Gear Trial Experiment to Reduce Groundfish Bycatch in the Offshore Scallop Fishery on Georges Bank

T. M. McIntyre, R. Cunningham, G. Robert, and R. Branton

Science Branch, Maritimes Region
Population Ecology Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
PO Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia
B2Y 4A2

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GEAR TRIAL EXPERIMENT TO REDUCE GROUNDFISH BYCATCH IN THE OFFSHORE SCALLOP FISHERY ON GEORGES BANK

by

T.M. McIntyre[1]
R. Cunningham[2]
G. Robert[3]
R. Branton[3]

Science Branch, Maritimes Region
Population Ecology Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
PO Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia
B2Y 4A2

[1]Evans Computer Applications Ltd, 6424 Norwood St, Halifax, NS B3H 2L3
[2]Pernix Technology, 225 Crane Hill Rd., Westphal, NS B2Z 1J5
[3]Population Ecology Division, BIO, PO Box 1006, Dartmouth, NS B2Y 4A2

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ABSTRACT

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Gear trials were conducted to examine the effectiveness of various devices to reduce the bycatch of groundfish in the offshore scallop fishery on Georges Bank. The species of most concern were cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and yellowtail flounder (*Limanda ferruginea*). The devices in this gear trial included an experimental rake designed to deflect the groundfish upwards through an escape route before retention by the bag (deflector rake). The other devices attached to a traditional rake included high intensity lights, strobe lights, and sound pingers. They were meant to elicit a startle and flight reaction in the groundfish ahead of the rake.

The groundfish bycatches, cod and haddock in particular, were very low for all experimental series making it difficult to compare the effects of the gear modifications on the bycatch of these species. Repeating the experiment at other times of the year could get higher bycatch. The deflector rake did not result in any significant (p-values >0.05) reduction in bycatch. For some species, the light and sound devices did produce a significant (p-values ≤0.05) reduction in bycatch. However, not a single modification produced a reduction for all species considered.

RÉSUMÉ

McIntyre, T.M., R. Cunningham, G. Robert, and R. Branton. 2006. Gear trial experiment to reduce groundfish bycatch in the offshore scallop fishery on Georges Bank. Can. Manuscr. Rep. Fish. Aquat. Sci. 2745: iv + 32p.

On a fait des essais d'engins de pêche pour étudier l'efficacité de réduction des prises accidentelles de poisons de fond dans la pêche hauturière au pétoncle sur le banc Georges. Les espèces d'intérêt étaient la morue (*Gadus morhua*), l'aiglefin (*Melanogrammus aeglefinus*) et la limande à queue jaune (*Limanda ferruginea*). On a essayé une drague expérimentale dont le but était de détourner le poisson par en haut via une voie d' échappement avant d' être retenu dans la poche de la drague (drague détournante). Les autres essais comportaient des lampes à haute intensité, des lumières stroboscopiques et des émetteur d'ultrasons fixés à une drague conventionnelle. Ces dispositifs devaient inciter une réaction de surprise et de fuite au sein des poissons en avant de la drague.

Les prises accidentelles de poissons de fond, surtout de morue et d'aiglefin, étaient très basses dans tous les essais expérimentaux; ce qui rend difficile la comparaison des effets des modifications apportées à l'engin de pêche sur la capture accidentelle de ces espèces. Répéter les mêmes essais à un autre temps de l'année pourrait donner des prises accidentelles plus élevées. La drague détournante n'a pas eu de réduction significative sur les prises accidentelles (*p* >0.05). Les dispositifs de lumière et de son ont eu une diminution significative pour certaines espèces (*p* ≤0.05). Cependant, aucune modification n'apporta une réduction pour toutes les espèces considérées.

INTRODUCTION

The Georges Bank scallop bycatch reduction study was conducted aboard the F.V. Cape Keltic from September 6^{th} to September 21^{st}, 2005. The purpose of the study was to examine the effectiveness of various devices to reduce the bycatch of groundfish by commercial scallop fishing gear. It is becoming more common in the assessment of fish stocks to use an ecosystem approach which considers harm or mortality to non-targeted resources by a fishery. Mortality estimates from the Georges Bank offshore scallop fishery of Eastern Georges Bank cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and yellowtail flounder (*Limanda ferruginea*) are used in the assessments of these stocks by the Transboundary Resource Assessment Committee (TRAC). The estimated discards of these three species from observer coverage of the offshore scallop fishing vessels is of sufficient magnitude that it must be taken into account (TRAC 2005a; TRAC 2005b; TRAC 2005c). It is for this reason that we are most concerned with these three groundfish species in this study of bycatch reduction.

Previous studies have been conducted in the United States on the effect of gear modifications to reduce bycatch of groundfish in the sea scallop fishery. The Atlantic Sea Scallop Fishery Management Plan (Amendment 10), prepared by the New England Fishery Management Council (2004), summarizes some studies where ring size and twine top mesh size were altered. The increase in ring size resulted in minor reductions in small fusiform fish and small flatfish. However, the report indicates that any reductions in overall finfish bycatch were minimal and in fact the catch of larger finfish may have actually increased with the increase in ring size. Studies where the mesh size of the twine top was increased demonstrated some significant reductions in bycatch of finfish. Undesirable losses in the scallop catch were also realized with this type of gear modification.

Bycatch reduction studies have been conducted in shrimp fisheries (Cooper *et al,* 1991; Isakesen *et al,* 1992) and finfish fisheries (Larsen and Isakesen, 1993; Halliday and Cooper, 1997) using separating devices in trawl nets to successfully divert unwanted species toward an escape route. The devices used in these experiments were separator grates that were selective for the size of the desired species. The desired species were able to pass through the grate, while the undesired bycatch was too large to pass through the grate and was diverted toward an opening in the top of the trawl net.

An experimental rake was developed for this study of bycatch reduction in the offshore scallop fishery. The new rake has a series of panels behind the pressure plate that are meant to deflect the groundfish upwards toward escape openings along the top of the pressure plate (see Figure 1 for detailed drawings of the 'deflector' rake). To determine its effectiveness on reducing groundfish bycatch, the deflector rake was compared to a traditional commercial scallop rake in a series of side-by-side tows. Similar studies to reduce bycatch in scallop gear by using a diverting mechanism were not discovered in a literature search.

Pernix Technology Ltd was contracted to assist with the development of methods and/or devices to reduce the bycatch of groundfish. For this trial, Pernix provided commercially available light and sound production devices to elicit a startle/flight reaction in the groundfish prior to the approach of the rake. The light and sound production devices were separately attached to a traditional rake with the light or sound production device projecting ahead of the rake. The effectiveness of each device on reducing groundfish bycatch was compared in a series of side-by-side tows to another traditional rake without such devices. A review of the literature did not reveal any studies that used light or sound production devices to reduce groundfish bycatch in scallop fisheries. However, as detailed in the By-Catch Reduction Research Report prepared by Pernix Technology Ltd (2004), there has been research into the use of sound projectors and strobe lights to deter fish. Strobe lights were found to be an effective deterrent in many fish species (Maiolie *et al* 1999; Anon 1995). Acoustic pingers used as alarms on gillnets have been effective in reducing bycatch of small cetaceans, but have not shown significant differences in capture of undesired finfish (Trippel *et al* 1999).

MATERIALS AND METHODS

This bycatch reduction study was conducted onboard a commercial scallop dragger, F.V. Cape Keltic. Captain Ross Hartman and the crew carried out vessel and fishing operations. Standard commercial scallop fishing techniques were used during this study.

GEAR

A standard, New Bedford offshore, 4.57-metre (15-foot) commercial rake frame and bag were used for the control rake. The bag was constructed of 8.9-centimetre (3.5 inch) rings, joined by 2 links on the back and 3 links on the belly. The rope back was 15.24-centimetre (6-inch) square mesh. This rake was towed on the starboard side of the vessel for all comparative tows.

Experimental rake design

The first experimental rake used for the comparative tows was the deflector rake. This rake was also 4.57 metres wide and used a bag identical to that on the control rake. The ring size and the rope back were also the same. There is a series of panels behind the pressure plate that are meant to deflect the groundfish upwards toward escape openings along the top of the pressure plate. These deflector panels are made with two sections, one that is fixed and the other that is able to slide overtop of the other or extend closer to the sea floor. The panels are also hinged so that they maybe angled closer toward the pressure plate, which would reduce the size of the opening through which the groundfish can escape (See Fig. 1 for a detailed drawing of the rake).

The panels were positioned in three ways for three series of comparative tows versus the control rake. In the first series of tows the deflector panels were positioned so that the movable panel was pushed to the extreme upwards position over top of the other portion of the panel. The angle of the panels was the same angle as the pressure plate, leaving the space below the panels at a maximum. This configuration of the panels will be referred to as the high position from herein.

In the second series of tows the deflector panels were positioned so that the movable panel was at the extreme downward position, extending the deflector panels to the lowest possible position. The angle was the same as that of the high position configuration. This experimental series will be referred to as the low position from herein.

In the third series of tows with the deflector rake, the deflector panels were positioned in the low position again, but the angle of the panels was changed so that the deflector panels were angled closer to the pressure plate. This effectively closed off the opening above the pressure plate through which the groundfish were intended to escape. This configuration will be referred to as the closed position from herein. This series of tows was conducted as a way to determine whether or not the openings above the deflector plates were actually deflecting the catch upwards.

Light and sound production devices

The light and sound production devices used for the next three series of tows were mounted on another traditional style rake. The configuration of the bag was identical to that of the control rake. The first series of tows in the light and sound portion of the survey used four high intensity lights mounted in the pressure plate of the rake, directed ahead of the rake. Two lights were angled slightly higher than the other two lights. The second series of tows used two strobe lights attached to the tow bars, just ahead of the pressure plate. The third series of tows used high frequency pingers that were mounted near the centre of the tow bars on the rake. All of these devices were directed ahead of the rake to attempt to cause a startle reaction in the potential bycatch, thus allowing time for escape from the approaching rake. These experimental devices are herein referred to as high intensity, strobe, and pingers (technical specifications for each device are listed in Appendix 1).

FISHING OPERATIONS

Tow duration was 30 minutes and the vessel speed was kept at a commercial fishing towing speed – approximately 8.3 to 10.2 kmph (4.5 to 5.5 knots). Tow tracks were recorded using electronic charting software. Figure 2 shows the locations of all the tows conducted during the study. A large area of the Canadian side of Georges Bank was covered during the study.

A series of comparative tows were made between each of the potential bycatch reduction devices and the control rake. The control rake was fished on the starboard side of the vessel and the experimental rakes were fished on the port side. Towing for each comparison took place over a period of 24 hours. Tow locations were not randomly selected for this study. Fishing was conducted where it was thought that groundfish would be encountered to determine the effectiveness of the bycatch reduction devices compared to the traditional rake. A series of tows (n=20) were also made using two traditional rakes without modifications to allow for comparison of the catches from the port versus the starboard sides of the vessel. This series of tows also took place over a period of 24 hours, which allowed for comparison of catches in the day (n=10) versus catches in the night (n=10).

After each tow, the catch from each rake was separated by species. The scallops from each rake were recorded as number of baskets (baskets used were approximately 60 litres in volume). The numbers of cod, haddock, yellowtail, other flounders, skate (non-specified), and monkfish were recorded. Length frequencies were recorded for cod, haddock, and yellowtail. Additional species that were caught are listed in Table 1. All scallops and fish species were returned to the sea immediately after sorting and counting.

A portion of time during this study was devoted to obtaining underwater video footage during fishing operations. This camera work was done as a compliment to the comparative tows. Cameras were mounted on the experimental rake that carried the light and sound production devices (see Appendix 1 for technical specifications for the cameras and recording devices). Four hours of camera footage were recorded; one hour for each of the two light devices, one hour for the sound pingers, and one hour without any devices attached to the rake. These tows were done during daylight hours only. The field of view from the one camera did not provide a full picture of what species were encountered by the rake, but it provides a view of the bottom and some fish species, as well as, their reactions to the rake. This video information is not considered in the analysis of the gear comparisons in this study because it does not provide a quantitative estimate of the fish that were able to avoid the gear, however it will provide valuable information in the development of future studies.

DATA ANALYSIS

Prior to statistical analysis of the data, the raw data for each tow was prorated to a standard distance. Each tow was 30 minutes in duration, but because of the variation in vessel speed, tides and surface conditions the tows may cover different amounts of bottom within the 30-minute tow. Four kilometres was chosen as the distance to which the catch data from all tows would be prorated.

A preliminary look at the data was completed by plotting the differences by tow between the control and the experimental rakes for each experimental series (Figures 3-8). The differences were calculated by subtracting the number of fishes or the baskets of scallops in the experimental rake from the numbers in the control rake. Positive differences would therefore imply that the control rake had a higher catch than the experimental rake; negative differences would indicate a higher catch in the experimental rake. These plots give an indication of the result of the tow series and also illustrate the magnitude of any outliers.

Summary statistics for each experimental tow series by species are given in table 2. Results of matched-pairs Student's t-tests and non-parametric Wilcoxon matched-pairs signed ranks tests are also included for each experimental series/species category. The tests were run to statistically prove whether there was a significant difference (p-value ≤ 0.05) between the mean catch of a species/tow series in the control rake versus the experimental rake (null hypothesis: difference in mean catch = 0; alternative hypothesis: difference in mean catch was ± 0 according to the sign of the observed mean difference in the catch).

RESULTS

Student's t-tests were performed to compare the mean catch for each species category between the two sides of the vessel and between the day and night tows. The p-values for the port side versus starboard side catches ranged from 0.06 to 0.96 for all the species categories tested. The p-values associated with the t-test for the comparison of catch from tows in the day versus night ranged from 0.15 to 0.66.

Figures 3 through 8 illustrate the differences in catches per tow between control and experimental rakes for each experimental series in the study. A higher proportion of positive points on the difference plot would give you a general impression that the experimental rake was effective in reducing bycatch of that particular species; the opposite would be so if the result of the difference plot was a higher proportion of negative points. For example, the plot of the differences between tows for yellowtail caught in the high position deflector rake series (Figure 3) reveals a large number of negative differences in tows between the control and experimental rake. Therefore, the deflector rake does not appear to be effective at reducing the bycatch of yellowtail.

Summary statistics and results of Student's t-tests and Wilcoxon signed ranks tests for all species categories/experimental series during the bycatch reduction study are given in Table 2. Mean catches for the control and experimental rake in each experimental series are given for each species category. The number of non-zero tows in each category is indicated in parentheses after the mean. Using the same example as in the previous paragraph, there were 20 out of the 24 tows for the high position series where yellowtail flounder were caught in the control rake. There were 21 out of 24 tows where yellowtail flounder were caught in the experimental rake. Mean difference (D) is given for each series/species category. A negative difference indicates a higher bycatch in the experimental rake. The mean difference of yellowtail flounder caught between the two rakes in the high position series was –5.536. A 95 % confidence interval around the mean difference is provided for each species/series comparison as well as a standard error of the mean D. The p-values from the Student's t-tests and the Wilcoxon signed ranks tests are also given. Those results that are found to be significantly different (p-value ≤ 0.05) are indicated by bold text.

DISCUSSION

VESSEL SIDE AND DAY VERSUS NIGHT COMPARISON

The comparison of catches between the port side versus the starboard side of the vessel showed no significant difference (p-value>0.05) between catches for all species categories. The day versus night comparison also produced a non-significant difference (p-value>0.05) between the catches from tows carried out in day compared to during the night.

SCALLOP CATCHES

Although reducing groundfish bycatch is the focus of this study, a reduction in the catch of scallops per tow by any bycatch reduction device would result in an increase in tow distance to maintain the catch of scallops, thus increasing the time the gear would spend on the bottom and possibly the bycatch of groundfish. For this reason, the difference in catches of scallops between the control and experimental rakes was also examined.

The deflector rake caused a decrease in the catch of scallops compared to the control rake when the panels were in either the high and low positions. This difference was significant in the case of the high position experimental tow series (2.15E-11, 9.01E-06). It was obvious from observation of the catches during the trip that there was a significant reduction in the catch of scallops by the deflector rake. It was assumed that the scallops were escaping capture by being directed upwards along the deflector panels and out through the escape openings above the pressure plate. For this reason it was decided that the angle of the deflector panels would be changed to be closer to the pressure plate, essentially closing the route to the escape openings. The difference in catches between the control rake and the closed panel rake was very low and not significant. This provides some evidence that the deflector rake was experiencing an undesirable loss of scallops through the escape openings that were meant for escapement of groundfish.

Catch differences of groundfish in the high intensity light, strobe light, and pingers experimental tow series were all very low and in the negative direction. The difference was significant between the control and experimental rakes in the strobe and pingers experimental tows (p-values<0.05). The mean differences in both of these series were actually less than one basket of scallops. It is likely that these results are just noise and not actually meaningful.

BYCATCH REDUCTION RESULTS

Deflector rake

The high position series produced a negative difference in catch between the rakes for all species categories. This means the experimental rake caught more fish than the control rake. These results were statistically significant for yellowtail, flounder (ns), and monkfish only (p-values between 0.035 and 1.88E-05). The difference between the catch of skate in the two rakes was very small and not significant. The cod and haddock catches were extremely low in this series of tows and thus did not provide sufficient data to determine whether this rake modification changed the level of bycatch of cod or haddock. Overall, the results illustrate that this rake modification was not effective in reducing groundfish bycatch. In fact, the deflector rake in the high position was effective in catching more flatfish and monkfish than the traditional rake.

The low position series also produced a negative difference in catch between the two rakes for all species categories, indicating a higher bycatch in the experimental rake. Only the results for the yellowtail and the flounder (ns) were found to be significantly different (p-values between 0.003 and 0.041). This indicates that the modification in the gear caused the opposite of the desired reduction of bycatch for yellowtail and flounder (ns). Again, the deflector rake caught more flatfish than the traditional rake. There was no significant difference in catch between the two rakes for the other species that were compared. The catches of cod and haddock in this series were also very low and did not provide any real indication of an effect of the modified rake on the catch.

The closed position series produced a mix of negative and positive differences between the catch in the two rakes for all species categories. All of the differences in catch between the control and experimental rakes were very low and none proved to be significantly different (p-values>0.05).

High intensity lights

The high intensity light series produced a positive difference in the catch of cod, yellowtail, flounder, and skate between the two rakes. This indicates that the experimental rake had a lower bycatch of these species. This difference was only significant for the yellowtail and cod catches (p-values<0.05). The cod catch difference was only found to be significant with the non-parametric Wilcoxon signed ranks test. There was one tow in this series that had a much higher catch of cod and this created a higher difference between tows compared to the other tow differences. This one value may be the reason for the significant difference in the cod catches between the two rakes. There was a negative difference between experimental and control rakes catches of haddock and monkfish, indicating a higher catch in the experimental rake. Both differences were very low and not significant (p-values>0.05).

Strobe lights

The strobe light series produced very low differences in catch between the control and experimental rakes for all species categories. The comparison of haddock catches between the two rakes produced a significant difference in the positive direction (p-values = 0.009 and 0.014). This indicates that there was significantly less haddock captured in the rake with the strobe lights. It should be noted that the actual number of haddock caught in both rakes was very low and there was only about half of the tows where fish were actually captured by either rake (see Table 2 for mean catches).

High frequency sound pingers

The high frequency pingers series produced very low differences in catches between the two rakes for all species. All differences were positive with the exception of cod and skates. The positive difference indicates a lower bycatch in the rake with the pingers. The positive difference in the catches for flounder was the only one found to be significantly different (p-value = 0.004.

SUMMARY

In conclusion, the deflector rake did not produce any significant reduction in bycatch. In some cases the deflector rake caught significantly more groundfish. The light and sound experimental series produced a mix of positive and negative reductions in bycatch for all species categories. There were some species that showed a significant reduction in bycatch (p-values<0.05) caught by the light or sound modified rakes, but there was not one modification that produced a reduction for all species categories.

The groundfish bycatch, cod and haddock in particular, were very low for all experimental series making it difficult to truly compare the effects of the modifications to the gear on the bycatch of these species. If these potential bycatch reduction devices are to be further tested, it may be necessary to repeat the survey at different times of year when the bycatch species of concern may be more plentiful.

RECOMMENDATIONS

Discussions about the next step in bycatch reduction studies in the offshore scallop fishery on Georges Bank resulted in the following conclusions:

- It is critical to better understand the behaviour of the traditional scallop fishing rake. The New Bedford rake has been in service for over 50 years with few changes brought to its design. Various sensors are available to better understand pressure exerted by the shoes, pressure plate, etc. Understanding the basics may lead to improvements in gear efficiency. This could translate into a reduced time the rake is on the bottom, which could possibly lead to a reduction in groundfish bycatch.

- Advances in technology, miniature cameras for example, allow for real time observations of fish reactions during fishing. Information on light levels at the bottom, noise generated by the rake itself, and fish reaction behaviour to these variables would be useful for further bycatch studies. Another issue that needs to be studied is whether a portion of the fish bycatch is caught when the rake is hauled back.

- As there was a reduction in bycatch of flatfish species in the experimental series using light production devices, further investigation into the use of various light sources is recommended. Other useful information to obtain would be the projected distance of the lights underwater. It may be worthwhile to use a light that has a greater projection so the finfish detects the light earlier, thus allowing a longer amount of time to escape capture by the rake.

Gear trials reported here were first attempts at discovering practical ways of reducing groundfish bycatch in the offshore scallop fishery. Although preliminary, this study has identified several avenues of further research that have potential in addressing the avoidance of bycatch in the Canadian offshore scallop fishery.

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Table 1. List of all species caught during the scallop bycatch reduction survey.

COMMON NAME	**SCIENTIFIC NAME**
AMERICAN LOBSTER	*Homarus americanus*
ATLANTIC COD	*Gadus morhua*
ATLANTIC HALIBUT	*Hippoglossus hippoglossus*
CUNNER	*Tautogolabrus adspersus*
FLOUNDER, UNIDENTIFIED	*Pleuronectidae*
HADDOCK	*Melanogrammus aeglefinus*
HAKE, UNIDENTIFIED	*Urophycis sp.*
JONAH CRAB	*Cancer borealis*
LONGHORN SCULPIN	*Myoxocephalus octodecimspinosus*
MONKFISH	*Lophius americanus*
OCEAN POUT	*Macrozoarces americanus*
OFF-SHORE HAKE	*Merluccius albidus*
SEA RAVEN	*Hemitripterus americanus*
SEA SCALLOP	*Placopecten magellanicus*
SHORT-FIN SQUID	*Illex illecebrosus*
SILVER HAKE	*Merluccius bilinearis*
SKATES, UNIDENTIFIED	*Rajidae*
SQUIRREL OR RED HAKE	*Urophycis chuss*
WHITE HAKE	*Urophycis tenuis*
YELLOWTAIL FLOUNDER	*Limanda ferruginea*

Table 2. Summary statistics and results of Student's t-test and Wilcoxon signed ranks test for all experimental series during the bycatch reduction survey. Mean catches for the control and experimental rake in each experimental series are given for each species category. The number of non-zero tows in each category is indicated in parentheses after the mean catch (there were no zero tows for scallops during the survey). Mean difference (D) is given for each series/species category. A negative difference indicates a higher catch in the experimental rake. Probabilities equal to/less than 0.05 indicates a significant difference.

Species category, treatment, and sample size (n)	Controls: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Experimentals: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Mean D ± 95% CI	Standard error of mean D	Student's t-test probability (1-sided)	Wilcoxon signed ranks probability (1-sided)
Cod						
High Position (24)	0.036 (1)	0.111 (2)	-0.075 ± 0.19	0.091	0.21	0.296
Low Position (22)	0.087 (2)	0.124 (3)	-0.037 ± 0.2	0.096	0.352	0.554
Closed (19)	0.344 (4)	0.304 (6)	0.04 ± 0.319	0.152	0.398	0.542
High Intensity (20)	1.56 (9)	0.582 (4)	0.978 ± 1.28	0.609	0.062	**0.018**
Strobes (20)	0.463 (6)	0.381 (7)	0.082 ± 0.456	0.218	0.356	0.337
Pingers (20)	0.183 (4)	0.357 (6)	-0.174 ± 0.29	0.139	0.112	0.135
Haddock						
High Position (24)	0 (0)	0.114 (2)	-0.114 ± 0.175	0.084	0.093	0.09
Low Position (22)	0 (0)	0.193 (2)	-0.193 ± 0.323	0.154	0.113	0.091
Closed (19)	1.363 (10)	0.913 (6)	0.451 ± 0.811	0.388	0.13	0.187
High Intensity (20)	0.228 (5)	0.233 (3)	-0.005 ± 0.348	0.166	0.488	0.458
Strobes (20)	0.515 (7)	0.142 (3)	0.373 ± 0.304	0.145	**0.009**	**0.014**
Pingers (20)	0.673 (5)	0.486 (8)	0.188 ±0.717	0.343	0.295	0.458

Species category, treatment, and sample size (n)	Controls: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Experimentals: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Mean D ± 95% CI	Standard error of mean D	Student's t-test probability (1-sided)	Wilcoxon signed ranks probability (1-sided)
Yellowtail						
High Position (24)	4.579 (20)	10.116 (21)	-5.536 ±2.278	1.089	**1.88E-05**	**0.0002**
Low Position (22)	2.697 (13)	6.824 (13)	-4.127 ± 3.323	1.587	**0.008**	**0.003**
Closed (19)	0.814 (7)	0.558 (6)	0.256 ± 0.451	0.216	0.125	0.084
High Intensity (20)	15.067 (20)	11.6 (20)	3.466 ± 3.0	1.434	**0.013**	**0.015**
Strobes (20)	5.765 (20)	5.152 (19)	0.613 ± 1.486	0.71	0.199	0.172
Pingers (20)	0.812 (8)	0.341 (4)	0.47 ± 0.692	0.331	0.086	0.118
Flounder (NS)						
High Position (24)	1.666 (17)	2.726 (21)	-1.061 ± 1.098	0.525	**0.027**	**0.035**
Low Position (22)	3.927 (16)	6.064 (21)	-2.137 ± 2.448	1.17	**0.041**	**0.025**
Closed (19)	2.945 (16)	2.779 (15)	0.166 ± 1.252	0.598	0.392	0.321
Flounder (NS) cont'd						
High Intensity (20)	4.732 (19)	2.769 (18)	1.963 ± 2.431	1.162	0.054	0.081
Strobes (20)	2.357 (16)	1.984 (17)	0.373 ± 1.043	0.499	0.232	0.251
Pingers (20)	3.049 (17)	1.869 (15)	1.18 ± 0.832	0.397	**0.004**	**0.004**
Skates (NS)						
High Position (24)	23.183 (24)	23.84 (24)	-0.657 ± 4.074	1.947	0.37	0.37
Low Position (22)	25.129 (22)	32.497 (22)	-7.368 ± 10.1	4.827	0.07	0.102
Closed (19)	23.045 (18)	24.602 (19)	-1.557 ± 3.791	1.811	0.2	0.29
High Intensity (20)	24.421 (20)	22.828 (20)	1.593 ± 4.103	1.96	0.213	0.157
Strobes (20)	17.274 (20)	18.062 (20)	-0.789 ± 3.666	1.752	0.329	0.434
Pingers (20)	14.617 (20)	16.246 (20)	-1.629 ± 3.493	1.669	0.171	0.148

Species category, treatment, and sample size (n)	Controls: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Experimentals: Mean catch: no. or bu./standardized tow - 4km (number of non-zero tows)	Mean D ± 95% CI	Standard error of mean D	Student's t-test probability (1-sided)	Wilcoxon signed ranks probability (1-sided)
Monkfish						
High Position (24)	3.592 (22)	4.732 (23)	-1.14 ± 1.085	0.518	**0.019**	**0.018**
Low Position (22)	3.941 (19)	3.958 (22)	-0.017 ± 1.379	0.659	0.49	0.484
Closed (19)	3.226 (18)	4.079 (18)	-0.853 ± 1.711	0.818	0.155	0.175
High Intensity (20)	5.252 (18)	5.413 (20)	-0.163 ± 1.893	0.904	0.429	0.345
Strobes (20)	3.247 (17)	2.942 (17)	0.305 ± 1.801	0.861	0.363	0.656
Pingers (20)	4.633 (20)	4.293 (16)	0.34 ± 1.35	0.645	0.302	0.232
Scallops						
High Position (24)	12.312	5.633	6.679 ± 1.205	0.576	**2.15E-11**	**9.01E-06**
Low Position (22)	8.557	6.909	1.648 ± 2.478	1.184	0.089	0.051
Closed (19)	9.197	9.237	-0.04 ± 1.3	0.621	0.475	0.665
High Intensity (20)	9.075	9.587	-0.512 ± 1.036	0.495	0.157	0.142
Strobes (20)	5.9	6.5	-0.6 ± 0.651	0.311	**0.034**	**0.016**
Pingers (20)	5.108	5.715	-0.608 ± 0.564	0.269	**0.018**	**0.017**

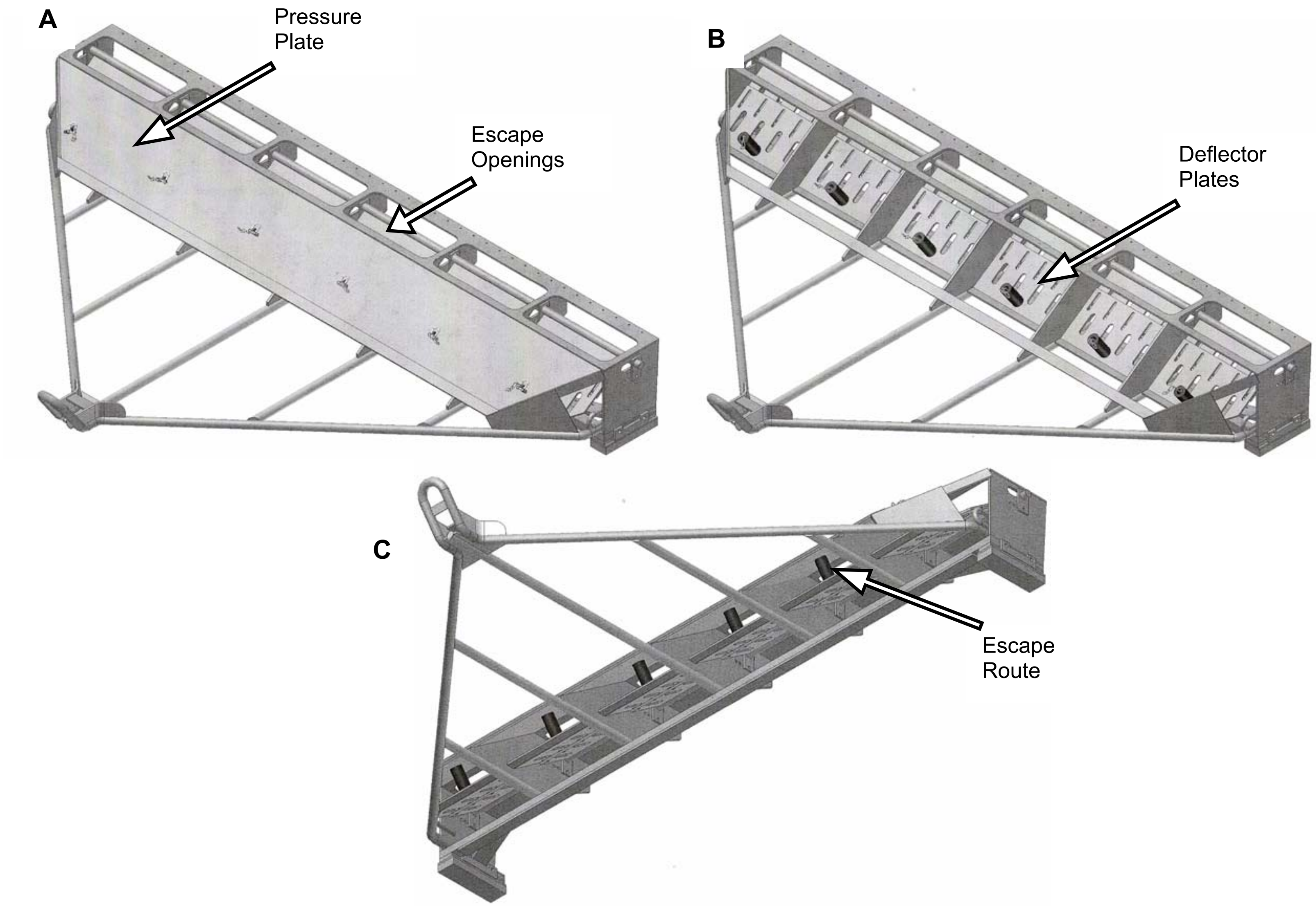


Figure 1. Drawing of the 'deflector' rake developed for this study to attempt to reduce the bycatch of groundfish in the scallop fishery. A.) illustrates the escape openings above the pressure plate; B.) pressure plate removed to show deflector panels; C.) ventral view of the rake.

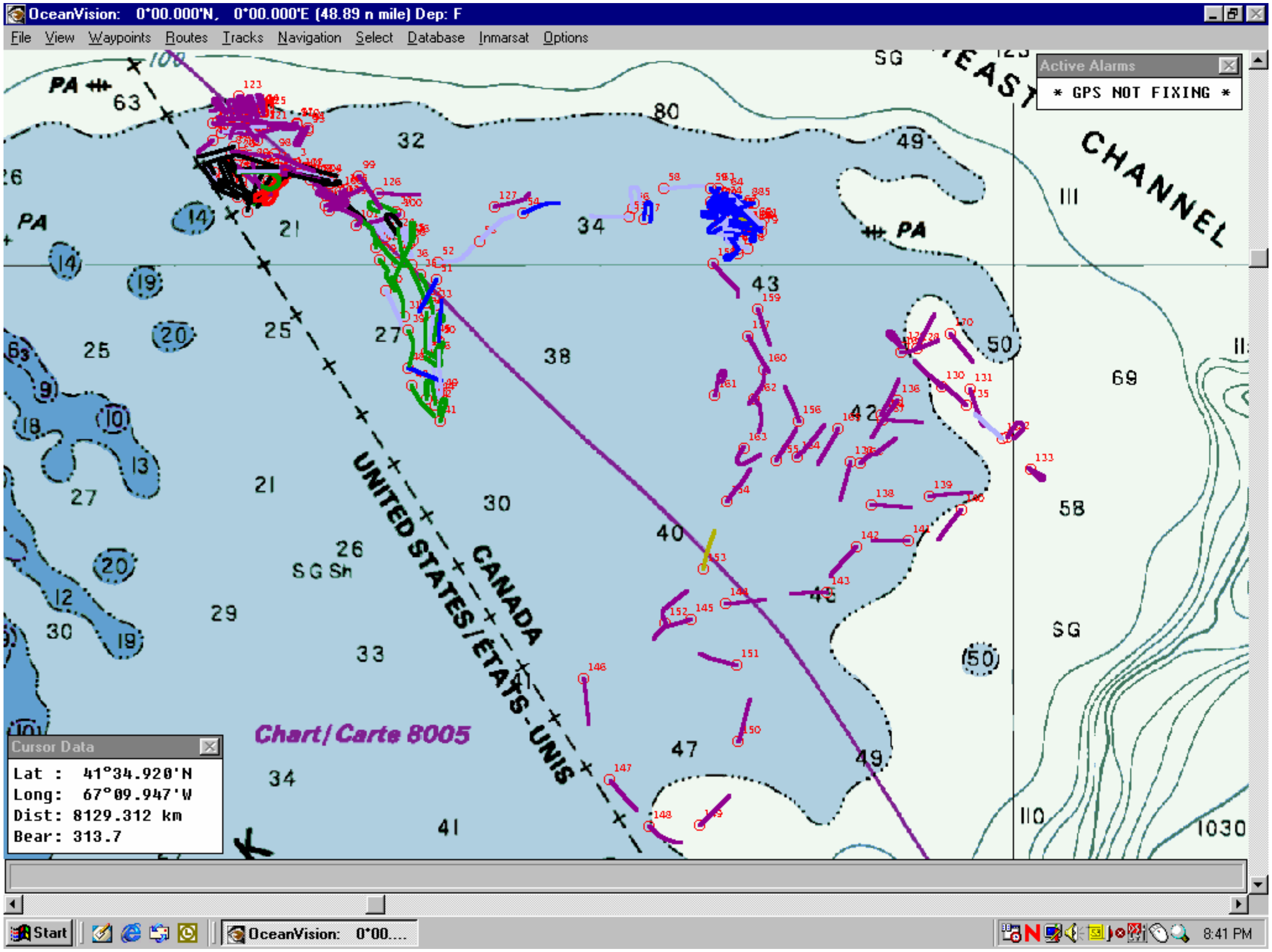


Figure 2. Map of survey tracks for all comparative tows conducted during the scallop bycatch reduction survey.

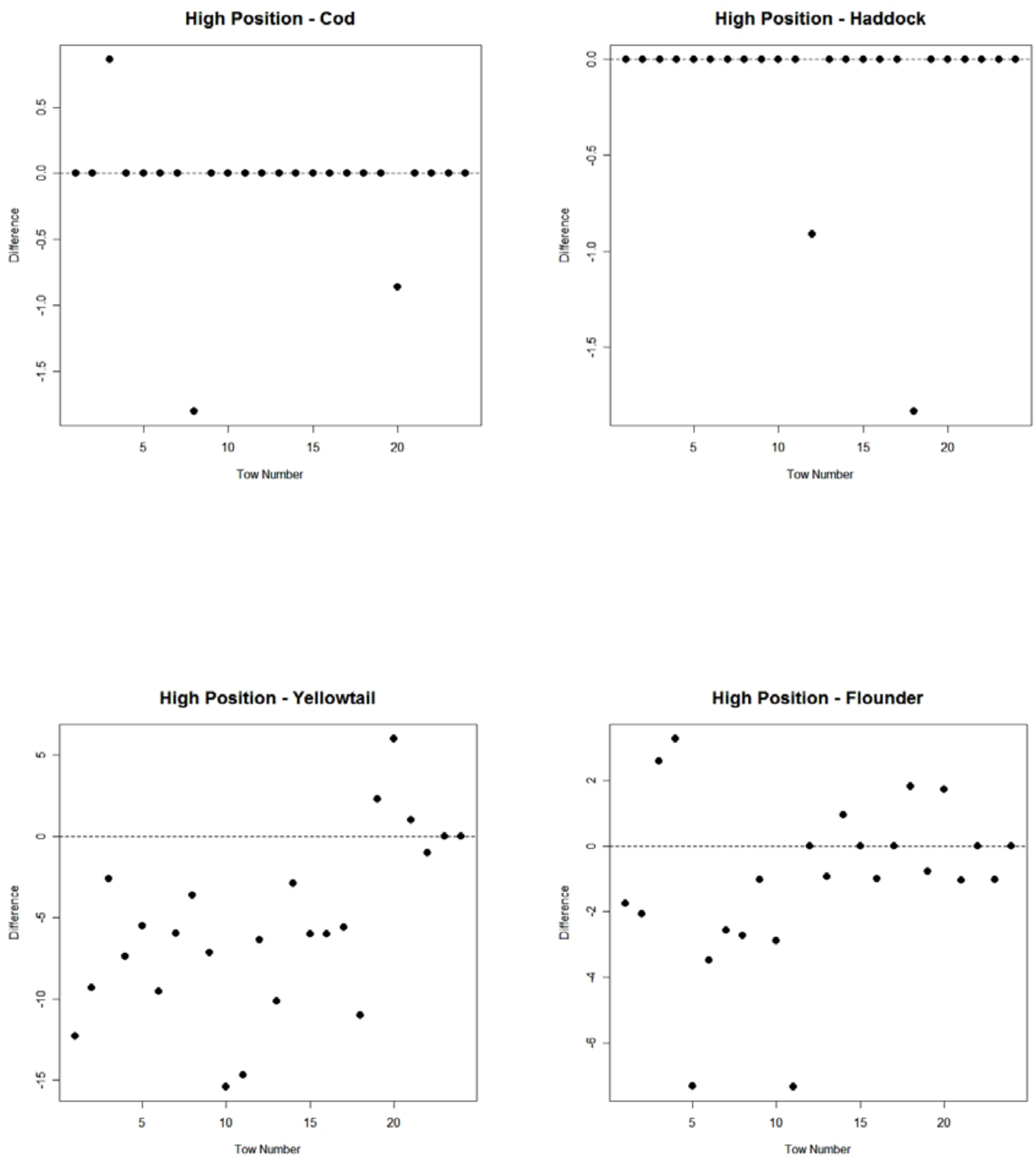
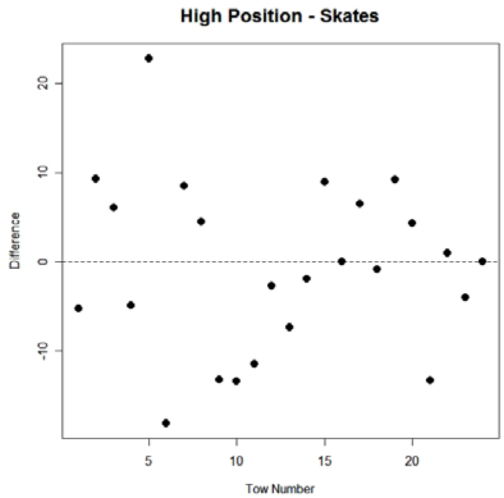
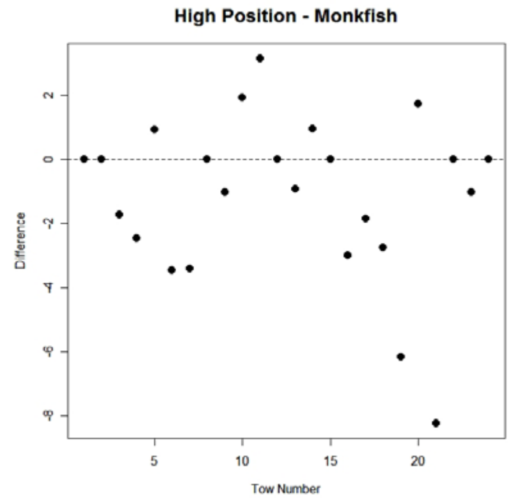


Figure 3a. High position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.





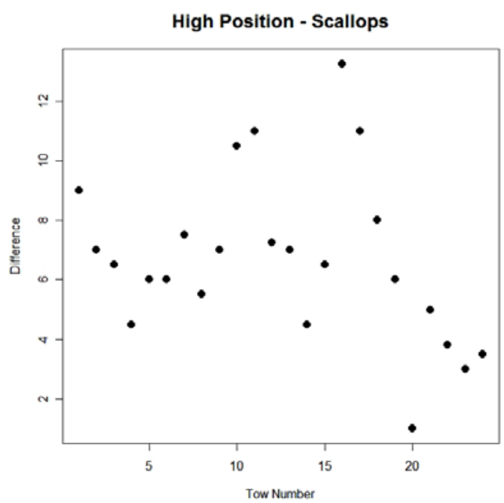


Figure 3b. High position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

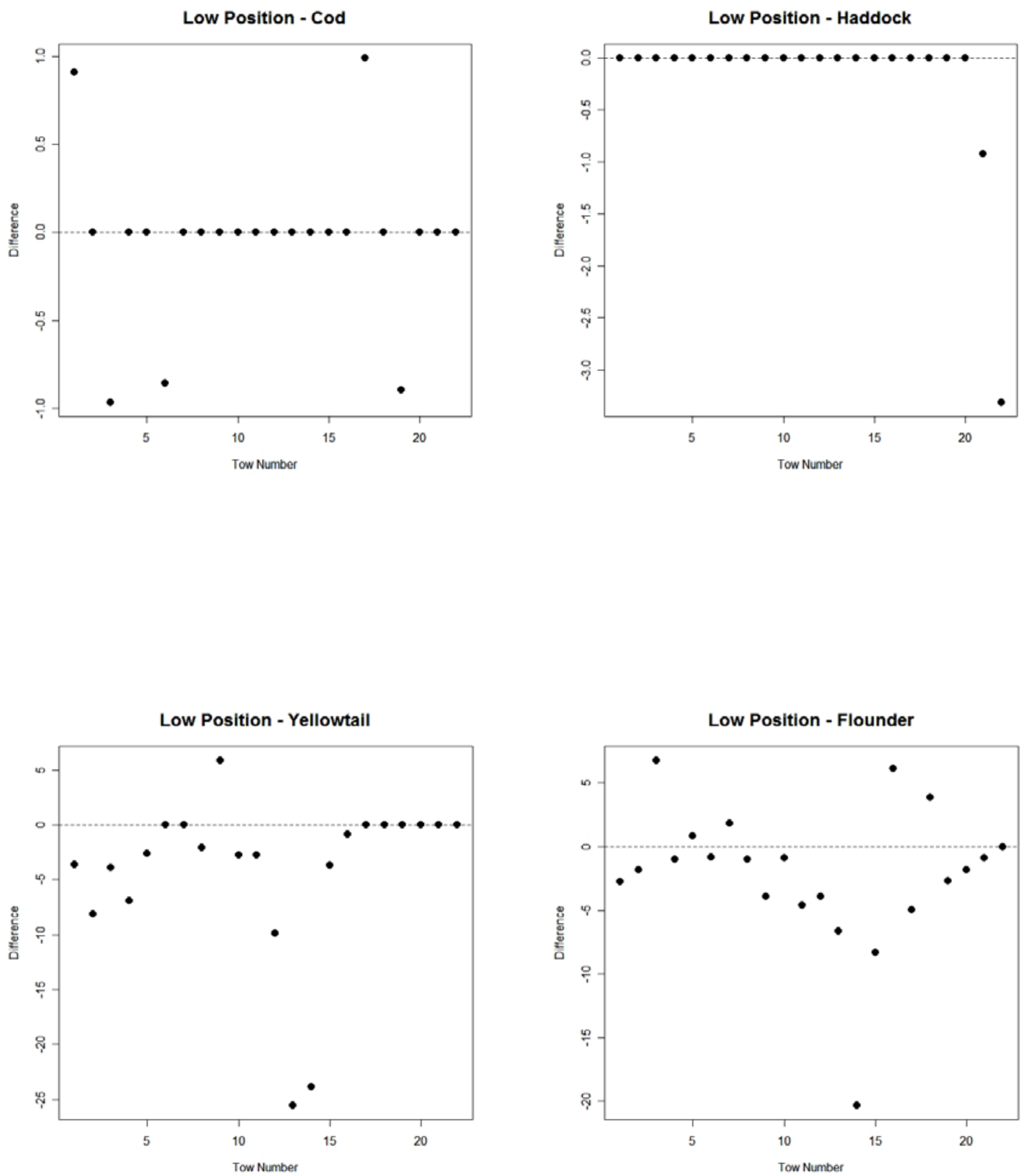


Figure 4a. Low position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

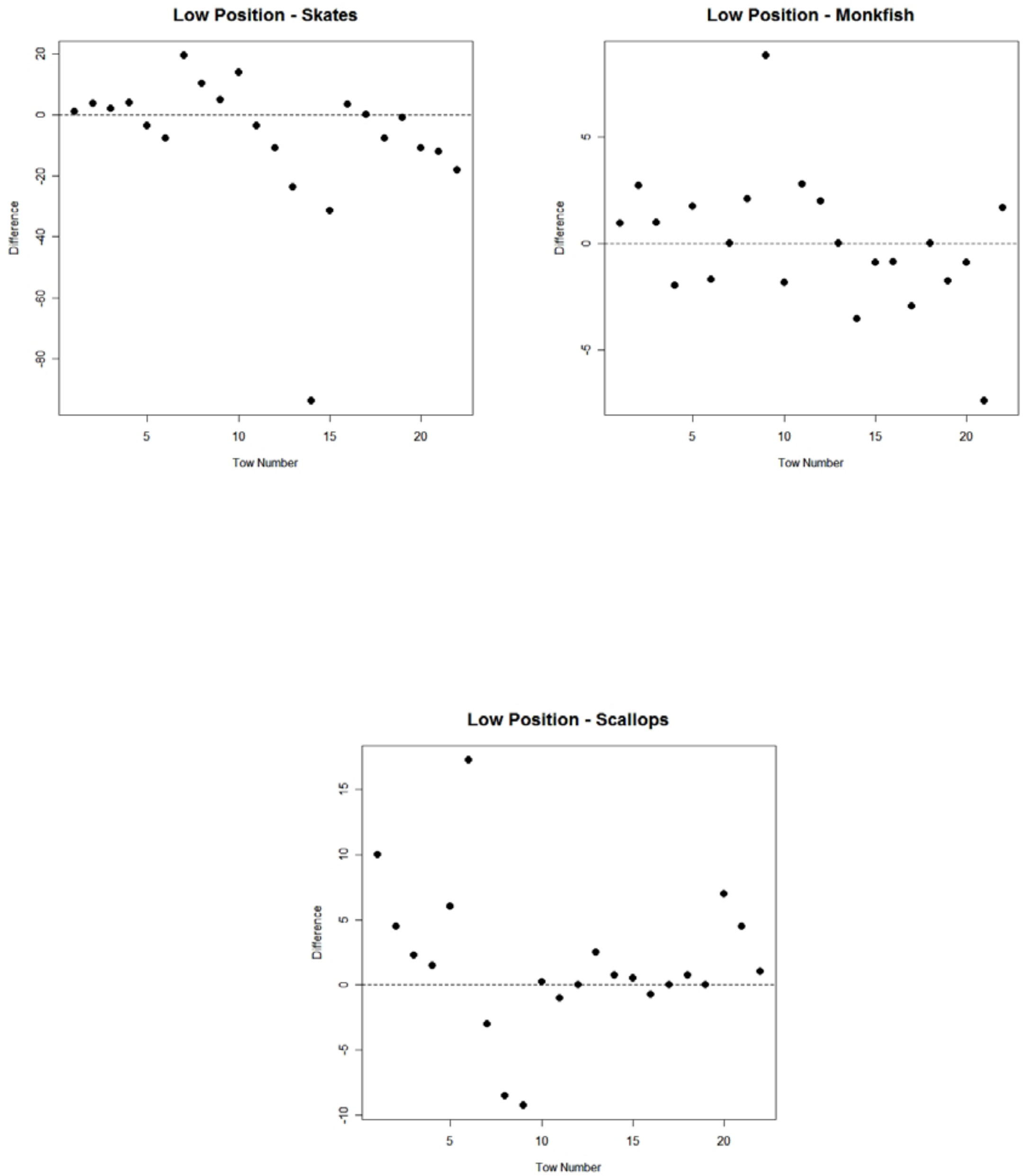


Figure 4b. Low position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

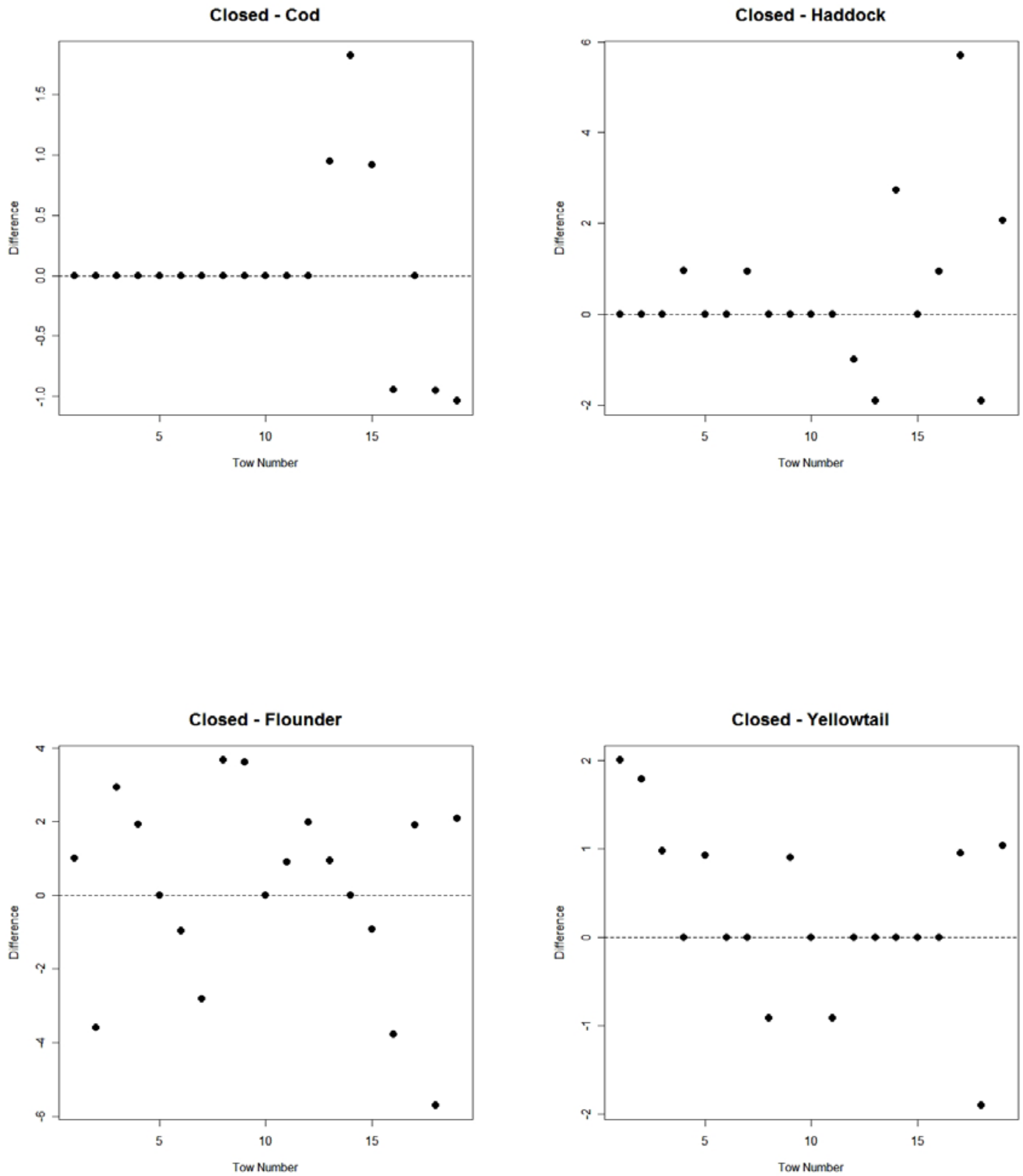


Figure 5a. Closed position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

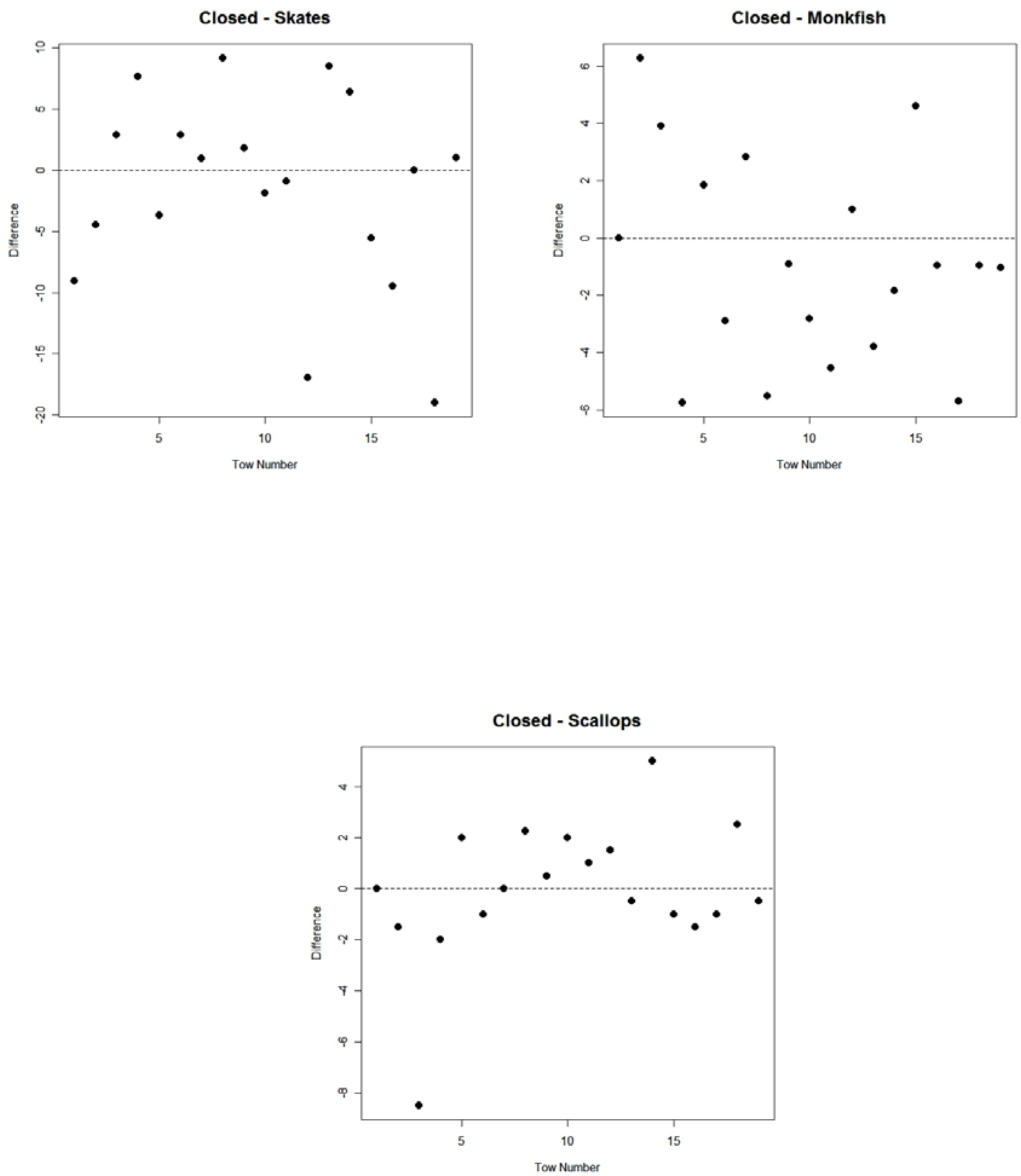


Figure 5b. Closed position experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

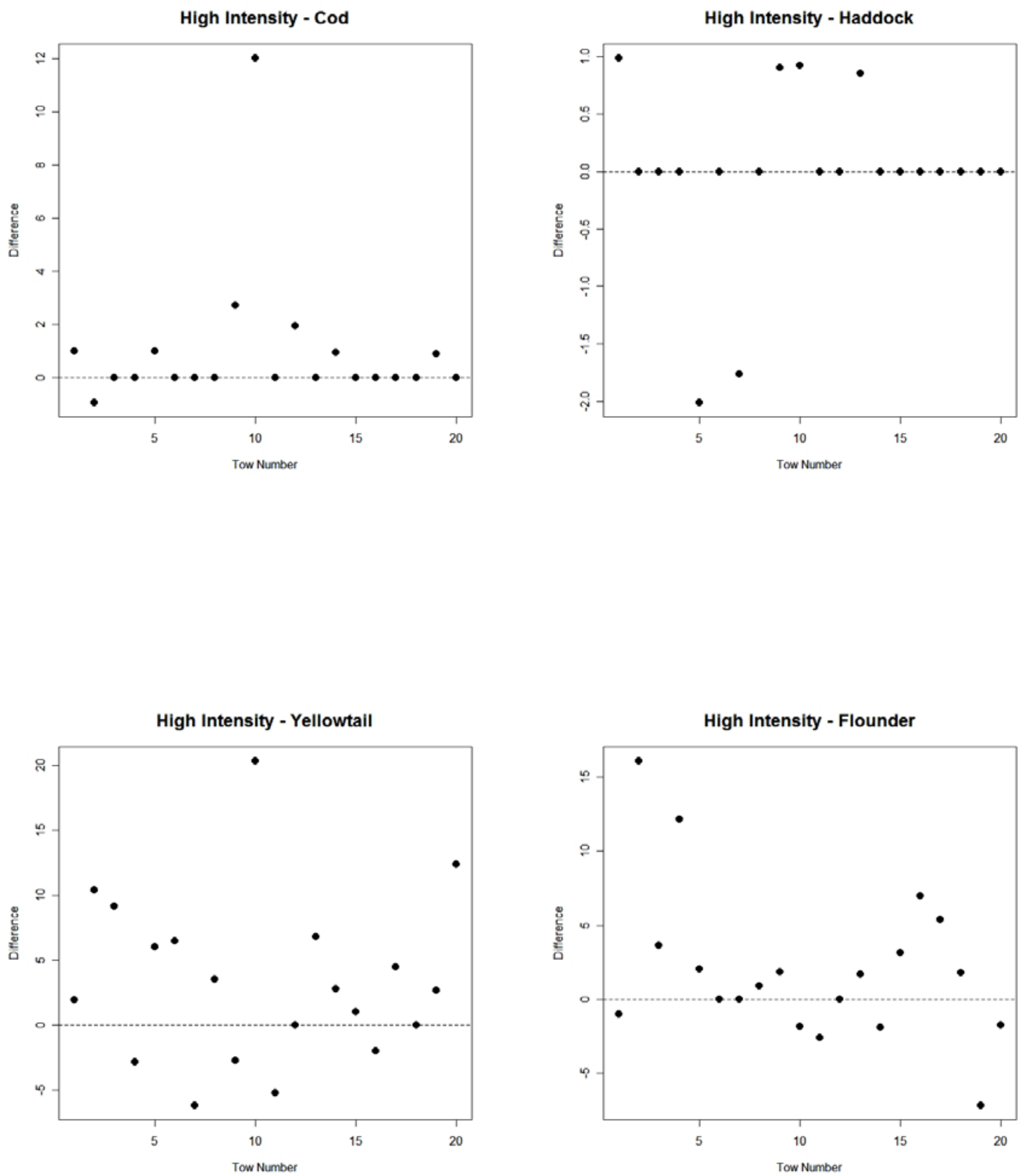


Figure 6a. High intensity lights experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

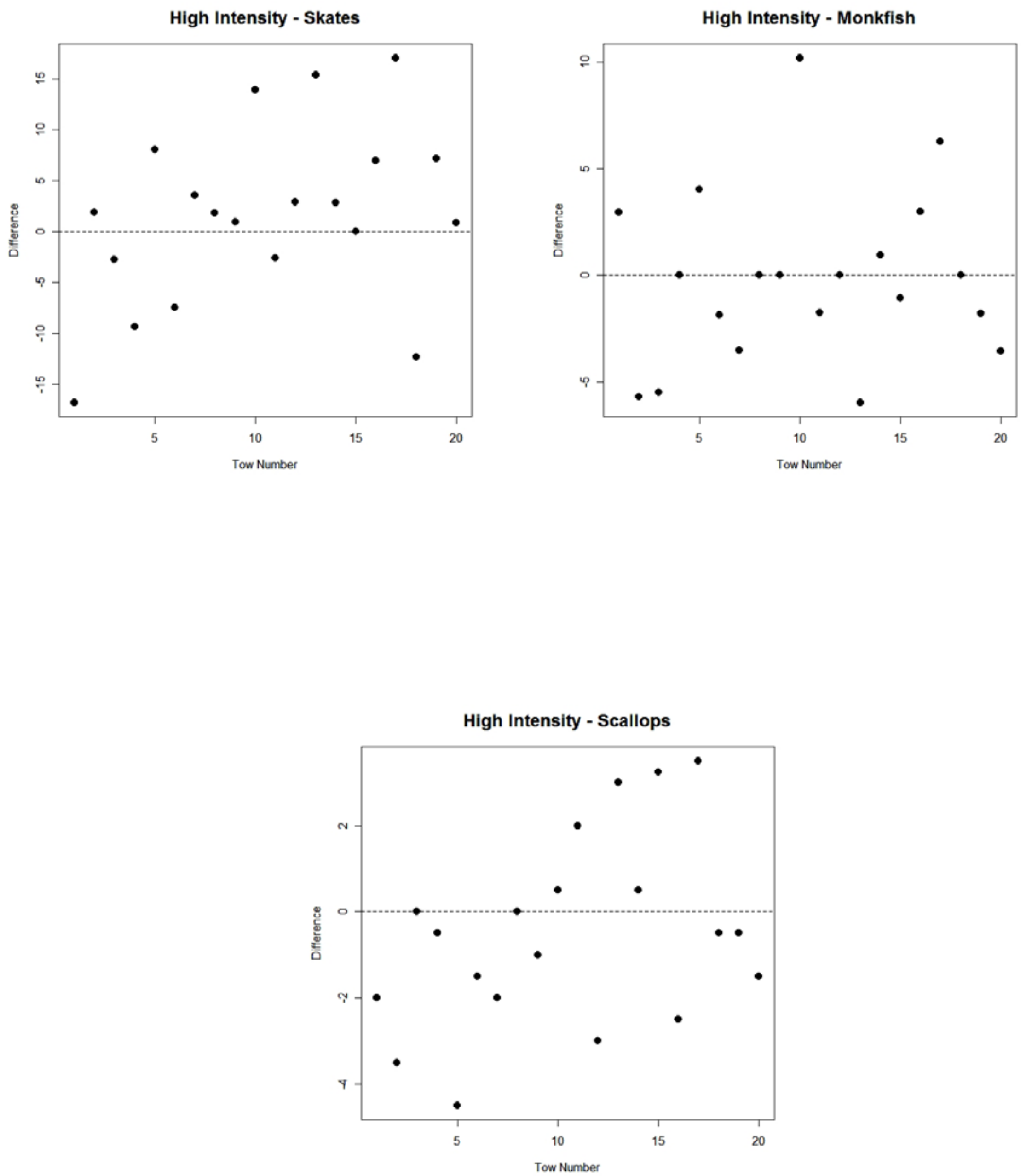


Figure 6b. High intensity lights experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

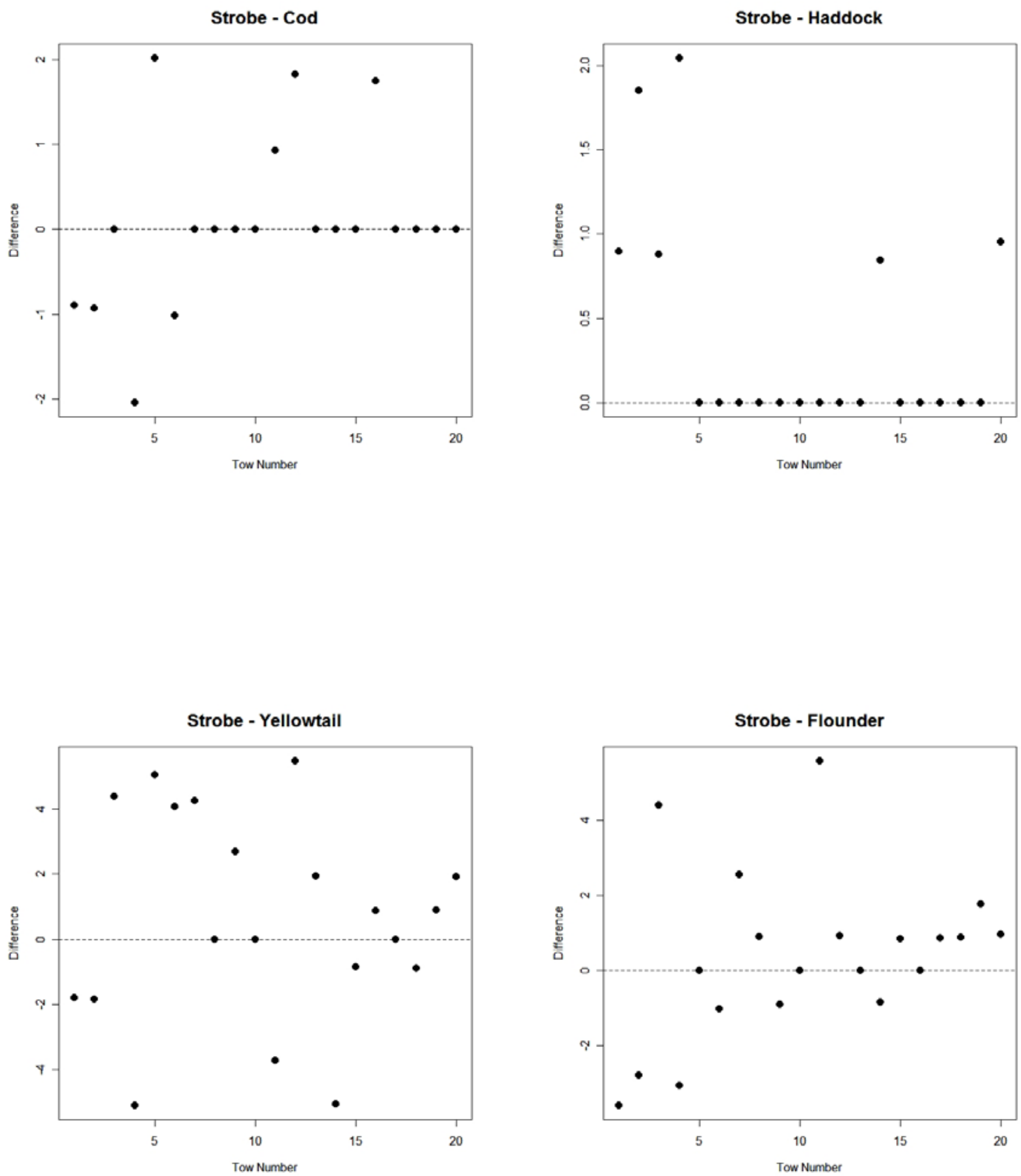


Figure 7a. Strobe light experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

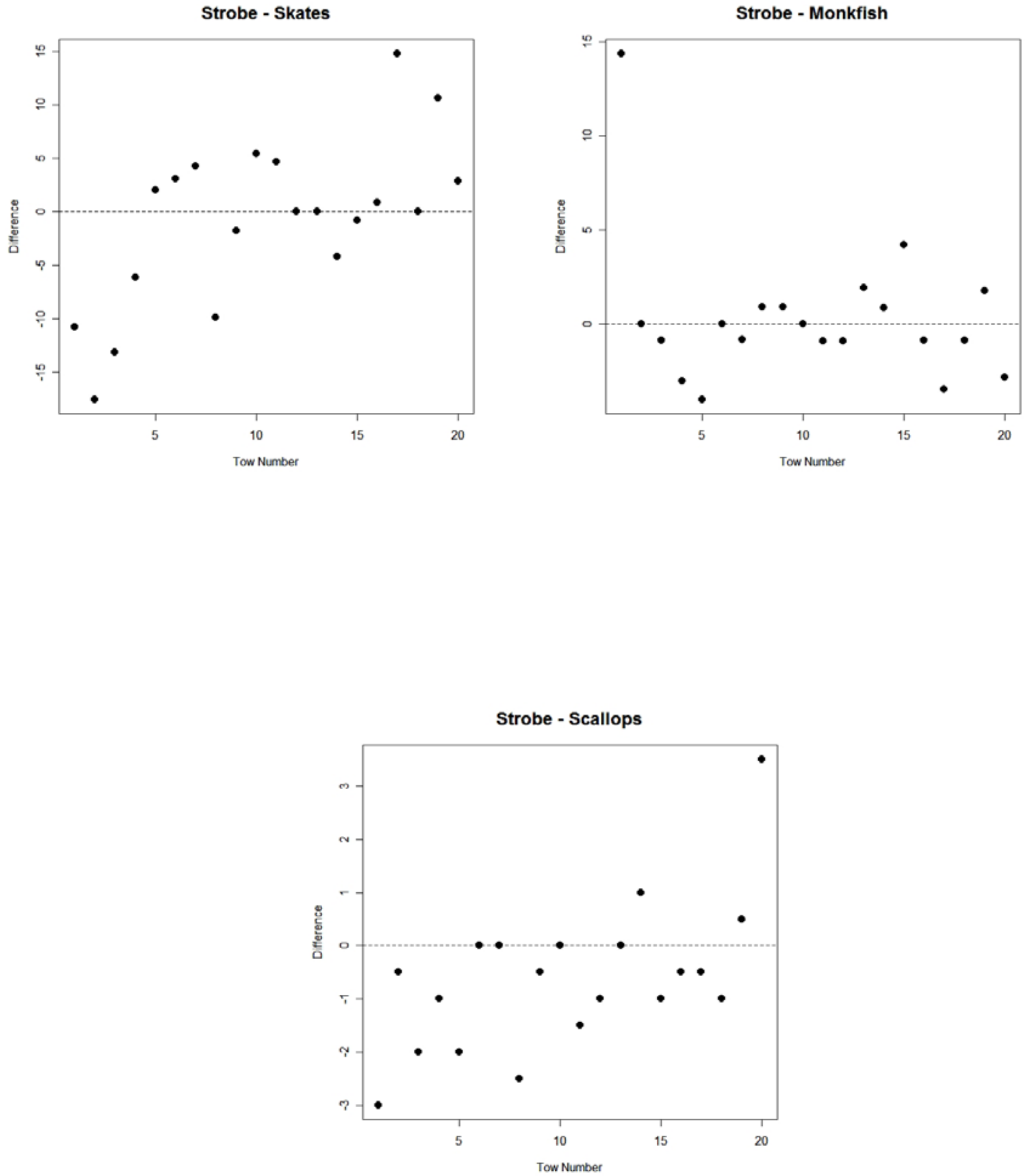


Figure 7b. Strobe light experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

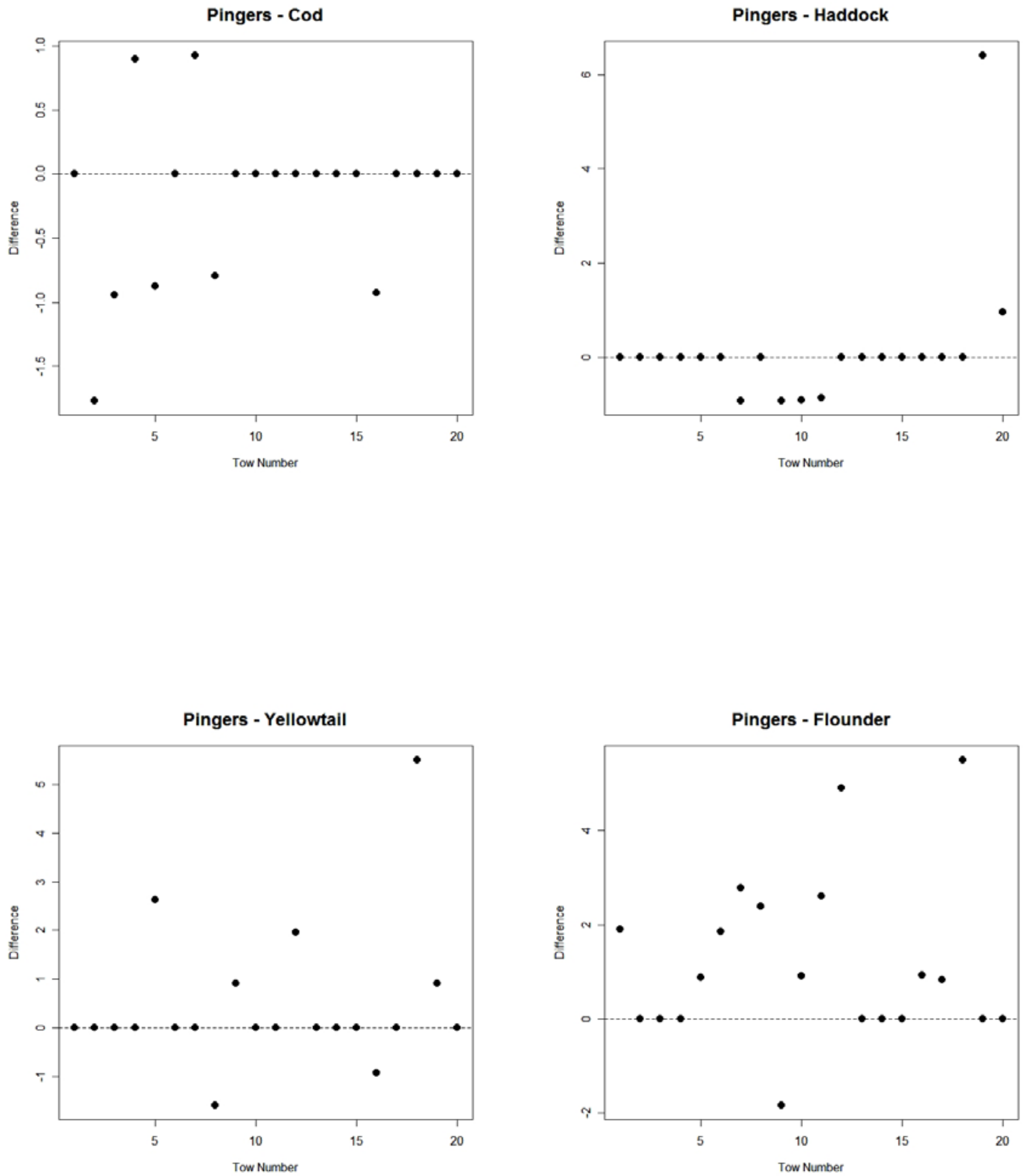


Figure 8a. High frequency pingers experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

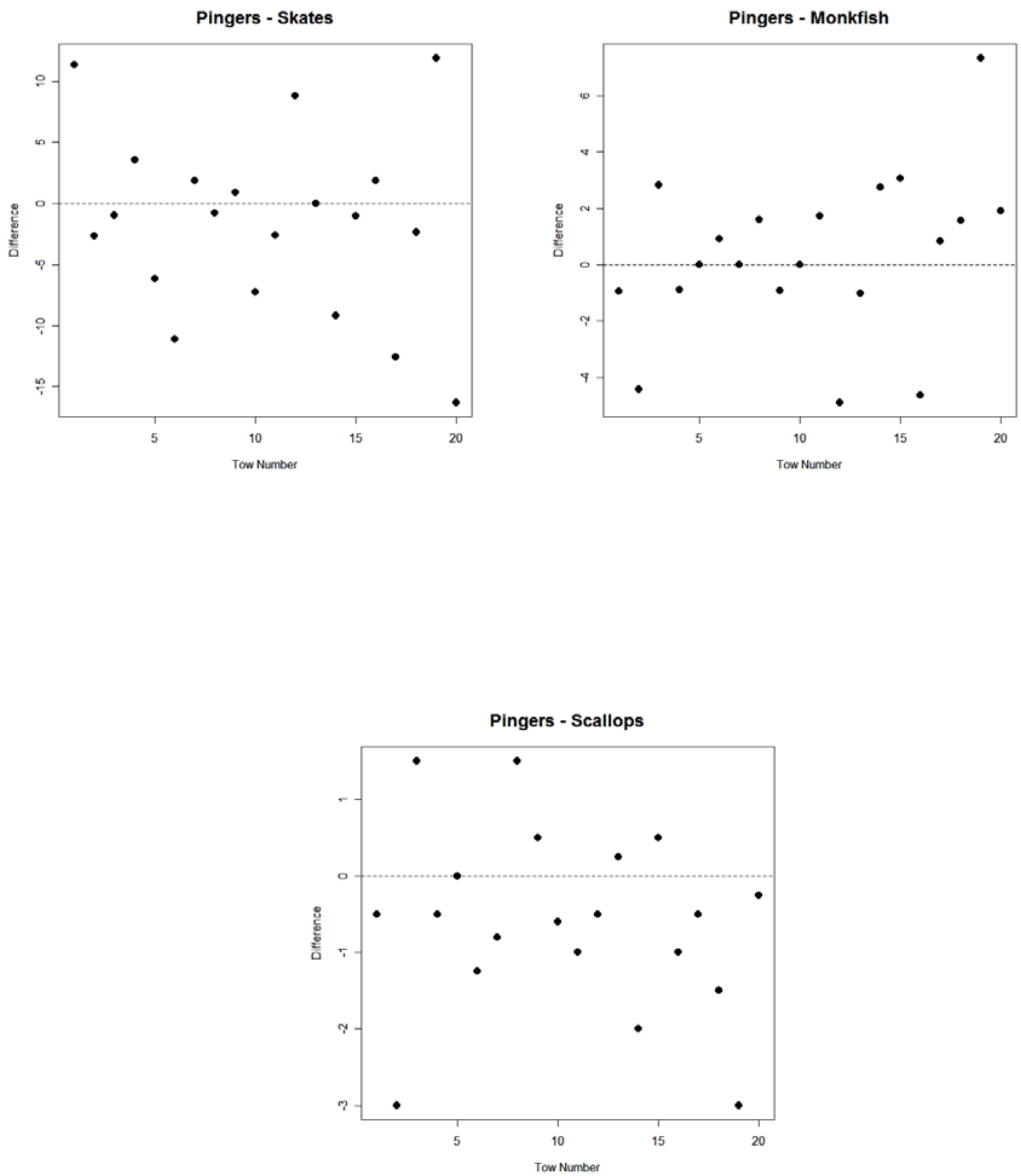


Figure 8b. High frequency pingers experimental series. Plots of the difference between control and experimental rakes (control rake minus experimental rake as numbers of fishes or baskets of scallops per 4 km tow). Positive differences result when there is a reduction in the catch by the experimental rake; negative differences are due to a higher catch in the experimental rake.

APPENDIX 1

TECHNICAL SPECIFICATIONS

Light and sound production devices

High intensity lighting
Pelican Sabrelite 2020 underwater light
high intensity LED white light, highly collimated
35 lumens luminous flux

Strobe lighting
Princeton Tec AquaStrobe
xenon strobe white light
2-3 Joules flash energy
70 flashes per minute

Acoustic pinger
Fumunda Marine Products FMDP-2000 pinger
Frequency 10 kHz +/- 2 kHz
Repeat interval 4 s +/- 0.2 s
Source level 132 dB re 1microPascal at 1 m +/- 4 dB

Low light camera and control system

OE15-100 Enhanced CCD Camera
Low Light CCD Camera
Horizontal Res. (15-100/15-101) 560/570 TV lines
Full video sensitivity 1.1 x 10-2 Lux (faceplate)
Focus control & Cable Compensation
Supply 14-30V dc @ 675mA
Titanium Alloy Housing - Depth Rating 3000m
Length, diam., weight air/water - 225, 80mm, 1.5/1.0kg

OE1232 Control system – Integrated monitor and camera control unit
OE1232 Camera Control Unit
Sony PVM-9044QM 9" Colour Monitor
Panasonic AG-MD830 S-VHS Video Recorder
Rugged Integrated Enclosure
Supply 115/240V ac (50/60Hz)
Width, depth, height, weight - 330,600/620 mm, 40.0kg