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Effects of Gear Modifications on the Trawl Performance and Catching Efficiency of the West Coast Upper Continental Slope Groundfish Survey Trawl

ROBERT R. LAUTH, STEPHEN E. SYRJALA, and SCOTT W. McENTIRE

Introduction

Bottom trawl surveys are an important source of fishery-independent data for assessing, monitoring, and managing groundfish populations. NOAA's National Marine Fisheries Service (NMFS) has been conducting groundfish bottom trawl surveys along the west coast continental shelf for more than 30 years (Dark and Wilkins, 1994). It was not until 1984 that the Resource Assessment and Conservation Engineering (RACE) Division of the NMFS Alaska Fisheries Science Center (AFSC), initiated a pilot groundfish bottom trawl survey of the upper continental slope (Raymore and Weinberg, 1990). Compared to the shelf, the west coast upper continental slope (WCUCS) is a challenging environment in which to do a trawl survey because of the extreme depths (183–1,280 m), steep and irregular bathymetry, submarine canyons, and muddy bottom. The survey was motivated by the need for information on the commercially important species inhabiting the slope region. These species, referred to as the deep-water complex (DWC), include Dover sole, *Microstomus pacificus*; sablefish, *Anoplopoma fimbria*; shortspine thornyhead, *Sebastolobus alascanus*; and longspine thornyhead, *S. altivelis*. Starting in 1988, the WCUCS groundfish bottom-trawl surveys were done on an annual basis (Parks et al., 1993; Lauth et al., 1997; Lauth, 1997a, b). The NOAA ship *Miller Freeman*, a 66 m stern trawler, has been the principal vessel for conducting these surveys. The spatial coverage of annual surveys has varied. In 1997, the entire west coast, from Point Conception, Calif. (lat. 34°30'N) to the U.S.–Canada border, was surveyed. WCUCS groundfish bottom trawl surveys prior to 1997 were limited to only sections of the west coast, so it was necessary to combine several years of survey data in order to obtain a coastwide synoptic view of the DWC.

Data from the WCUCS surveys are used to estimate biomass, generate data on the length and age composition, and to describe other biological characteristics of slope groundfish species. West coast stock assessment scientists rely heavily on survey data as input into groundfish stock assessment models (Jacobson, 1990, 1991; Methot, 1992, 1994; Turnock and Methot, 1992; Ianelli et al., 1994; Turnock et al., 1994; Brodziak et al., 1997; Crone et al., 1997; Rogers et al., 1997). Stock assessments based on these survey results are used by fishery managers and the Pacific Fishery Management Council to establish annual harvest guidelines for the DWC. Maintaining a time series as a

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ABSTRACT—Since 1984, annual bottom trawl surveys of the west coast (California–Washington) upper continental slope (WCUCS) have provided information on the abundance, distribution, and biological characteristics of groundfish resources. Slope species of the deep-water complex (DWC) are of particular importance and include Dover sole, Microstomus pacificus*; sablefish,* Anoplopoma fimbria*; shortspine thornyhead,* Sebastolobus alascanus*; and longspine thornyhead,* S. altivelis*. In the fall of 1994, we conducted an experimental gear research cruise in lieu of our normal survey because of concerns about the performance of the survey trawl. The experiment was conducted on a soft mud bottom at depths of 460–490 m off the central Oregon coast. Treatments included different combinations of door-bridle rigging, ground-gear weight, and scope length. The experimental design was a 2 × 2 × 2 factorial within a randomized complete-block. Analysis of variance was used to examine the effects of gear modifications on the engineering performance of the trawl (i.e. trawl dimensions, variation in trawl dimensions, and door attitude) and to determine if catch rates in terms of weight and number of DWC species and invertebrates were affected by the gear modifications. Trawl performance was highly variable for the historically used standard trawl configuration. Improvements were observed with the addition of either a 2-bridle door or lighter ground gear. Changes in scope length had relatively little effect on trawl performance. The interaction of door bridle and ground gear weight had the most effect on trawl performance. In spite of the standard trawl's erratic performance, catch rates of all four DWC species and invertebrates were not significantly different than the 2-bridle/heavy combination, which did the best in terms of engineering performance. The most important factor affecting DWC catch rates was ground gear. Scope length and the type of door bridle had little effect on DWC catch rates. Subsequent revisions to survey gear and towing protocol and their impact on the continuity of the slope survey time series are discussed.*

representative measure of relative abundance of the DWC species requires that a consistent sampling tool and standardized sampling methods be used during trawl surveys. The validity of the slope time series was challenged in 1993 when a representative of the fishing industry, invited to participate on the survey cruise, observed inconsistencies with the design and operation of the survey trawl. It was brought to our attention that the doors were sometimes falling over onto their bails and that the ground gear was digging very hard into the mud causing the net dimensions to decrease or oscillate during a tow.

Following the 1993 survey, RACE scientists, with input from the fishing industry and net manufacturers, reevaluated the design and operation of the survey trawl. It was concluded that steps should be taken to improve the standard survey trawl's performance and, consequently, the credibility of the survey. The fact that the survey trawl was not operating to engineering specifications raised questions similar to those discussed by Carrothers (1981) and Walsh et al. (1993) about potential sources of bias and variability in resource assessment trawl survey data. If it was the aim of a resource assessment survey to control variability and eliminate possible bias from the time series, it followed that the survey trawl should perform as it was designed and in a consistent manner.

Before we could improve trawl performance, we had to learn what was causing it to behave the way it did. A comparative gear experiment was done in 1994 to test the effects of selected gear modifications on standard survey trawl performance. The term "trawl performance" as used herein refers to the performance of the trawl from an engineering perspective and has nothing to do per se with how the trawl catches fish. Trawl dimensions (net width, door spread, and net height), variation in trawl dimensions, door attitude, and bottom contact of the ground gear were the factors used to assess trawl performance. We wanted to know how gear changes affected various aspects of trawl performance. The experiment involved testing two methods of door rigging, two types of ground gear, and two scope lengths: a total of eight gear configurations. These were chosen because they were relatively simple modifications that had potential for improving the engineering performance of the survey trawl. Also implemented was a more accurate and precise method for determining the amount of wire payed out and a more standardized method for controlling winches after brakeset. Analysis of variance (ANOVA) was used to evaluate the effects of gear modifications on trawl dimensions and door pitch and roll angles. The null hypotheses tested were that trawl performance factors measured were not affected by the three gear modifications examined or their interactions.

An inevitable outcome of the trawl performance part of this gear experiment was to incorporate modifications that improved trawl performance into future surveys. However, making modifications to a survey sampling trawl is not a trivial matter. Modifications may change the trawl's catching efficiency, introduce a new bias, and thereby compromise the continuity of the time series used for doing stock assessments. Therefore, we wanted to see how catch rates varied for each DWC species among all combinations of the three gear modifications. Since we were likely to chose the treatment with the "best" trawl performance as a new standard, we also wanted to compare catch rates for the various trawl configurations with the old standard WCUCS survey trawl. To test whether the gear modifications had a significant effect on catch rates, ANOVA was again used. This time, however, the ANOVA was done using the within-block ranks of the catch rates, both in terms of weight and number, for each DWC species. The effects of gear changes on catch rates of invertebrates were also analyzed, since invertebrates are passive in response to a moving trawl and are another indicator of changes to the trawl's catching efficiency. Ultimately, the WCUCS survey trawl and sampling protocol were modified, and there were changes in addition to what was judged "best" in this experiment. In the discussion, we compare the original standard survey trawl and towing protocols with the new standard trawl and procedures implemented beginning with the 1995 WCUCS survey. The relevance of these differences to the continuity of the slope survey time series is also discussed.

Methods

Research was conducted aboard the NOAA ship *Miller Freeman* between 30 October and 13 November 1994. The study area lies off the Oregon coast between lat. 45°05' and 45°36' N (Fig. 1), and depths within the sampling area ranged from 460 to 490 m. The bottom in the study area is flat or gently sloping, composed of soft mud, free of rocky reefs or obstructions, and was generally typical of areas sampled during the WCUCS survey.

As indicated previously, the study was conducted with the same trawl used for the slope surveys. The trawl, described by Lauth et al. (1997), was a high-opening 4-seam "Nor'eastern" trawl constructed of polyethylene mesh. The standard ground gear used 8-inch rubber disks strung on a 13 mm long-link chain attached to a 13 mm long-link chain fishing line. The total dry weight of the standard ground gear with fishing line was about 1,590 kg. The trawl doors used on the survey are 1.8 × 2.7 m V-doors weighing l,000 kg each. A single bridle, consisting of a pair of 3.05 m, 13 mm long-link chains, joined each door's aft pad eyes to the transfer line. The trawl wire on the *Miller Freeman* is 25 mm in diameter with a swedged wire core weighing 3 kg/m. Trawl warp lengths of 930 m were used with the standard slope trawl based on scope tables from the 1988–93 WCUCS surveys for a target depth of 465 m.

We suspected one cause of the trawl's poor performance was that the heavy ground gear was digging too hard into the soft mud seafloor resulting in excessive drag and the net loading up with mud. We chose as one modification to reduce the dry weight of the ground gear by 270 kg. This was done by: l) replacing the long-link chain running through the rubber disks with 19 mm cable, 2) removing the chain fishing line, and 3) attaching the ground gear directly to the footrope without toggles. Wire clamps were used instead of toggles to hold sections of the rubber cookies in place.

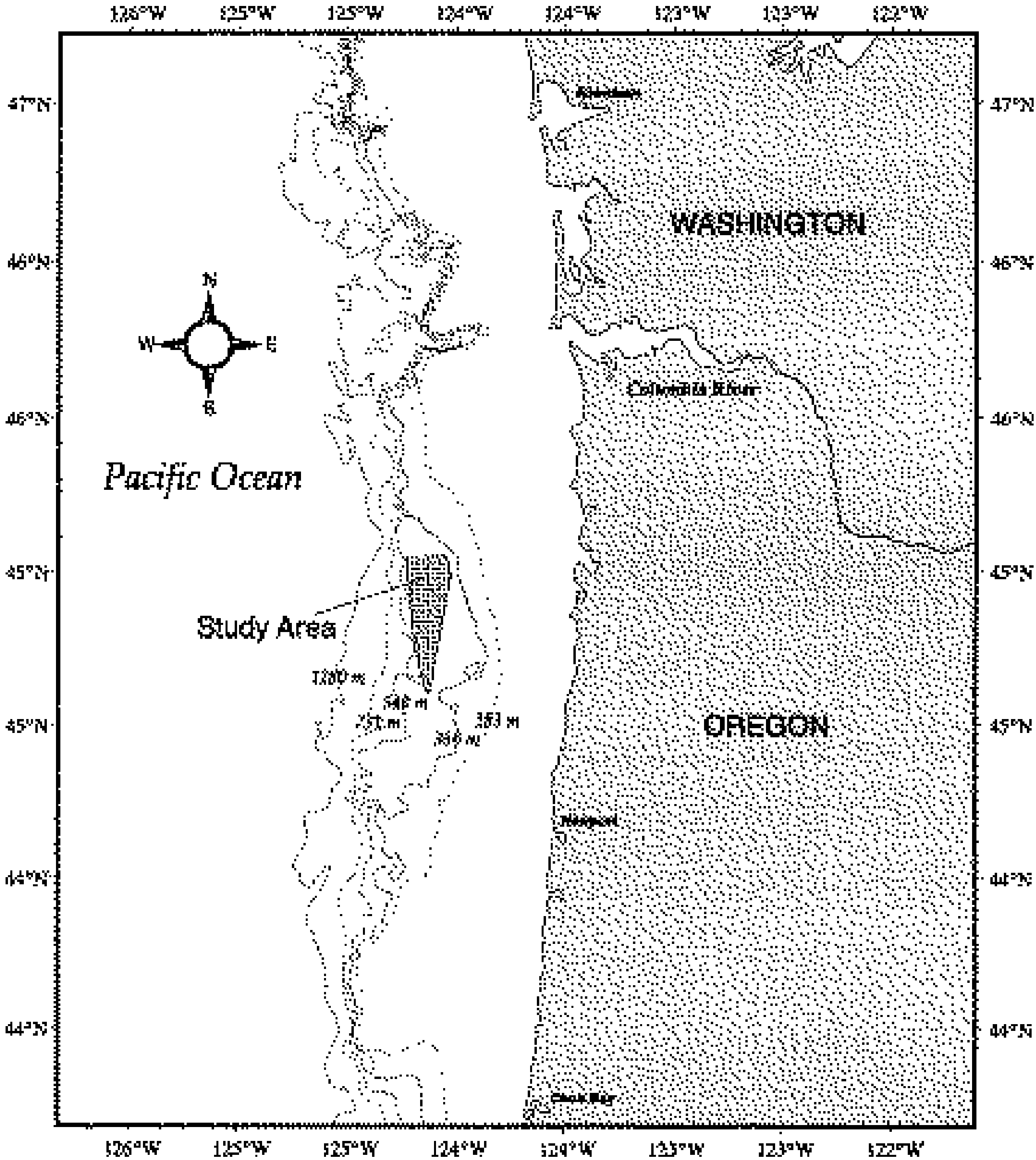


Figure 1.—Location of the 1994 west coast upper continental slope groundfish bottom trawl experiment.

Another concern was the weight of the trawl warps. Data collected at the beginning of this experiment established that an average of 617 m of wire was needed for the net to settle at a depth of 465 m at our standard towing speed of 3.7 km/h (2 knots). In the case of our standard trawl, which used 930 m of wire at that depth, the 300+ m of extra trawl wire was perhaps causing the doors to be unstable or possibly to fall over at slow towing speeds. As a compromise, a shorter scope of 767 m (617 m + 150 m) was chosen as a second modification for this experiment. This was sufficient wire to ensure that the net would not rise off the bottom with normal variations in sea conditions and vessel speed.

There were also indications from survey gear mensuration data and test-tank observations (Rose[1]) that doors with a single bridle were unstable and sometimes fell over at a 3.7 km/h towing speed. Many west coast fishermen use an additional forward bridle attachment to help stabilize the door at towing speeds less than 4 km/h. Consequently, it was decided to use the 2-bridle attachment as the third gear modification. The 2-bridle attachment has two pairs of 13 mm long-link chain, with 33 links leading from the forward, and 22 links from the aft pad eyes. To check the angle of the door relative to the ground (angle of attack), the doors were suspended by the bridle chains using a forklift and the angle was measured using an inclinometer. The door angle measured 40° before and after the cruise.

There were some aspects of the trawling procedure that were not well standardized for the 1988–93 surveys and had to be corrected prior to conducting the experiment. Especially important was the variability found during tests made after the 1993 survey in the performance of the ship's Rapp-Hydema[2] winch system. Because of inconsistencies in its two main functions (i.e. warp metering and pressure adjustment/balance on the warps), these functions were not used during the experiment. Instead, metering was accomplished by marking the warps and, rather than using the system's autotrawl function, winch brakes were set for the duration of each tow.

The experimental design used in this experiment was a 2 × 2 × 2 factorial within a randomized complete-block design. Twelve blocks were used with a total of 96 successful trawls. Within each block, each of the eight combinations of gear modifications (Table 1) was fished in a random order. Each block was completed before the next block was begun. The work was facilitated by the use of a dual net reel that held two trawls: one with "heavy" ground gear and one with "light" ground gear.

Sampling was done on a 24-h basis. Several electronic instruments were attached to the trawl to monitor its performance. A SCANMAR acoustic sensor was used to measure net height; that is, the distance from the center of the headrope to the bottom. SCANMAR sensors were also used to measure net width (distance between upper wing tips) and the distance between the doors. Also attached to the headrope were a Branker XL-200 data logger for measuring depth and temperature and a Furuno acoustic link netsounder for observing net height and the approximate position of the ground gear relative to the bottom. Tilt sensors were used for measuring door pitch and roll angles. They were attached to the backside middle of each door. Since the door tilt sensors were only capable of recording angles within a 90° arc, they were mounted in a way that allowed measurements of up to 45° on either side of the door's vertical axis. A bottom contact sensor was used to detect if the ground gear was in contact with the bottom. It was mounted on a triangular metal frame attached to the footrope where the lower breastline of the wing attaches to the footrope.

Table 1.—The 8 combinations (treatments) of gear modifications used for the 1994 west coast upper continental slope trawl survey gear experiment.

Treatment	Bridle (1 or 2)	Ground gear (Heavy or light)	Scope[1] (Long or short)
I[2]	1	Heavy	Long
II[2]	1	Heavy	Short
III	1	Light	Long
IV	1	Light	Short
V	2	Heavy	Long
VI	2	Heavy	Short
VII	2	Light	Long
VIII	2	Light	Short

[1] 930 m is the "long" and 767 m is the "short" "scope."
[2] 1-bridle door/heavy ground gear is the standard survey trawl.

Scientists, officers, and deck crew worked together to standardize fishing procedures. A scientist familiar with trawling was always present in the trawl house during fishing operations to monitor adherence to standardized protocols. Also, AFSC gear experts participated in the cruise to ensure that the trawl gear and associated rigging were properly maintained. Vessel speed while the trawl was being set was between 5.5 and 6.5 km/h. Vessel speed gradually decreased to 3.7 km/h at brakeset and this speed was maintained as closely as possible throughout each haul. The target duration of a trawl sample was 30 minutes. A haul began when the ground gear first touched bottom and ended when it lost contact with the bottom. The Furuno netsounder was used to monitor ground-gear contact during a haul, but actual bottom time was figured using the bottom contact sensor times after trawling was completed. If the gear was damaged or the trawl hung up, the haul was considered unsatisfactory and it was repeated in a different part of the study area. During the experiment, a new site was found for each trawl haul. Position data were collected at 6-sec intervals for each haul using a Global Positioning System (GPS) receiver. The position data were used to monitor ground speed, track the trawl's path, and estimate distance fished. Average speed of the vessel over ground and distance fished were calculated from the position data and the trawl's actual bottom time.

Gear performance was compared using data from the SCANMAR mensuration system and the bottom contact and door sensors. Samples of the catch from each haul were sorted to the lowest possible taxon, weighed, measured, and counted. Catch data were standardized by area swept (km^2). Area swept was calculated by multiplying the average net width by distance fished.

Analysis of variance was used to examine the effect of gear modifications on the engineering performance of the trawl (i.e. trawl dimensions, variation in trawl dimensions, and door attitude) and to determine if catch rates in terms of weight and number of each DWC species and invertebrates were affected

[1] Rose, Craig. NMFS Alaska Fisheries Science Center, Seattle, Wash. Personal commun., June 1994.

[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

by the gear modifications (Table 2). The independent, discrete variables in the analysis were DOOR, SCOPE, GROUND GEAR, and their two- and three-way interactions. The dependent variables used in the ANOVA included the trawl performance data and the catch per unit effort (CPUE) for the DWC species and invertebrates. But the dependent variable CPUE data did not satisfy the ANOVA assumptions of normality and homoscedasticity. Conover (1980: 337) presents one approach for dealing with this situation: that of ranking the dependent observations and then performing the usual parametric analysis on the nonparametric rank-transformed data. He states that when the results of analyses on both untransformed and rank transformed data differ substantially, "the analysis on ranks is probably more accurate than the analysis on the (untransformed) data and should be preferred." To compensate for differences among the blocks due to environmental factors, procedural variability, and other unknown sources of variation, each dependent variable value was assigned a rank from 1 to 8 within its block. Test results of all factors and interactions in the ANOVA model using ranked data are reported. After the statistically significant effects were identified using ranked data ($P < 0.05$), the analysis was repeated using the unranked data with the block effect added in the model. This was done to obtain a measure of the effect on catch rates due to the significant variables.

Table 2.—List of variables included in analysis of variance (ANOVA) of trawl performance and trawl catch. Trawl catch rates were assigned ranks from 1 to 8 within each block.

Dependent variables	Discrete independent variables
Trawl performance	
Average door spread (m)	
Average net width (m)	
Average net height (m)	
S. D. door spread (m)	Door
S. D. net width (m)	Scope
S. D. net height (m)	Ground gear
Port roll angle (deg.)	Door × Scope
Port pitch angle (deg.)	Door × Ground gear
Starboard roll angle (deg.)	Scope × Ground gear
Starboard pitch angle (deg.)	Door × Ground gear × Scope
Trawl catch rates	
Ranked weight CPUE (kg/km^2)	
Ranked number CPUE (no./km^2)	

Results

General Description of Trawl Performance

The performance of the standard trawl configuration (1-bridle/heavy) was highly variable; this was true for both long and short scopes (Fig. 2, 3). The 1-bridle/heavy treatment was the most variable of the 8 combinations. Net widths for these treatments would commonly bounce between 8 m and 20 m, and door bails often came up with mud on them indicating that doors fell over during some tows. During some of the tows the trawl closed down to about 8 m and stayed at that width for the rest of the tow.

Trawl performance was more stable with the addition of either the 2-bridle door (Fig. 6–9) or the light ground gear (Fig. 4, 5, 8, and 9) regardless of scope length. There was relatively little variability in gear dimensions for the 2-bridle door/light ground gear combination. The lighter ground gear appeared to reduce drag and put less strain on the doors as indicated by reduced pitch and roll angles (Table 3). A negative aspect of the 2-bridle door and light groundgear combination was its apparently poor bottom contact. This is evident from the sporadic increases in net height in many hauls (Fig. 8, 9), and in the data on bottom contact (Fig. 10).

Average door pitch and roll angle data (Table 3) were obtained for most hauls. The average roll angle for the standard trawl (1-bridle/heavy) ranged from 33.1° to 37.1° towards the bail side of the door. However, these average angles were artificially low because the door tilt sensors did not record angles exceeding 45°. Mud present on the door bails, as well as the variability observed in the plots of net dimensions, suggest that the doors were falling over during hauls with the standard trawl configuration. The mean door roll angle for the 2-bridle/heavy combination was less than that for the 1-bridle/heavy and ranged from 23.0° to 28.7°. There was no evidence that doors used with the 2-bridle/heavy combination fell over. With the light ground gear, door roll angles were much less than with the heavy gear for both the 1-bridle and 2-bridle doors. Mean angles for the light ground gear ranged from 8.8° toward the bail side to 5.4° toward the bridle side.

Door pitch angles also varied among the types of gear modification (Table 3). Average pitch angles for the 1-bridle door were less than the 2-bridle door for all treatments. The average pitch angle for the 2-bridle door ranged from 14.4° to 16.9° and it remained relatively constant with changes in scope or ground gear. The average pitch angle for the 1-bridle door ranged from 1.0° to 13°. Unlike the 2-bridle door, average pitch angle decreased considerably with the use of the light ground gear. Ranges decreased from 9° to 13° for the 1-bridle/heavy to 1.0° to 5.5° for the 1-bridle/light. Like the 2-bridle door, scope length had little effect on average pitch angle.

Bottom contact of the ground gear was another means of assessing trawl performance. Bottom contact data were obtained for 81 hauls (Fig. 10). The bottom contact sensor only measured the occurrence of contact and not the degree or angle of contact. In general, contact was acceptable for all the combinations of gear modifications except the 2-bridle/light/long and 2-bridle/light/short. With these two combinations, the ground gear frequently lost contact with the bottom. As indicated previously, the variable bottom contact for the 2-bridle/ light combination can also be seen in Figures 8 and 9 where net height suddenly increases as a result of the net lifting off bottom. Close comparison of the graphs in Figure 10 with those in Figures 8 and 9 shows the correspondence between loss of bottom contact and increases in net height.

Trawl Performance ANOVA

The overall means, ranges, and standard deviations of the dependent variables included in the ANOVA are listed in Table 4 and the statistical results are shown in Table 5. The ANOVA of trawl performance data corroborates what was presented in the section describing general trawl performance. The most important factor affecting trawl performance was the interaction between the door bridle and ground gear (Table 5). The DOOR ×

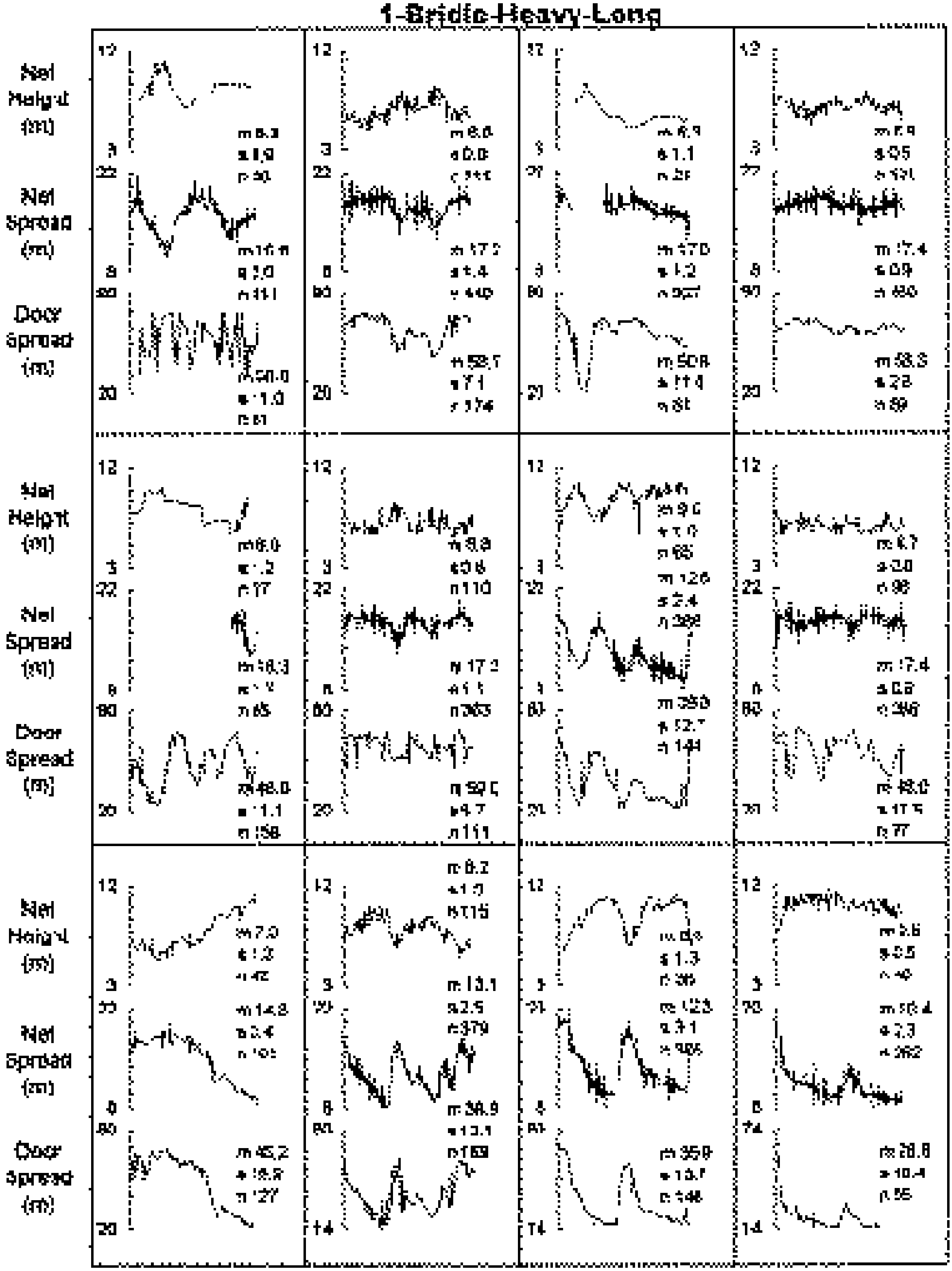


Figure 2.—SCANMAR net height, net width, and door spread during the course of each tow for the 1-bridle-heavy-long gear treatment (m=average, s=standard deviation, n=number of observations).

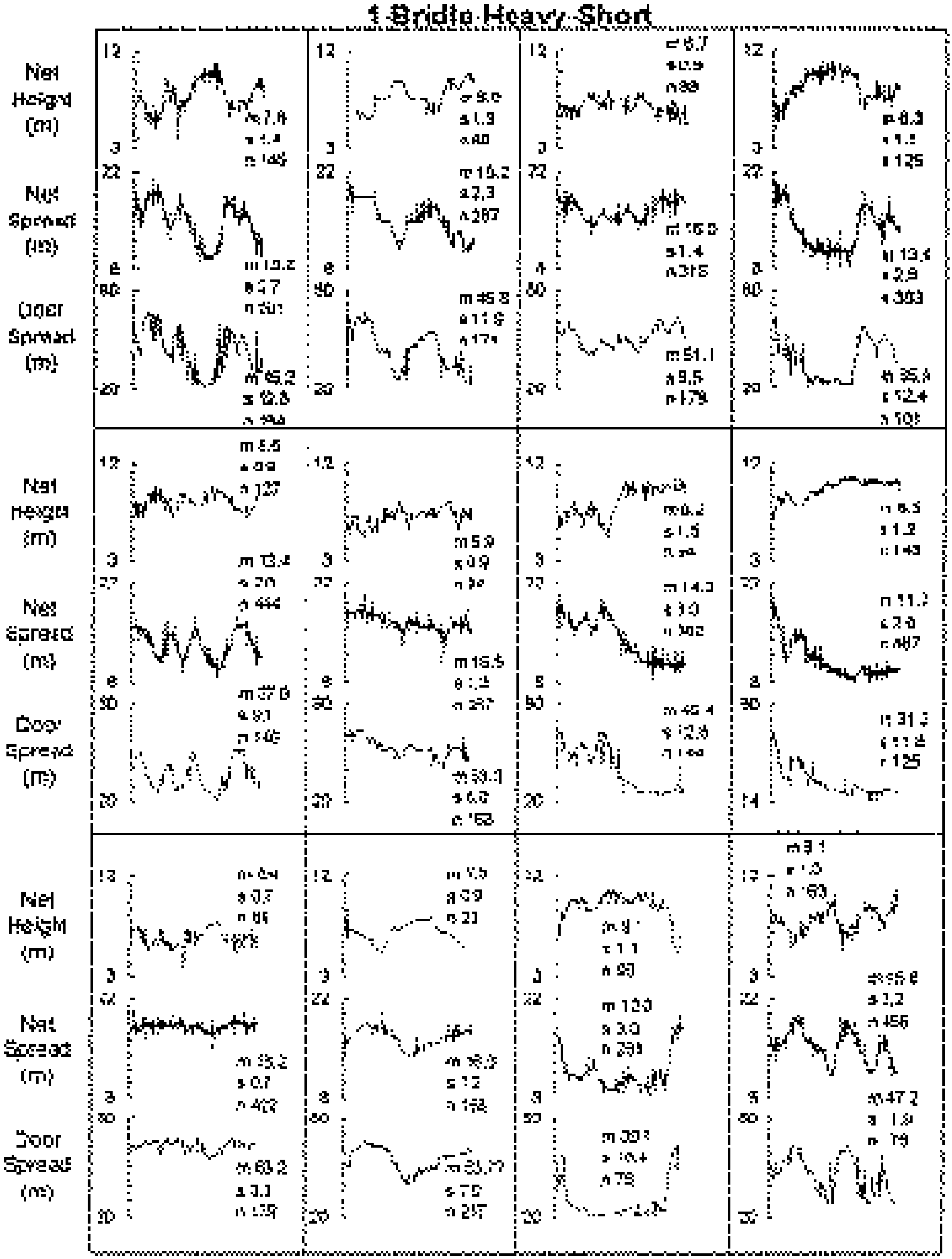


Figure 3.—SCANMAR net height, net width, and door spread during the course of each tow for the 1-bridle-heavy-short gear treatment (m=average, s=standard deviation, n=number of observations).

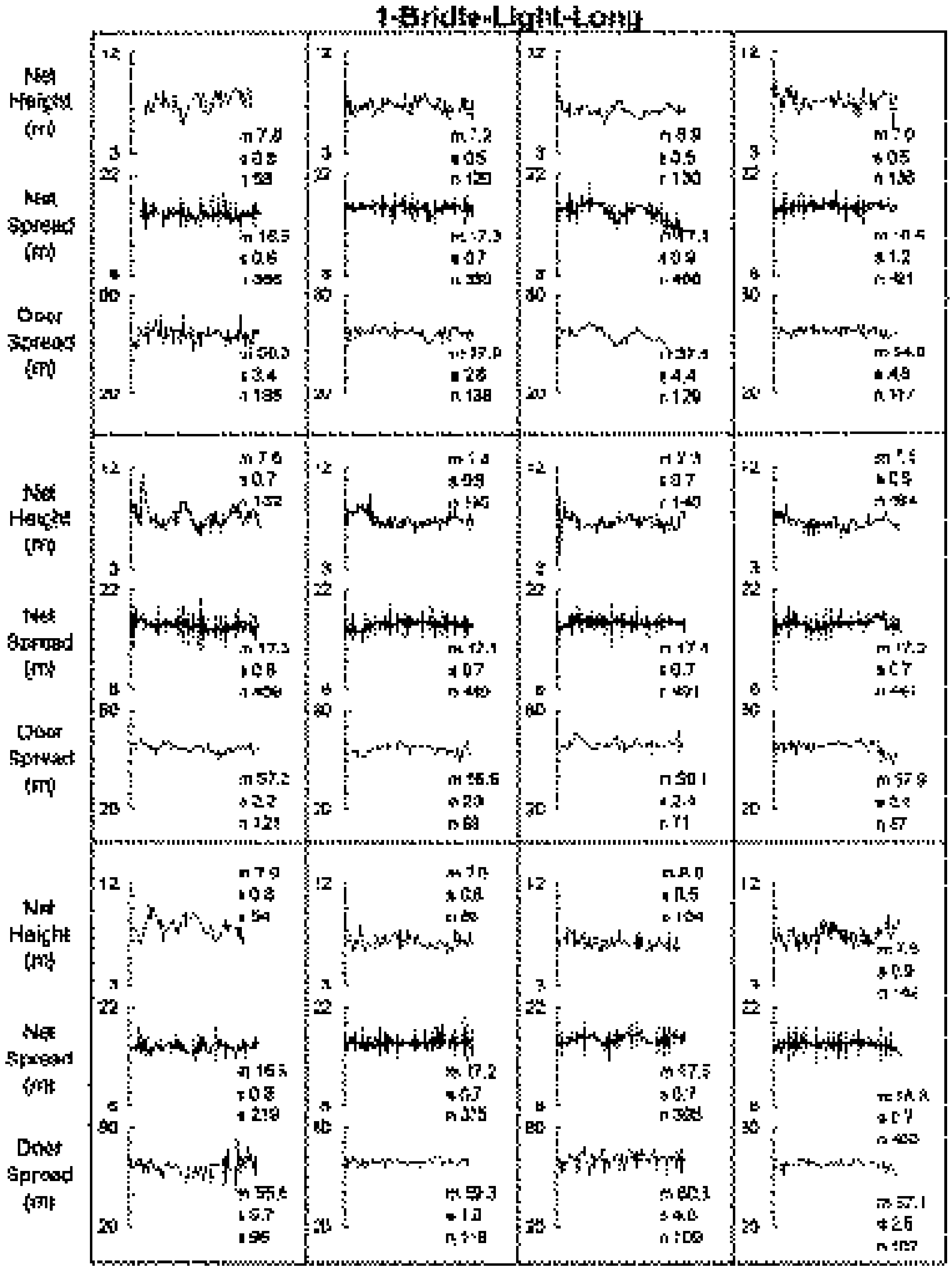


Figure 4.—SCANMAR net height, net width, and door spread during the course of each tow for the 1-bridle-light-long gear treatment (m=average, s=standard deviation, n=number of observations).

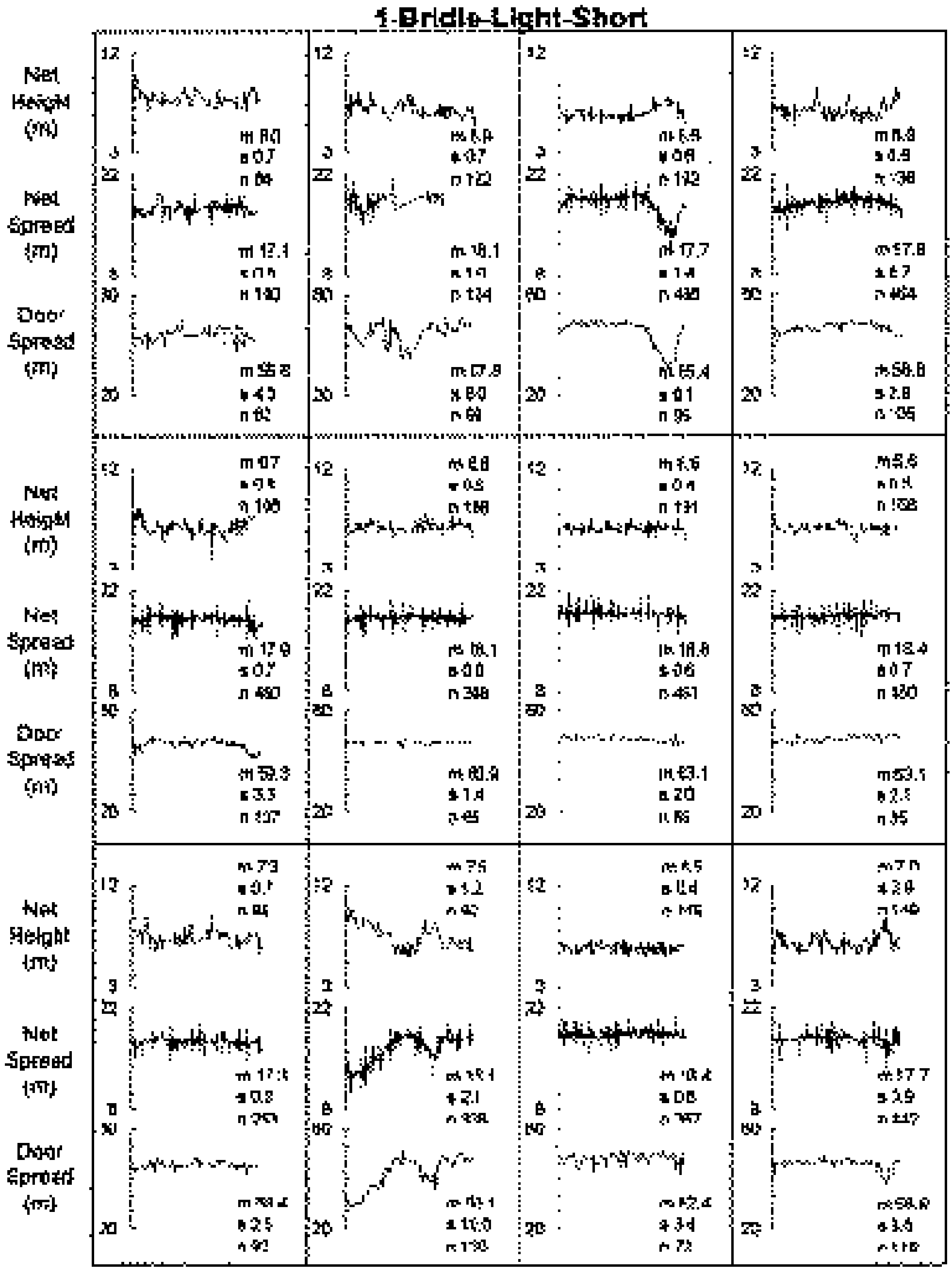


Figure 5.—SCANMAR net height, net width, and door spread during the course of each tow for the 1-bridle-light-short gear treatment (m=average, s=standard deviation, n=number of observations).

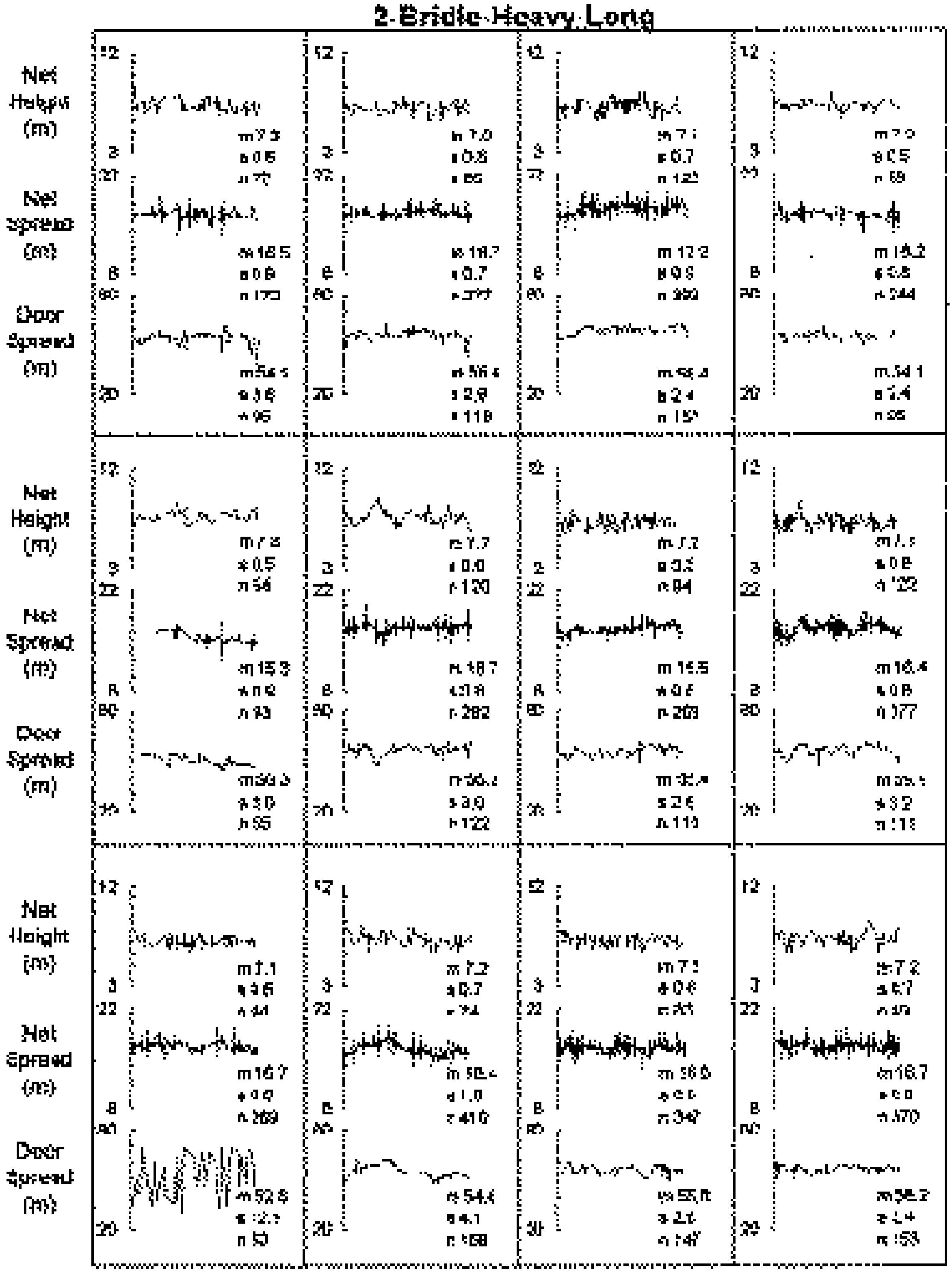


Figure 6.—SCANMAR net height, net width, and door spread during the course of each tow for the 2-bridle-heavy-long gear treatment (m=average, s=standard deviation, n=number of observations).

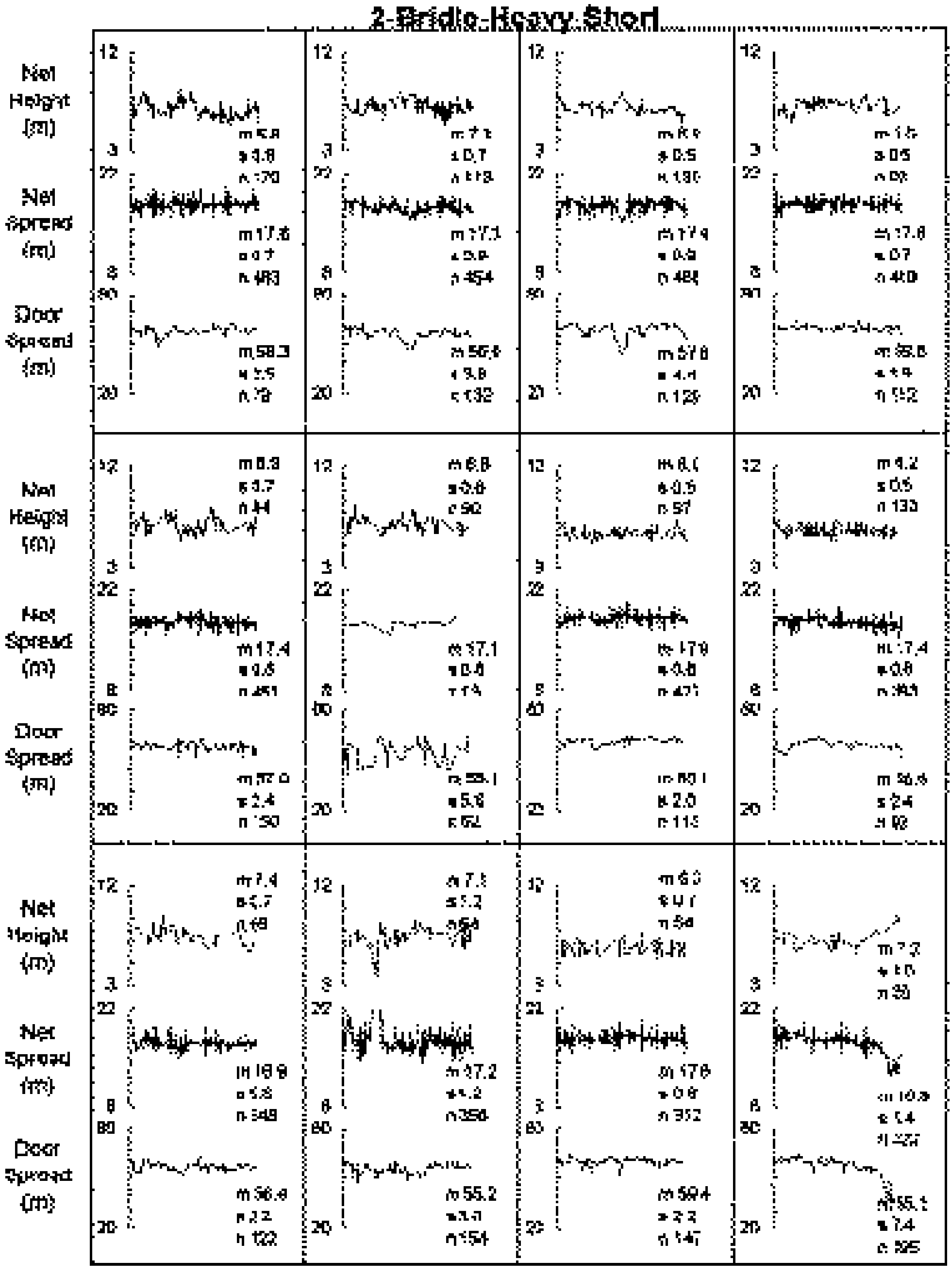


Figure 7.—SCANMAR net height, net width, and door spread during the course of each tow for the 2-bridle-heavy-short gear treatment (m=average, s=standard deviation, n=number of observations).

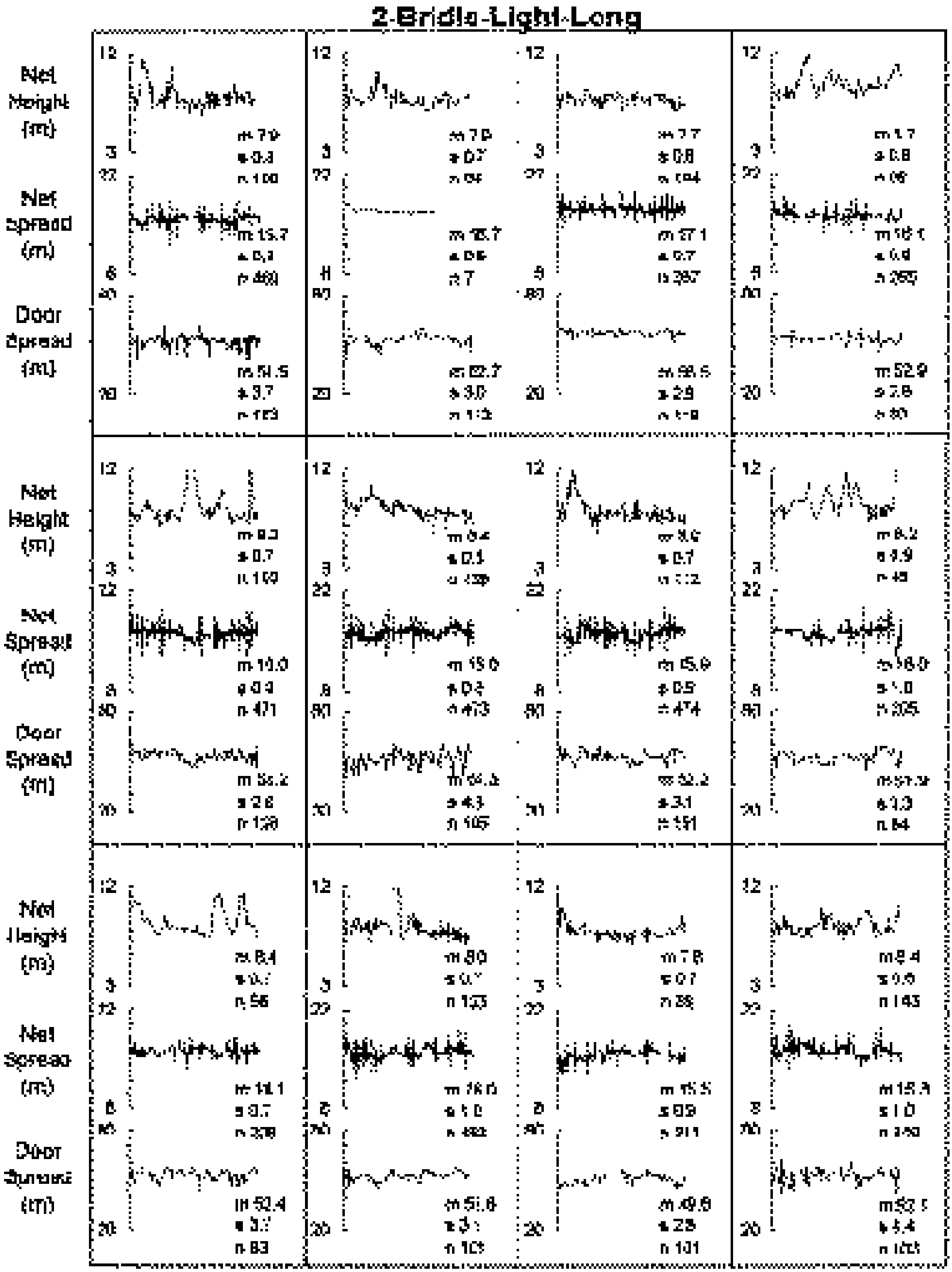


Figure 8.—SCANMAR net height, net width, and door spread during the course of each tow for the 2-bridle-light-long gear treatment (m=average, s=standard deviation, n=number of observations).

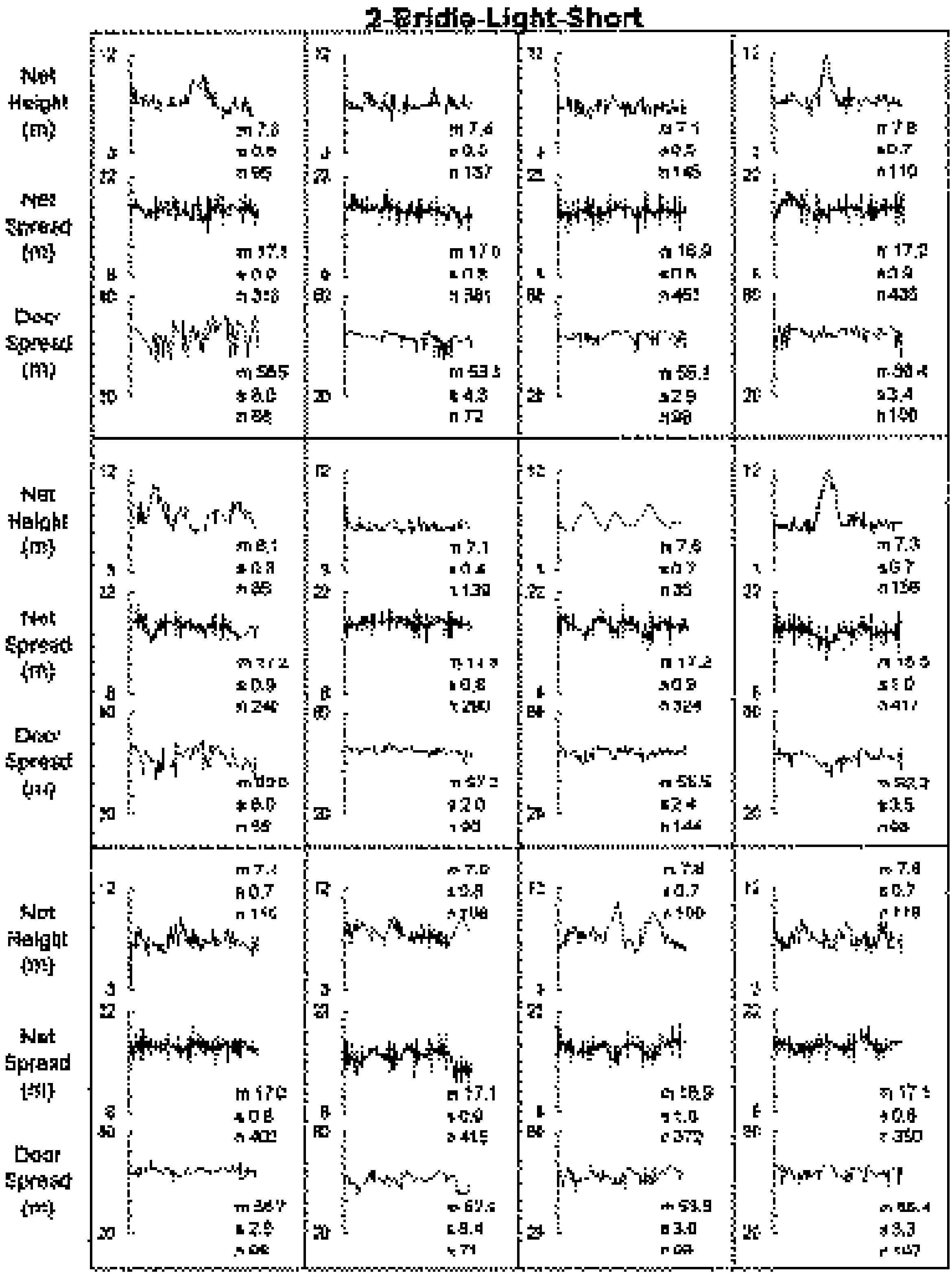


Figure 9.—SCANMAR net height, net width, and door spread during the course of each tow for the 2-bridle-light-short gear treatment (m=average, s=standard deviation, n=number of observations).

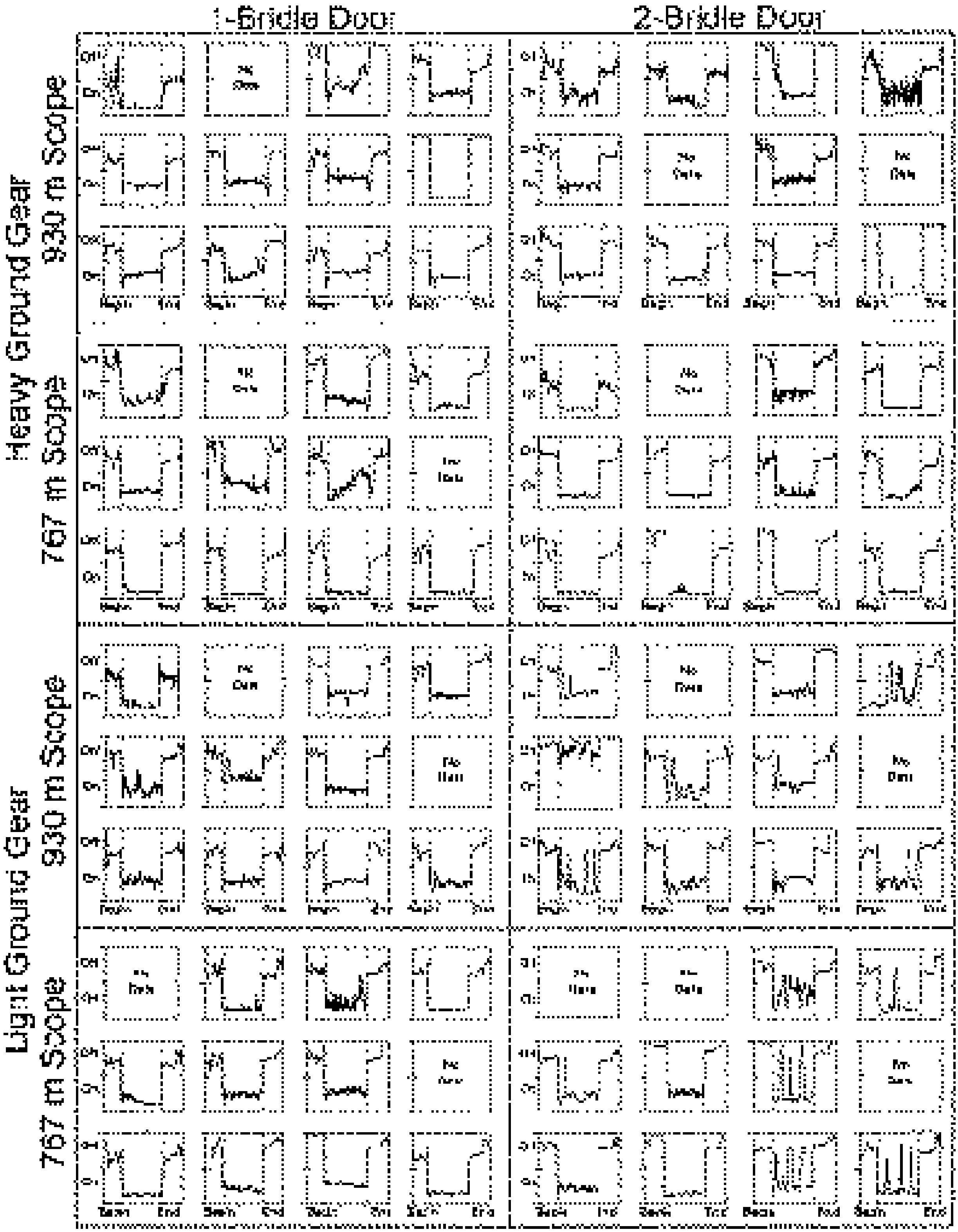


Figure 10.—Bottom contact during the course of each experimental tow grouped by gear treatment.

GROUND GEAR interaction was highly significant for all of the trawl performance variables. This means that the effect of ground gear was different depending on which door was used and vice versa.

Average net width and door spread were wider with the light ground gear when using the 1-bridle door (Fig. 11). The opposite was true for the 2-bridle door. Similarly, the average net width and door spread were wider with the 2-bridle door when using the heavy ground gear but the converse was true for the light ground gear. The DOOR × GROUND GEAR interaction for average net height was the inverse of average net width and door spread.

The standard deviation of net width, net height, and door spread all had a similar DOOR × GROUND GEAR interaction (Fig. 12). Trawl dimensions were more variable for the heavier ground gear when combined with the 1-bridle door. Compare this to the 2-bridle door, which had no difference between the two ground gear treatments. The 1-bridle door also had more variable trawl dimensions than the 2-bridle door, but only when using the heavy ground gear.

Both types of doors had greater pitch angles with the heavy ground gear (Fig. 13), and the 2-bridle door had greater pitch angles with either ground gear compared to the 1-bridle door. Roll angles were also greater with the heavy ground gear and the 1-bridle door roll angle was greater than the 2-bridle door with the heavy ground gear. There was not as much difference between the two door bridles when the light ground gear was used.

Scope was a significant main effect for average net width, average net height, and the door roll angle (Fig. 11, 13). Average net widths and port and starboard roll angles increased and average net height decreased with shorter scope.

Table 3.—Average port and starboard roll and pitch-angle data by tow and by treatment. Positive roll angles indicate roll toward the bail-side of the door and positive pitch angles indicate that the front end is elevated relative to rear.

		Heavy ground gear				Light ground gear			
		Scope 930 m		Scope 767 m		Scope 930 m		Scope 767 m	
Tilt sensor	Block	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle
Starboard roll	1		22.5	33.3	19.1		–1.4	7.8	–1.2
	2	25.0	19.8	40.0	34.2	2.8	5.0	17.5	15.3
	3	25.8	20.0	40.9	33.3	–10.8	15.8	4.8	2.6
	4	20.4	17.2	37.6	25.8				–1.0
	5		19.2	40.9	28.8	–4.1		9.0	17.4
	6	41.4	40.9	37.3	22.8	36.1	4.1	–1.9	39.8
	7	38.5	37.4	41.3	39.0	–5.3	1.7		3.9
	8	31.0			18.5				
	9	30.1	20.6	13.8	25.6	–2.2	1.2	–0.9	6.5
	10	38.4	17.6	27.3	23.9	–7.0	4.0	18.2	8.1
	11	39.5	19.0	39.6	19.5	4.2	4.9	8.3	4.1
	12	41.1	21.2	35.4	22.2	–2.0	1.2	–2.4	0.8
	Mean	33.1	23.2	35.2	26.0	1.3	4.1	6.7	8.8
	S.D.	7.6	8.0	8.2	6.6	13.8	4.9	7.7	11.9
Port roll	1		18.3	35.2	20.3		6.9	3.1	2.9
	2	45.0	19.0	34.7	34.7	–8.6		–4.0	4.4
	3	26.5	31.5	33.6	34.0	–19.4	8.5	–4.8	
	4	12.8	21.7	40.7	32.4		–2.0	–3.0	9.9
	5	32.9	13.8	43.0	29.9	0.0	5.2	14.0	15.3
	6	32.0	30.5	32.5	23.4	–16.4	0.2	–11.2	6.0
	7	40.0	21.0	40.0	24.0	–8.0	4.2	5.0	–1.4
	8	26.7			22.9				
	9	32.5	21.8	28.7	34.7	11.6	9.9		13.9
	10	36.8	26.0	37.4	31.6	–4.4	3.2	20.9	10.6
	11	41.9	22.5	41.7	24.2	–3.5	1.6	3.9	–1.5
	12	44.1	27.4	40.3	32.6	–0.1	–1.3	–1.1	0.8
	Mean	33.7	23.0	37.1	28.7	–5.4	3.6	3.0	6.1
	S.D.	9.5	5.4	4.5	5.3	9.2	4.0	9.5	6.1
Starboard pitch	1		17.0	14.3	15.7		15.4	7.2	15.1
	2	14.0	16.7	15.3	17.9	6.1	15.2	8.1	13.8
	3	13.8	18.9	15.7	19.1	4.2	14.1	3.1	14.8
	4	11.2	16.1		17.8		14.9	4.9	14.2
	5	13.9	15.0	13.4	15.5	1.3	15.5	5.0	12.5
	6	14.6	16.9	14.2	15.0	4.9	15.5	5.2	14.7
	7	7.9	10.1	7.2	11.3	5.5	15.5	–0.9	15.5
	8	16.5			18.4				
	9	13.2	16.5	9.7	15.2	4.5	13.3	5.2	12.1
	10	14.9	18.7	10.5	20.7	5.2	15.7	7.2	14.1
	11	12.1	19.0	13.6	19.6	7.2	16.1	9.9	16.5
	12	8.8	17.5	16.3	17.1	6.2	14.4	6.2	15.0
	Mean	12.8	16.6	13.0	16.9	5.0	15.0	5.5	14.4
	S.D.	2.6	2.5	2.9	2.6	1.7	0.8	2.8	1.3
Port pitch	1		15.1	11.0	14.7		16.7	1.0	15.9
	2	10.4	16.5	10.7		1.1	15.2	1.2	
	3	10.2	18.3	13.6	19.0	–1.3	18.4	3.1	15.7
	4	5.6	16.5				16.6	0.7	
	5	8.6	12.7	5.3	13.3	2.0	16.4	3.1	14.0
	6	10.3	14.9	9.3	15.2	–1.9			15.0
	7	4.6	14.6	2.4	16.9		15.8	3.4	
	8								
	9		18.0						
	10	13.4	18.1	17.5	14.0	1.3	17.3	7.4	16.6
	11	8.6		11.0	17.5	4.8	16.6	3.1	16.9
	12								
	Mean	9.0	16.1	10.1	15.8	1.0	16.6	2.9	15.7
	S.D.	2.8	1.9	4.7	2.0	2.4	1.0	2.1	1.0

Trawl Catch ANOVA

Tables 6 and 7 list the unranked number and weight CPUE data by DWC species and by haul and also give the mean and standard deviation by treatment.

The most important factor affecting trawl catches was the discrete variable GROUND GEAR (Table 8). Catch rates for all the DWC species and the invertebrates were significantly higher in terms of weight and number with the heavier ground gear (Fig. 14–18).

The scope length had an effect on longspine thornyhead ranked number CPUE and invertebrate ranked weight

Table 4.—Means, ranges, and standard deviations of variables used in analysis of variance to test the effects of gear modifications on trawl performance.

		Range		
Variable	Mean	Min.	Max.	S.D.
Average door spread (m)	53.6	29.8	63.2	6.52
Average net width (m)	16.5	9.3	18.8	1.53
Average net height (m)	7.6	6.2	10.1	0.78
S.D. door spread (m)	5.4	1.4	17.4	4.09
S.D. net width (m)	1.1	0.5	3.4	0.68
S.D. net height (m)	0.8	0.4	1.5	0.23
Port roll angle (deg.)	16.2	–5.4	37.1	16.25
Port pitch angle (deg.)	10.9	1.0	16.6	6.25
Starboard roll angle (deg.)	17.3	1.3	35.2	13.62
Starboard pitch angle (deg.)	12.4	5.0	16.9	4.65

CPUE. Catch rates were higher in both cases with the long scope. Table 9 lists the cumulative weight of all major invertebrates from all hauls combined in descending order of abundance. The five most common invertebrates in trawl catches were unidentified sea anemones (order Actiniaria), the orange-pink sea urchin, *Allocentrotus fragilis*; *Psiliaster pectinatus*; clay-pipe sponge, *Aphrocallistes vastus*; and *Myxoderma platyacanthum rhomaleum*.

The only instance where the DOOR × SCOPE interaction was significant was for shortspine thornyhead ranked weight CPUE. Shortspine thornyhead had higher catches for the 2-bridle/short compared to the 1-bridle/short treatment (Fig. 17). Differences between the 1-bridle/long and short, 2-bridle/long and short, and between the 1-bridle/long and 2-bridle/long treatments were not remarkable.

Dover sole ranked number CPUE had a significant DOOR × GROUND GEAR interaction. Catches were significantly higher with the heavy ground gear when using the 1-bridle but not the 2-bridle door. The 1-bridle/heavy treatment also caught significantly more Dover sole than the 2-bridle/heavy treatment but the same was not true for the light ground gear. In all other cases, the DOOR effect and all other interaction terms were not significant at a level of $\alpha = 0.05$.

Discussion and Summary

The primary objective of the gear experiment was to learn about the behavior of the standard survey trawl and to use this information as a basis for recommending changes to the trawl and associated fishing procedures. Based on the results, we rejected the null hypothesis that trawl performance was equal among all combinations of the three gear modifications. The experiment showed that variability in trawl dimensions decreased after modifications to the door bridle attachment and ground gear weight. Of the eight combinations of gear modifications, there was no doubt that, regardless of scope length, the 2-bridle/heavy and the 1-bridle/light had the most consistent performance. Net dimensions remained steady, door roll and pitch decreased, and the doors did not fall over onto the bottom. The poorest performing configuration was the standard trawl (1-bridle/heavy) which behaved inconsistently with either scope length; that is, door spread and net width oscillated significantly and the doors frequently fell over. In spite of the standard trawl's erratic performance, catch rates of all four DWC species and invertebrates were not significantly different than the 2-bridle/heavy combinations, which did the best in terms of engineering performance. These results support the thesis that catch rates for the standard trawl and the 2-bridle/heavy are the same. All combinations with the light ground gear performed well, but bottom contact was poor with the 2-bridle door and catch rates were significantly lower for all DWC species and invertebrates. This experiment clearly showed that reducing the weight of the ground gear affected the capturing efficiency of the trawl.

Physical differences between the two ground gears we compared were minor except for a 270 kg difference in dry weight. Yet we observed a major difference in how each of the two ground gears tended bottom and caught fish. Poor bottom contact of the 2-bridle/light treatment was obvious, and escapement under the ground gear may be one rea-

Table 5.—Results of ANOVA testing the effects of gear modifications on trawl performance.

Item	Deg. free-dom	Mean square	F-Statistic	P-Value
Average net width (m)				
Block	11	1.53	1.05	0.41
Door	1	6.96	4.77	0.03
Scope	1	9.94	6.81	0.01
Ground gear	1	24.41	16.72	<0.0001
Door × Scope	1	2.14	1.47	0.23
Door × Ground gear	1	45.52	31.18	<0.0001
Scope × Ground gear	1	1.37	0.94	0.34
Door × Scope × Ground gear	1	1.52	1.04	0.31
Residual error	77	1.46		
Average net height (m)				
Block	11	0.55	1.39	0.19
Door	1	0.00	0.00	0.99
Scope	1	3.71	9.38	0.003
Ground gear	1	0.37	0.92	0.34
Door × Scope	1	1.25	3.16	0.08
Door × Ground gear	1	14.55	36.77	<0.0001
Scope × Ground gear	1	1.01	2.55	0.11
Door × Scope × Ground gear	1	0.00	0.00	0.99
Residual error	77	1.50		
Average door spread (m)				
Block	11	18.48	0.72	0.72
Door	1	149.73	5.81	0.02
Scope	1	46.50	1.80	0.18
Ground gear	1	501.47	19.44	<0.0001
Door × Scope	1	46.19	1.79	0.18
Door × Ground gear	1	1,081.72	41.94	<0.0001
Scope × Ground gear	1	11.45	0.44	0.51
Door × Scope × Ground gear	1	7.39	0.29	0.59
Residual error	77	25.79		
S.D. net width (m)				
Block	11	0.19	0.85	0.59
Door	1	8.60	39.17	<0.0001
Scope	1	0.24	1.08	0.30
Ground gear	1	8.20	37.34	<0.0001
Door × Scope	1	0.10	0.44	0.51
Door × Ground gear	1	8.31	37.88	<0.0001
Scope × Ground gear	1	0.02	0.07	0.79
Door × Scope × Ground gear	1	0.00	0.01	0.92
Residual error	77	0.22		
S.D. net height (m)				
Block	11	0.03	1.15	0.33
Door	1	0.70	23.20	<0.0001
Scope	1	0.10	3.37	0.07
Ground gear	1	0.67	22.08	<0.0001
Door × Scope	1	0.02	0.66	0.42
Door × Ground gear	1	0.73	23.99	<0.0001
Scope × Ground gear	1	0.08	2.53	0.12
Door × Scope × Ground gear	1	0.00	0.10	0.75
Residual error	77	0.03		
S.D. door spread (m)				
Block	11	6.48	0.78	0.66
Door	1	276.25	33.21	<0.0001
Scope	1	0.38	0.05	0.83
Ground gear	1	280.41	33.71	<0.0001
Door × Scope	1	0.00	0.00	0.98
Door × Ground gear	1	297.76	35.80	<0.0001
Scope × Ground gear	1	19.36	2.33	0.13
Door × Scope × Ground gear	1	0.49	0.06	0.81
Residual error	77	8.32		
Port pitch angle				
Block	9	13.40	2.71	0.01
Door	1	1,527.37	308.79	<0.0001
Scope	1	1.62	0.33	0.57
Ground gear	1	215.75	43.62	<0.0001
Door × Scope	1	18.77	3.80	0.06
Door × Ground gear	1	233.94	47.30	<0.0001
Scope × Ground gear	1	0.06	0.01	0.91
Door × Scope × Ground gear	1	2.43	0.49	0.49
Residual error	44	4.95		
Starboard pitch angle				
Block	11	16.86	4.85	<0.0001
Door	1	941.32	271.06	<0.0001
Scope	1	0.64	0.18	0.67
Ground gear	1	499.31	143.78	<0.0001
Door × Scope	1	1.73	0.50	0.48
Door × Ground gear	1	170.03	48.96	<0.0001
Scope × Ground gear	1	0.02	0.00	0.95
Door × Scope × Ground gear	1	1.02	0.29	0.59
Residual error	67	3.47		
Port roll angle				
Block	11	69.10	1.60	0.12
Door	1	41.75	0.97	0.33
Scope	1	612.35	14.15	0.0004
Ground gear	1	17,047.58	394.02	<0.0001
Door × Scope	1	23.49	0.54	0.46
Door × Ground gear	1	1,160.63	26.83	<0.0001
Scope × Ground gear	1	1.01	0.02	0.88
Door × Scope × Ground gear	1	87.53	2.02	0.16
Residual error	65	43.27		
Starboard roll angle				
Block	11	143.06	2.07	0.04
Door	1	215.54	3.13	0.08
Scope	1	343.06	4.97	0.03
Ground gear	1	11,763.82	170.58	<0.0001
Door × Scope	1	0.06	0.00	0.98
Door × Ground gear	1	744.44	10.79	0.002
Scope × Ground gear	1	47.97	0.70	0.41
Door × Scope × Ground gear	1	8.04	0.12	0.73
Residual error	63	68.96		

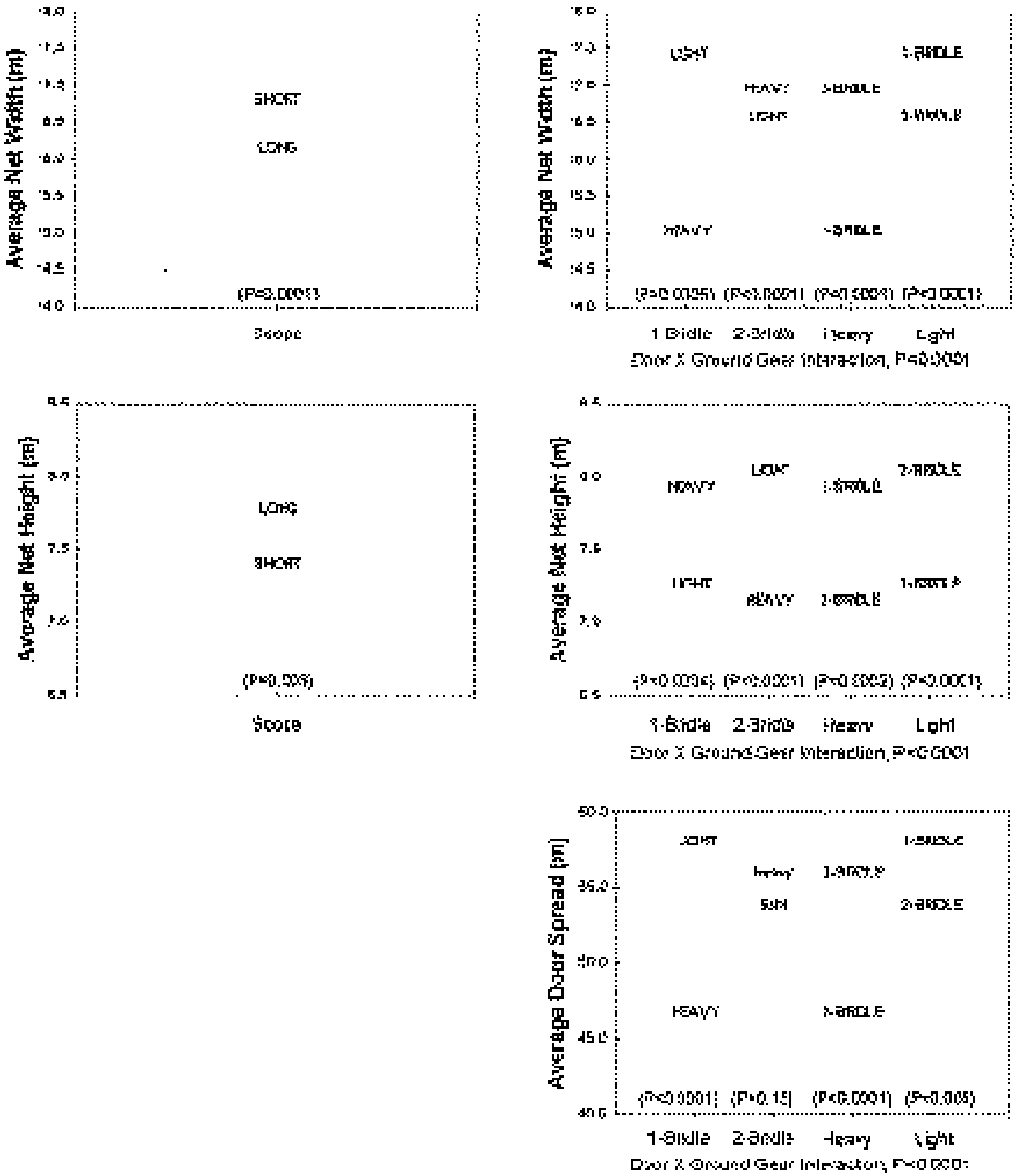


Figure 11.—Results of ANOVA to test the effects of the gear treatments and their interactions on the means of door spread, net width, and net height. Statistically significant effects (P<0.05) are with uppercase letters.

son for its lower catch rates. We did not detect the ground gear rising off bottom during the 1-bridle/light treatments, but the contact may have been lighter than with the heavy ground gear, allowing more fish escapement.

The most obvious and direct way fish escape trawl capture is through gaps between the ground gear and bottom or between the ground gear and footrope. The size of those gaps depends on trawl dimensions, bottom contact, and the length of drop chains connecting the ground gear to the footrope. Canadian, European, and U.S. researchers have attempted to estimate fish escapement beneath trawls by using a series of trawl bags underneath the ground gear (Engås and Godø, 1989; Dahm and Wienbeck, 1992; Godø and Walsh, 1992; Walsh, 1992; Munro et al., 1997; Weinberg and Munro[3]). Escapement greater than 50% for some groundfish species has been observed (Engås and Godø, 1989; Dahm and Wienbeck, 1992; Godø and Walsh, 1992; Walsh 1992).

Engås et al. (1988) compared the effects of two very different types of ground gear on a Norwegian survey trawl and found that the rockhopper ground gear caught haddock and small cod more effectively than a trawl with bobbins. Different visual or acoustic signals produced by the two ground gear types may also affect catching efficiency. Main and Sangster (1983) studied the effects of light and heavy ground gear on a North Sea trawl. Divers made direct observations comparing heavier bobbin roller gear and light "grass" ground gear and found that the bobbin roller gear was more easily seen and noisier. They concluded that visual and acoustic cues could affect the reactions of fishes to the gear.

Ground gear can also indirectly affect fish catching efficiency by influencing trawl performance. Each DWC species may react differently to an oncoming trawl depending on their general behavior and what aspect of the trawl is encountered. A ground gear change can alter the dynamics of the entire trawl system and the way a fish reacts to it. For example, the heavy ground gear of the WCUCS trawl put considerable strain on the doors, resulting in more extreme roll and pitch angles. Doors fell over with the 1-bridle/heavy treatment, and the door spread and net width were narrower and more erratic. Sablefish show more off-bottom behavior (Adams et al., 1995) and they are powerful swimmers capable of long migrations (Shaw and Parks, 1997). Thornyheads, on the other hand, are sedentary, are frequently observed in depressions or next to objects, and move little unless disturbed (Wakefield, 1990; Krieger, 1993). Sablefish could escape using any number of routes around the side, over the top, or under the ground gear. In

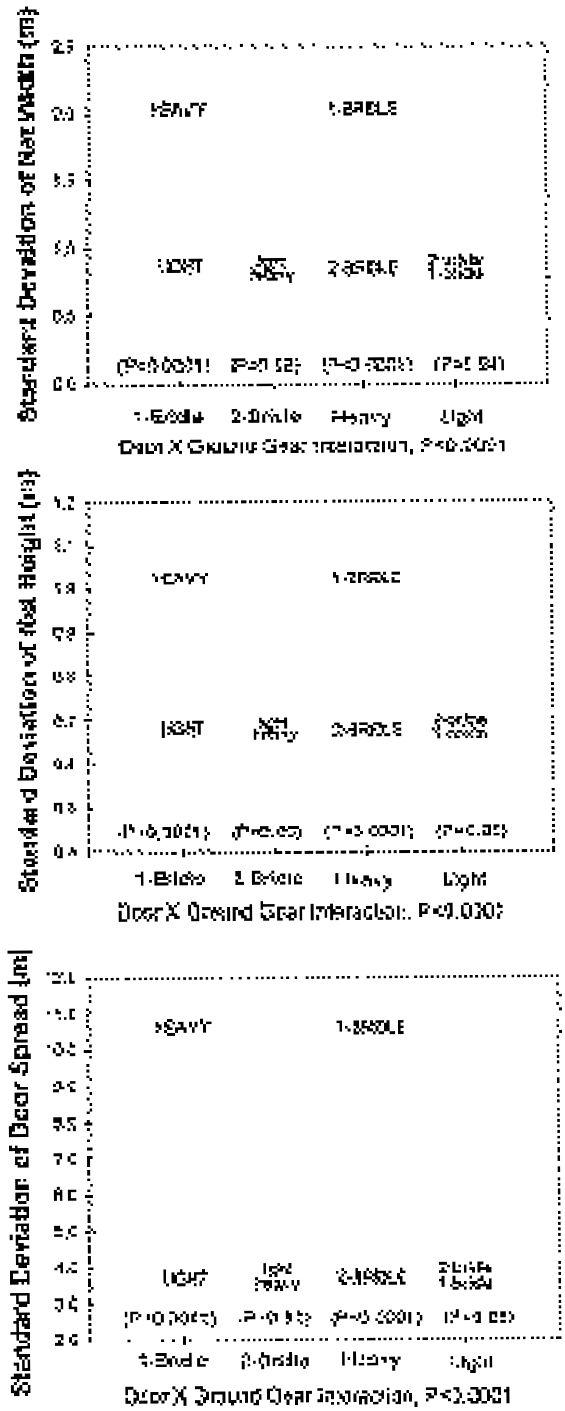
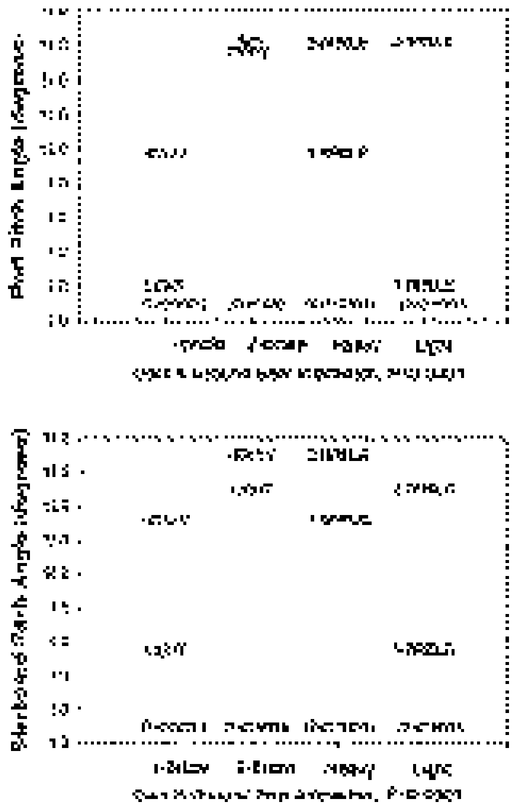


Figure 12.—Results of ANOVA to test the effects of the gear treatments and their interactions on the standard deviations of door spread, net width, and net height. Statistically significant effects (P<0.05) are with uppercase letters.

[3] Weinberg, K. L., and P. T. Munro. The effect of artificial light on escapement beneath a survey trawl. Unpubl. manusc., 20 p. Avail. at Alaska Fish. Sci. Cent., 7600 Sand Point Way N.E., Seattle, WA 98115.



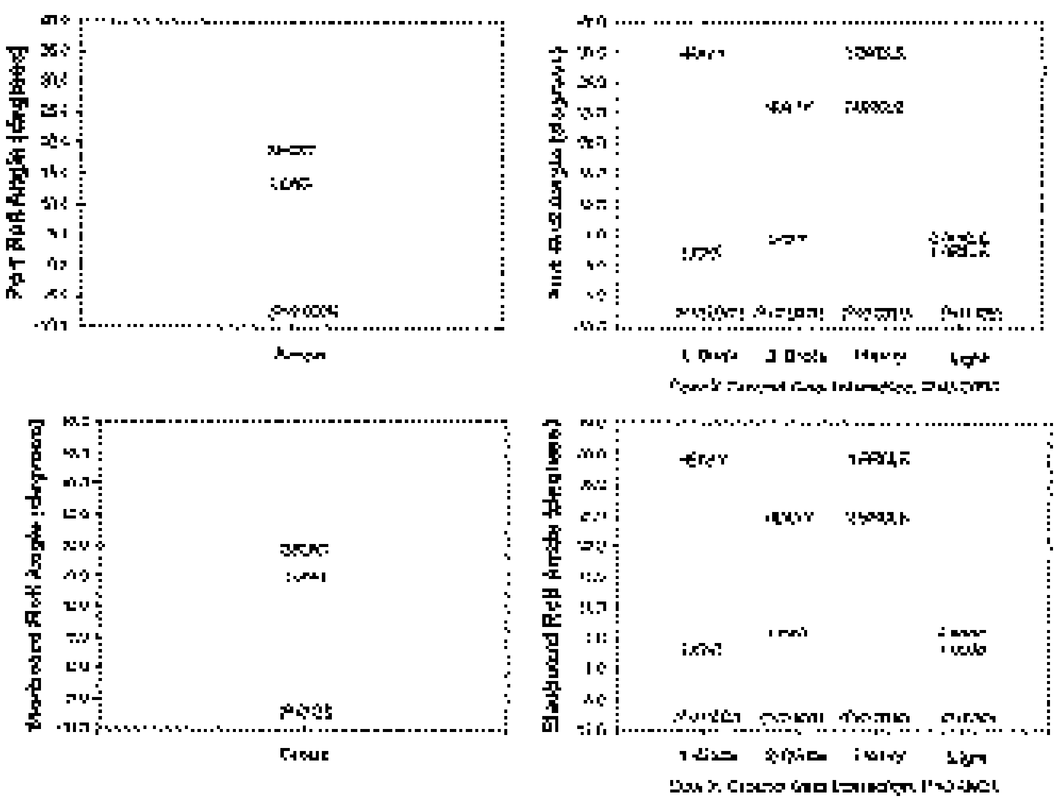


Figure 13.—Results of ANOVA to test the effects of the gear treatments and their interactions on door attitude. Statistically significant effects (P<0.05) are with uppercase letters.

contrast, by the time a thornyhead encounters the ground gear of an oncoming trawl, its only portals of escape are straight ahead or under the ground gear, through the meshes, or into the trawl. In any case, the effects of changes on trawl geometry and trawl performance to catching efficiency will vary depending on what aspect of the trawl the fish encounters and the fish's behavior when the trawl is first detected (Foster et al., 1981; Engås and Godø, 1986).

This experiment detected few significant effects of the scope on trawl performance or catch rates. The opportunity for observing scope effects was limited because we tested only two scope lengths at a single target depth. If a scope effect existed, however, a measurable difference would be expected with the 163 m difference between the two scope lengths that we used. With the 1-bridle/light and the 2-bridle/heavy treatments, trawl performance was consistent with either long or short scope. Similarly, both scopes had equally inconsistent trawl performance with the 1-bridle/heavy treatment, and both scope lengths had poor bottom contact with the 2-bridle/light treatment. Scope can affect the upward vector of the warp tension on the doors, which can affect door behavior and, thereby trawl performance (Carrothers, 1981). The short scope did result in significantly less door spread and net width, but differences were less than 1 m. Rose and Walters (1990) showed that inverse scope was a good predictor for net width but that the effect diminished in deeper water. At greater depths, the inward tension caused by the hydrodynamic force on trawl warps may minimize the effects of changes in scope length.

The only catch rates significantly affected by scope were those of longspine thornyhead number and invertebrate weight. The fact that the scope effect was significant for longspine thornyhead number but not weight indicates that smaller-sized longspine thornyheads (<12 mm), which did not contribute significantly to the total weight, were being captured more effectively with treatments having the longer scope. Invertebrates are not highly motile and have a static response to the trawl so there must be an active mechanism for herding the invertebrates into the trawl's path. Turbulent wakes generated by the doors contain dirt and detritus off the sea bed and roughly follow the bridles to the wingtips (Carrothers, 1981; Main and Sangster, 1981). Longer scopes may have generated turbulent wakes that pushed sedentary invertebrates and small and weak-swimming longspine thornyhead into the path of the trawl resulting in higher catch rates.

Door changes can affect capture efficiency of a trawl (Main and Sangster, 1979, 1981; Byrne and Forrester, 1987), but in this experiment the door modification itself showed no direct effect on catch rates. The NMFS Northeast Fisheries Science Center did hundreds of paired tows and found that a change in

Table 6.—Catch rates (kg/km^2) for selected fish species by block and by treatment.

		Catch rate (kg/km^2)							
		Heavy ground gear				Light ground gear			
		Scope 930 m		Scope 767 m		Scope 930 m		Scope 767 m	
Species	Block	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle
Dover sole	1	832	234	150	445	910	302	1,124	211
	2	618	111	867	301	442	152	134	788
	3	278	281	135	171	60	179	110	203
	4	193	160	233	33	222	123	105	133
	5	152	148	1,067	1,122	689	193	509	607
	6	286	163	115	64	283	257	94	211
	7	753	569	539	837	712	1,284	446	457
	8	1,001	981	2,133	1,167	1,019	2,208	412	854
	9	112	472	53	16	10	37	49	71
	10	1,187	303	1,381	1,666	213	144	1,193	380
	11	619	325	580	417	338	330	192	409
	12	1,680	630	1,015	837	933	632	1,042	402
	Mean	643	365	689	590	485	487	451	394
	S.D.	480	257	634	532	354	638	432	251
Sablefish	1	1,076	1,106	1,004	586	614	961	464	907
	2	1,538	801	1,526	710	636	210	1,115	421
	3	577	1,869	775	554	111	576	496	1,150
	4	973	410	268	140	157	0	39	148
	5	382	179	174	656	496	1,070	671	197
	6	1,040	189	613	670	283	79	293	351
	7	696	1,587	797	1,258	491	1,084	465	836
	8	972	710	1,359	2,004	323	685	675	1,152
	9	1,163	587	1,911	582	1,330	1,005	1,230	766
	10	380	1,292	1,203	1,141	670	723	435	450
	11	405	471	532	326	247	611	999	769
	12	415	1,005	983	630	330	987	703	289
	Mean	801	851	929	771	474	666	632	620
	S.D.	380	538	513	491	328	388	346	355
Longspine thornyhead	1	53	204	248	15	6	256	9	39
	2	417	196	143	289	126	221	118	225
	3	63	125	58	32	77	92	48	186
	4	53	56	390	386	304	144	231	86
	5	118	166	511	395	687	340	442	274
	6	284	176	194	195	153	66	137	227
	7	352	142	226	257	153	115	137	156
	8	109	145	835	84	137	533	132	519
	9	724	561	596	508	675	477	461	480
	10	510	763	24	1,340	295	567	10	11
	11	4	12	37	2	5	11	2	5
	12	455	467	521	532	239	390	361	176
	Mean	262	251	315	336	238	268	174	199
	S.D.	230	225	256	367	228	191	165	166
Shortspine thornyhead	1	641	808	845	590	938	815	739	887
	2	1,091	641	656	1,031	732	773	705	1,275
	3	914	761	618	931	502	596	679	1,123
	4	527	978	1,135	1,010	1,122	444	850	855
	5	653	597	1,220	844	816	703	744	750
	6	940	1,362	1,042	1,109	1,175	1,253	1,172	1,154
	7	1,327	1,291	1,225	982	1,584	1,319	882	891
	8	1,471	1,466	905	1,574	875	902	1,194	1,405
	9	903	1,033	818	852	743	649	614	741
	10	1,352	1,110	527	1,223	848	803	681	1,246
	11	372	562	1,081	634	453	458	294	495
	12	958	1,237	1,015	1,005	1,176	699	956	536
	Mean	929	987	924	982	914	785	792	947
	S.D.	343	313	235	259	315	271	245	294

doors significantly affected catch rates for Atlantic cod, *Gadus morhua*; haddock, *Melanogrammus aeglefinus*, and other species (Byrne and Forrester, 1987). Our door modification was a minor change in comparison. Another difference was that they did not standardize their catch data for area swept, so significant changes in catch rates could be attributable to changes in area swept resulting from changes in trawl performance. Our analysis tested the effects of the different door types after standardizing catch data for area swept and taking into account variation from other gear effects.

Some of the obvious limitations of this experiment were its limited number of tows, low statistical power, and restricted depth. We attempted to control sources of variation using the randomized block experimental design (Bergh et al., 1990) and by ranking the data (Conover, 1980). The limited depth range of this gear experiment was another drawback because the WCUCS slope survey is conducted at depths ranging from 183 to 1,280 m, and the observed gear effects may vary with species and depth. For example, shortspine thornyhead, longspine thornyhead, and Dover sole each have a distinct bathymetric demography (Jacobson and Hunter, 1993; Jacobson and Vetter, 1996). Furthermore, depth dependent environmental conditions may affect the way each species responds to trawl modifications.

Table 7.—Catch rates (no./km^2) for selected fish species by block and by treatment.

		Catch rate (no./km^2)							
		Heavy ground gear				Light ground gear			
		Scope 930 m		Scope 767 m		Scope 930 m		Scope 767 m	
Species	Block	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle	1-Bridle	2-Bridle
Dover sole	1	1,970	300	338	1,058	2,043	497	2,850	361
	2	699	272	1,559	639	901	317	196	1,413
	3	428	405	221	322	90	236	173	383
	4	386	215	387	113	391	210	180	325
	5	404	282	1,702	1,803	992	306	783	1,067
	6	540	320	218	174	382	412	135	292
	7	1,109	870	707	1,098	882	1,383	728	438
	8	1,114	1,173	3,769	1,316	1,079	3,856	494	1,320
	9	156	393	128	64	31	68	117	127
	10	1,292	352	2,585	2,808	296	149	2,026	534
	11	1,237	607	726	814	689	760	351	653
	12	2,329	821	1,333	1,524	1,193	644	1,185	492
	Mean	972	501	1,139	978	747	737	768	617
	S.D.	670	302	1,121	813	564	1,044	863	420
Sablefish	1	805	779	705	369	464	564	353	638
	2	1,048	570	903	426	422	158	699	301
	3	428	1,215	607	258	90	371	318	737
	4	745	307	211	113	120	0	26	118
	5	249	156	145	429	397	672	476	167
	6	618	256	463	494	206	63	189	227
	7	459	986	471	760	323	708	336	438
	8	743	481	892	1,346	199	482	494	763
	9	750	393	1,228	418	737	508	672	413
	10	274	705	888	669	532	477	322	309
	11	271	364	403	271	172	396	729	564
	12	333	792	761	418	306	741	508	203
	Mean	560	584	640	498	331	428	427	407
	S.D.	261	319	317	318	190	245	212	224
Longspine thornyhead	1	1,887	2,756	4,680	418	495	4,278	299	971
	2	7,366	5,431	3,419	5,174	3,265	6,022	2,934	3,697
	3	6,072	4,571	2,759	1,707	6,126	3,573	2,541	3,067
	4	2,648	3,313	5,938	5,376	5,236	2,103	3,656	2,634
	5	3,514	5,755	7,494	5,323	11,679	5,439	6,463	3,035
	6	6,357	4,230	4,302	4,298	3,379	1,903	2,828	4,158
	7	8,378	4,525	4,410	6,758	4,939	4,343	4,453	3,097
	8	4,344	6,920	8,917	4,875	6,702	5,173	4,966	7,394
	9	13,909	13,582	9,542	7,655	10,313	6,734	7,249	8,396
	10	13,434	17,623	261	12,676	7,358	11,757	900	478
	11	77	1,609	1,815	222	488	661	27	564
	12	16,137	10,027	9,709	6,576	6,824	10,247	7,479	3,939
	Mean	7,010	6,695	5,270	5,088	5,567	5,186	3,650	3,452
	S.D.	5,118	4,754	3,096	3,397	3,416	3,259	2,563	2,435
Shortspine thornyhead	1	5,328	4,373	3,581	3,347	8,049	4,643	5,048	4,828
	2	5,054	3,720	3,911	5,235	4,391	3,676	4,080	6,071
	3	8,767	5,121	6,759	9,662	5,558	4,955	6,325	5,809
	4	5,848	9,386	6,219	5,939	6,710	2,463	4,815	6,007
	5	5,099	4,911	6,481	4,780	4,677	3,850	4,057	3,735
	6	5,173	8,492	6,943	8,131	5,847	9,164	6,761	7,147
	7	7,651	9,920	6,800	5,603	8,261	8,203	6,442	4,348
	8	12,173	12,216	2,878	17,853	7,327	2,635	8,780	4,870
	9	5,126	6,660	4,809	6,593	4,389	3,824	3,975	5,343
	10	8,616	6,227	5,170	3,824	5,438	4,625	8,072	13,720
	11	3,555	5,070	7,742	7,992	4,734	4,030	4,995	3,472
	12	6,155	7,330	6,250	5,201	8,445	4,028	6,181	3,302
	Mean	6,546	6,952	5,629	7,013	6,152	4,675	5,794	5,721
	S.D.	2,363	2,589	1,534	3,874	1,548	2,022	1,576	2,774

Revised Survey Gear and Towing Protocol

After considering the gear performance results, we decided that the 2-bridle door should be selected as a permanent change to the WCUCS survey trawl starting in 1995. This and one other modification were made to the trawl in addition to several changes to towing procedures. The other change to the trawl was a reduction in the number of links in the 9 mm drop chains attaching the fishing line to the footrope from 5 links to 2 links. Towing protocol changes included towing speed, tow duration, scope ratio, trawl warp metering, and trawling mode of the Rapp-Hydema winch system. Target vessel speed over ground was increased from 3.7 km/h (2.0 knots) to 4.3 km/h (2.3 knots) with an acceptable range of ±0.6 km/h. Speed was increased slightly to improve vessel steerage and to increase power to the doors to further improve the consistency of trawl performance. Tow duration for depths greater than 732 m was reduced from 60 to 30 minutes so that tow duration was equal for all depths. As mentioned in the Methods section, the ship's Rapp-Hydema winch system was performing inconsistently and its warp metering and pressure adjustment/balance functions were questionable. Scope ratios used from 1989 to 1993 were probably variable between depths and survey years because the trawl warp metering system was unreliable and the standard scope table was not strictly followed. A new standard scope table, based on empirical data from the 1994 gear experiment, was used starting in 1995. The new scope table most closely resembles the original or "long" scope table (e.g. 900 m compared to 930 m at a target depth of 465 m). New survey protocol also required that trawl wires be marked at 50 m intervals and that wire marks be used exclusively for determining the amount of wire payed out during trawl operations. Rather than using the autotrawl function, equal amounts of wire were payed out on both sides and the winch brakes are set for the duration of each tow.

Table 8.—Results of ANOVA testing the effects of gear modifications on standardized ranked sample densities.

Item	Deg. free-dom	Mean square	F-Statistic	P-Value
Ranked Dover sole (kg/km^2)				
Door	1	4.17	0.86	0.36
Scope	1	1.04	0.21	0.64
Ground gear	1	26.04	5.37	0.02
Door × Scope	1	18.38	3.79	0.055
Door × Ground gear	1	22.04	4.55	0.04
Scope × Ground gear	1	4.17	0.86	0.36
Door × Scope × Ground gear	1	1.50	0.31	0.58
Residual error	88	4.85		
Ranked Dover sole (kg/km^2)				
Door	1	12.04	2.43	0.12
Scope	1	1.50	0.30	0.58
Ground gear	1	20.17	4.08	0.047
Door × Scope	1	12.04	2.43	0.12
Door × Ground gear	1	18.38	3.71	0.06
Scope × Ground gear	1	4.17	0.84	0.36
Door × Scope × Ground gear	1	0.38	0.08	0.78
Residual error	88	4.95		
Ranked sablefish (kg/km^2)				
Door	1	0.67	0.14	0.71
Scope	1	1.50	0.31	0.58
Ground gear	1	63.38	13.30	0.0004
Door × Scope	1	10.67	2.24	0.14
Door × Ground gear	1	7.04	1.48	0.23
Scope × Ground gear	1	1.04	0.22	0.64
Door × Scope × Ground gear	1	0.38	0.08	0.78
Residual error	88	4.77		
Ranked sablefish (kg/km^2)				
Door	1	0.67	0.13	0.72
Scope	1	0.17	0.03	0.86
Ground gear	1	42.67	8.56	0.004
Door × Scope	1	10.67	2.14	0.15
Door × Ground gear	1	8.17	1.64	0.20
Scope × Ground gear	1	1.50	0.30	0.58
Door × Scope × Ground gear	1	1.50	0.30	0.58
Residual error	88	4.98		
Ranked shortspine thornyhead (kg/km^2)				
Door	1	2.04	0.42	0.52
Scope	1	0.67	0.14	0.71
Ground gear	1	32.67	6.66	0.01
Door × Scope	1	5.04	1.03	0.31
Door × Ground gear	1	18.38	3.75	0.06
Scope × Ground gear	1	4.17	0.85	0.36
Door × Scope × Ground gear	1	9.38	1.91	0.17
Residual error	88	4.91		
Ranked shortspine thornyhead (kg/km^2)				
Door	1	6.00	1.20	0.28
Scope	1	0.17	0.03	0.86
Ground gear	1	20.17	4.05	0.05
Door × Scope	1	20.17	4.05	0.05
Door × Ground gear	1	0.67	0.13	0.72
Scope × Ground gear	1	1.50	0.30	0.58
Door × Scope × Ground gear	1	16.67	3.34	0.07
Residual error	88	4.98		
Ranked longspine thornyhead (kg/km^2)				
Door	1	3.38	0.75	0.39
Scope	1	37.50	8.35	0.005
Ground gear	1	51.04	11.37	0.001
Door × Scope	1	1.04	0.23	0.63
Door × Ground gear	1	1.50	0.33	0.56
Scope × Ground gear	1	1.04	0.23	0.63
Door × Scope × Ground gear	1	13.50	3.01	0.09
Residual error	88	4.49		
Ranked longspine thornyhead (kg/km^2)				
Door	1	2.04	0.42	0.52
Scope	1	0.67	0.14	0.71
Ground gear	1	35.04	7.23	0.009
Door × Scope	1	0.38	0.08	0.78
Door × Ground gear	1	16.67	2.44	0.07
Scope × Ground gear	1	12.04	2.48	0.12
Door × Scope × Ground gear	1	10.67	2.20	0.14
Residual error	88	4.84		
Ranked invertebrates (kg/km^2)				
Door	1	0.17	0.07	0.79
Scope	1	266.67	119.73	<0.0001
Ground gear	1	37.50	16.84	<0.0001
Door × Scope	1	0.17	0.07	0.79
Door × Ground gear	1	2.67	1.20	0.28
Scope × Ground gear	1	0.17	0.07	0.79
Door × Scope × Ground gear	1	0.67	0.30	0.59
Residual Error	88	2.23		

Table 9.—Cumulative weight for the 20 most common invertebrates caught during the 1994 west coast upper continental slope trawl gear experiment.

Scientific name	Common name	Sum of weight (kg)
Actiniaria (order)	Sea anemone unident.	608.81
Allocentrotus fragilis	Orange-pink sea urchin	524.67
Psilaster pectinatus	Starfish	380.20
Aphrocallistes vastus	Clay pipe sponge	261.14
Myoxoderma platyacanthum rhomaleum	Starfish	147.23
Ophiuroidea (class)	Brittlestarfish unident.	96.71
Octopus sp.	Octopus unident.	89.99
Neptunea amianta	Snail	45.90
Pseudostichopus mollis	Sea cucumber	43.77
Porifera (phylum)	Sponge unident.	31.62
Berryteuthis magister	Magistrate armhook squid	31.25
Pasiphaea pacifica	Glass shrimp	25.19
Brisaster sp.	Heart urchin unident.	17.28
Amphiophiura ponderosa	Brittlestarfish unident.	16.33
Chionoecetes tanneri	True Tanner crab	15.42
Cephalopoda (class)	Squid unident.	11.30
Scyphozoa (class)	Jellyfish unident.	10.66
Hexactinellida (class)	Glass sponge unident.	8.85
Salpida (order)	Salps unident.	7.13
Asteroidea (class)	Starfish unident.	5.08

Changes to the Trawl Survey and Time Series Continuity

Maintaining a time series as a representative measure of relative abundance of the DWC species requires that the trawl survey use a consistent sampling gear and standardized sampling methods. The sampling gear and methods used for the WCUCS trawl surveys up until 1993 had some inconsistencies. To correct them, we implemented changes to both the slope survey trawl and towing protocols starting in 1995. By making modifications, we faced the dilemma of what effect they might have on fish catching efficiency of the trawl, and ultimately, the continuity with the existing data time series used for assessing the stocks. We concluded from this experiment that catch rates for all four DWC species were not different between the standard survey trawl and the 2-bridle/heavy. However, there is no empirical data to determine if the revisions in addition to the 2-bridle door (as mentioned above) would further affect the way the trawl captures fish. Hence, one can only speculate how the collective changes affect the trawl's fish catching efficiency and time series continuity.

A primary concern is whether there was a shift in the measure of relative abundance from the trawl surveys before and after the modifications. It is conceivable that the collective changes helped to increase the precision of survey results without introducing a new bias. If such were the case, only the width of the error bars surrounding indices would change and the time series continuity would not be compromised. On the other hand, if a new bias was introduced by the additional changes, there would be an accompanying shift in

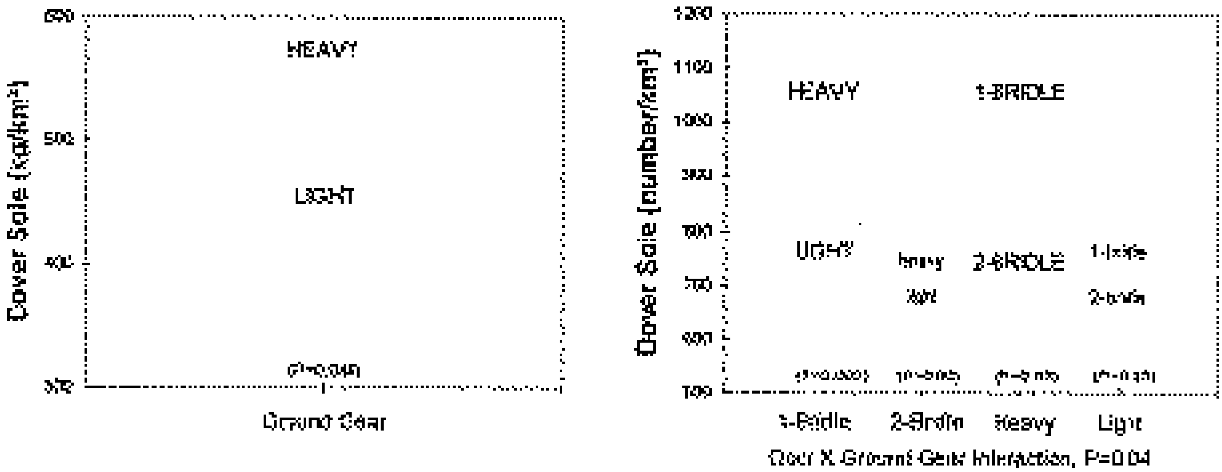


Figure 14.—Results of ANOVA to test the effects of gear modifications and their interactions on Dover sole catch rates. Catch rate estimates are from an ANOVA done on unranked catch rates and probability values are from an ANOVA done on ranked catch rates. Statistically significant effects (P < 0.05) are with uppercase letters.

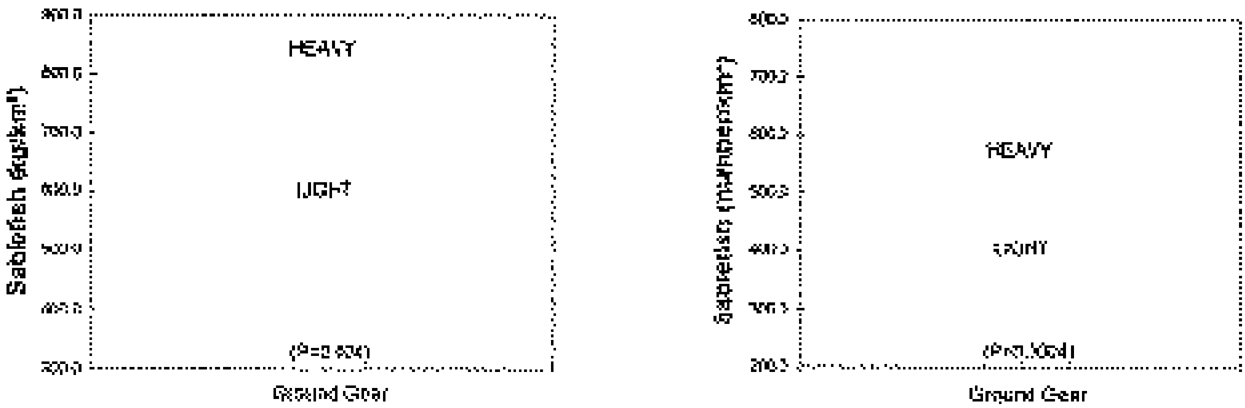


Figure 15.—Results of ANOVA to test the effects of gear modifications and their interactions on sablefish catch rates. Catch rate estimates are from an ANOVA done on unranked catch rates and probability values are from an ANOVA done on ranked catch rates. Statistically significant effects (P < 0.05) are with uppercase letters.

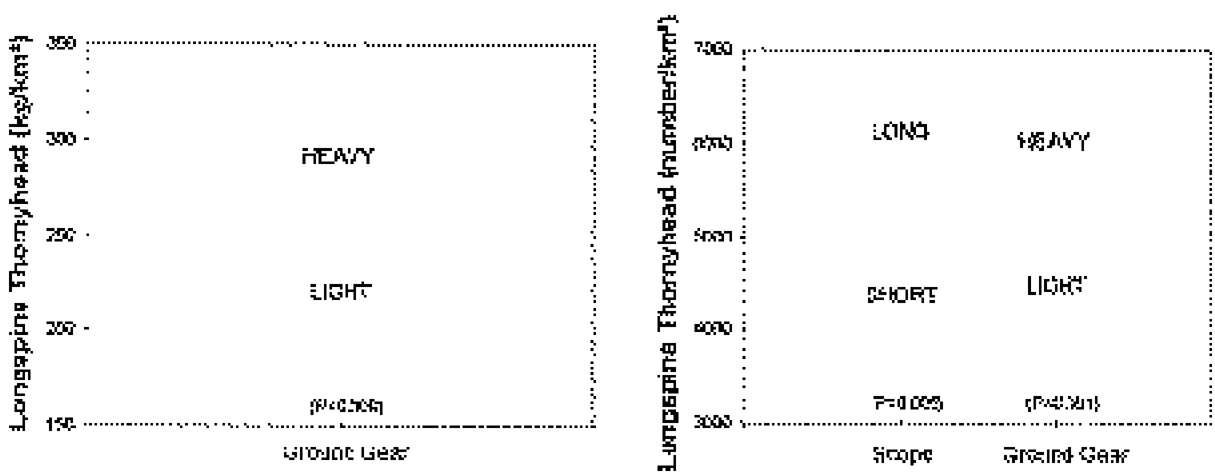


Figure 16.—Results of ANOVA to test the effects of gear modifications and their interactions on longspine thornyhead catch rates. Catch rate estimates are from an ANOVA done on unranked catch rates and probability values are from an ANOVA done on ranked catch rates. Statistically significant effects (P < 0.05) are with uppercase letters.

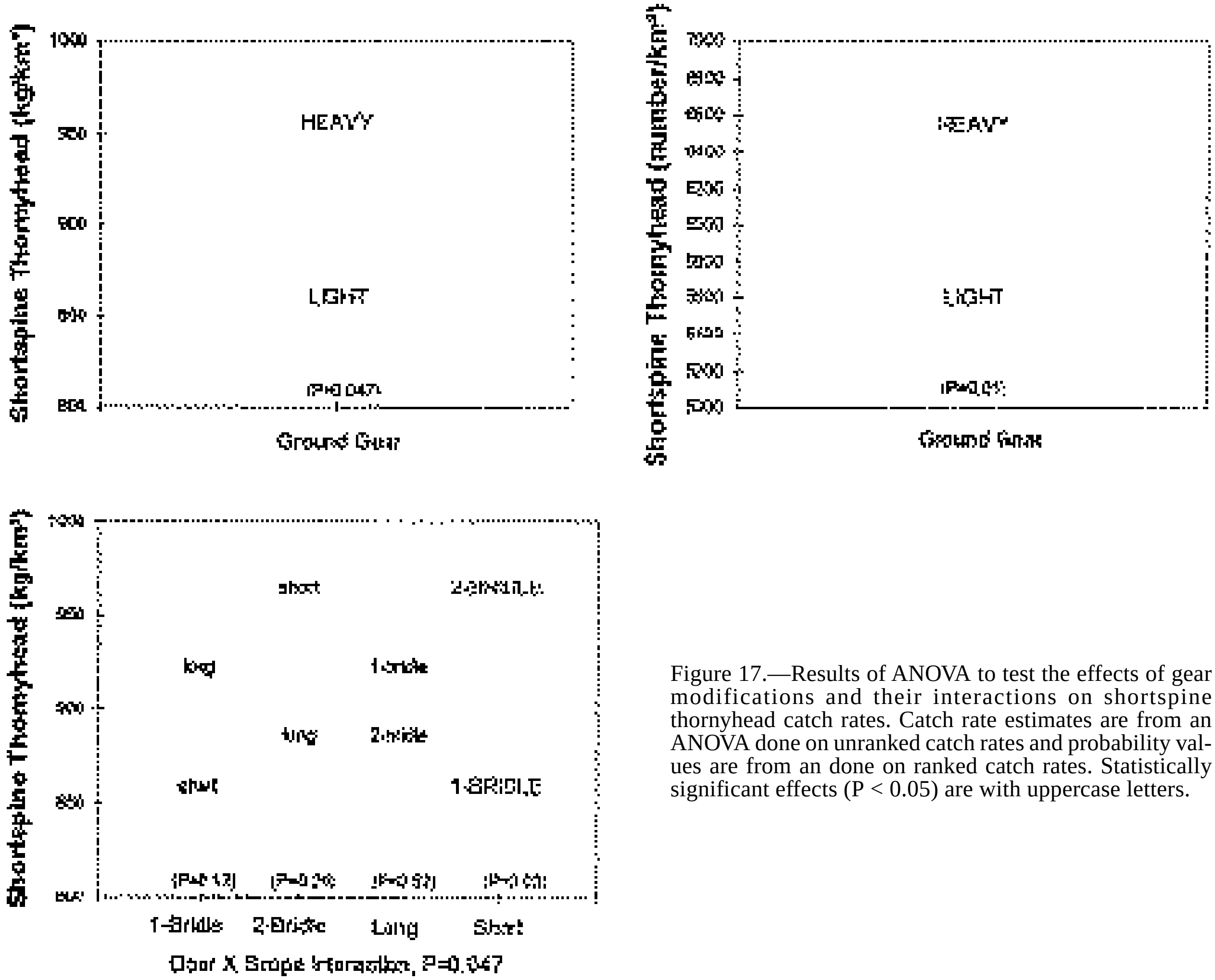


Figure 17.—Results of ANOVA to test the effects of gear modifications and their interactions on shortspine thornyhead catch rates. Catch rate estimates are from an ANOVA done on unranked catch rates and probability values are from an done on ranked catch rates. Statistically significant effects (P < 0.05) are with uppercase letters.

the survey's abundance indices and inclusion of the newer survey data as part of the existing time series would be suspect.

Changes to trawl warp metering, winch control, and scope ratio corrected inconsistencies associated with variability in sampling methodology so that tows could be repeated in a more standardized fashion. Results from this experiment also indicated that scope had little effect on catch rates except for longspine thornyhead numbers and invertebrate weight. These changes arguably helped to increase the precision of trawl catches without introducing a new bias.

Changes to target tow speed, tow duration, and drop-chain length are all changes with a directional component, and it is possible they could have introduced new biases into survey data (Carrothers, 1981; He, 1993; Walsh et al., 1993). Unfortunately, there are no experimental data or published information describing what direct effects these revisions might have on catch rates of the DWC species. The dynamics of trawl and fish behavior are complicated so without such data it is hard to speculate if and how these revisions would affect catch rates. The increase in speed was small, and it is likely that trawling officers aboard the *Miller Freeman* tended toward the faster towing speeds prior to 1994 in order to prevent the trawl from collapsing and to maintain better vessel control. The change in tow duration was only for tows deeper than 732 m. The original rationale for having hour-long tows at greater depths was that it was suspected that there were fewer fish at depth and more time was necessary to get an adequate sample. The change in drop chain length could have affected catch rates by narrowing the escape route between the ground gear and footrope. Video of the slope trawl ground gear and comparative gear experiments by other researchers using trawl underbags indicate that more escapement is occurring underneath the ground gear and not between the gaps between the ground gear and footrope.

Acknowledgments

We would like to thank all the cruise participants for their hard work during

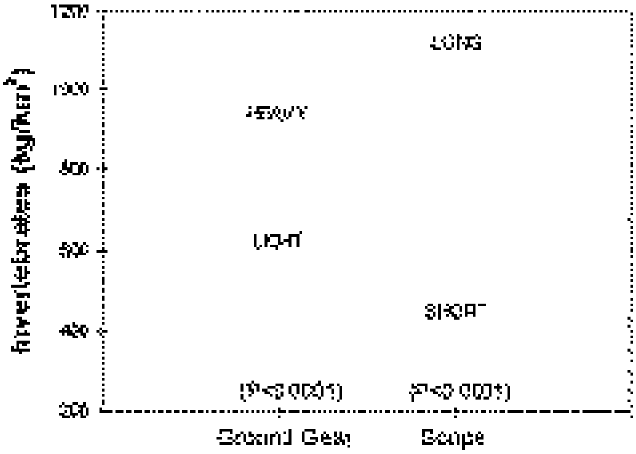


Figure 18.—Results of ANOVA to test the effects of the gear treatments and their interactions on invertebrates catch rates. Catch rate estimates are from an ANOVA done on unranked catch rates and probability values are from an ANOVA done on ranked catch rates. Statistically significant effects (P < 0.05) are with uppercase letters.

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Literature Cited

Adams, P. B., J. L. Butler, C. H. Baxter, T. E. Laidig, K. A. Dahlin, and W. W. Wakefield. 1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. Fish. Bull. 93:446–455.

Bergh, M. O., E. K. Pikitch, J. R. Skalski, and J. R. Wallace. 1990. The statistical design of comparative fishing experiments. Fish. Res. 9:143–163.

Brodziak, J., L. Jacobson, R. Lauth, and M. Wilkins. 1997. Assessment of the Dover sole stock for 1997. *In* Status of the Pacific coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998, Appendix, 133 p. Avail. from Pac. Fish. Manage. Counc., 2130 SW Fifth Ave., Suite 224, Portland, OR 97201.

Byrne, C. J., and J. R. S. Forrester. 1987. Effect of a gear change on a standardized bottom trawl survey time series. *In* Proceedings. Oceans '87. The ocean—an international workplace. Vol. 2. Marine Engineering; Policy, Education and Technology Transfer, p. 617–621. IEEE Ocean Eng. Soc., N.Y. Publ. IEEE-87CH2498-4.

Carrothers, P. J. G. 1981. Catch variability due to variations in groundfish otter trawl behavior and possibilities to reduce it through instrumented fishing gear studies and improved fishing procedures. *In* W. G. Doubleday and D. Rivard (Editors), Bottom trawl surveys, p. 247–257. Can. Spec. Publ. Fish. Aquat. Sci. 58.

Conover, W. J. 1980. Practical nonparametric statistics, 2nd ed. John Wiley and Sons, N.Y., 420 p.

Crone, P. R., R. D. Methot, R. J. Conser, R. R. Lauth, and M. E. Wilkins. 1997. Status of the sablefish resource off the U.S. Pacific coast in 1997. *In* Status of the Pacific coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998, Appendix, 135 p. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Dahm, E., and H. Wienbeck. 1992. Escapement of fish underneath the groundrope of a standard bottom trawl used for stock assessment purposes in the North Sea. ICES-CM-1989/B:20, 22 p.

Dark, T. A., and M. E. Wilkins. 1994. Distribution, abundance, and biological characteristics of groundfish off the coast of Washington, Oregon, and California, 1977–1986. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 117, 73 p.

Engås, A., and O. R. Godø. 1986. Influence of trawl geometry and vertical distribution of fish on sampling with bottom trawl. J. Northwest Atl. Fish. Sci. 7(1):35–42.

________ and ________ . 1989. Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. J. Cons. Cons. Int. Explor. Mer 45:269–276.

________ , J. A. Jacobsen, and A. V. Soldal. 1988. Catch comparison between rockhoppers and bobbin ground gear on the Norwegian bottom sampling trawl. ICES-CM-1988/B:31, 12 p.

Foster, J. J., C. M. Campbell, and G. C. W. Sabin. 1981. The fish catching process relevant to trawls. *In* W. G. Doubleday and D. Rivard (Editors), Bottom trawl surveys, p. 229–246. Can. Spec. Publ. Fish. Aquat. Sci. 58.

Godø, O. R., and S. J. Walsh. 1992. Escapement of fish during bottom trawl sampling - implications for resource assessment. Fish. Res. 13:281–292.

He, P. 1993. Swimming speeds of marine fish in relation to fishing gears. *In* C. S. Wardle and C. E. Hollingworth (Editors), Fish behavior in relation to fishing operations, p. 183–189. ICES Mar. Sci. Symp. 196.

Ianelli, J. N., R. Lauth, and L. D. Jacobson. 1994. Status of the thornyhead (*Sebastolobus* sp.) resource in 1994. *In* Status of the Pacific coast groundfish fishery through 1994 and recommended acceptable biological catches for 1995, Appendix D. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Jacobson, L. D. 1990. Thornyheads-stock assessment for 1990. *In* Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991, Appendix D. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

________ . 1991. Thornyheads-stock assessment for 1991. *In* Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1992, Appendix D. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Jacobson, L. J., and J. R. Hunter. 1993. Bathymetric demography and management of Dover sole. N. Am. J. Fish. Manage. 13:405–420.

________ and R. D. Vetter. 1996. Bathymetric demography and niche separation of thornyhead rockfish: *Sebastolobus alascanus* and *Sebastolobus altivelis*. Can. J. Fish. Aquat. Sci. 53:600–609.

Krieger, K. J. 1993. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. Fish. Bull. 91:91–96.

Lauth, R. R. 1997a. The 1995 Pacific West Coast upper continental slope trawl survey of groundfish resources off southern Oregon and northern California: Estimates of distribution, abundance, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-80, 110 p.

________ . 1997b. The 1996 Pacific West Coast upper continental slope trawl survey of groundfish resources off Washington and Oregon: Estimates of distribution, abundance, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-81, 156 p.

________ , M. E. Wilkins, and P. A. Raymore Jr. 1997. Results of trawl surveys of groundfish resources of the West Coast upper continental slope from 1989 to 1993. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-79, 342 p.

Main, J., and G. I. Sangster. 1979. A study of sand bottom trawling gear on both sand and hard ground. Scott. Fish. Res. Rep. 14, 15 p.

________ and ________ . 1981. A study of sand clouds produced by trawl boards and their possible effect on fish capture. Scott. Fish. Res. Rep. 20, 20 p.

________ and ________. 1983. Fish reactions to trawl gear — a study comparing light and heavy ground gear. Scott. Fish. Res. Rep. 27, 17 p.

Methot, R. D. 1992. Assessment of the west coast sablefish stock in 1992. *In* Status of the Pacific coast groundfish fishery through 1992 and recommended acceptable biological catches for 1993. Appendix D. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

________ . 1994. Assessment of the west coast sablefish stock in 1994. Appendix B. *In* Status of the Pacific coast groundfish fishery through 1994 and recommended acceptable biological catches for 1995. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Munro, P. T., K. L. Weinberg, and D. Somerton. 1997. Estimating size-dependent capture rates at the footrope of two different kinds of survey trawls. ICES-CM-1997/W:06, 18 p.

Parks, N. B., F. R. Shaw, and R. L. Henry. 1993. Results of a 1988 trawl survey of groundfish resources of the upper continental slope off Oregon. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-23, 164 p.

Raymore, P. A., Jr., and K. L. Weinberg. 1990. 1984 spring and autumn surveys of Pacific West Coast upper continental slope groundfish resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-179, 196 p.

Rogers, J. B., L. D. Jacobson, R. Lauth, J. N. Ianelli, and M. E. Wilkins. 1997. Status of the thornyhead resource in 1997. *In* Appendix: Status of the Pacific coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998, 91p. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Rose, C. S., and G. E. Walters. 1990. Trawl width variation during bottom trawl surveys: causes and consequences. *In* L-L. Low (Editor) Proceedings of the Symposium on Application of Stock Assessment Techniques to Gadoids, p. 57–67. Int. North Pac. Fish. Comm. Bull. 50.

Shaw, F. R., and N. B. Parks. 1997. Movement patterns of tagged sablefish, *Anoplopoma fimbria*, recovered on seamounts in the northeast Pacific Ocean and Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 130, p. 151–158.

Turnock, J. M., and R. D. Methot 1992. Status of west coast Dover sole in 1992. Appendix E. *In* Status of the Pacific coast groundfish fishery through 1991 and recommended acceptable biological catches for 1992. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Turnock, J. M., M. Wilkins, M. Saelens, and R. Lauth. 1994. Assessment of the west coast Dover sole in 1994. Appendix C. *In* Status of the Pacific coast groundfish fishery through 1994 and recommended acceptable biological catches for 1995. Avail. from Pac. Fish. Manage. Counc., 2130 S.W. Fifth Ave., Suite 224, Portland, OR 97201.

Wakefield, W. W. 1990. Patterns in the distribution of demersal fishes on the upper continental slope off central California with studies on the role of ontogenetic vertical migration in particle flux. Ph.D. thesis, Scripps Institution of Oceanography, University of California, San Diego, CA.

Walsh, S. J. 1992. Size-dependent selection at the footgear of a groundfish survey trawl. N. Am. J. Fish. Manage. 12(3):625–633.

________ , A. Koeller, and W. D. McKone (Editors). 1993. Proceedings of the International Workshop on Survey Trawl Mensuration, Northwest Atlantic Fisheries Centre, St. John's Newfoundland, March 18–19, 1991. Can. Tech. Rep. Fish. Aquat. Sci. No. 1911.

West, C. W. 1981. Factors affecting bottom trawl behavior: Results of experiments with 83/112 Eastern trawls towed from the NOAA ship *Miller Freeman*. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-16, 36 p.