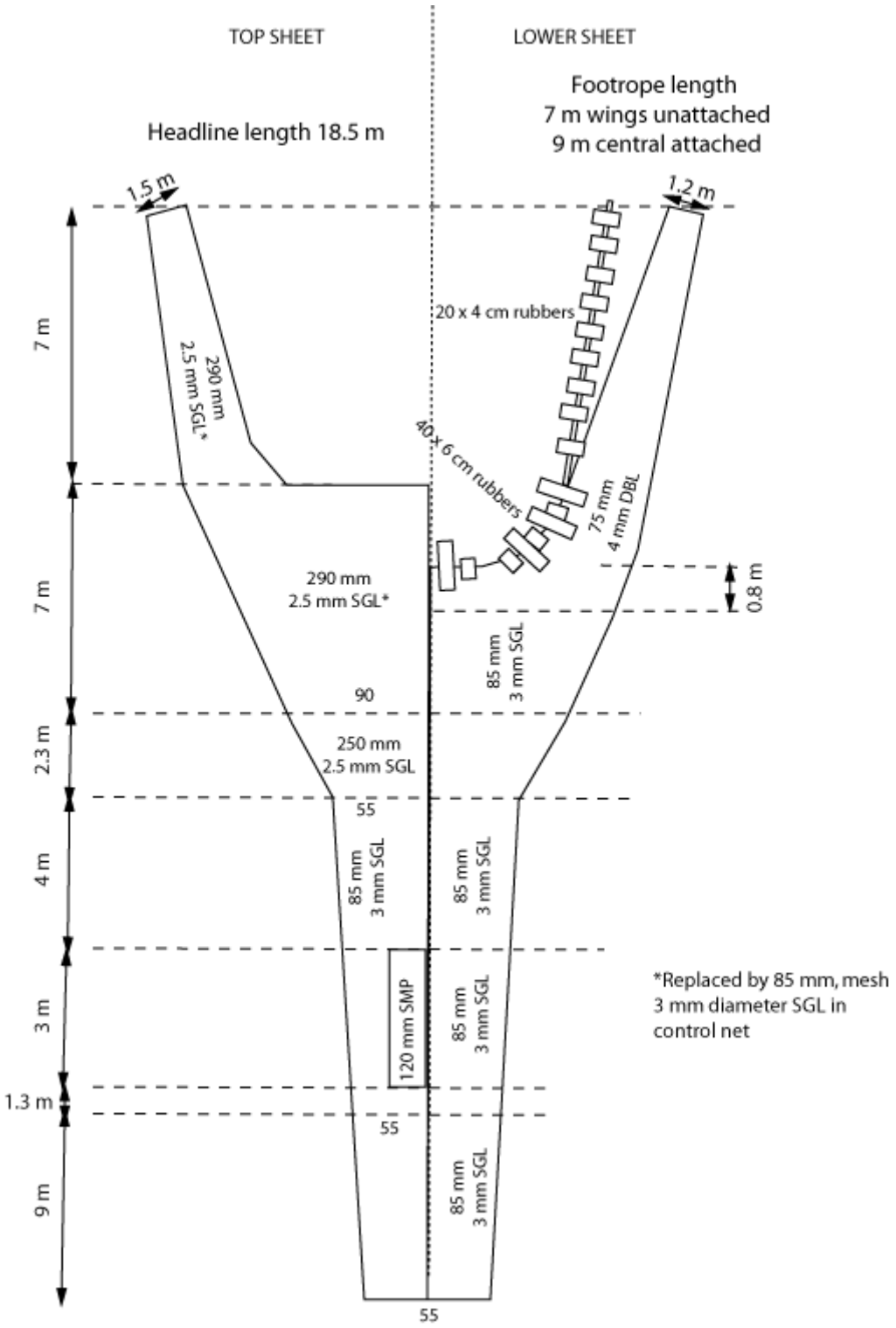


Figure 3: Test and control trawl

Table 1

Mesh sizes in mm measured using Omega electronic gauge (n=20)[1]

Before trip 1				
	Un-modified trawl		Modified trawl	
	mean	sd	mean	sd
Sidewall	86.9	1.4	84.9	1.7
Cod-end	84.0	1.5	84.4	1.8
Top-sheet	na	na	291.1	2.8
At end of trip 1/Before trip 2				
	Un-modified trawl		Modified trawl	
Sidewall	86.4	1.5	84.7	1.8
Cod-end	84.9	1.7	84.2	1.7
Top-sheet	na	na	290.2	2.0
At end of trip 2				
	Un-modified trawl		Modified trawl	
Sidewall	85.2	1.3	83.8	1.5
Cod-end	82.7	1.7	81.5	2.2
Top-sheet	na	na	291.1	1.8

[1] The square mesh panel meshes were measured at 120 mm using un-forced calipers at the start of the trial but not re-measured.

Table 2a

Tow summary for trip 1

Haul	Date	Shoot Lat	Shoot Lon	Shoot time	Tow length (mins)	Tow length (m)	Side test trawl fished	Control trawl door spread (m)	Test trawl door spread (m)	Weather
1	12-Feb-10	57.17	-6.55	07:50	180	12.2	Pt	31.4	39.6	Calm, wind force 2, cloud 3/8, sunny spells
2	12-Feb-10	57.17	-6.76	11:50	185	12.6	Pt	32.9	38.4	Calm, wind force 2, cloud 3/8, sunny spells
3	13-Feb-10	57.18	-6.94	07:45	180	12.1	Pt	37.8	44.8	Calm, wind force 1, cloud 7/8, overcast
4	13-Feb-10	57.02	-6.99	12:05	185	12.6	Pt	33.2	40.2	Calm, wind force 1, cloud 7/8, overcast
5	14-Feb-10	57.16	-7.06	07:45	180	12.3	Stbd	35.1	40.5	Calm, wind force 2, cloud 7/8, overcast
6	14-Feb-10	57.05	-7.11	11:40	220	13.9	Stbd	37.5	44.8	Calm, wind force 2, cloud 7/8, overcast
7	15-Feb-10	57.15	-7.05	08:00	175	12.1	Stbd	38.7	43.4	Slight swell, wind force 3, cloud 8/8, showers
8	15-Feb-10	57.05	-7.08	11:50	180	12.2	Stbd	37.2	44.5	Slight swell, wind force 3, cloud 8/8, showers
9	16-Feb-10	56.41	-6.41	08:20	180	12.2	Stbd	33.1	38.8	Swell, wind force 2, cloud 6/8, sunny spells
10	16-Feb-10	56.41	-6.63	12:00	200	12.7	Stbd	32.0	35.1	Swell, wind force 2, cloud 6/8, sunny spells

Table 2b

Tow summary for trip 2

Haul	Date	Shoot Lat	Shoot Lon	Shoot time	Tow length (mins)	Tow length (km)	Side test trawl fished	Control trawl door spread (m)	Test trawl door spread (m)	Weather
11	08-Mar-10	56.45	-6.41	07:30	180	13.2	Stbd	36.6	38.1	Slight swell, wind force 1-2, cloud 1/8, sunny
12	08-Mar-10	56.46	-6.41	11:20	190	14.7	Stbd	36.0	39.0	Slight swell, wind force 1-2, cloud 1/8, sunny
13	09-Mar-10	56.45	-6.41	07:15	180	13.2	Stbd	38.0	38.1	Slight swell, wind force 1-2, cloud 2/8, sunny
14	09-Mar-10	56.44	-6.46	11:10	180	13.8	Stbd	36.6	42.1	Slight swell, wind force 1-2, cloud 2/8, sunny
15	10-Mar-10	56.80	-6.40	07:30	175	13.2	Pt	35.1	40.2	Slight swell, wind force 2, cloud 7/8, overcast
16	10-Mar-10	56.80	-6.78	11:50	180	13.7	Pt	36.0	40.8	Slight swell, wind force 2, cloud 7/8, overcast
17	11-Mar-10	56.96	-7.14	07:50	180	12.0	Pt	38.1	41.1	Swell, wind force 2-3 freshening, cloud 6/8, overcast
18	11-Mar-10	57.08	-7.10	11:30	175	12.7	Pt	36.3	39.6	Swell, wind force 3-4, cloud 6/8, overcast
19	12-Mar-10	56.14	-6.60	07:00	185	13.7	Pt	37.2	40.2	Swell, wind force 2-3, cloud 5/8, overcast
20	12-Mar-10	56.91	-6.55	10:50	180	13.5	Pt	36.0	39.0	Swell, wind force 2-3, cloud 5/8, overcast

Figure 4: Modified trawl laid out on Oban quay

Figure 5: Modified and unmodified trawl being shot (modified trawl is on the port side)

Figure 6: Gear being shot showing the arrangement of floats

After each tow the starboard net was first recovered on-board and the catch emptied through the forward hatch into the hopper. This sample was covered with a large tarpaulin to prevent any mixing between the catch from the modified and unmodified nets. The port net was then landed and the catch emptied on top of the tarpaulin (Figure 7). Each catch was sorted into species and the total amount of each species caught determined with motion compensated, validated marine scales (Unisystem AB, U85516/U13702, serial number 21335/21334, test certificate TC5623, certification body Nederlands Meetinstituut, date of certification 19 November 2009). From each catch the carapace lengths (rear of eye orbit to end of thorax) of 200 *Nephrops* were recorded using digital callipers (Chronos Engineering, Model 1199W-616, serial 601381, date of certification 09 May 2009) after which the *Nephrops* sub-sample was weighed. For the commercial gadoid species by-catch, individual lengths were recorded for the total catch of each species. Of the non-gadoid commercial species, hake was caught in relatively large quantities on Trip 1 and sub-sampling was applied with 50 individuals being measured per net per haul. On Trip 2 it was decided that it would be sensible to include hake as a target species and the number of individuals measured per net per haul was increased to at least 200. For non-commercial species, lengths of all the catch were recorded except where numbers were large (species such as poor cod) where lengths were determined on a weighed sub-sample.

All fish for which the vessel had no quota were discarded after completion of the second haul each day.

Figure 7: Catch in the hopper prior to sorting

Figure 8: Fish by-catch sorted by species ready for measuring and weighing

Results

Gear Performance

There was a clear tendency for the otter board to clump distance to be greater for the test trawl and this effect persisted when the towing side was swapped. This effect was probably caused by the reduced drag from the large mesh topsheet compared with the standard 80 mm topsheet. Overall there were no problems in fishing the nets.

General Catch Results

An overall summary of the catches by weight is given in Table 3 and Figures 9 and 10. Almost exactly the same proportions of species (comprising the top 95% by weight) were caught in the control and test trawl during the first trip (Figure 9). A similar result was observed for the second trip except that the proportion of *Nephrops* to hake was greater (Figure 10). The main species caught (by weight and numbers) on both trips was *Nephrops* but considerable quantities of juvenile hake were also caught. Other species caught in reasonable numbers included poor cod, whiting, grey gurnard, long-rough dab, dogfish and common dragonets. On the second trip, blue whiting and witch were more prevalent. All species caught are listed in Tables 4 and 5. Overall 43 species were caught during Trip 1 and 39 species during Trip 2.

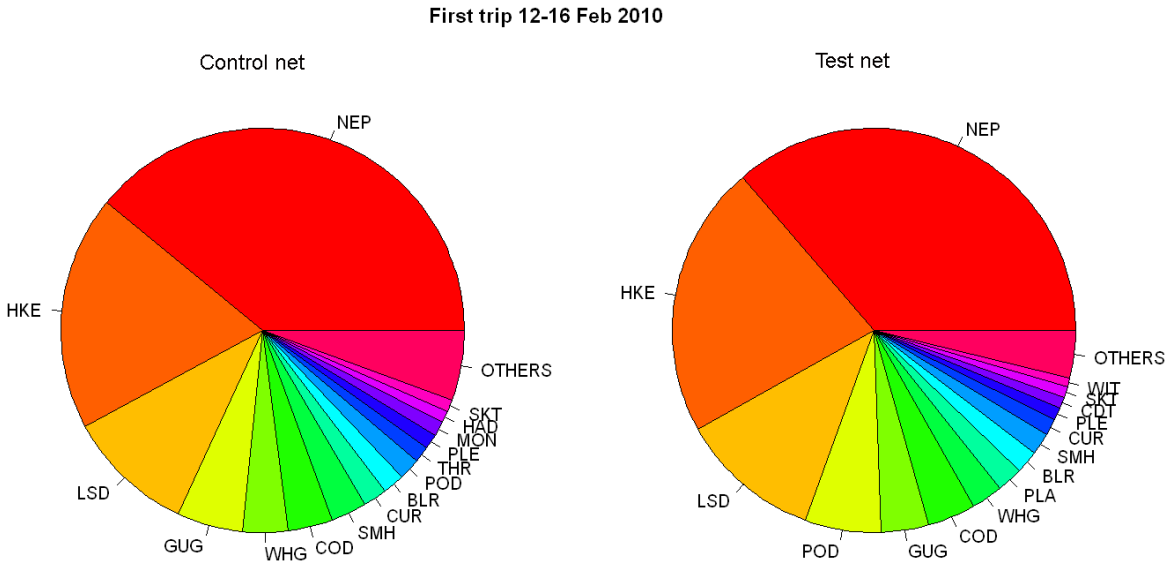


Figure 9: Species contributing 95% of total catch by weight for trip one.
Blond ray (BLR); Cod (COD); Cuckoo ray (CUR); Common dragonet (CDT); Grey gurnard (GUG); Hake (HKE); Lesser spotted dogfish (LSD); Long-rough dab (PLA); Monkfish (MON); Plaice (PLE); Poor cod (POD); Common skate (SKT); Smooth hound (SMH); Thornback ray (THR); Whiting (WHG); Witch (WIT).

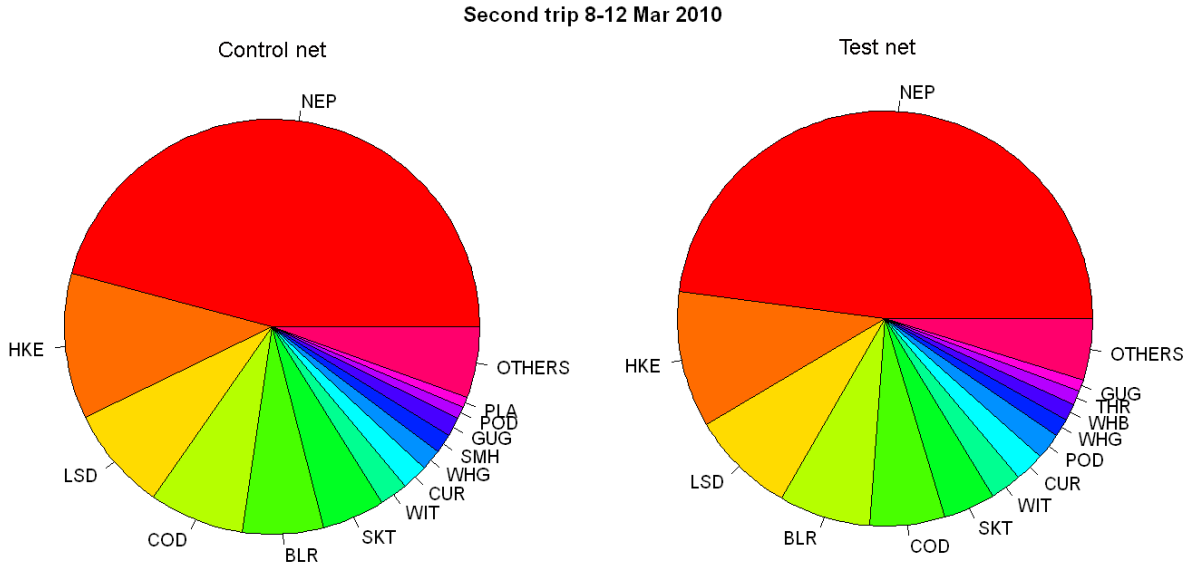


Figure 10: Species contributing 95% of total catch by weight for trip two.
Blond ray (BLR); Cod (COD); Cuckoo ray (CUR); Common dragonet (CDT); Grey gurnard (GUG); Hake (HKE); Lesser spotted dogfish (LSD); Long-rough dab (PLA); Monkfish (MON); Plaice (PLE); Poor cod (POD); Common skate (SKT); Smooth hound (SMH); Thornback ray (THR); Whiting (WHG); Witch (WIT).

Table 3

Summary of the main commercial species catch composition by weight.

Haul	Control net codend catch (kg)								Haul	Test net codend catch (kg)							
	Nephrops	Whiting	Haddock	Cod	Hake	Plaice	Anglerfish	Turbot		*Nephrops*	Whiting	Haddock	Cod	Hake	Plaice	Anglerfish	Turbot
1	61.9	7.6	3.5	6.2	43.0	1.6			1	54.2	2.3	0.5	2.6	41.7	1.5		
2	18.4	5.3	0.1	2.6	13.2	0.3			2	31.8	4.8		1.7	8.5	0.8		
3	50.3	3.2	0.6	2.7	21.6	3.1			3	50.3	4.0	1.2	11.5	30.8	1.6	0.3	
4	22.0	7.5	0.1	5.6	24.5	0.8	2.1		4	22.2	5.0	0.3	3.5	37.6	2.1		
5	66.9	4.4	0.5	3.8	54.5	1.4	11.1	0.8	5	69.7	1.9	0.6	6.4	50.4	1.9	1.1	1.5
6	50.3	4.3	0.5	11.7	42.4	1.7	3.5		6	56.4	6.1	0.1	15.3	69.4	2.0	1.1	
7	69.3	1.9	0.7	5.2	23.2	3.7			7	51.5	0.8	0.1	4.9	28.5	2.8		
8	51.8	3.6	0.5	10.7	30.6	3.2	1.1		8	46.5	4.2	0.3	4.8	39.1	2.0	2.1	2.7
9	144.7	9.5	6.0	1.7	29.0	1.4			9	141.5	6.2	4.0	11.2	36.7	0.4		
10	73.2	9.5	2.7	5.7	11.3	1.8			10	86.9	7.9	2.7	2.4	24.1	1.3		4.8
11	143.3	2.8	1.2	11.0	26.7				11	191.8	1.4		6.0	19.7	0.3		
12	139.5	0.6		18.5	3.3				12	150.3	0.7		6.9	12.4			
13	120.1	0.4		21.4	3.6	0.3			13	209.9	0.8		56.7	2.6	0.0		
14	113.3	0.3		37.5	7.5	0.2			14	126.3	0.9	0.2	14.3	0.9			
15	21.6	4.2	1.1	6.3	14.3	3.0			15	18.4	6.7		3.0	11.6	2.0	0.9	
16	52.6	3.3	1.9	1.2	42.9	2.5	9.9		16	58.2	1.0	0.8	0.6	62.8	2.4	9.7	
17	45.2	2.5	2.5	10.9	27.4	0.8			17	41.8	1.4	1.6	4.1	19.9	1.7		
18	55.1	4.4	0.5	10.7	20.5	2.5	1.0		18	46.4	1.7	3.3	13.1	16.6	2.3		
19	30.1	3.0	1.0	0.9	20.4	1.9	0.2		19	26.0	4.8	0.9	1.9	26.4	4.3		
20	11.1	3.8	1.4	0.2	14.5		0.4		20	12.9	6.4	1.7	1.4	23.4	0.5		

Table 4

Total numbers of fish caught by species during first trip (12-16 Feb) *indicates that the total number caught was estimated on at least one haul from a weighted sub-sample from whole catch.

Species	Number caught		Overall Rank	Species	Number caught		Overall Rank
	Control trawl	Test Trawl			Control trawl	Test Trawl	
*Nephrops**	28286	29002	1	Blue Whiting	15	5	23
Hake*	5071	4088	2	Megrim	4	12	24
Poor cod*	4381	1189	3	Three bearded rockling	8	7	25
Whiting*	597	601	4	John Dory	7	7	26
Grey gurnard*	311	798	5	Anglerfish	4	8	27
Long-rough dab*	660	154	6	Herring	4	5	28
Dogfish	268	241	7	Lesser silver smelt	4	5	29
Common dragonet*	359	87	8	Scaldfish	8		30
Cod	140	128	9	Solenette	3	5	31
Haddock	125	129	10	Turbot	4	1	32
Plaice	113	121	11	Ling		4	33
Witch	87	97	12	Spurdog	1	2	34
Lemon sole	68	56	13	Pollack	3		35
Smooth hound	38	72	14	Five bearded rockling		2	36
Forkbeard	64	37	15	Dover sole	1	1	37
Cuckoo ray	39	57	16	Boar fish	1		38
Blond ray	41	40	17	Conger eel		1	39
Red gurnard	22	40	18	Goldsinny	1		40
Dab	42	16	19	Pogge	1		41
Thornback ray	12	30	20	Scad		1	42
Common skate	12	29	21	Sea scorpion	1		43
Tub gurnard	27	8	22				

Table 5

Total numbers of fish caught by species during second trip (8-12 Mar) *indicates that the total number caught was estimated on at least one haul from a weighted sub-sample from whole catch.

Species	Number caught		Overall Rank	Species	Number caught		Overall Rank
	Control trawl	Test Trawl			Control trawl	Test Trawl	
*Nephrops**	29704	37402	1	Dab	7	21	23
Hake*	2334	2843	2	Lesser silver smelt	4	19	24
Poor cod*	892	2066	3	Megrim	12	8	25
Blue Whiting	428	914	4	Three bearded rockling	5	11	26
Whiting	380	561	5	Thornback ray	10	3	27
Witch	256	371	6	Anglerfish	6	3	28
Long-rough dab*	205	306	7	John Dory	5	3	29
Grey gurnard*	29	148	8	Solenette	2	2	30
Dogfish	150	181	9	Ling	2	1	31
Common dragonet*	67	163	10	Piper	3		32
Cod	117	95	11	Pogge	2	1	33
Haddock	108	99	12	Reticulated dragonet	1	1	34
Plaice	73	93	13	Pollack	2		35
Blond ray	121	25	14	Dover sole		2	36
Forkbeard	49	61	15	Sprat	1		37
Common skate	57	39	16	Conger eel	1		38
Lemon sole	44	46	17	Mackerel	7	21	39
Cuckoo ray	57	29	18				
Smooth hound	39	24	19				
Spurdog	19	24	20				
Red gurnard	19	18	21				
Herring	7	28	22				

General Catch Trends for the Target Species

Catch trends were generally similar comparing the test and control nets for *Nephrops*, hake, whiting, haddock and cod across all hauls (Figures 11 and 12).

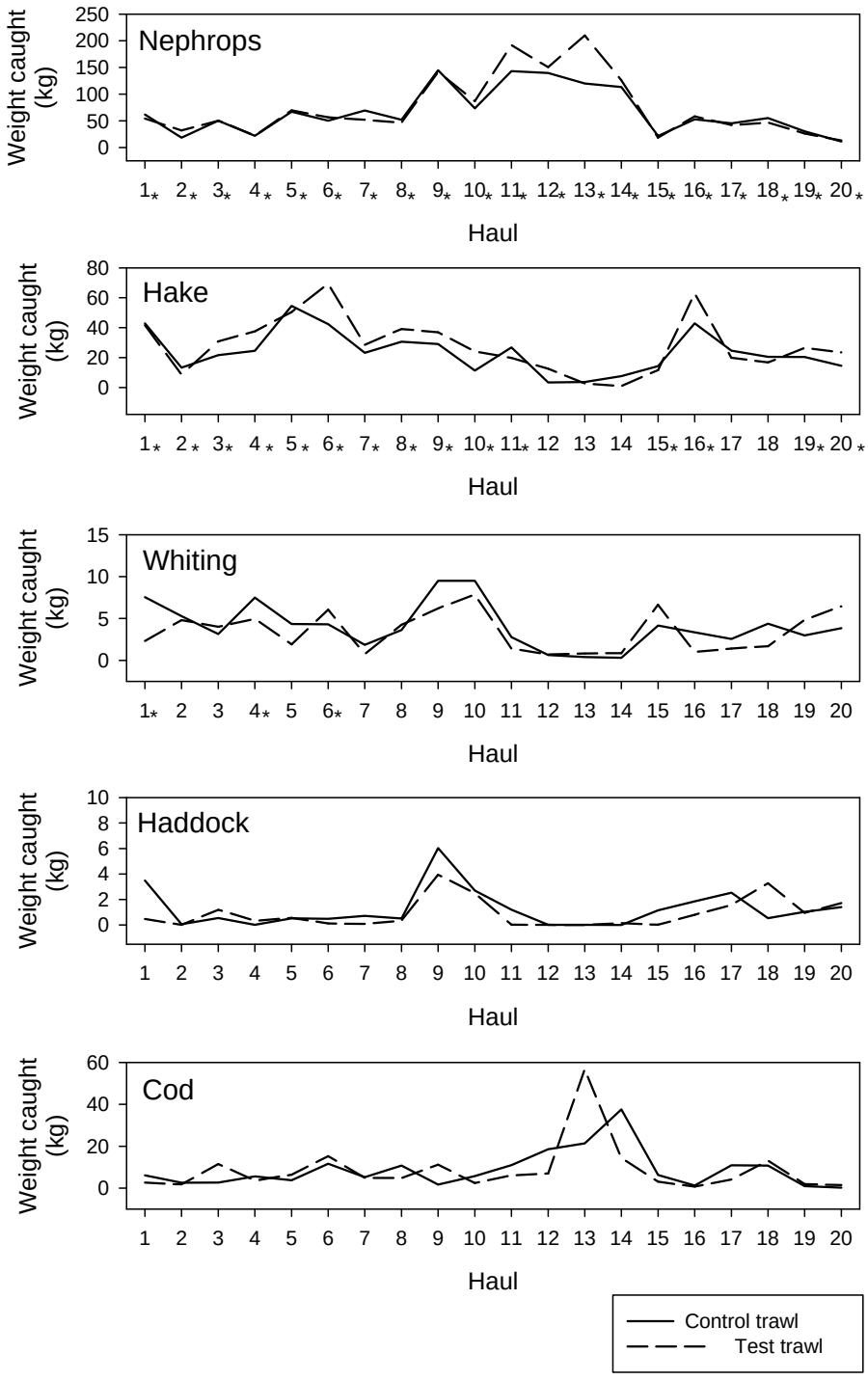


Figure 11: Weight of main target species caught across all tows in each trip.

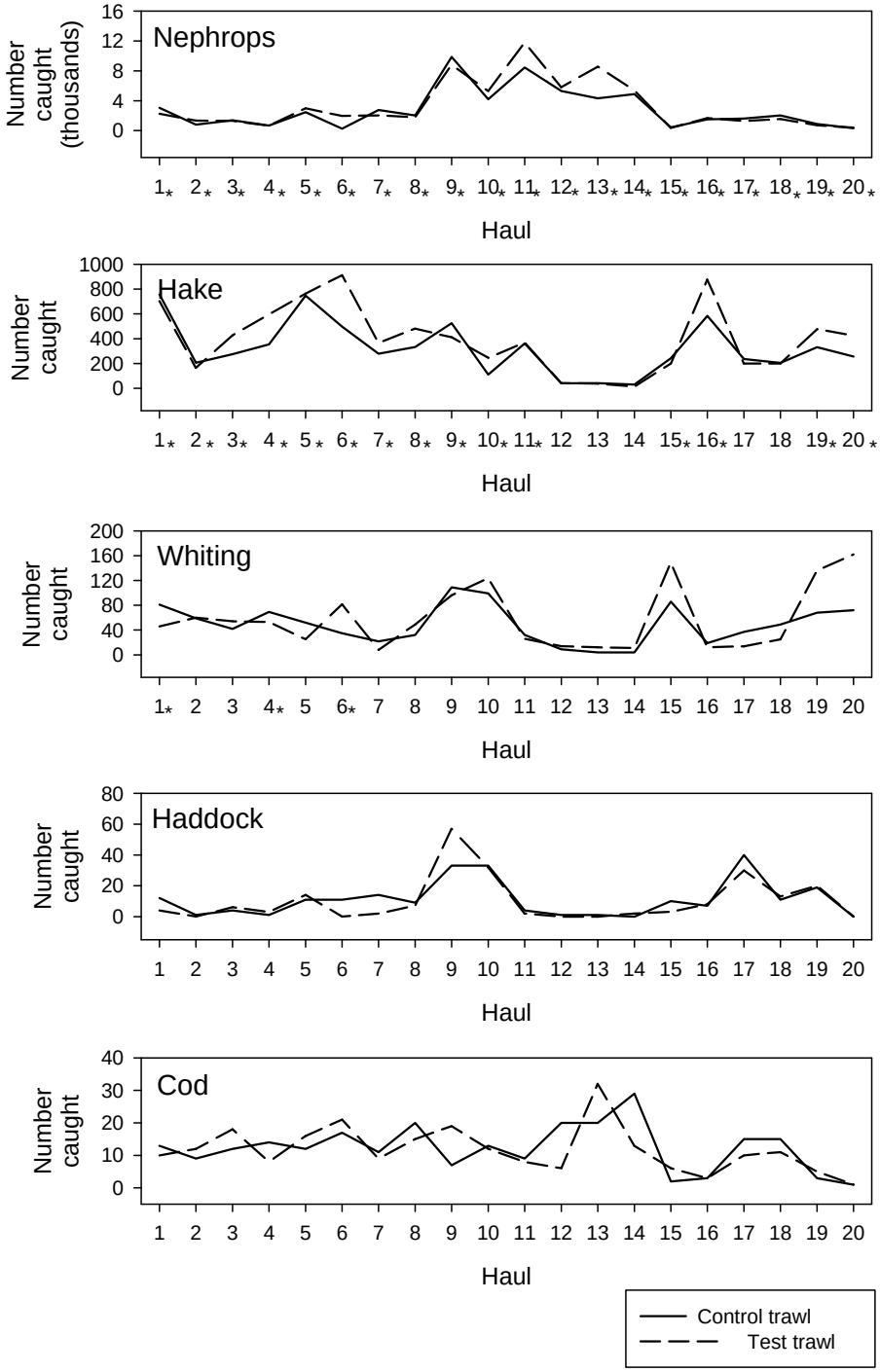


Figure 12: Total numbers of main target species caught across all tows in each trip. An asterisk next to the haul number indicates that total numbers caught was estimated from a weighed sub-sample for that haul.

There were no obvious trends for the test net to catch less than the control net and in some hauls it seemed to catch more, in terms of both weight and numbers. This was particularly noticeable for hake (Figures 13 and 14). Statistically only differences between the total catches of hake in the test and control nets in terms of weight were significant at the 0.95 probability level when tested using the Wilcoxon signed ranks paired non-parametric test (p=0.036). This might be related to the larger spread of the test net since catch data

were not corrected for the difference in door spread between the gears. Although there is a pattern in the relative weight of haddock and whiting caught in the test and control trawls in relation to the total weight (Figure 13) there was a rather small range in total weights for both species and this pattern is unlikely to be meaningful.

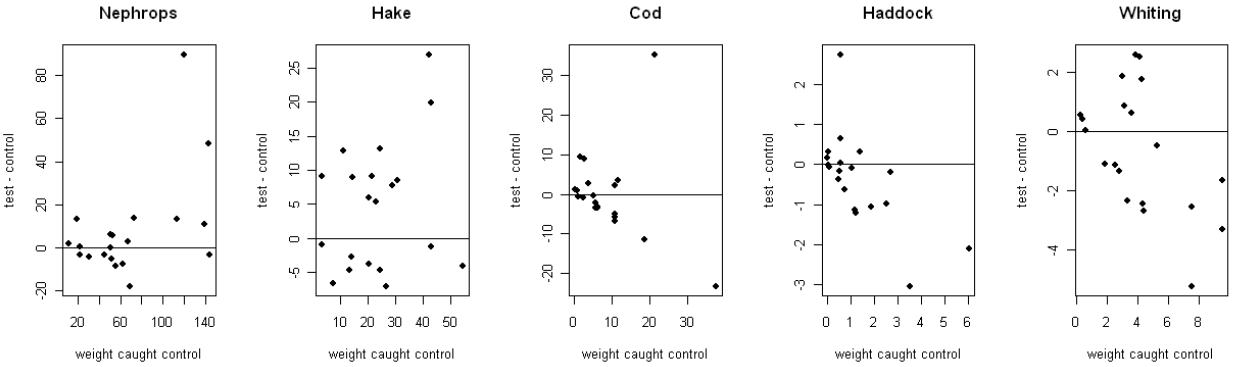


Figure 13: Differences between weight of target species caught in the test and control trawls against weight of target species in the control net.

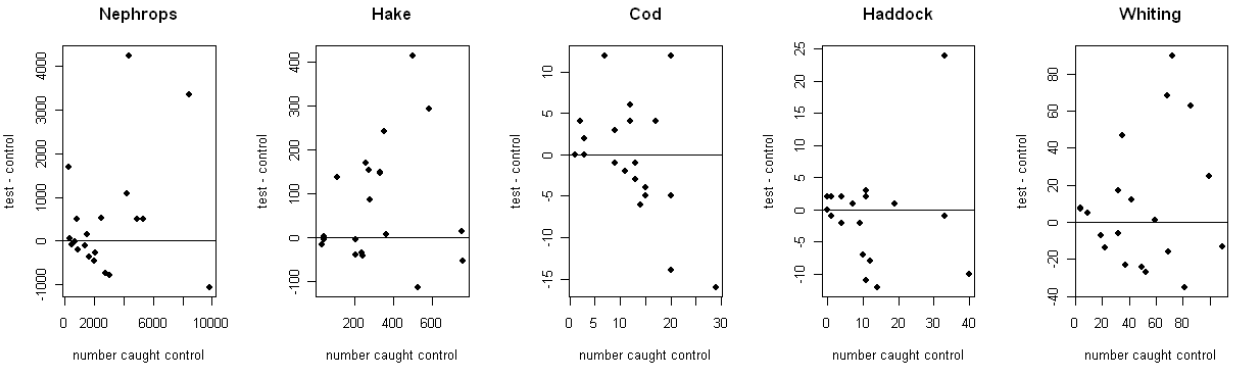


Figure 14: Difference between numbers of target species caught in the test and control trawls against numbers of target species in the control net.

Catch Comparison by Length for the Target Species

The catches of the target species by length were firstly compared for the test and control nets using Lowess smoother plots (Figures 15-19). Visual inspection of these plots suggests that the sizes and amount of *Nephrops* caught was not greatly different between the control and test trawl hauls. For hake, there is a suggestion that the test trawl caught more hake < 25 cm in length than the control trawl. There were insufficient cod and haddock caught to fit meaningful Lowess smoothers. For whiting, there was a suggestion from some hauls that the test net caught more smaller whiting compared with the control net.

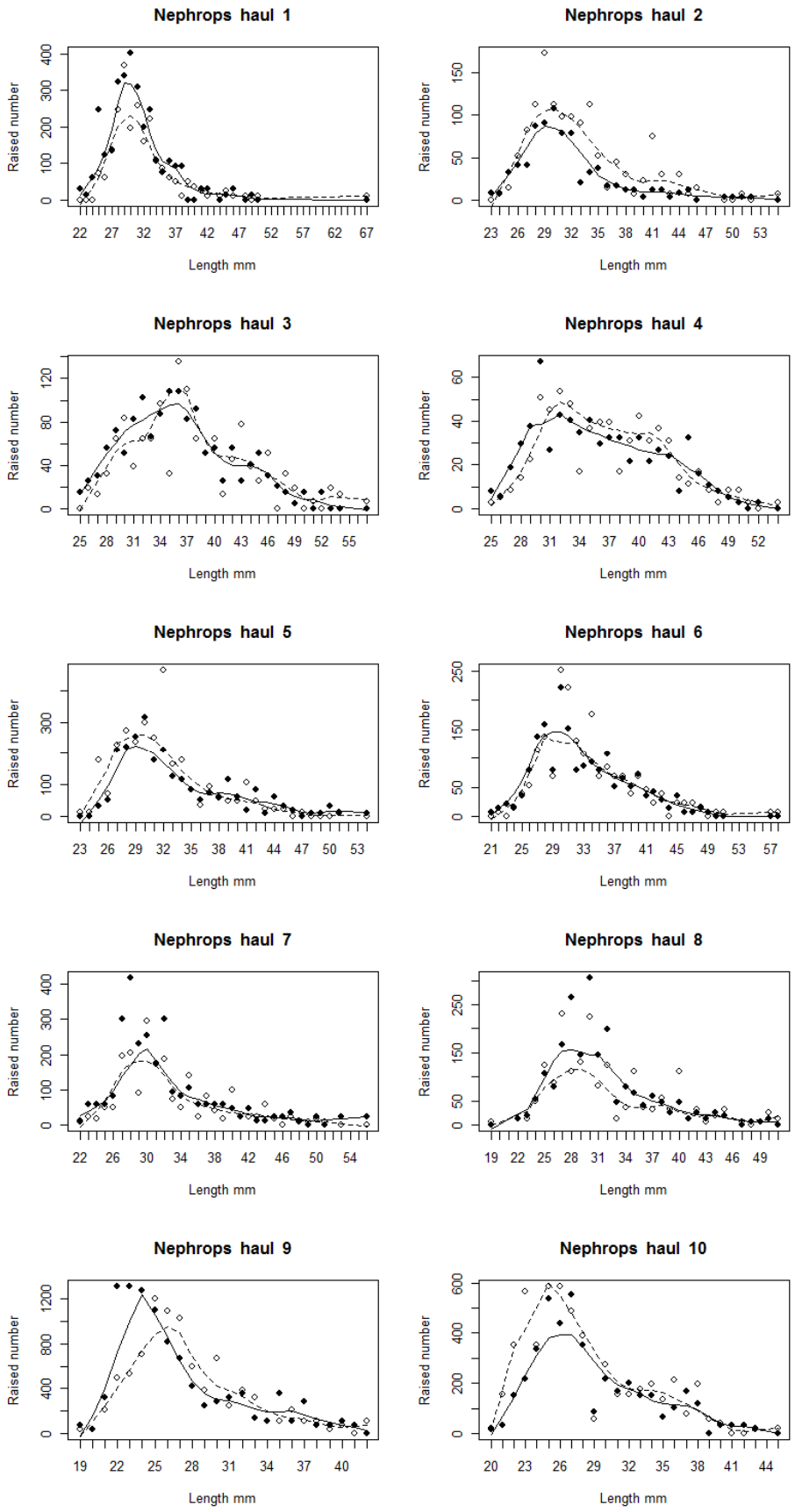


Figure 15a: Catch of *Nephrops* by haul and size. Trend line is Lowess. Solid dots and line are control trawl, open circles and dashed line is the test trawl.

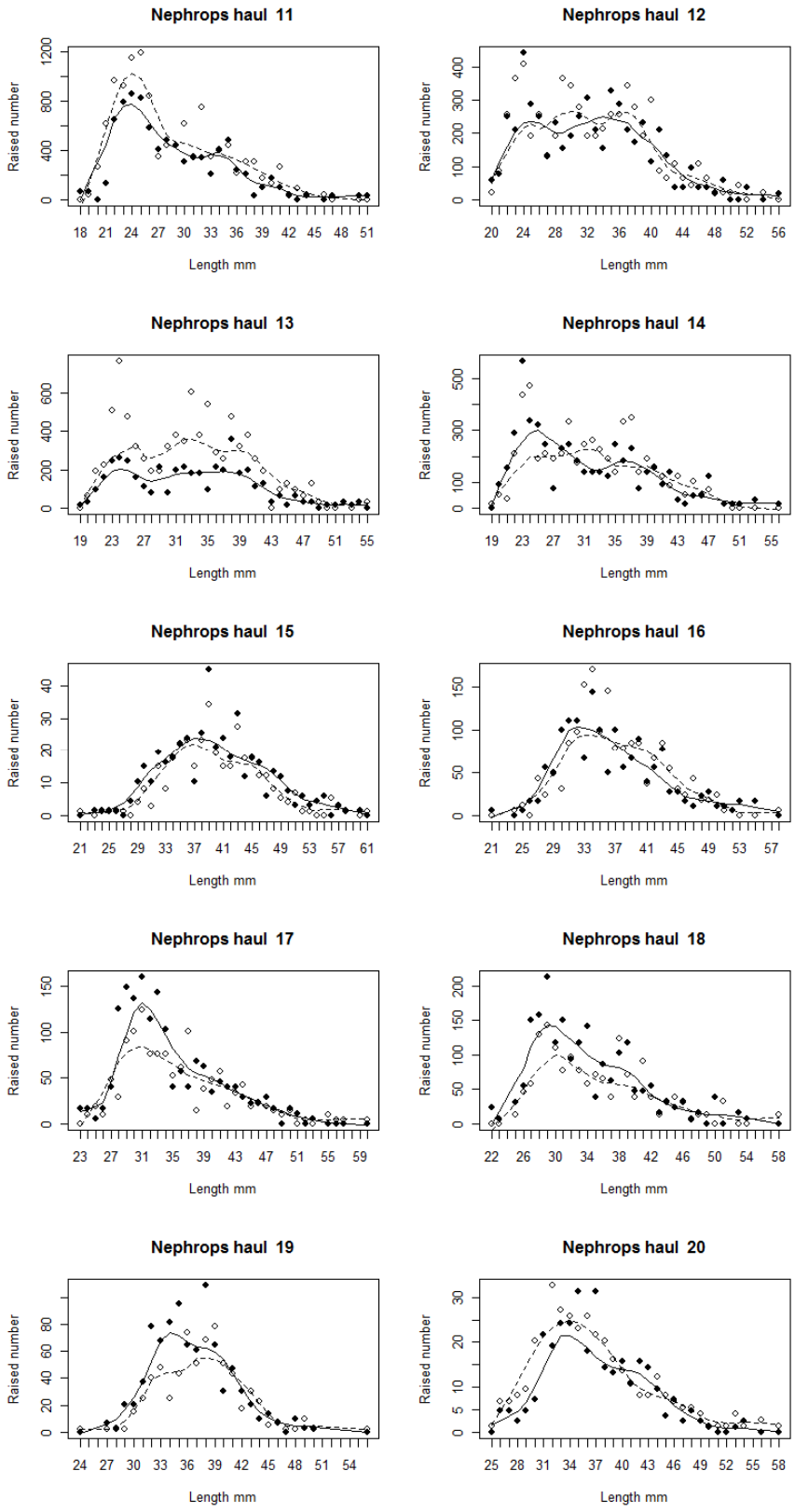


Figure 15b: Catch of *Nephrops* by haul and size. Trend line is Lowess. Solid dots and line are control trawl, open circles and dashed line is the test trawl.

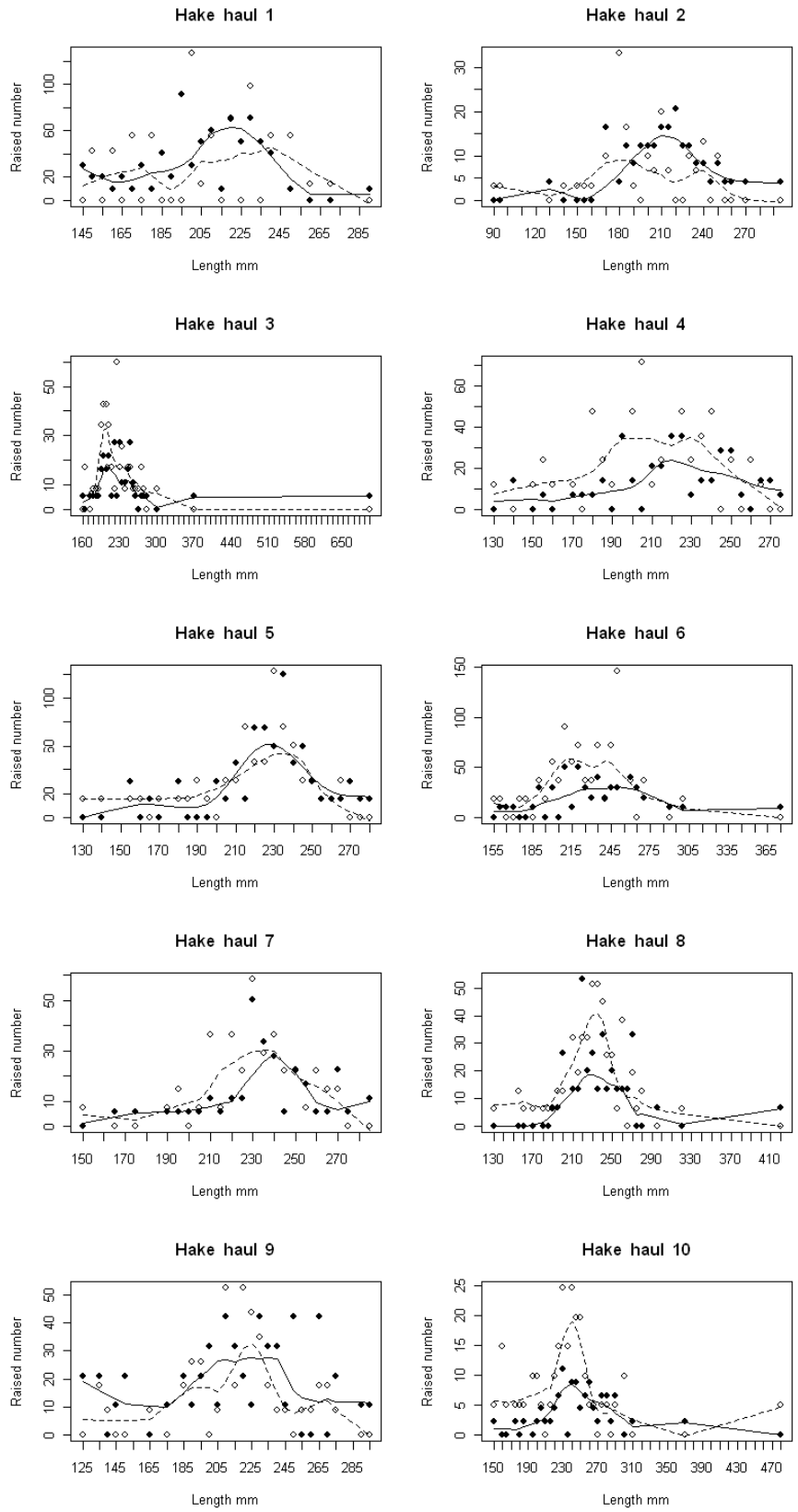


Figure 16a: Catch of hake by haul and size. Trend line is Lowess. Solid dots and line are control trawl, open circles and dashed line is the test trawl.

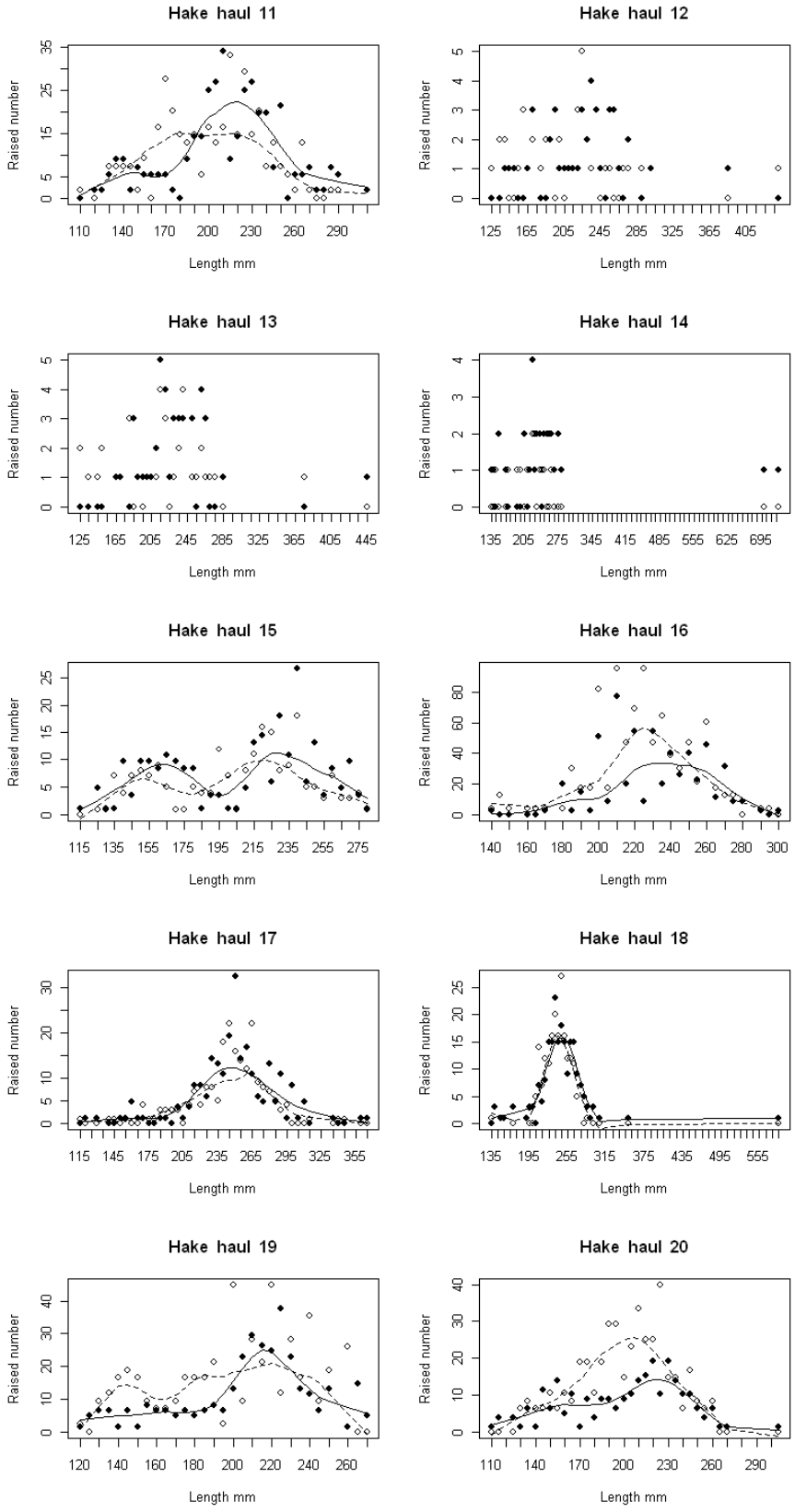


Figure 16b: Catch of hake by haul and size. Trend line is Lowess. Solid dots and line are control trawl, open circles and dashed line is the test trawl.

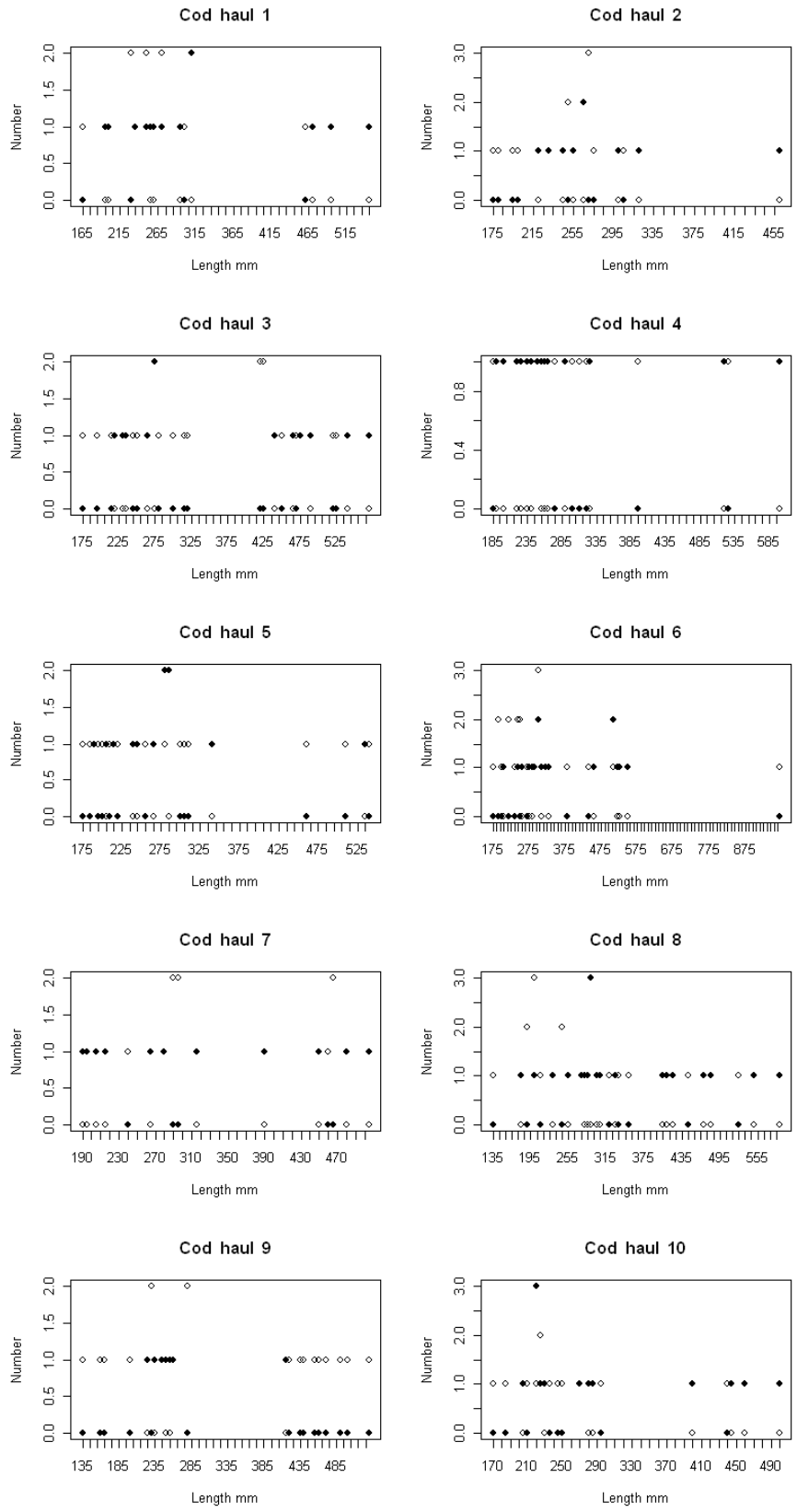


Figure 17a: Catch of cod by haul and size. Solid dots are control trawl, open circles are the test trawl.

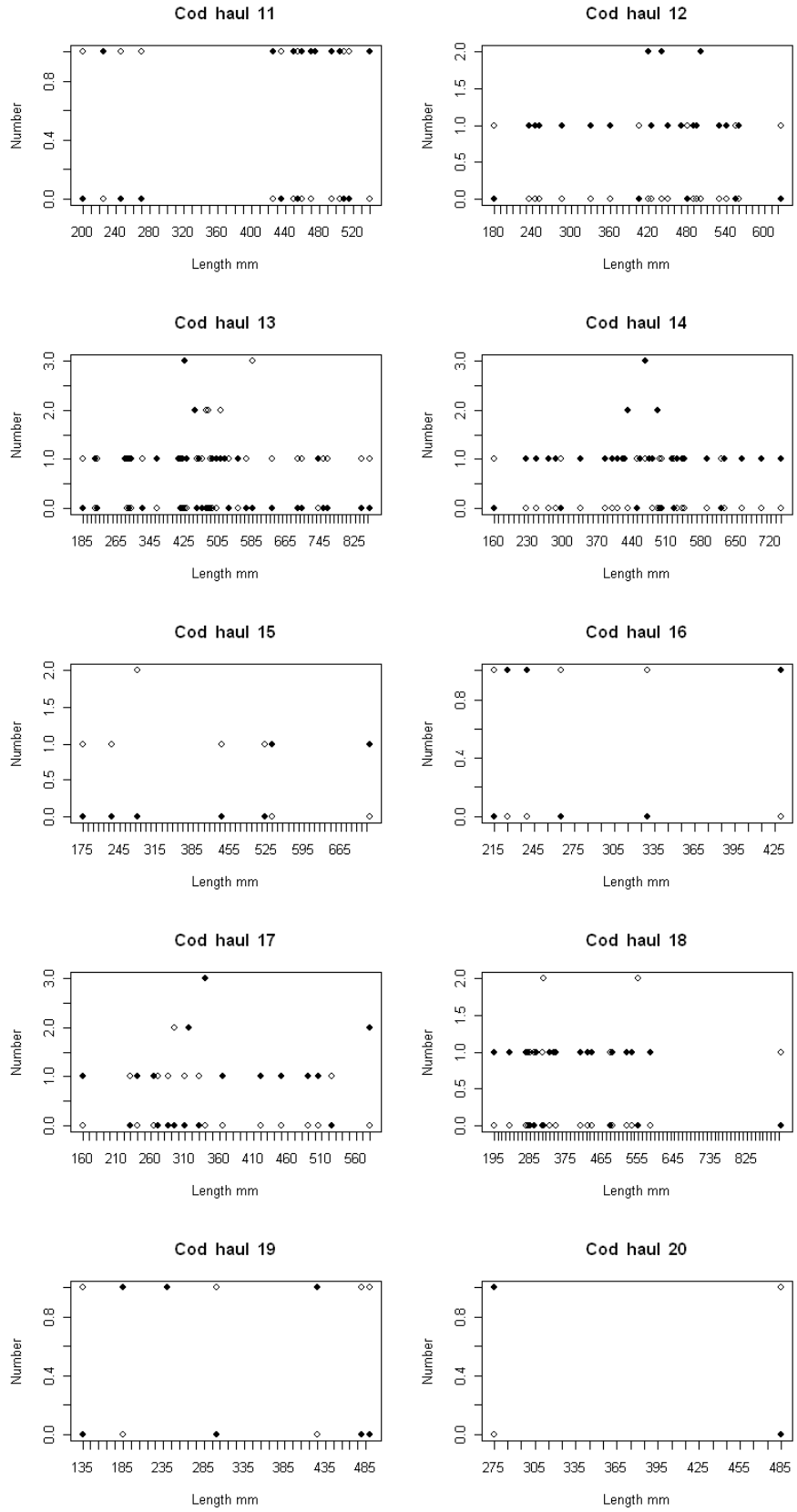


Figure 17b: Catch of cod by haul and size. Solid dots are control trawl, open circles are the test trawl.

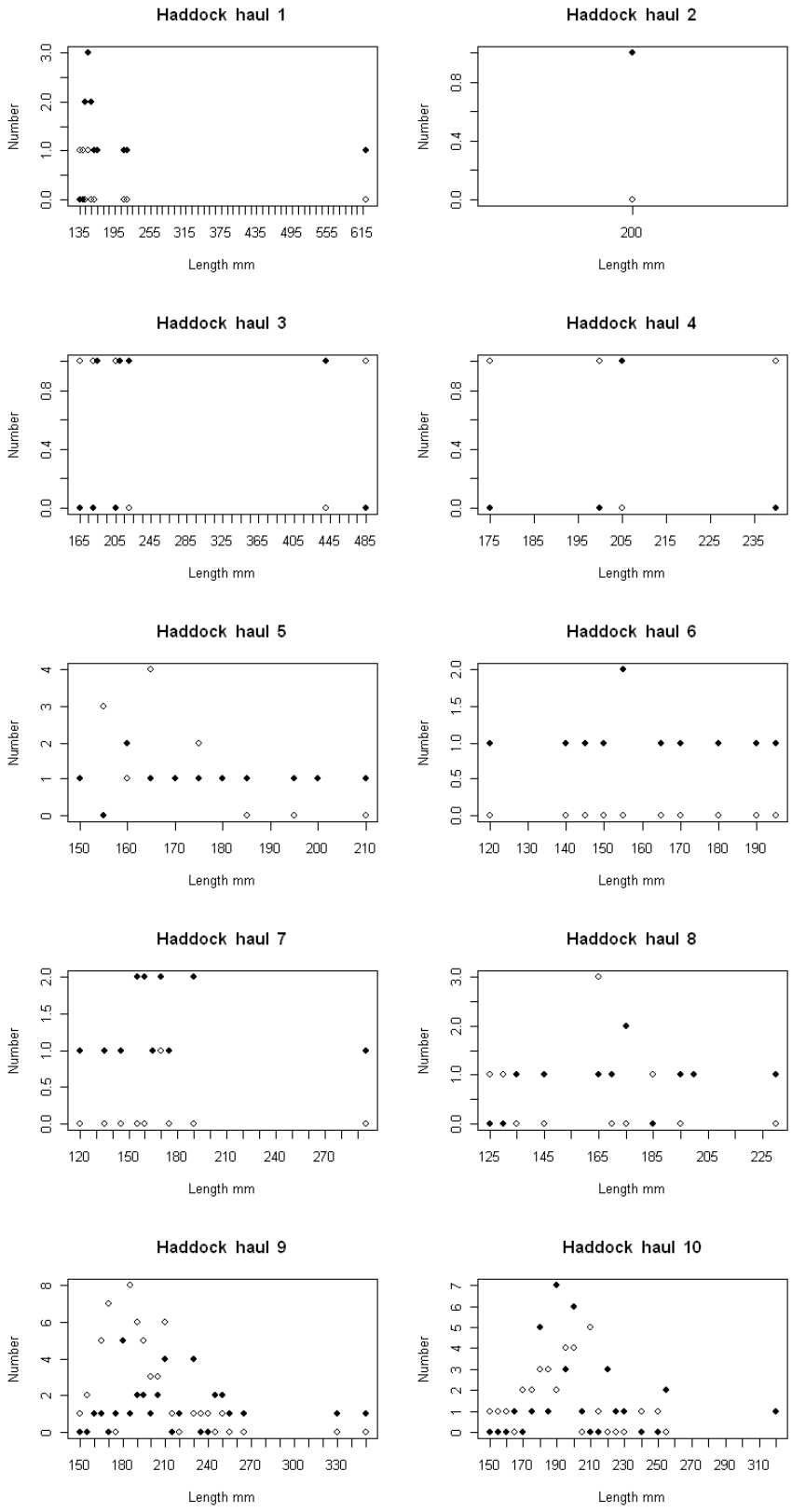


Figure 18a: Catch of haddock by haul and size. Solid dots are control trawl, open circles are the test trawl.

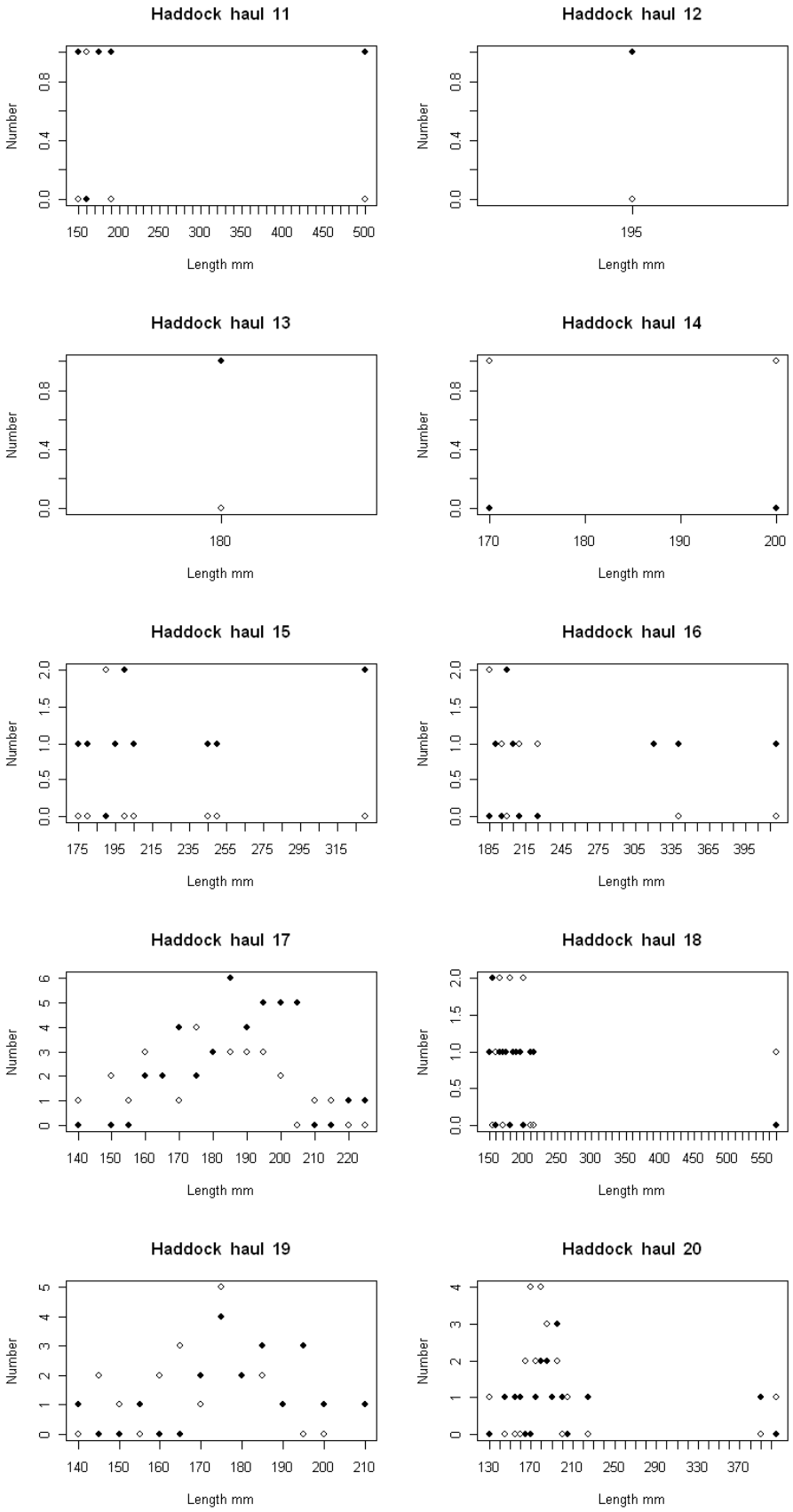


Figure 18b: Catch of haddock by haul and size. Solid dots are control trawl, open circles are the test trawl.

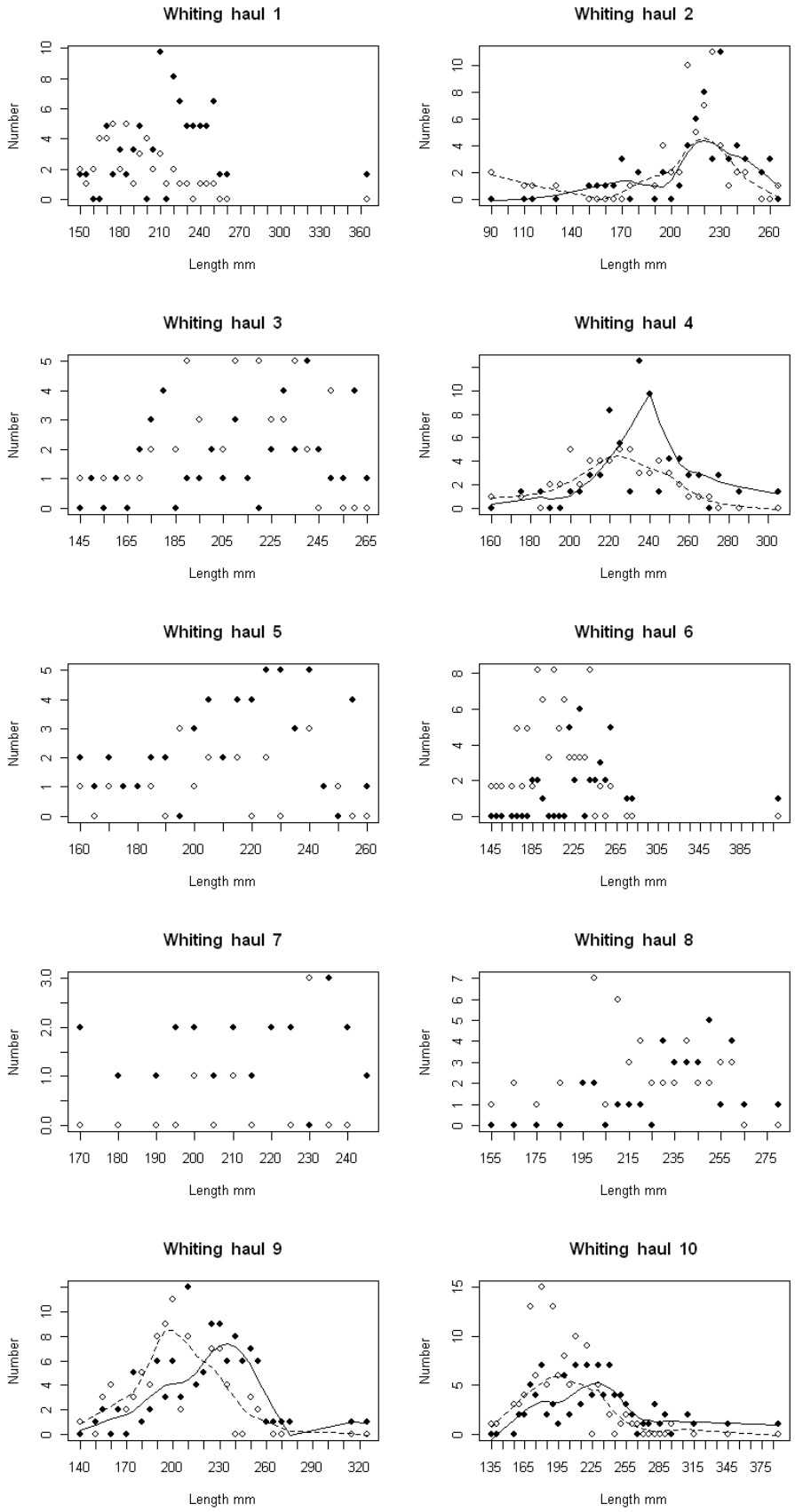


Figure 19a: Catch of whiting by haul and size. Solid dots are control trawl, open circles are the test trawl.

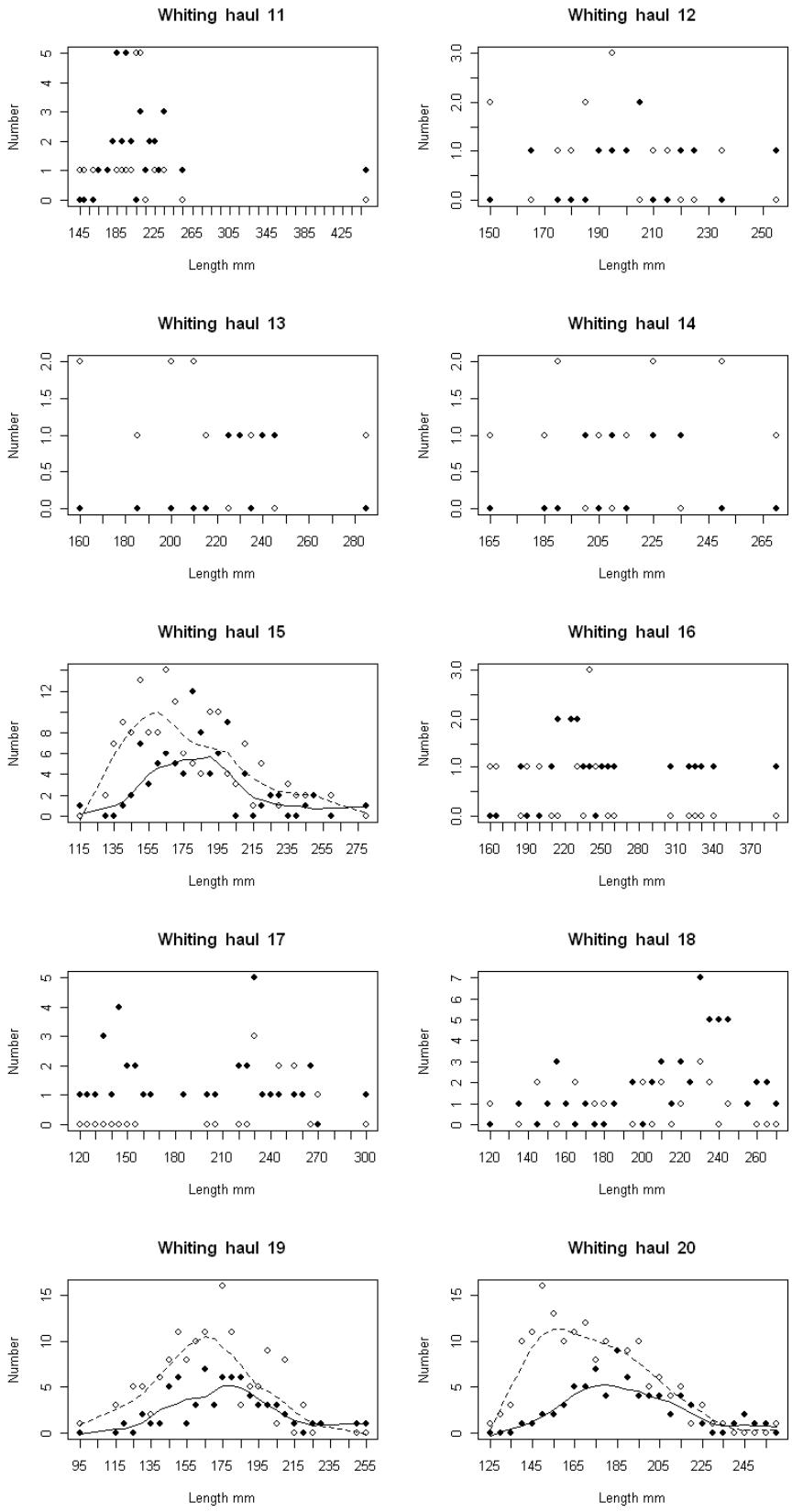


Figure 19b: Catch of whiting by haul and size. Solid dots are control trawl, open circles are the test trawl.

Statistical Analysis of the Catch Data for Cod, Haddock, Whiting, Hake and *Nephrops*

Further analysis was undertaken by modelling the data using the smoother based method on Fryer et al. (2003) implemented in R.

Data were firstly analysed for any differences in relative catch by length for cod, whiting, haddock, hake and *Nephrops* between trips one and two and then between the tows where the test net was on the port side and when the test net was on the starboard side (Table 6).

Table 6

Statistical test results for comparisons between the relative catch rates (test net to control net by length class) between trips and the side of the vessel that the test net was towed.

	Relative catch	
	Between trips (p value)	Between sides (p value)
Nephrops	0.976	0.115
Hake	0.217	0.824
Cod	0.176	0.679
Haddock	-	-
Whiting	0.225	0.524

This analysis indicated that there were no significant differences between catches by length for any of the species (excluding haddock, where too few fish were caught to undertake the analysis) comparing the two trips made or comparing tows where the test net was rigged on the port or starboard side. Further analyses were therefore performed on the overall dataset.

In the smoother plots the relative catch comparing the test and control nets is shown. Values above 0.5 indicate a greater catch rate at that size for the test net. The shaded area is the 95% interval based on 1000 bootstrap iterations.

***Nephrops*:** There was a slight tendency for the test net to catch fewer small *Nephrops* (<32 mm carapace length) and slightly more *Nephrops* larger than this size (Figures. 20a and 20b). However, this effect was not statistically significant at the 5% level (Table 7).

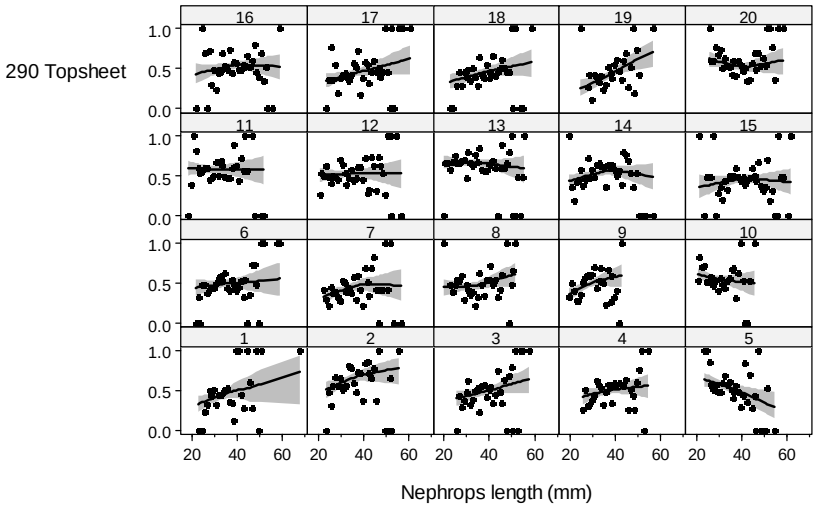


Figure 20a: Smoother based analyses of *Nephrops* catch by carapace length by haul.

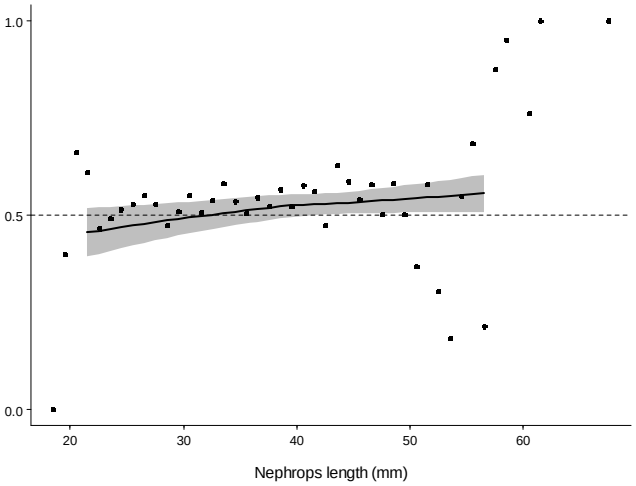


Figure 20b: Smoother based analysis of *Nephrops* catch by carapace length (all hauls).

Hake: There was a clear tendency for the test net to catch more small hake < about 25 cm, Figures 21a and 21b). This effect was highly statistically significant (p=0.002, Table 7). The majority of hake caught were less than 30 cm in length and too few larger fish were caught to allow fitting of the overall smoother above this size (Figure 21b).

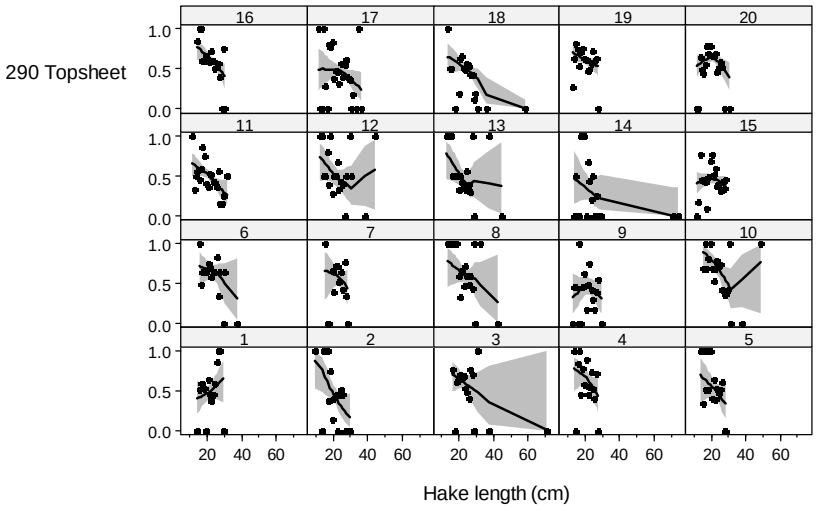


Figure 21a: Smoother based analyses of hake catch by length by haul.

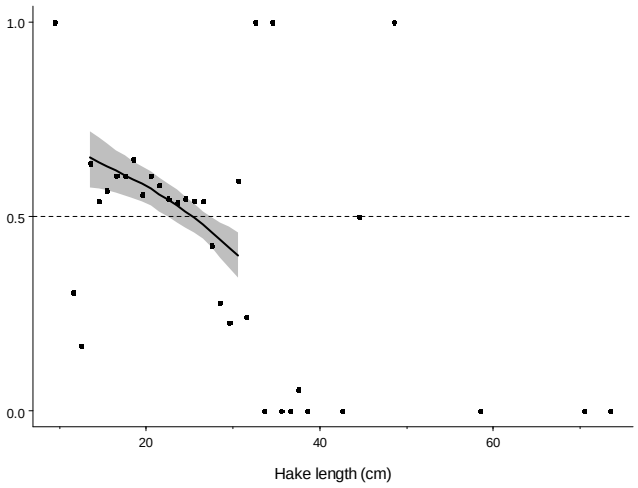


Figure 21b: Smoother based analysis of hake catch by length (all hauls).

Cod: There were no clear trends in comparative catches of cod by length (Figures 22a and 22b) although overall catch rates were relatively low so this result must be treated cautiously. The overall effect was not statistically significant (Table 7).

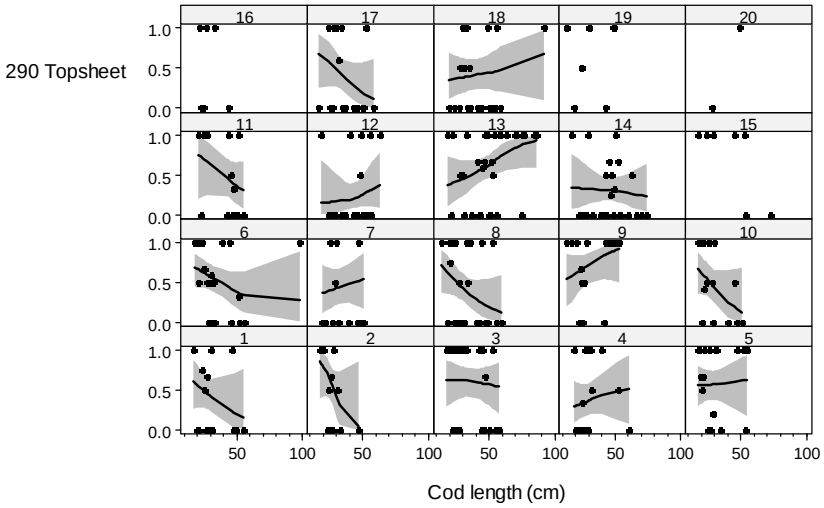


Figure 22a: Smoother based analyses of cod catch by length by haul.

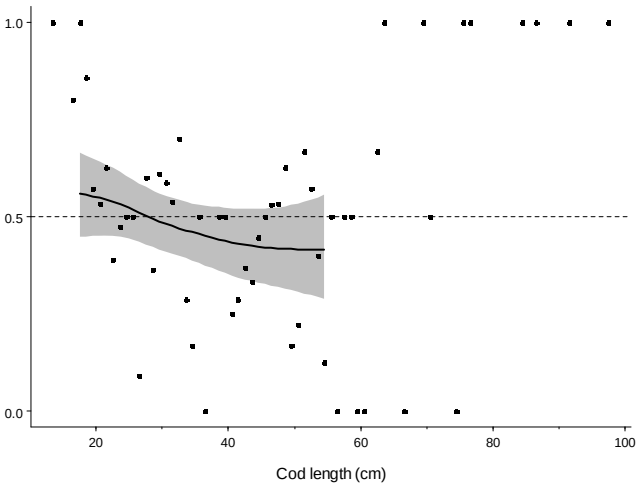


Figure 22b: *22b* Smoother based analysis of cod catch by length (all hauls).

Haddock: Too few haddock were caught to allow smoother fitting. Figure 23a is shown for completeness only.

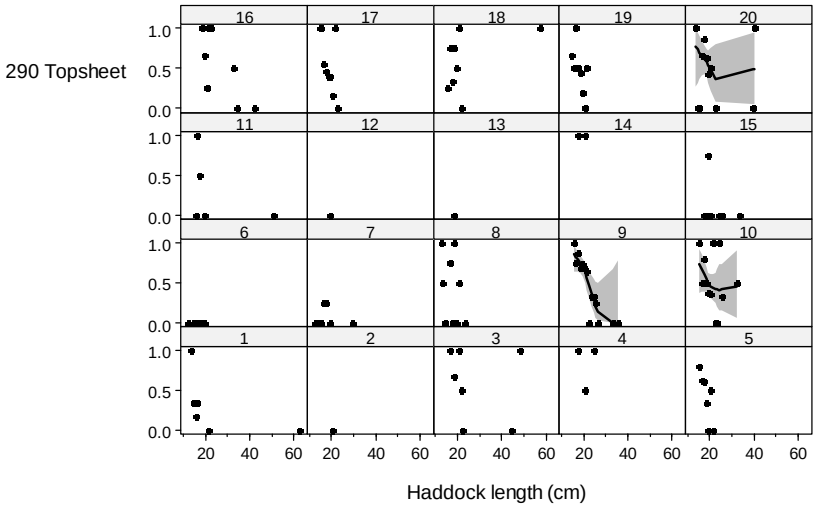


Figure 23a: Smoother based analyses of haddock catch by length by haul.

Whiting: There was a tendency for the test gear to catch relatively more small whiting (less than about 22 cm length). For fish between about 22 cm and 28 cm the test net caught relatively fewer than the control and for larger whiting there were insufficient data to extend the smoother (Figures 24a and 24b). The trend in relative catch with length was highly significant (p<0.001, Table 7).

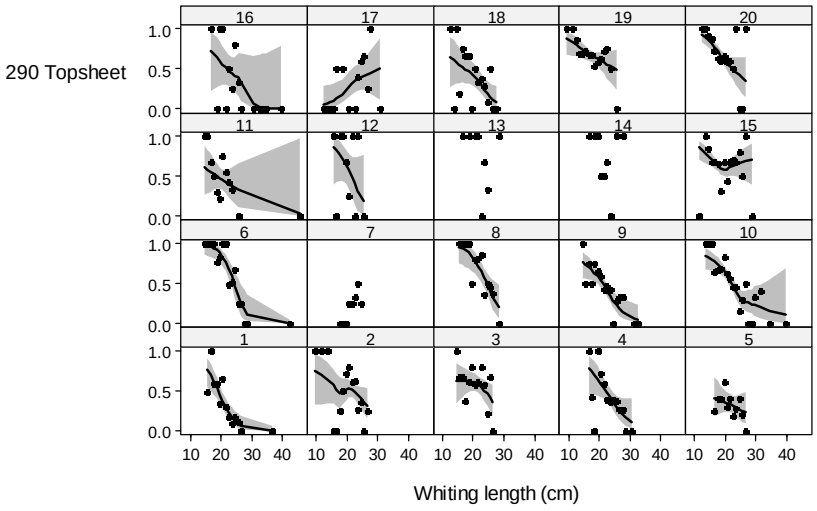


Figure 24a: Smoother based analyses of whiting catch by length by haul.

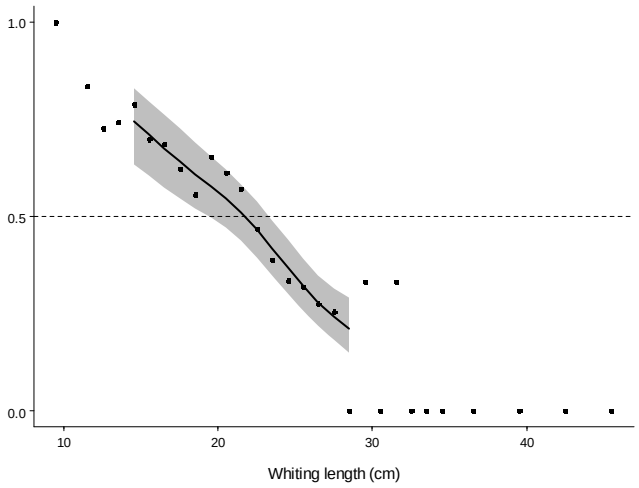


Figure 43b: Smoother based analysis of whiting catch by length (all hauls).

Table 7

Overall statistical test results.

Species	Between test gear and control gear (p value)
Nephrops	0.097
Hake	0.002**
Cod	0.229
Haddock	-
Whiting	<0.001***

Discussion

The twin-rig otter-trawl fishery for *Nephrops* is of significant economic importance, particularly on the west of Scotland. Because the fishery uses an 80 mm mesh there are, as in other similar fisheries, significant by-catch issues (Graham & Ferro 2004). Of particular concern at present is by-catch of juvenile gadoids, particularly of cod. Even though the area fished was selected as one where the skipper thought there would be small fish, data from the present trip showed rather low catches of gadoids, particularly of cod and haddock. However, relatively large amounts of juvenile hake were caught on most hauls. This has not been seen previously by the skipper and may reflect a change in stock status or distribution for this species but might also just reflect the unusually cold conditions in the winter of 2010. By-catch of hake by the west coast twin-rig fisheries may become an issue of concern in the future if this pattern persists.

The gear modification tested did not appear to have a clear beneficial impact on fish by-catch although this could not be properly evaluated for larger cod as low numbers were caught overall. For whiting and hake the test net seemed to catch more, not less, smaller fish. This may have been caused by the wider spread of the net as evidenced by the measured differences in clump to door distances during towing.

In addition other species such as cuckoo, blond and thornback ray and common skate were caught on most hauls. Spurdog were also caught on some hauls particularly on the second trip. The conservation status of elasmobranchs is of general concern with common skate and spurdog listed on the OSPAR List of Threatened and/or Declining Species and Habitats for the west of Scotland. Future gear trials will need to consider not only reductions in the by-catch of gadoids but also reducing the by-catch of these incidental species if the twin-rig fisheries are to become more environmentally sustainable.

The gear modification tested did not affect the catches of *Nephrops*. The reduced drag of the modified gear appeared to allow a wider spread and may have contributed to slightly higher catches on some hauls (although overall this was not statistically significant). Although the use of large mesh in the topsheet did not appear to confer much conservation advantage in terms of reducing by-catch, it may reduce drag and therefore fuel consumption. This gear modification should be explored further in terms of its value in reducing running costs and the carbon footprint of this fishery.

Acknowledgements

This study would not have been possible without the enthusiastic support of the vessel owners and skipper (Mr Willie Burke and Mr Vincent Williams) nor the co-operation and help of the crew of the *Charmel*. At Marine Scotland, Jim Drewery, Bob Kynoch, Keith Summerbell and Barry O'Neill provided invaluable support and advice to this study.

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Graham, N. & R.S.T. Ferro. 2004. The *Nephrops* fisheries of the Northeast Atlantic and Mediterranean - A review and assessment of fishing gear design. International Council for the Exploration of the Seas, ICES Co-operative Research Report, 270, 40 pp.

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