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FINAL REPORT ON THE RESULTS OF THE 1988 WEST COAST GROUNDFISH MESH SIZE STUDY

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PART I. EXECUTIVE SUMMARY

The West Coast Groundfish Mesh Size Study is a multiphase, interdisciplinary research effort. This report focuses on the results of Phase II, the preliminary field study conducted in 1988. In addition to describing field and analytical methods and results, we also discuss the planning process that was used to design and conduct the study, and present the rationale for decisions that were ultimately made.

Extensive effort was expended in developing the experimental design for the field study. At an early stage it was determined that gross revenues per trawling hour was the key response variable to be examined in developing the experimental design. A general methodology for evaluating statistical designs for comparative fishing experiments was developed, and applied to data collected previously on the West Coast groundfish fishery. Results of this application were used to select a final experimental design for the 1988 field work. The decision was made to test four experimental codend types (3", 4.5" and 5" diamond mesh codends, and 5" square codends), and to use a randomized complete block design. This required that all four experimental codend types be employed during each fishing trip. Experimental fishing permits were obtained which allowed participating vessel owners and skippers to use detachable codends, and also waived trip quota restrictions. A great deal of effort was also expended in developing experimental codend design, overseeing codend construction, soliciting and coordinating industry participation, hiring and training field samplers, and developing field, data recording and data analysis procedures.

A total of 26 experimental trips were conducted aboard 21 vessels during 1988. Average trip duration was 4.5 days, resulting in a total of 117.5 days of sampling effort. Tows were assigned to one of two sub-studies: (1) Rockfish: Fishing directed at a mixture of rockfish (*Sebastes* spp.) using roller gear on hard bottom, and (2) Flatfish: Fishing using mud gear or combination mud-roller gear on soft bottom directed primarily at the deepwater assemblage, but also including relatively shallow water tows directed at a mixture of flatfish and other species.

The results clearly demonstrated that codend mesh size and type have a significant impact on important characteristics of the catch when fishing occurs under commercial production conditions. Specifically, in many instances increases in diamond mesh size resulted in significant decreases in gross revenues per trawling hour, catch sorting time, and discarded catch weight, and increases in mean length of individual species and in the extent of gilling. Although analyses conducted for individual species were less conclusive than those conducted on data for all species combined, individual species responses were similar to the results seen for the combined data.

Differences in responses were seen between the rockfish and flatfish sub-studies. Mean duration of flatfish tows was more than twice that of rockfish tows. Rockfish fishing generated more revenues than flatfish fishing (on a per trawling hour basis), but rockfish fishing was much more variable in terms of catch amounts and species composition of the catch. Gilling is a much greater problem for rockfish than for flatfish fishing.

Our results indicate that there is a need to conduct additional research on the effects of changing codend type on the fishery. With the sample sizes obtained, large changes in gross revenues per trawling hour (DPH) were detected, but greater sample sizes would be needed to estimate smaller (but important) changes in DPH. The same is true for many of the other response variables examined, particularly, individual species responses. The 1988 field work examined only four codend types and two fishing strategies, and there is a need to extend the fieldwork to other codend mesh sizes and other segments of the fishery. Field work to be conducted during 1989 and 1990 will produce a great deal of additional information. Results of the 1988 field study will provide information needed to develop appropriate experimental designs for these later field studies.

In addition to field studies, further analytical and modeling work is needed to fully evaluate the consequences of alternative mesh size regulations. While the analyses presented in this report are relevant to an assessment of short-term effects of changes in mesh size and shape, the long-term effects of such changes must also be considered. Such analyses will be conducted as part of the fifth and final phase of this study.

PART II: INTRODUCTION

The multispecies groundfish resources off the west coast of the United States are under increasing pressure from a diversified fishing effort. This has caused implementation of management regimes by the Pacific Fishery Management Council (PFMC) that many believe to be overly complex, inefficient and wasteful. There is also concern that some fish stocks are inadequately conserved by present management techniques, and hope that alternative approaches may enhance production and the economic status of the fishery.

The fishing industry and those who regulate it have repeatedly requested that research be conducted to assess the potential for mesh size regulations to improve management since the Fishery Management Plan for groundfish (Pacific Fishery Management Council 1982, Section 13,3,1(3)) was developed. Several obstacles have prevented such studies from coming to fruition. The expense of the requisite studies is very large, and no single funding source is available to fully support these studies. The research requires an interdisciplinary approach and must involve coordination of the efforts of persons with diverse areas of expertise. In addition, there is a risk that if such studies were conducted, the results could indicate that mesh size regulations may not significantly improve management of the fishery. The potential risk of failure of such research to solve existing problems, coupled with the high costs of conducting and coordinating the research, led funding entities to hesitate to provide funds for the research. The lack of adequate research on mesh size effects has prevented evaluation of the costs and benefits of alternative mesh size regulations, which could lead to regulatory changes benefitting the industry.

However, during the past few years, much progress has been made in obtaining funding for, and conducting, mesh size research. Results of these preliminary efforts indicate that there is a good chance that research in this area will ultimately produce substantial benefits. Application of the results of such studies may greatly enhance the biological production and economic condition of the fishery, reduce discard of fish, and reduce sorting time at sea. Effective formulation of mesh size regulations could simplify and reduce the costs of management, reduce the severity of alternative management measures, allow for easier and less expensive enforcement, and provide more equitable management.

In order to evaluate, and ultimately to realize, the potential benefits of mesh size research and application to the Pacific groundfish fishery, a four-phase research plan was initially developed. Recently, the research plan has been modified to include five phases. The project is structured so that the information derived in each phase is used to develop subsequent phases. Major objectives for each phase are as follows:

Phase I: Compile life history and fishery information on species of major importance to the West Coast groundfish trawl fishery. Develop a model (expansion of the Pikitch (1987) model) of the fishery. Using existing data, apply the model to estimate the magnitude of benefits that could be realized through gear regulation changes. If Phase I indicates that significant benefits may accrue from further analysis of gear effects, proceed to Phase II.

Phase II: Design and conduct a pilot field study in 1988 to obtain a preliminary assessment of the effects of various trawl codend mesh sizes and configurations on catch amount, composition, value and sorting time, and to provide data needed to plan Phase III.

Phase III: Design and conduct a comprehensive field study under commercial fishing conditions during 1989 to obtain a more complete assessment of the effects of codend mesh size and shape on important fishery responses.

Phase IV: Design and conduct a field study under commercial fishing conditions during 1990 to obtain an assessment of the effects of codend mesh size and shape, focusing on previously underrepresented fishing strategies and geographic areas (i.e., beach draggers and California rockfish vessels).

Phase V: Refine the model developed in Phase I to permit examination of dynamic effects, and to incorporate variability and uncertainty of model parameters. Using data obtained during Phases II, III, and IV, apply the model to predict the short- and long-run consequences of changes in codend mesh size and shape on bioeconomic yields of the West Coast groundfish fishery. Integrate the results of the gear studies with information from previous studies into a synthetic framework for the analysis of the impacts of management alternatives. Present the results to the PFMC, its advisory bodies, and the broader scientific community.

Phase I was completed in December 1987. Results of Phase I predicted that an increase in trawl codend mesh size would both increase equilibrium yields from a segment of the fishery and reduce the sensitivity of yield to changes in effort (Vaga and Pikitch 1988), potentially reducing the need for, or severity of, alternative management measures. Phase I also documented the paucity of empirical information on the selectivity properties of trawl codends and the sensitivity of the results to the gear selectivity parameters (Vaga and Pikitch 1988; Rogers and Pikitch 1989). Thus, Phase I results indicated that changes in mesh size regulations could potentially yield large benefits, but that field and further analytical research were needed to accurately determine optimal mesh sizes for management purposes. The PFMC urged that remaining phases of the study be conducted.

This report focuses on the results of Phase II, the preliminary field study conducted in 1988. In addition to describing field and analytical methods and results, we also discuss the planning process that was used to design and conduct the study, and present the rationale for decisions that were ultimately made.

PART III: APPROACH

1. PRELIMINARY CONSIDERATIONS

1.1 The Planning Process

From the outset it was recognized that successfully conducting a project of this nature would require input from persons with diverse areas of expertise. Thus, an advisory group was established, which included fishermen, gear specialists, fishing industry association leaders, scientists and managers from state and federal agencies, and researchers from other universities. The individuals who participated in the Mesh Size Advisory Group, and their respective affiliations, are listed in Appendix A. The Mesh Size Advisory Group met several times during the course of Phase II. In addition to attending group meetings, members also provided advice and support on an as-needed basis. In particular, members of the advisory group helped to recruit fishermen throughout the course of the study, and contributed greatly to gear design and modification. We also sought the opinions of fishermen participating in the study, and consulted others not directly associated with the project on numerous occasions.

1.2 Identification of Critical Response Variables

Figure 1 shows a hypothetical yield trajectory for a fishery which, from an initial state at equilibrium, is suddenly subjected to a change in gear type used by the fishing fleet. In this example, the gear change envisaged is an increase in codend mesh size. The immediate effect is a drop in yield, due to a movement of selectivity towards larger, older and less abundant fish and away from the more abundant smaller fish. However, in this example, with the increase in mesh size, more of the smaller fish will grow and survive to adulthood, and eventually, yields will increase to a new equilibrium level.

Earlier modeling studies conducted for various segments of the Pacific trawl groundfishery (Pikitch 1987; Vaga and Pikitch 1988) indicated that an increase in mesh size would result in an increase in sustainable yields over the long term, but did not consider short-term non-equilibrium effects. These immediate effects deserve attention, since if short-term losses are very severe, the fishing industry could face financial disaster, and not survive to experience the increased sustainable yields forecast by scientists. Furthermore, estimates of long-term effects are less certain than short-term predictions, because the former are dependent on the accuracy of a number of assumptions about population dynamics and the response of the fishing fleet to a change in regulations. In contrast, many of the short-term consequences of a change in mesh size can be measured directly in the field. While estimates of long- and short-run effects are both needed to formulate changes in management policy, we focused on the ability to measure short-run effects in determining key response variables upon which to base the experimental design.

The most important yield-related quantity was identified to be the cash value of a tow per unit of tow time, C, and this measure was therefore chosen as the critical design response variable. We define t to be the variable denoting tow time and let c_{qm} be the catch by weight from a single tow using net m, for species q. When there are Q marketable species in a fishery, the cash value of a tow per unit tow time, using gear type m, C_m, is

$$C_m = \frac{\sum_{q=1}^{Q} p_q c_{qm}}{t} \tag{1}$$

where p_q is the price per unit weight in dollars for species q (q = 1,..., Q).

Differences in C_m among gear types with different codend mesh sizes were anticipated to be accompanied by differences in the mean length of fish caught. Logically, catches should decrease and fish mean length should increase with an increase in mesh size. Mean length estimates thus provide an additional check on the tow cash value results. In addition, information on length-frequency distributions of fish retained by codends of different mesh sizes is needed to estimate species-specific gear selectivity coefficients. These estimates will play a key role in developing refined predictions of long-term effects of mesh size changes, which will be pursued in later phases of the study.

Mean fish lengths by species for a single tow are given by μ_q, where

$$\mu_q = (\sum_{i=1}^{n_q} l_{iq})/n_q \tag{2}$$

where n_q is the total number of fish from species q in the catch of an unspecified tow, and l_{iq} is the length of the ith fish caught of species q.

1.3 Decision to Use Commercial Vessels

The decision to use a large number of commercial trawl vessels operating under production fishing conditions instead of research charters was made at a very early stage of planning for the 1988 field work. A major advantage of this decision was its cost-effectiveness, since vessel time would be donated by fishermen under this plan, whereas additional funding would have been required to charter vessels. In addition, a strong argument was presented by fishermen that the results of data collected on charters had little credibility with the fishing community. From a scientific standpoint it was acknowledged that extrapolating the results from research charters to the commercial fleet would involve making a number of questionable assumptions, which could be avoided by carrying out the experiments under as close to ordinary commercial operating conditions as possible.

This decision ruled out the possibility of using specialized fishing techniques often employed in gear experiments, such as covered codends (Margetts 1956, 1959; Otterlind 1959; Hodder and May 1964; Robertson 1983; Robertson et al. 1986), trouser trawls, or parallel trawls. The advantage of such techniques is that they reduce variability of the data obtained, thus reducing the amount of sampling effort needed to detect differences among treatment types (Pope 1963; Pope et al. 1975). However, these techniques may also generate biased results (Stewart and Robertson 1985), limiting the direct application of results to management decision-making.

Overall, it was felt that the advantages of conducting our experiment under commercial conditions outweighed the advantages of other techniques. However, we recognized that the experimental design would have to be carefully planned in order to make the best use of available resources, and to assure that the results obtained would be statistically reliable.

1.4 Identification of Mesh Types for 1988 Field Work

The codend mesh types that were eventually chosen for field work in 1988 were 3", 4.5", and 5" diamond and 5" square. This choice was motivated by a number of different factors.

In the first instance, there was consensus by all interested parties that as many codend types as possible should be investigated. There was also, however, an appreciation that increasing the number of treatment types would increase the sampling effort required to obtain statistically significant results. Preliminary calculations showed that no more than four treatment types could be used, given the available sampling resources.

The 3" and 4.5" mesh codends were chosen primarily because they corresponded to existing minimum mesh size regulations for gear types employed in the fishery. It was also thought that the large size difference between the 3" and the 4.5" mesh would result in good contrast between responses, and hence easily lead to statistically significant results with the moderate sampling resources available. Moreover, the view was expressed that one of the first changes in mesh size regulations that might be contemplated is the replacement of the 3" minimum mesh size by 4.5", and good data would be needed to argue the merits of such a decision.

Mesh sizes smaller than 3" were not considered because it is unlikely that decreases in regulatory minimum mesh size would be considered for the groundfish complex, and because discard rates were anticipated to be unacceptably high for mesh sizes less than 3".

A larger diamond mesh size was proposed as the third treatment type. The basis for this proposal was that three seemed to be the minimum number of mesh size treatment levels needed to define catch responses for a particular mesh type (in this case, diamond mesh). The decision to use a 5" codend as the larger diamond mesh was based on a number of considerations. First, previous modeling work predicted that maximum equilibrium yield for a segment of the fishery would occur at a mesh size of approximately 5" (Pikitch 1987). While better data contrast may have been obtained with a mesh size that exceeded 5", there were concerns that catch rates might drop off very rapidly to sub-economic levels for larger mesh sizes. If the drop-off was quite severe, it may have been difficult or impossible to use the data obtained to extrapolate results to intermediate-sized meshes. Finally, there was a concern that gilling (fish wedged in the meshes of the net by their gills) rates might become unacceptably high for mesh sizes larger than 5", particularly for rockfish.

The idea of using a square mesh codend was then put forward. This proposal was motivated by theoretical and empirical considerations, both of which show that square meshes stay more open during fishing, when compared with diamond meshes (Robertson 1982, 1983, 1986). This causes square mesh netting to be more selective than diamond mesh netting, thus allowing larger numbers of juveniles to escape and grow to adulthood for meshes of the same size. Recent scientific results also suggest that the mortality rate of fish escaping from square mesh codends may be lower than that for fish escaping from diamond mesh codends (Main 1988; DeAlteris and Reifsteck 1988). Successful voluntary and legislated commercial use of square mesh codends has occurred in Europe and on the east coast of North America.

Arguments against using a square mesh codend in the experiment included the potential for greater expense and difficulties in obtaining and repairing square mesh netting; lesser strength of square mesh codends (see, for example, Robertson and Polanski 1984); and skepticism about whether square mesh would ever become a regulatory tool.

An early agreement to use the three diamond mesh codends was reached at an April 1988 meeting of the Mesh Size Advisory Group. It was also decided that a 5" square codend would be used, because this choice would allow a direct comparison of square and diamond mesh codends of the same mesh size to be made.

1.5 Geographic Scope

The geographic extent of the 1988 mesh size study was set by the fishing grounds which fall under the jurisdiction of the Pacific Fishery Management Council, and thus included waters offshore of the states of California, Oregon, and Washington. Resources available for 1988 field work limited the number of trips that could be conducted, and also expenditures for transport of samplers among ports. Because of these limitations, it was not possible to sample vessels operating along this entire section of coast. Instead, the intent was to obtain a representative sample of major groundfish trawling activities in the region, while focusing effort on perhaps three major fishing ports, one in each state. We also recognized that the actual geographic distribution of sampling would be determined to a large extent by the ports of operation of vessel owners that agreed to participate in the study.

1.6 Experimental Fishing Permits

Issuance of experimental fishing permits (EFP's) was crucial to the successful implementation of the planned field work. Two experimental fishing permits were obtained: one at the federal level, approved by the National Marine Fisheries Service Northwest Regional Office; and a second, issued by the Oregon Department of Fish and Wildlife. Major provisions of both state and federal EFP's were identical and were discussed at a meeting of the Pacific Fishery Management Council prior to approval. It was not necessary to obtain EFP's from the states of Washington and California. Representatives from each of these states gave input into the conditions of the federal EFP during the PFMC discussion, and agreed to honor these provisions at the state level.

The EFP's permitted fieldwork to be conducted in a manner which differed from regular commercial fishing operations in two major respects. First, they allowed detachable codends to be used throughout the experiment, with codend mesh sizes ranging from three to six inches. Detachable codends were needed in order to minimize disruption of commercial fishing activities during the experiment. The study design required that two or more codends of different mesh sizes be fished in randomized order during individual fishing trips.[1] It would have been too time-consuming to switch nets (rather than just codends) several times during a trip, and would have greatly reduced the number of vessels willing and able to participate in the study. Also, few vessels in the fishery carry two or more nets of identical design. Thus, use of several nets might have contributed additional variability to the results, and could have confounded the effects of net type and codend mesh size, neither of which was desirable.

Secondly, the EFP's contained a provision allowing for the commercial sale of fish caught in excess of existing trip quota limits. In order to meet the primary objectives of the study, it was necessary for fishermen to target their efforts throughout the experiment on concentrations of commercially important species managed by trip limits. Meaningful sample sizes for the experiment could not have been obtained without the potential to exceed such limits, and it would have been wasteful not to allow such excess catches to be sold. In addition, the waiver of trip limit restrictions eliminated the possibility of confounding the effects of mesh size and trip quotas on fishing strategy and catch disposition.

Although not the primary reason for requesting an exemption from trip limit restrictions, this provision was a major commercial incentive, which facilitated recruitment of boats into the study. This incentive was particularly important since fishermen were not paid directly for their partici-

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[1] The reasons why this design requirement was needed are given in detail in Chapter 2 on Experimental Design.

pation in the study, and were required to accommodate two observers aboard their vessel, perform frequent gear changes, and use gear that may have been much less efficient than that ordinarily used.

1.7 The Rockfish and Flatfish Sub-Studies

In a previous study of the West Coast groundfish trawl fishery, five major fishing strategies, distinguished by gear used, target species, and depth of fishing, were described (Pikitch 1987; Pikitch et al. 1988). These were as follows: (1) Bottom rockfish trawling (BRF)—tows conducted using roller gear on hard ocean bottom, with the primary target of the tows being one or more species of rockfish. (2) Midwater trawling (MID)—tows conducted using midwater trawl gear above bottom, primarily targeted at widow rockfish (*Sebastes entomelas*) and Pacific hake (*Merluccius productus*). (3) Deepwater Dover sole trawling (DWD)—tows conducted on soft ocean bottom in areas generally exceeding 100 fathoms deep, using mud gear, roller gear, or mud-roller combination gear. An important target species of this fishing strategy is Dover sole (*Microstomus pacificus*), but sablefish (*Anoplopoma fimbria*) and *Sebastolobus* spp. are also important components of the catch. (4) Nearshore mixed-species trawling (NSM)—tows conducted using mud gear on soft bottom in areas generally less than 100 fathoms deep; primary target species were a mixture of flatfish. (5) Shrimp trawling (SHR)—tows conducted using shrimp trawls, targeting primarily on pink shrimp (*Pandalus jordani*), but with catches also including various quantities of groundfish species.

Because of limited resources for the 1988 study, it was necessary to focus attention on two strategies. The DWD and BRF fishing strategies were initially selected because they were among those most impacted by trip quotas (Pikitch 1987; Pikitch et al 1988), and because preliminary analyses indicated that they represented the extremes in terms of variability in catch composition and amount. However, a small number of tows conducted using the NSM strategy were observed during the 1988 field study. It is unlikely that analysis of the data obtained during 1988 for the NSM strategy alone would be useful because the small sample sizes obtained are unlikely to yield statistically significant results. Moreover, the 100-fathom contour line which separates the DWD and NSM strategies is a rather arbitrary boundary. Species composition changes gradually over a broad range of depths, and thus, differences in species composition between these strategies are greatest at depth extremes. These factors led to a decision to combine NSM and DWD tows in analysis of the 1988 data. Thus, for purposes of the 1988 mesh size project only, we defined two sub-studies as follows:

1. Rockfish: Fishing directed at a mixture of rockfish (*Sebastes* spp.) using roller gear on hard bottom (i.e., the BRF strategy).

2. Flatfish: Fishing using mud gear or combination mud-roller gear on soft bottom, directed primarily at the DWD assemblage, but also including relatively shallow water tows (<100 fathoms) directed at a mixture of flatfish and other species (i.e., the NSM strategy).

Since some boats target both flatfish and rockfish within a trip, the two sub-studies were run concurrently.

The long-run strategy of this project is to maintain the distinctions among the various components of the trawl fishery. Thus, in contrast to the procedures employed in this report, analyses of the larger data base obtained during the course of the study (1988-1990) will be performed separately for each fishing strategy.

1.8 Solicitation of Trawler Participation

Letters soliciting participation in the study were sent to approximately 350 trawl vessel owners and operators by University of Washington personnel on two separate occasions, first in early April and then late in May 1988. The addresses were supplied by the Oregon Department of Fish and Wildlife, the Washington State Department of Fisheries, the California Department of Fish and Game, and the Fishermen's Marketing Association. Newsletters of both the Oregon Trawl Commission (formerly the Otter Trawl Commission of Oregon) and the Fishermen's Marketing Association ran articles about the study which also solicited trawler participation.

Further efforts to solicit trawler participation were made by telephone, and through personal contact with fishermen at major fishing ports and at Pacific Fishery Management Council meetings. A total of 48 trawl vessel owner-operators responded to the various efforts made, and all were included in the experimental fishing permit.

1.9 Codend Design and Construction

We attempted to meet several objectives in designing the codends for the 1988 field experiment. First, in order to be able to attribute differences in catch characteristics among experimental codends to mesh size or shape, it was necessary to construct all codends of similar materials and of equal dimensions. We also desired the design to be close to that most commonly used by West Coast trawl fishermen, yet also be acceptable to all trawl fishermen we were likely to work with. Since the vessels involved in the study differed from one another in a number of respects, these design objectives were a challenge to meet. Specifically, the codends had to be appropriate for (1) trawl vessels ranging from 50 feet to 120 feet in length, (2) vessels targeting bottom rockfish, flatfish, and roundfish, (3) vessels fishing from 10 fathoms to 600 fathoms deep, and (4) vessels fishing as far north as the Canadian border and as far south as San Francisco, California.

Initial input on codend design was sought from the Mesh Size Advisory Group, which included a commercial trawl fisherman from Northern California (Dr. Richard Young). We also discussed codend design with three net builders, several commercial trawl fishermen, and personnel of the National Marine Fisheries Service's net-building loft in Seattle. On the basis of the input from these various sources, we developed preliminary specifications for the experimental codends. These specifications were included in the second mailing to trawlers, soliciting their comments on the design as well as their participation in the study. Final specifications for major characteristics of the experimental codends are given in Table 1. In addition to what is listed in Table 1, codends contained splitting rings, splitting straps, and detachable floats. Participating trawlers provided pucker ropes.

2. EXPERIMENTAL DESIGN

2.1 Consideration of Different Experimental Designs and Determination of Sample Sizes

Planning for the 1988 study included detailed consideration of the statistical design of the field work. The concerns that were addressed during this period of the study were the need to obtain results in a logistically feasible manner that were also statistically reliable. Because of limited sampling resources, the need to minimize sampling effort was considered in some depth.

The specific work undertaken focussed on the evaluation of experimental designs in which treatment types are apportioned between fishing trips in different ways. Two extreme scenarios were identified (see Figure 2). In the first, Design A, a single codend treatment type is used on each fishing trip. The alternative to this, Design B, is to use all codend treatment types of interest on each fishing trip. Design B utilizes statistical blocking, in which the study is broken down into smaller, basically similar sub-studies, and is closely related to the method of alternative tows (Jensen and Hennemuth 1966; Smolowitz 1983).

It was anticipated that the blocking approach would require a smaller sample size (i.e., number of fishing trips) to achieve significant results. The disadvantage of blocking is that it requires frequent codend changes, which interferes with normal fishing operations. Thus, the first task during the experimental design phase was to estimate the extent of reduction of required sample size that would result from using a blocked design, compared with the more easily implemented unblocked design. This permitted an assessment of whether the extent of the reduction in sample size outweighed the extra work involved in making frequent codend changes at sea, and thus facilitated the selection of a design that would maximize use of sampling resources.

2.2 Variance Components and Sample Size

The variance of the critical response variables, the revenue per tow time and mean fish lengths, consists of a contribution from the variance due to trip ($\sigma^2{}_T$), which is due to the distinguishing characteristics of different trips—such as vessel size and power, weather conditions, skipper and crew; and variance due to tow ($\sigma^2{}_H$)—the average tow-to-tow variance on a trip. Estimates of these variance components are crucial for evaluating the relative advantages of blocking since they appear in the denominator mean squares of the F-test for the null hypothesis. For the null hypothesis, "no treatment effect," the trip-to-trip variance component appears in the denominator of the F statistic for Design A, but is eliminated from the F statistic for the blocked design, Design B.

Existing data (circa February 1988) were used to estimate the variance components $\sigma^2{}_T$ and $\sigma^2{}_H$. These data were the result of a preceding study of the Pacific trawl groundfishery, which is described by Pikitch et al.(1987). The estimates of variance components for tow revenues and fish lengths are reproduced in Tables 3 and 4, respectively. These were used to calculate an estimate of the sample size (number of fishing trips) required to reject the null hypothesis "no codend treatment effect" for the dollar per hour (C_m) and mean fish length response variables. Sample size estimates were derived for a range of possible magnitudes of codend effects using techniques discribed by Scheffe (1959) and Peng (1967). All calculations were made for a significance level (α) of 0.10 and power ($1-\beta$) set equal to 0.8, using tables of noncentral F (Pearson and Hartley 1962). Further details on the estimation of $\sigma^2{}_T$, $\sigma^2{}_H$ and the methodology used to derive sample size estimates are given in Bergh et al. (in press).

The sample size results reported in Bergh et al. (in press), are summarized in Table 5 for the dollar per hour response variable, and in Tables 6 and 7 for the mean fish length responses. These demonstrate that in most cases the advantages of blocking are substantial, with reductions in sample size ranging from a factor of four to a factor of ten. These results led to the proposal to use a blocking procedure for the 1988 field work. This proposal was presented to the Mesh Size Advisory Group and was accepted.

2.3 Selection of a Final Experimental Design

A very common situation in the groundfishery in question is that fishing trips might often be terminated because of unforeseen events—either weather, gear damage, or some other factor. Design B discussed above would only require that codends be applied in random order so that an equal number of tows are conducted with each codend over the entire trip. It is conceivable that this simple randomization procedure could produce sequences of tows in which, if there are, say, four treatment types, the first five or six tows use only two of the treatment types. In this case, an early trip termination would lead to the loss of the ability to examine all planned comparisons.

An alternative to Design B is a randomized complete block design (Design C), in which each set of four consecutive tows directed at a particular assemblage (flatfish or rockfish) constitutes a block. Within each block, each of the four experimental codends would be fished once, according to a predetermined, randomized design. The advantages of Design C over Design B are twofold. First, with a randomized complete block design, the chances of obtaining data on all four experimental codends when an early trip termination occurs are greater than for Design B (Figure 3). The second advantage of Design C is that it is likely to reduce intra-block variance. For these reasons, we selected Design C for implementation of the 1988 field work.

2.4 The Response Model and the Null Hypothesis for the Randomized Complete Block Design

The analysis of variance (ANOVA) model for the randomized complete block design (Design C) discussed in the previous section is (e.g., Cochran and Cox 1957; Myers 1972; Johnson and Leone 1977):

$$y_{m,j} = \mu + \alpha_m + \beta_j + \varepsilon_{m,j} \tag{3}$$

where

$y_{m,j}$ = the transformed observed value for the mth gear type (m=1,2,...,r), of the jth block (j=1,2,...,T),
μ = the overall mean response,
α_m = the effect of the mth gear type,
β_j = the effect of the jth block,
ε_{mj} = error term associated with the variation in the mth gear type (m=1,2,...,r), of the jth block (j=1,2,...,T).

The ε_{mj} are assumed to be normally distributed with a mean of zero, and a variance $\sigma^2{}_\varepsilon$ which is independent of m and j.

The null hypothesis is

$$H_0: \ \alpha_1 = \alpha_2 = ... = \alpha_r = 0$$

i.e., that there is no treatment effect.

2.5 The Problem of Null and Zero Values

In data which are collected without careful planning, it is very common to have missing values (i.e., cells with "null" response values, in the matrix of observations intended for an ANOVA).

The result would then be an unplanned, incomplete block design, which in general would have unestimable treatments (Bock 1975).

In the mesh size study, null values arise when a tow yields no scientific information—for example, when the fishing gear does not fish correctly. Null values are distinct from zero response values. The latter arise when a properly conducted tow yields no fish, or very few fish. Depending on the nature of the specific response value in question, zero responses may or may not be classed as null responses.

The null value problem has to be dealt with in a satisfactory manner while the data are being gathered in order to obtain a complete block design. For the mesh size study, we thought it was most important to assure that blocks would be complete for the dollars per hour response variable. To do this, an "aborted tow" procedure was defined. This procedure formalizes the definition of a null value, and specifies how to obtain a complete block in an objective manner.

For the dollar per hour response variable, zero responses were defined to be null responses, and the associated tow was therefore classified as an aborted tow. A complete list of aborted tow definitions is given in Table 8; this list includes tows yielding a total of less than 50 pounds of fish. The occurrence of an aborted tow initiated a re-randomization procedure that guaranteed that a complete block of non-zero, non-null data would ultimately be obtained for the dollars per hour response variable. It involved applying the sequence of untried treatment types, including the codend currently on the fishing gear, in a new random order. The intent of the re-randomization procedure was to prevent the skipper and crew from anticipating the forthcoming treatment type, and reacting to it subjectively by choice of target species, or tow depth or location, thus jeopardizing the objectivity of the experiment. This procedure was part of a broader strategy of maintaining the objectivity of the field work, which involved the approximate blind trial procedure described in the next section.

2.6 Approximating Blind Trials

As mentioned above, human expectations can have a detrimental effect on a field trial and adversely affect the statistical reliability of experimental results. The ideal precaution against this is to conduct blind trials, in which the treatment type (in this case, codend type) in use is unknown to the fishing crew. Preliminary trials at sea attended by the statistical team showed that attainment of blind trials was virtually impossible, and that some sacrifices would have to be made. A procedure was agreed upon, in which the skipper would specify the upcoming tow location, depth, gear type, and target species, approximately 15 minutes prior to setting the net. This commitment was then recorded in writing, and only then was the codend type for the tow announced by the on-board samplers.

2.7 Subsampling Procedures

Consideration of different procedures for subsampling the catch centered around the time constraint imposed by the need to complete sampling work on a tow before the arrival of the next tow's catch on deck. From previous experience it was known that tow duration varied from 15 minutes to six hours. The subsampling procedure therefore had to be flexible enough to take advantage of extra time, as it arose. Conversely, when time was very limited, the subsampling procedure had to guarantee that critical information would nevertheless be recorded. This flexibility was achieved by formalizing the priorities of obtaining various kinds of data (see page 19). Samplers could therefore use their discretion, in conjunction with the priority list, to modify the quantities and types of data collected. The most common time-saving measures taken were to measure fewer fish for length information, or not to sex fish. Further details on subsampling procedures are presented in the next section.

3. DATA RECORDED

While information on certain aspects of the study was collected at the conclusion of the field work, most of the data collected were taken at sea or following each trip. The data recorded in the field can be divided into data which are pertinent to the fishing trip in general, and data relating to a particular tow of that trip. Trip information includes vessel and gear specification data, trip economic data, and information about landings for the trip as a whole. The tow-by-tow data include those related to the catch obtained, and information on how and where the trip was conducted. A summary of data collected on each fishing trip and for each tow is presented in Table 9. A brief description of data collection and recording methods for selected items is given below.

3.1 Trip Data

Information on vessel characteristics and specifications of gear used was obtained at the beginning of the trip from the skipper. Separate specification forms were completed for each type of trawl net on board. The trawl gear used for each tow conducted was later recorded on the haul form. The skipper's economic plans and expectations for the trip were also recorded at the beginning of the trip. Details included the list of target species, processor requests and limits, and the gross revenue needed for the trip to be a success or to break even. At the end of the trip the skipper's rating of the economic success of the trip, the basis for the success rating, the reason for ending the trip, and trip expenses were recorded.

Estimated pounds retained was recorded from the vessel's logbook at the conclusion of each tow. The total pounds landed was obtained at the conclusion of the trip from fish processing plant records ("fish tickets"). Fish ticket information included total pounds landed, total pounds "weighed back" (landed, but not sold), price per pound, and total payment by species or species group.

3.2 Tow Data

3.2.1 Tow Data Unrelated to Catch

The information under the heading "Haul Information" in Table 9 was recorded for each tow, or each sub-tow when applicable, regardless of the catch which was obtained. The following definitions and procedures were rigorously applied.

a. A sub-tow was defined as hauling the net off the bottom, and then resetting the gear to tow over the same location or another location without bringing the catch on board.
b. The starting time of a tow (time start) was defined as the time when the vessel stopped letting the cable out.
c. The end of a tow (time finish) was defined as the time when the vessel began hauling the cable in.
d. Average tow depth recorded was the average tow depth determined by the skipper.
e. Fishing strategy was recorded prior to the start of the tow and was based on the skipper's declared depth, bottom type, and gear type.

Other pre-tow information was also collected and recorded on the haul information form prior to the start of the tow, in accordance with the approximate blind trial procedure described above.

3.2.2 Tow Catch Data

In the following sections, we highlight some of the important aspects of the data recorded on the catch for each tow.

In order to estimate the species composition of the catch, the following procedure was used. The skipper's estimate of the weight of the total codend contents ("skipper hail weight estimate") was recorded. This estimate was assumed to refer to the contents released onto the deck after the codend purse string was loosened, and therefore excluded fish wedged in the meshes of the codend (i.e.,"gillers").

For catches greater than 1,000 pounds, a random sub-sample of five baskets (approximately 350 pounds) was taken. This was supplemented by collecting the entire catch of those species judged to be relatively rare in the catch. For catches between 500 and 1,000 pounds, all fish on one side of an imaginary dividing line through the catch on the deck were placed into baskets.

Again, this was supplemented by collecting the entire catch of "rare" species. For catches of less than 500 pounds, the entire catch was retained in baskets.

All fish were then sorted into baskets according to species and disposition (utilized or discarded) and weighed. For each weight measurement taken, codes were recorded to indicate whether the weight represented 100% of the catch of that species, or only a subsample of that species, and whether the weight was measured or estimated. In addition, for those portions of the catch that were discarded, the reason for discarding was recorded.

In most cases, the catch of gillers was small, and therefore the entire catch of gillers was weighed and sampled to determine the species composition of this component of the catch. For the few cases when this was not possible, samplers weighed half of the gillers, and recorded the giller catch weight as twice this estimate. As for the non-gilled catch, for each weight measurement taken, codes were recorded indicating the reason for discarding, whether the weight represented 100% of the giller catch of that species, or only a subsample of that species, and whether weight was measured or estimated.

During initial planning, a list of focus species for obtaining length data was determined (Table 10). In the field, the objective was to measure the lengths of 100 fish of each focus species that appeared in the tow. This would frequently require that fish in addition to those obtained in the weight subsample be collected. The truncated total fish length was recorded, i.e., a value of 30 cm would be recorded for fish between 30 and 31 cm. The weight of all fish for a given species used for length measurements was recorded.

The objective of 100 length measurements was frequently not met, either because the entire catch contained fewer than 100 individuals of each focus species, or because of time constraints. When time was a limiting factor, certain tasks were dropped. These are listed below in the order in which they generally were eliminated—i.e., sexing was the first task to be dropped.

a. Eliminate sexing.
b. Eliminate estimated weights for fish measured.
c. Reduce the sample size from 100 to 50 fish.
d. Disregard species with fewer than 10 individuals in the catch.

For each fish, the data recorded were species, size, sex and disposition (utilized or discarded).

3.2.3 Timing of Events

For various tasks conducted after each tow was hauled on board, data on both vessel time and person time needed to complete each task were recorded. For example, for a task that started at 1200 hours and ended at 1400 hours, with one person working from 1200 to 1330 hours and another from 1200 to 1400 hours, the vessel time was recorded as 2 hours, and the person time was calculated at 3.5 (i.e., 1.5 + 2) hours.

Catch sorting time was measured from the time that at least one crew member began sorting the catch, and ended when the deck was cleared of fish. It excluded the extra time needed to ice fish, hose the deck and take breaks. Similarly, giller picking time was measured from the time that at least one crew member began picking, until the net was clear of all gillers. Time spent shaking gillers was included in estimates of giller picking time. Time spent hauling the net through the water to clean off gillers was recorded as such in the comments section of the relevant form.

In instances where some damage to the nets occurred, the time spent mending nets was recorded. The time spent changing codends between tows was also recorded and included time spent to change floats for vessels that used floats.

For aborted tows, all information that could be obtained without handling fish was recorded. This included all the tow data not related to the actual catch, and estimated total catch weight.

3.3 Measurement of Actual Mesh Sizes

Mesh size refers to the distance between knots (diamond mesh) or seams (knotless square mesh) along a diagonal by placing tension along the other diagonal (i.e., lengths L_a and L_b, Figure 4a,b). Although the square mesh measurement was taken along the diagonal (Figure 4b), the square configuration was maintained while fishing (Figure 4c) because of the method of hanging the material between the riblines.

Inconsistent measurements of the diamond mesh web may be encountered because of asymmetrical shapes caused by the knots. It is possible to obtain differences in size estimates of up to 1/8 inch depending on precisely how and where measurements are taken (e.g., see possibilities L_c and L_d, Figure 4d,e). In addition, a certain amount of net stretching is expected after the first few tows on account of material fatigue and knot tightening. The overall result of these effects is that actual mesh sizes of the experimental codends may differ from the desired target mesh sizes.

All codend mesh measurements were recorded at the conclusion of the 1988 field work. Codend sets A-C were fished during 1988, whereas codend set D was not used (Table 18). The following measuring procedure was used:

a. Meshes were stretched and measured across the diagonal (L_a and L_b, Figure 4a,b) using a graduated wedge designed by the research team. This wedge was accurate to the nearest 1/8 inch, and could accommodate mesh sizes ranging from 2.5 inches to 6 inches.

b. Meshes were chosen from the top and right codend panels (determined by facing the codend from the puckered end with chafing gear underneath). Measurements were taken along diagonal lines between the riblines beginning at the puckered end; every fifth mesh was measured. Four rows of mesh per panel were measured.

4. DATA ANALYSIS METHODS

4.1 General Types of Analyses Performed

The analysis of the 1988 field data was organized around three broad aims, as follows: testing hypotheses, estimating gear effects and mean responses by treatment type, and performing post-hoc sample size calculations for use in planning future field work.

A summary of the general procedures used for each of the four types of analysis conducted is given below. This is followed by a detailed description of the analyses performed for specific response variables.

4.2 Testing the Null Hypothesis of No Mesh Type Effect

The null hypothesis can be formally expressed as:

$$H_0\text{:}\ \alpha_1 = \alpha_2 = \ldots\alpha_r$$

where α_m is the effect of the mth mesh type. In most cases, analysis of variance (ANOVA) was used to test the null hypothesis of no mesh type effect. For those response variables for which the data distribution met the assumptions of ANOVA (i.e., normal distribution and homogeneous variance), the analysis was performed on the raw data. In other cases, the data were first transformed using a logarithmic or logit transformation before performing the ANOVA.

In performing ANOVA's for some response variables, the ANOVA model was modified from that described by equation (3) in Section 2.4 to include covariates. Tow depth was included as a covariate in most cases, even though it may not have always been statistically significant. Tow time (or, alternatively, the logarithm of tow time) was included as a covariate in a smaller number of cases.

Thus, for ANOVA's performed using both depth and some function of tow time (i.e., raw data or log-transformed tow time data) as covariates, the ANOVA model took one of the following two forms:

$$y_{mj} = \mu + \alpha_m + \beta_j + \nu T_{mj} + \psi C_{mj} + \varepsilon_{mj} \tag{4}$$

or

$$y_{mj} = \mu + \alpha_m + \beta_j + \nu \ln[T_{mj}] + \psi C_{mj} + \varepsilon_{mj} \tag{5}$$

where T_{mj} and C_{mj} = respectively, tow time, and average tow depth for the tow in block j performed using mesh type m,

ν = the regression coefficient associated with the covariates T_{mj} (eq. 4), and $\ln[T_{mj}]$ (eq. 5),

ψ = regression coefficient associated with the covariate C_{mj} (average tow time, in equations 4 and 5),

and μ, α_m, β_j, and ε_{mj} are as defined in equation (3) in section 2.4.

Thus far, in discussing procedures for performing ANOVA, we have covered the issues of data transformation and model specification (i.e., number and type of covariates). Another important decision that had to be made was to determine how much of the data collected should be used in each analysis. As described earlier, the experimental design selected assured that all blocks of data would be complete with respect to the dollars-per-hour (DPH) response variable. That is, because of our definition of an aborted tow (see Table 8), none of the complete blocks contained either zero or null observations for DPH. However, many trips contained tows that did not form part of a complete block. This could arise, for example, when nine successful tows were completed during a trip where four experimental codends were used. In this example, the trip would result in two complete blocks of data for DPH, and one tow which was not part of a block. Tows that were not part of a complete block were excluded from the analyses so that the data set used would be "balanced" in the statistical sense, permitting use of more powerful statistical techniques.

Of potentially greater consequence were decisions related to the portions of the data set to be used for response variables other than DPH. It was not possible to design the experiment in such a manner as to avoid null or zero responses for all other response variables. For example, a complete block of four rockfish tows could contain catches of a particular species in only three of the four tows. Thus, when analyzing the effect of mesh type on the catch of this species, we needed to decide whether to include blocks such as the example block described above which contained one zero response, or to restrict the analysis to blocks for which each tow contained at least some catch of the species. Similarly, in analyzing the data for this example species to determine whether mean length differed among mesh types, we would again need to decide whether to exclude tows which did not contain that species in the analysis. In the latter case, the lack of length data for a particular tow would be treated as a null (missing data) response, rather than as a zero response.

Because balanced data sets are preferable to unbalanced data sets for statistical analysis, we generally excluded blocks containing zero or null responses from the ANOVA. However, in these cases, we usually performed a supplementary analysis to determine whether there was a tendency for zero or null responses to occur with equal frequency for all mesh types, or, alternatively, if zero or null responses occurred more frequently for particular mesh types. The supplementary analysis generally took the form of a contingency table approach for which data were transformed to discrete counts (representing frequency of occurrence by data category), and a chi-square statistic computed.

The adjusted mean responses, the p-values and the post-hoc sample size calculations from the ANOVA's F-statistic associated with the null hypothesis of no mesh effects are reported in the tables. The p-values from t-tests for all possible pairwise comparisons between different treatment types are also given.

4.3 Estimating Mean Response by Treatment Type

The second aim of the analysis of the 1988 field data was to estimate the expected (i.e., mean) response level for each treatment type. These means were calculated by adjusting the average response for the 4.5-inch codend by the treatment factor estimates, α_m, for the other treatment types. In this manner, the 4.5-inch codend result is treated as the standard against which the responses for other codend types are compared. For log transformed variables (for example, dollars per hour), the model used to perform the analysis implies

$$\ln\mu_3 - \ln\mu_{4.5} = \alpha_3 - \alpha_{4.5}$$

The adjusted mean for the 3-inch codend is therefore:

$$\mu_3 = \mu_{4.5}e^{\alpha_3 - \alpha_{4.5}}$$

and similarly, for the 5-inch diamond codend, it is:

$$\mu_5 = \mu_{4.5}e^{\alpha_5 - \alpha_{4.5}}$$

The adjusted means reflect the relative difference between response variables for different treatment types due to treatment effect only (i.e., for the same covariates and blocking factors). It is important to note, however, that for some species-specific responses (i.e., mean catch for a particular species), the mean response for a given codend type calculated by the above procedure could often be greater than the mean response calculated using data from all tows conducted. This is because, as stated in the previous section, only complete blocks containing non-zero responses were used in the analysis.

Readers should therefore focus their attention on the relative differences in catch between codend types rather than on absolute mean responses by codend type. The relative differences calculated should be representative of actual relative differences in those cases where zero responses occurred with equal frequency among codend types. For those cases where zero responses tended to predominate in catches obtained by one or more specific codend types, the relative differences calculated by the above procedure may be inaccurate, and interpretation of the effects of codend type on the response should be focused on the results of the supplementary, contingency table approach, rather than on the results of the ANOVA.

The calculation procedure for obtaining adjusted means for responses which were logit-transformed is described in Appendix A.

4.4 Post-Hoc Sample Size Calculations

The third and final aim of the analyses was to use the variance estimates obtained for key response variables to estimate the sample sizes needed to reject the null hypothesis of no treatment effect for all pairwise comparisons. Post-hoc sample size calculations were performed using the method detailed in Bergh et al. (in press). The main result which is reported is the sample size needed to reject the null hypotheses, $\alpha_3 = \alpha_{4.5}$, $\alpha_5 = \alpha_{4.5}$, $\alpha_3 = \alpha_5$, $\alpha_5 = \alpha_{5s}$, $\alpha_{5s} = \alpha_{4.5}$, and $\alpha_{5s} = \alpha_3$. Critical information needed for this calculation is the mean square error from the ANOVA, the estimate of σ_ε^2.

We computed a non-centrality ϕ for use with tables similar to Pearson and Hartley's non-central F tables of the form

$$\phi = \frac{\Delta_\alpha \sqrt{T}}{2\sigma_\varepsilon}$$

where T is the number of complete blocks, and

$$\Delta_\alpha = \left| \hat{\alpha}_{m'} - \hat{\alpha}_{m''} \right|,$$

where m' and m" are all possible combinations of treatment types, and the gear factors used are the actual estimates obtained from the 1988 data set. The iterative algorithm given in Bergh et al. (in press) was used to find the value of T which would provide the projected power (1-β) needed to reject each of the null hypotheses in turn. However, we used an α level of 5% instead of the 10% used in Bergh et al., because there was a concern that given the large number of pairwise tests performed, the experimental error rate would be much larger than the nominal level of $\alpha = 0.1$ chosen for this study. The same power level of 80% used in Bergh et al. (in press), was used in the calculations reported here.

The assumptions associated with the above sample size calculations include:

1. The absolute difference in sample means is normally distributed.
2. The difference in sample means from the preliminary field study is an accurate interval for the mesh size effect to be detected in subsequent studies. (Note, it is the absolute difference that is important, not the sample means themselves.)

3. The mean square error observed during the preliminary field study is representative of the error variance to be observed in subsequent studies.

The reliability of the sample size calculations will depend on the degrees of freedom used in estimating the MSE from the preliminary study. Should the preliminary estimate of MSE be too large, the sample size calculations will over-predict the required numbers of blocks, and vice versa.

For pairwise comparisons where the null hypothesis was not rejected, the sample size calculations enabled the identification of those comparisons for which rejection of the null could be expected following the performance of a feasible number of additional blocks. Similarly, the calculations also identified pairwise comparisons where the number of additional blocks needed to reject the null hypothesis was so large as to be practically unfeasible. This information was vital for planning the 1989 phase of the mesh size study.

4.5 Analyses Performed for Specific Response Variables

4.5.1 Tow Duration and Occurrence of Aborted Tows

We performed an ANOVA using the simple linear model (equation 3) on tow duration to test the null hypothesis "There is no difference in tow time among mesh types" using data from complete blocks only. Separate ANOVA's were performed for the 3- and 4-codend data sets. The purpose of these analyses was twofold. First, they provided some measure of the effectiveness of our "approximate" blind trial procedure. In addition, it was important to assess whether differences in tow duration occurred for different mesh types, so that such differences could be taken into account in subsequent analyses of other response variables if necessary.

We examined the occurrence of aborted tows by mesh type using a contingency table approach. The analysis was performed using data for all tows conducted during 1988, combining data from both the rockfish and the flatfish sub-studies. The purpose of this analysis was to determine whether there were detectable differences in reliability of the different codend types. In addition, it enabled an assessment of whether the aborted tow criteria listed in Table 8 may have contributed to bias in the interpretation of the catch rates of different mesh types.

4.5.2 Analyses Performed for Response Variables Involving All Species Combined

A detailed set of analyses was performed for the dollars per hour (DPH) response variable, since this was identified as the critical response variable at the start of the study. The data on DPH were transformed using a logarithmic transformation prior to performing the ANOVA. The model for the ANOVA was that for a blocked design with both tow duration and average tow depth as covariates (equation 4). ANOVA's were performed separately for the 3- and 4-codend data sets and for each sub-study (flatfish and rockfish), resulting in a total of four ANOVA's. Only data from complete blocks were used in the analyses. As stated previously, our experimental design assured that none of the complete blocks would contain any null or zero responses.

The extent of gilling (i.e., occurrence of fish wedged in the meshes of the net) by mesh type was considered by examining three different response variables: (1) Total giller weight per trawling hour, (2) the proportion of gilled fish (by weight) in the total catch for each tow, and (3) the time it took to pick all gillers from the codend. ANOVA's were performed for each of these response variables for four segments of the data set: Flatfish sub-study—3-codend data set; flatfish sub-study—4-codend data set; rockfish sub-study—3-codend data set; and rockfish sub-study—4-codend data set. All the ANOVA's were performed using data from complete blocks only, and using average tow depth as a covariate. For the giller picking time response variable, one set of ANOVA's was performed with tow time as an additional covariate, and another set conducted without tow time as a covariate.

The data on the proportion of catch weight of each tow gilled were transformed using the logit transformation prior to performing ANOVA. The logarithmic transformation was first applied to the data on giller picking times and giller weight per hour prior to performing ANOVA. However, because some tows did not result in any fish being gilled, there were a number of zero responses for both of these variables. Because the log of zero is undefined, some procedure needed to be developed to handle zero responses. Our solution was to replace zero responses with a value equal to one half of the smallest non-zero response observed in the data set for each variable.

Because of the occurrence of zero responses in the data set, supplementary contingency table tests were performed for the giller picking time response variable. For the 3-codend data set, giller picking time categories were 0-5 minutes, 5-20 minutes, and greater than 20 minutes. The number of tows with giller picking time in each of these three categories was computed for each diamond mesh size, and then a χ^2 statistic and its associated significance level (α) were computed. A similar analysis was performed for the 4-codend data set, except that in this case, the time categories used were 0-10 minutes and greater than 10 minutes.

Catch sorting time was analyzed in the same manner as giller picking time (i.e., the same data transformations and ANOVA models were applied, and contingency table analyses were performed for the 3- and 4-codend data sets).

Two response variables were analyzed to examine the effect of codend type on the extent of discarding. These were: (1) the proportion of the total catch weight discarded, and (2) total catch weight discarded (in pounds) per trawling hour. Discard proportion data were analyzed in the same manner as giller proportion data, and similarly, analyses performed for discard catch weight were the same as those conducted for the giller catch weight response variable.

4.5.3 Analyses Performed For Individual Species

Data from the flatfish and rockfish sub-studies were pooled for analyses performed for individual species in order to maximize sample sizes. Only complete blocks of data (on an individual species basis) were used in the analyses. Further, analyses were performed only for those species for which two or more complete blocks of data were obtained.

Response variables examined on an individual species basis were a subset of those examined for each sub-study, and included: total catch weight per trawling hour (equivalent to DPH for species of commercial value) and mean length by codend type. Methods used to analyze these response variables for individual species were similar to those used to examine response variables for data on all species combined.

In addition to the response variables discussed above, we estimated mean responses for the variables gilled weight as a proportion of individual species total catch weight, and discard weight as a proportion of individual species total weight.

5. RESULTS

5.1 Summary of Field Accomplishments

Twenty-six experimental fishing trips were conducted aboard 21 different vessels (Table 11). Average trip duration was 4.5 days, resulting in 117.5 days of sampling during 1988. During the trips sampled, a total of 410 tows was conducted, of which 345 tows were successful and 65 tows were aborted (Table 12). Thus, there was an average of 13.3 non-aborted tows conducted per experimental trip.

The geographic extent of field sampling ranged from approximately San Francisco, CA, to Blaine, WA (Figure 5). The distribution of sampling was less concentrated spatially than originally anticipated (Tables 13 and 14), largely because of the distribution of ports of operation of trawlers who indicated a willingness to participate in the study (Table 11). A total of 48 vessel-owners responded to the various solicitations of participation made, and all were included on the experimental permit. The highest response rates were obtained from the central Oregon and southern Washington-northern Oregon regions, while the response rate from owners of boats operating out of central California was lowest (Table 11). Consequently, most sampling effort occurred in the Columbia and Vancouver INPFC areas (Tables 13 and 14).

Diamond mesh codends became available in July, whereas the square mesh codends were not available until September 1988.[1] Thus, during the first six trips only the 3", 4.5" and 5.0" diamond mesh codends were used; and a complete block consisted of a sequence of three successful tows employing each of the codends once (in random order) at a particular assemblage (i.e., flatfish or rockfish). For the 7th through 26th trips, all four experimental codend types (5.0" square in addition to the three diamond mesh codends) were fished. For tows directed at rockfish, 45 complete blocks were obtained (21 blocks of 3 codends and 24 blocks of 4 codends), whereas for the flatfish strategy, 35 blocks (12 blocks of 3 and 23 blocks of 4 codends) were completed (Table 12).

During the course of the field work, trip or weekly quota restrictions were in force for five species groups (Table 15). However, as previously stated, trip poundage restrictions did not apply to experimental trips. Total landings, and landings of each species group managed by trip quotas for each trip are summarized in Table 16. Landings ranged from 6,980 to 142,578 pounds per trip, and totalled 1,194,817 pounds for all experimental trips combined. Trip quotas for one or more species groups were exceeded during 24 of the 26 trips conducted.

Length measurements recorded for focus species (for both gilled and non-gilled fish) are summarized in Table 17. The number of fish measured ranged from a low of 268 for bank rockfish, up to 12,558 for yellowtail rockfish, and totalled 66,285 measurements for all species combined. Approximately 87% of the measurements taken were of non-gilled fish (Table 17).

5.2 Actual Codend Mesh Sizes

Four complete sets of three diamond mesh experimental codends (3", 4.5" and 5") were constructed, but only three of the sets were used during 1988. Two of the three 5"-square codends constructed during 1988 were used in the field. The actual average mesh sizes of the codends measured by the research team at the conclusion of the 1988 field work differed somewhat from the measurements stated by the net manufacturers.

All codend meshes were larger than the sizes ordered, with the largest discrepancies, 0.17 to 0.49 inches, for the 3" nets (Table 18). Excesses for the other sizes were between 0.10 and 0.30 inches. Since the unused codend set (b) also had larger mesh sizes than were specified for manufacture, stretching was not the only cause. An important factor that could explain these discrepancies might be the interpretation of the definition of mesh size. For example, the net manufacturing company might have worked under the definition L_c in Figure 4. Another factor that may have contributed to the estimated averages is the pressure used to insert the measurement gauge. Our

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[1] The delay in availability of square mesh codends was due to additional shipping time (the sole supplier is located in Japan), and construction time relative to the diamond mesh codends.

measurement procedures matched those of law enforcement personnel closely. However, enforcement personnel are primarily concerned about whether the mesh size meets or exceeds a certain lower bound, rather than whether mesh sizes are measured accurately. For simplicity, in reporting results of various analyses in the remainder of this document, we refer to each of the experimental codends based on the manufacturer's declaration of mesh size rather than the actual measured mesh sizes.

5.3 Results of Tow Duration and Aborted Tow Analyses

Average tow duration differed greatly between the two sub-studies. Tows directed at flatfish generally lasted more than twice as long as those directed at rockfish (Tables 20 and 21). For the rockfish sub-study, tow duration differed significantly among codend types, both on an overall basis (Table 19), and for several of the pairwise comparisons (Tables 22, 23). For the flatfish sub-study the overall effect of codend type on tow duration was not significant, nor were any of the pairwise comparisons significant for the 3-codend data set. However, for the 4-codend data set significant differences in tow duration were found for three of the pairwise comparisons (3" vs. 4.5" diamond, 4.5" diamond vs. 5" square, and 5" diamond vs. 5" square) (Table 23).

For both rockfish and flatfish, trends in tow time by codend type were similar (Figures 6 and 7). That is, tow times for the 3" diamond and 5" square codends were shorter than those for the 4.5" and 5" diamond codends, with tow duration for the latter two codends being roughly the same. In some cases, observed differences in tow time were statistically significant, but small in magnitude. For example, for the 3-codend data set, the difference in mean tow times between the 3" and 4.5" codends for rockfish was only 0.06 hrs (3.6 minutes). The largest difference in tow times observed was 0.74 hrs (44.4 minutes) for flatfish tows conducted with the 4.5" diamond and 5" square codends.

The differences in tow times detected among codend types indicated that such differences should be accounted for in subsequent analyses of the effects of codend mesh type on other response variables of interest. This was accomplished by modifying the ANOVA to include tow time as a covariate, and by analyzing certain response variables, such as tow gross revenues, on a per unit tow time basis.

The likelihood that a tow would be aborted did not vary among codend types. (The probability level for the chi-square test of homogeneity of the frequency of aborted tows was 0.991). Therefore, the aborted tow criteria listed in Table 8 can be disregarded as a potential source of bias when comparing responses among codend types.

5.4 Results of Analyses Performed for Response Variables Involving All Species Combined

5.4.1 Presentation of Results

The response variables that fall under this category include dollars-per-trawl hour (DPH), giller weight per trawl hour, the proportion of gilled fish (by weight) in the catch, giller picking time, catch sorting time, discard weight per hour, and discard weight as a percentage of the total catch weight. The results of the ANOVA's performed for these response variables are summarized in Tables 19 through 25. Specifically, Table 19 presents the significance levels for tests of the null hypothesis, "There is no effect of codend type on response level;" Tables 20 and 21 contain estimated mean response levels for the flatfish and rockfish sub-studies, respectively; Tables 22 and 23 present significance levels for all possible pairwise comparisons among codend types for each response variable; and Tables 24 and 25 provide estimates of the number of blocks needed to detect significant differences among pairs of codend types. Tables 26 through 29 contain results of the supplementary contingency table tests performed for the giller picking time and catch sorting time response variables. In the sections that follow, we discuss the major results for each of the response variables in turn. Tabular results are in some cases illustrated in graphical form.

5.4.2 Results for the Dollars-per-Trawl Hour (DPH) Response Variable

For all four cases examined (rockfish and flatfish, 3- and 4-codend data sets), the overall mesh effect is highly significant ($p(F_{mesh} \leq 0.001)$), confirming the expectation that mesh size has a significant effect on gross revenues per trawl hour.

For the rockfish sub-study, all pairwise comparisons involving the 3" diamond mesh codend were statistically significant. The increase in gross revenue obtained with the 3" net compared with the 4.5" net is about threefold (the 95% confidence interval for that ratio R is $2.08 < R < 3.80$), and is the largest relative effect between two consecutive treatment types observed for this response variable (Figure 8). Differences between the 4.5", 5" diamond, and 5" square nets were not statistically significant. Moreover, there were inconsistencies in the results of the 3- and 4-codend data set. For example, for the 3-codend data set, mean gross revenues were higher for the 5" diamond codend than for the 4.5" diamond codend (contrary to expectation), whereas the reverse was the case for the 4-codend data set. Estimates of the number of blocks needed to detect significant differences in DPH among pairs of codends involving the 4.5" diamond, 5" diamond and 5" square codends ranged from 956 to 15,837 blocks. The costs of obtaining sample sizes of this magnitude are impractically large. Taken together, these results indicate that differences in DPH among the three larger codends are probably small for rockfish tows, and that additional research (within the scope of expected and anticipated funding levels) is unlikely to improve estimates of differences that may exist. The results clearly document, however, that an increase in mesh size from 3" to mesh sizes of 4.5" and greater would result in large declines in gross revenues of rockfish tows (on a per unit time basis) in the short term.

For flatfish tows, DPH declined as diamond mesh size increased, with consistent trends seen for both 3- and 4-codend data sets (Figure 9). Interestingly, DPH was greater for the 5" square codend than for the 5" diamond codend, although this result was not statistically significant. All pairwise comparisons among diamond mesh sizes were statistically significant for the 3-codend data set. For the 4-codend data set, which included the 5" square codend in addition to the three diamond mesh sizes, a reasonable amount of additional sampling effort would help to clarify the magnitude of difference in DPH for certain pairwise comparisons.

Comparing the results with respect to DPH of the two sub-studies, we see that on average rockfish fishing generates at least four times more revenue than flatfish fishing. However, rockfish fishing is much more variable as seen by comparing the rockfish and flatfish ANOVA MSE's, and more risky because of a higher frequency of gear damage caused by fishing on rocky bottom. For both rockfish and flatfish, declines were seen in DPH with increasing mesh size. However, for rockfish, the only significant declines were between the 3" diamond mesh codends and codends of larger mesh size. For flatfish, trends in DPH with increasing mesh size were more consistent, and differences in the magnitude of response tended to be smaller, than those for rockfish.

5.4.3 Results on Extent of Gilling by Codend Type

Three different response variables were examined to analyze the extent of gilling as a function of codend mesh type: Giller picking time, giller weight as a proportion of total catch weight, and giller weight per trawl hour.

Rockfish Results. For rockfish, the results of the ANOVA's performed indicated that codend mesh type has a significant effect (overall) on all three response variables. Trends observed were also similar for all three response variables, with mean giller picking time, the proportion of catch weight gilled, and giller weight per trawl hour all exhibiting increases with increased diamond mesh size (Figures 10, 12 and 14). However, not all of the pairwise comparisons were statistically significant, nor was the magnitude of response differences always similar for the 3- and 4-codend data sets. For example, for the 4-codend data set, the difference in giller picking times between the 4.5" and 5" diamond codends was small (0.25 minutes), whereas for the 3 codend data set, the difference in giller picking times between these two codends was much greater (5.6 minutes). As was seen for the DPH response variable, most pairwise comparisons among codend types involving the 3" diamond codend were statistically significant for response variables related to the extent of gilling, whereas many of the pairwise comparisons involving the three larger mesh codends were not statistically significant. Although results were not statistically significant, extent of gilling seen for the 5" square codend was consistently less than that observed for the 5" diamond codend, and for two of the response variables (giller picking time and giller weight per trawl hour) was also less than that for the 4.5" codend (Figures 11, 13 and 15).

For the giller picking time response variable, two ANOVA's were performed for each codend data set: One including the log of tow duration as a covariate and a second excluding tow time as a covariate. For the first ANOVA, the regression coefficient for the log-tow time covariate did not differ significantly from zero, indicating that the extent of gilling is independent of tow time. Results of both ANOVA's were also very similar.

The contingency table analyses of giller picking time produced chi-square statistics for rockfish for the overall treatment effect null hypothesis which was not significant at the $\alpha = 0.05$ level for either the 3- or 4-codend data sets (p levels were, respectively, 0.125 and 0.614). The nonsignificance of the contingency table analysis is indicative of a loss in statistical power that can occur when one uses counts based on discrete responses, rather than continuous measurements.

Flatfish Results. Results of analysis of the extent of gilling in flatfish tows were less straightforward than results for rockfish. However, overall gilling is much less of a concern for flatfish fishing than for rockfish fishing. For example, the mean weight of fish gilled per trawl hour was generally much lower for flatfish tows when compared with rockfish tows conducted using the same codend type (Figures 14 and 15). In addition, the maximum mean giller weight per trawl hour seen for the flatfish results was only 27.46 pounds (5" square codend), whereas for rockfish the maximum was 284.4 pounds (5" diamond codend).

For flatfish, results of the overall ANOVA's for giller picking time were not statistically significant for either the 3- or 4-codend data sets. In addition, trends in giller picking times were generally the opposite of those seen for rockfish, with giller picking time tending to decrease with increases in diamond mesh size (Figures 10 and 11). Interestingly, giller picking time was lowest for the 5" square codend, and pairwise comparisons involving this codend are statistically significant in some cases.

For the ANOVA's performed using log-tow time as a covariate, the regression coefficient of the covariate, η, is significantly different from zero ($\eta_3 = 0.712$, *S.E.* = 0.28) in the 3-codend analysis, but not in the 4-codend data set ($\eta_4 = 0.488$, *S.E.* = 32). Overall, a model of giller picking time increasing as a function of tow time is consistent with these results; however, the best value of η depends on which data set is used.

The contingency table analyses of giller picking times yielded chi-square statistics that were not statistically significant for either the 3- or 4-codend data sets. These results were not surprising, given the reduced statistical power of such tests relative to ANOVA, and the nonsignificant results obtained for ANOVA's based on the 3-codend data set.

Results for giller weight as a proportion of total catch weight were statistically significant for both the 3- and 4-codend data sets. As for rockfish, there was a tendency for the proportion of weight gilled to increase with increasing diamond mesh size (Figure 12), although not all pairwise comparisons among codend types were statistically significant. Results for the 5" square codend were similar to, and not detectably different from, those of the 5" diamond codend, which differs from the results seen for rockfish (Figure 13).

Results for giller weight per trawl hour were significant for the 3-codend data set, but not significant for the 4-codend data set. There was a tendency for giller weight in flatfish tows to increase with increasing mesh size, but the results were not as consistent as those for rockfish (Figures 14 and 15).

5.4.4 Results on Catch Sorting Time

Rockfish results. The ANOVA's performed on the 3- and 4- codend data sets using tow time as a covariate produced very similar results to those conducted without assuming tow time as a covariate. For the latter analyses, the estimated mean sorting times were, respectively, 56.73 (3"), 43.26 (4.5"), and 36.42 (5") minutes for the 3-codend data set, and 31.16 (3"), 34.89 (4.5"), 18.66 (5") and 17.31 (5" sq) minutes for the 4-codend data set (see Figures 16 and 17). Although these results suggest there may be some tendency for catch sorting time to decrease with increasing mesh size, the overall mesh effect and most pairwise comparisons (with the exception of the 3" vs. 5" comparison) were not statistically significant. The inconsistencies in mean sorting time estimates between the 3- and 4-codend datasets is therefore not surprising. The chi-square statistics produced from the contingency table analyses were also not statistically significant. Overall, these results indicate that further work is needed to determine whether catch sorting times vary significantly with codend type for rockfish tows, and that any differences that may be detected with additional data are likely to be small.

Flatfish results. As for the rockfish ANOVA's, results of the flatfish ANOVA's were similar for both ANOVA models used (ie. with and without tow time as a covariate), and we focus on the results of analyses for which tow time was included as a covariate. The estimated mean sorting times for flatfish tows were, respectively, 109.16 (3"), 68.36 (4.5"), and 42.85 (5") minutes for the 3-codend data set, and 112.35 (3"), 67.40 (4.5"), 35.19 (5") and 40.11 (5" sq) minutes for the 4-codend data set (Figures 16 and 17). In contrast to the results for rockfish, the overall mesh effect and most pairwise comparisons (with the exception of the 5" diamond vs. 5" square comparison) were statistically significant for the flatfish catch sorting times. The chi-square statistics produced from the contingency table analyses were also highly significant, with probability levels of 0.0001 and 0.005 obtained for the 3- and 4- codend results, respectively. These results clearly show that catch sorting time decreases greatly with increasing diamond mesh size for flatfish tows.

The estimated mean responses for both 3- and 4- codend data sets indicate that catch sorting times for the 5” diamond mesh codend is less than half that of the 3” diamond codend.

5.4.5 Results on Extent of Discards

Two response variables were analyzed to examine the effects of codend type on the extent of discarding: (1) the proportion of the total catch weight discarded, and (2) discarded catch weight per trawling hour. The trends seen for both response variables were similar for both rockfish and flatfish tows. Estimated differences among codends in the proportion of catch weight discarded were small, and most of the differences were not statistically significant. The exception to this was that the proportion of the catch discarded in flatfish tows conducted using the 3” codend was significantly higher than that of the larger diamond mesh codends for the 3-codend data set.

For both rockfish and flatfish tows, estimated catch weight discarded per trawling hour declined dramatically as diamond mesh size increased (Figures 18 and 19). Overall mesh effects, and most pairwise comparisons among diamond mesh codends were statistically significant. Differences in discards between the 5” square codend and the diamond codends were not statistically significant. For rockfish tows, estimated discards for the 5” square codend were lower than that for any of the diamond mesh codends. The 5” square codend produced slightly higher discard estimates than the 5” diamond mesh codend; however, the 5” square discard estimates were substantially lower than those of the 3” and 4.5” diamond mesh codends.

5.5 Results of Analyses For Individual Species

5.5.1 General Results for Individual Species

Overall, analyses of species-specific responses led to fewer statistically significant results than did those performed for all species combined. This was anticipated to some extent, because it was known that there is significant tow to tow variation in species composition among tows conducted within each of the rockfish and flatfish sub-studies. This resulted in fewer complete blocks of data being obtained on an individual species basis than on a sub-study basis. In addition, the variance of catches of individual species was often much larger than that for all species pooled together. As a result of smaller sample sizes and larger variances, the statistical significance of the overall mesh effect, and pairwise comparisons of responses were generally weaker than those seen for analyses of responses for all species combined (see Tables 30-41).

5.5.2 Individual Species Results on Catch Weight per Trawling Hour

For 6 of 10 species for which more than 2 blocks of complete data were obtained, total catch per trawling hour decreased consistently with increasing diamond mesh size for both the 3- and 4-codend data sets (Tables 30 and 31, Figures 20 to 23). Three of the 10 species showed a consistent decline in either the 3- or 4-codend data sets, and only 1 species (canary rockfish) did not show a consistent pattern in either data set. Thus, the results in catch seen for individual species are generally similar to the decline in dollars per trawling hour observed with increasing diamond mesh size for the rockfish and flatfish sub-studies. The overall treatment effect was significant for 7 of the 10 species in the 3-codend data set (Table 30), and for 6 of 10 species in the 4-codend data set (Table 31). A total of 17 out of a possible 30 pairwise comparisons, and 27 out of 60 comparisons were statistically significant at the 0.05 level for the 3- and 4-codend data sets, respectively (Tables 32 and 33). For both the 3- and 4-codend data sets, 8 of the 10 species show significant differences in catch weight per trawling hour for the 3" vs. 5" diamond mesh codend comparisons. For 8 of the 10 species examined using the 4-codend data set, the estimated catch per trawling hour in the 5" square codend exceeded that of the 5" diamond codend. However, only one of the pairwise comparisons between these two codends was significant at the $p<0.05$ significance level (i.e., rex sole, Table 33). Estimates of the number of complete blocks needed to reject the null hypothesis "There is no difference in mean catch per trawl hour among pairs of codend types" based on results obtained for the 3- and 4-codend data sets are given in Table 34 and 35, respectively.

Mean catch weight by codend type is also illustrated in Figures 20 and 22 (corresponding to the 3- and 4- codend data sets) for canary rockfish, yellowtail rockfish, widow rockfish, Pacific ocean perch and sharpchin rockfish. These species are among those most commonly caught in tows conducted in the rockfish sub-study. Note that mean yellowtail rockfish catch weight exceeded that of other rockfish species for most codend types. In addition, we obtained the largest number of complete blocks of data (27 blocks for the 3-codend data set, and 11 blocks for the 4-codend data set) for yellowtail rockfish than for any other species of rockfish. For the 3-codend data set, the overall mesh effect and both pairwise comparisons involving the 3" diamond mesh codend were statistically significant ($p<0.05$) for this species (Table 32). Results for the 4-codend data set were weaker, but the probability associated with the F statistic for 4 of 6 possible pairwise comparisons was less than 0.1 (Table 33).

The species composition of the catch of the flatfish sub-study was less variable than that of the rockfish sub-study. Thus, relatively high numbers of complete blocks of data were obtained for several species commonly caught in tows directed at the deepwater assemblage. For example, for the 3-codend data set, there were four species for which the number of complete blocks obtained exceeded 20 (Dover sole, rex sole, sablefish, and shortspine thornyhead) (Table 32). Mean catch weights of Dover sole, rex sole, sablefish, longspine thornyhead, and shortspine thornyhead by codend type are illustrated in Figures 21 and 23, for the 3- and 4- codend data sets, respectively. Note that mean catch weights of Dover sole and sablefish were similar for most codend types and exceeded those of other species in the deepwater assemblage.

For the 3-codend data set, the overall mesh effect and all pairwise comparisons were statistically significant for both Dover sole and rex sole (Table 32). For sablefish, the overall mesh effect was significant, as were pairwise comparisons involving the 3" diamond mesh codends. For longspine thornyhead, neither the overall mesh effect nor any of the pairwise comparisons were statistically significant. For shortspine thornyhead the overall mesh effect, and two of the pairwise comparisons (3" vs 5" and 4.5" vs 5") were significant.

For the 4-codend data set, mean catch weight in the 5" square mesh codend exceeds that of the 5" diamond mesh codend for four of the five species examined in the flatfish sub-study. These results are similar to the overall trend in catch weight for these two codends seen for flatfish tows (all species combined). However, probability levels associated with pairwise differences in catch weights for the 5" diamond and 5" square codends were less than 0.10 in only two cases (i.e., Dover sole, p=0.084; and rex sole, p=0.011).

5.5.3 Results on Mean Length by Codend Type for Individual Species

Results on mean length as a function of codend type are presented in Tables 36-41 and illustrated in Figures 24 through 27. For the 3-codend data set, 7 of the 9 species illustrated exhibit a consistent increase in mean length with increasing diamond mesh size (Table 36). These results are similar those seen for the DPH and total catch weight response variables (i.e., decreases in catch rates with increasing diamond mesh size should be accompanied by increases in mean length in the catch).

Greater variation is seen in the results of the 5" square vs. 5" diamond codend comparisons (Tables 37 and 39; Figures 26 and 27). For the 9 species examined, mean length in the 5" square codend exceeds that in the 5" diamond codend for 5 species, the reverse is the case for 3 species, and little difference in mean length between codend types is seen for 1 species. However, none of the pairwise comparisons of mean length involving these two codend types are statistically different (Table 39).

Fifteen of 27 pairwise comparisons of diamond mesh codends were significant at the $p<0.05$ level for the 3-codend data set (Table 38), whereas for the 4-codend data set, 17 of 54 possible pairwise comparisons were significant (Table 39). Estimates of the number of complete blocks needed to reject the null hypothesis: "There is no difference in mean length among pairs of codend types" based on results for the 3- and 4-codend data sets are given in Tables 40 and 41, respectively.

5.5.4 Results on Gilling Rates for Individual Species

Estimated means for the response variable giller weight of a species as a proportion of the total catch weight of that species are illustrated in Figures 28 and 29 for the 4-codend data set and provided in Table 42 for selected species. Overall, rockfish are far more prone to being gilled than are flatfish and roundfish. This is consistent with the much larger gilling proportions observed in the the rockfish sub-study compared to the flatfish sub-study for all species combined. Species with relatively large gilling rates (giller weight greater than 5% of total catch weight) include Pacific ocean perch, yellowtail rockfish, widow rockfish, and sharpchin rockfish. Species with relatively low gilling proportions (giller weight less than 5% of total catch weight) include Dover sole, rex sole, sablefish, longspine thornyhead, shortspine thornyhead and canary rockfish. Two of 4 species with substantial gilling rates exhibited a consistent increase in gilling proportion with increasing diamond mesh size, corroborating the results of the analyses for all species combined. Sharpchin rockfish and Pacific ocean perch show an increase in giller proportion from the 3" codend relative to the 4.5" codend, but a decrease from the 4.5" to 5" mesh codends. This result is probably due to the small size of adults of this species, which is more likely to escape through the 5" net than to be caught in it. Except for Pacific ocean perch which shows the opposite trend, gilling proportions for all "problematic" species are lower for the 5" square codend than for the 5" diamond codend.

5.5.5 Results on Discard Rates for Individual Species

Estimated means for the response variable discard weight of a species as a proportion of the total catch weight of that species are presented in Table 43 and illustrated in Figures 30 and 31 for the 4-codend data set for selected species . For the 3" diamond mesh codend, discard proportions of greater than 5% of the total catch weight of a species were estimated for Dover sole, rex sole, sablefish, Pacific ocean perch, longspine thornyhead, shortspine thornyhead, and sharpchin rockfish. Discard rates exceeded 5% in either or both of the larger mesh codends only for rex sole, Pacific ocean perch, sablefish, and sharpchin rockfish. For most species with substantial discard rates, discard proportion tended to decrease with increasing diamond mesh size. Exceptions to this general trend were seen for rex sole and sharpchin rockfish. For these species, discarding is often determined by market factors which are unrelated to fish length.

6. DISCUSSION AND CONCLUSIONS

The above results demonstrate several key points. We have shown that we were able to get the needed cooperation of vessel owners and skippers to conduct the research, and that our field techniques were feasible. We also clearly demonstrated that codend mesh size and type have a significant impact on important characteristics of the catch when fishing occurs under commercial production conditions. Specifically, we showed that in many cases increases in diamond mesh size result in significant decreases in gross revenues per trawling hour, catch sorting time, and discarded catch weight, and increases in mean length of individual species and in the extent of gilling. Although analyses conducted for individual species were less conclusive than those conducted on data for all species combined, individual species responses were similar to the results seen for the combined data.

Some interesting differences in responses were seen between the rockfish and flatfish substudies. Mean duration of flatfish tows was more than twice that of rockfish tows. Rockfish fishing generates more revenues than flatfish fishing (on a per trawling hour basis), but rockfish fishing is also much more variable in terms of catch amounts and species composition of the catch. Gilling is a much greater problem for rockfish than for flatfish fishing.

Our results indicate that there is a need to conduct additional research on the effects of changing codend type on the fishery. With the sample sizes obtained, large changes in gross revenues per trawling hour (DPH) were detected, but greater sample sizes would be needed to estimate smaller (but important) changes in DPH. The same is true for many of the other response variables examined, particularly, individual species responses. The 1988 field work examined only 4-codend types and two fishing strategies, and there is a need to extend the fieldwork to other codend mesh sizes and other segments of the fishery. Field work to be conducted during 1989 and 1990 will produce a great deal of additional information. Results of the 1988 field study will provide information needed to develop appropriate experimental designs for these later field studies.

In addition to field studies, further analytical and modeling work is needed to fully evaluate the consequences of alternative mesh size regulations. While the analyses presented in this report are relevant to an assessment of short-term effects of changes in mesh size and shape, the long-term effects of such changes must also be considered. Such analyses will be conducted as part of the fifth and final phase of this study.

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REFERENCES

Aitchison, J. 1955. On the distribution of a positive random variable having a discrete probability mass at the origin. American Statistical Association Journal. September 901-908.

Bergh, M.O., E.K. Pikitch, J.R. Skalski, and J.R. Wallace. In press. The statistical design of comparative fishing experiments. Fisheries Research (accepted for publication).

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., London (2) (19):533 pp.

Bock, R.D. 1975. Multivariate Statistical Methods in Behavioral Research. McGraw Hill, New York.

Butterworth, D.S., and P.A. Andrew. 1987. On the appropriateness of approaches used at ICSEAF to obtain TAC estimates from catch-effort data for hake. Colln scient. Pap. int. Commn SE. Atl. Fish. 14(1):161-192.

Cochran, W.G., and G.M. Cox. 1957 Experimental designs. 2nd Ed. New York: John Wiley & Sons.

DeAlteris, J.T., and D.M. Reifsteck. 1988. Selectivity of cod-ends on scup, *Stenotomus chrysops*, and the survivability of cod-end escapees: A preliminary report. Pages 38-53 in Proceedings of Square Mesh Workshop, Vol. I, St. Johns, Newfoundland, 25 November 1988.

De la Mare, W.K. 1986. Further consideration of the statistical properties of catch and effort data, with particular reference to fitting population models to indices of relative abundance. Rep. int. Whal. Commn 36:419-423.

Gulland, J.A. 1963. Approximations to the selection ogive, and their effect on the predicted yield. Pages 102-105 in The Selectivity of Fishing Gear, ICNAF Spec. Publ. 5.

Hodder, V.M., and A.W. May. 1964. The effect of catch size on the selectivity of otter trawls. ICNAF Research Bulletin 1:29-35.

Jensen, A.C., and R.C. Hennemuth. 1966. Size selection and retainment of silver and red hake in nylon codends of trawl nets. ICNAF Research Bulletin 3:86-101.

Johnson, N.L., and F.C. Leone. 1977. Statistics and experimental design in engineering and the physical science. Vol. II. Wiley, New York.

Main, J. 1988. Scale damage and survival of young gadoid fish escaping from the cod-end of a demersal trawl. In J. DeAlteris, ed., Proceedings of Selectivity and Survivability Workshop. URI Sea Grant Marine Advisory Service, Narragansett, RI.

Margetts, A.R. 1956. A mesh experiment with sisal, cotton and nylon codends. International Council for the Exploration of the Sea. C.M. 1956, Comparative Fishing Committee, No. 73.

Margetts, A.R. 1959. A preliminary report on the International Arctic Mesh Experiment. International Council for the Exploration of the Sea. C.M. 1959, Comparative Fishing Committee, No. 81.

Myers, J.L. 1972. Fundamentals of experimental design. Allyn and Bacon, Inc., Boston.

Otterlind, G. 1959. Report on Swedish trawl experiments in the southern Baltic. International Council for the Exploration of the Sea. C.M. 1959, Comparative Fishing Committee, No. 120.

Pacific Fishery Management Council. 1982. Pacific Coast groundfish plan. Portland, OR.

Pearson, E.S., and H.O. Hartley. 1962. Biometrika tables for statisticians. Vol. 1, 2nd Ed. Cambridge.

Peng, K.C. 1967. The design and analysis of scientific experiments. Addison-Wesley, London.

Pikitch, E.K. 1986. Impacts of management regulations on the catch and utilization of rockfish in Oregon. Proc. International Rockfish Symp., Anchorage, AK, October 20-22. Alaska Sea Grant Report 87-2.

Pikitch, E.K. 1987. Use of a mixed-species yield-per-recruit model to explore the consequences of various management policies for the Oregon flatfish fishery. Can. J. Fish. Aquat. Sci. 44(Supplement II):349-359.

Pikitch, E.K., D.L. Erickson, and J. Wallace. 1988. An evaluation of the effectiveness of trip limits as a management tool. NWAFC Proc. Rept. 88-27, 33 pp.

Pope, J.A. 1963. A note on experimental design. Pages 175-184 in The Selectivity of Fishing Gear. ICNAF Spec. Publ. 5.

Pope, J.A., A.R. Margetts, J.M. Hamley, and E.F. Akyuz. 1975. Manual of methods for fish stock assessment. FAO Fisheries Technical Paper No. 41.

Robertson, J.H.B. 1982. Square and hexagonal mesh codend design tests on FRV GOLDSEEKER and commercial trials results with square mesh codends on GEM, JANSEN II, and HARVEST REAPER. Scottish Fisheries Working Paper No. 3.

Robertson, J.H.B. 1983. Square and diamond mesh codend selectivity on haddock (*Melanogrammus aeglefinus* (L.)) using the alternate haul technique. Scottish Fisheries Working Paper No. 3.

Robertson, J.H.B. 1983. Square mesh cod-end selectivity experiments on whiting (*Merlangius merlangus* (L)) and haddock (*Melanogrammus aeglefinus* (L)). International Council for the Exploration of the Sea. C.M. 1984/B:30, Fish Capture Committee.

Robertson, J.H.B, and J. Polanski. 1984. Measurement of the breaking strength of square and diamond mesh netting. Scottish Fisheries Working Paper No. 9.

Robertson, J.H.B. 1986. Square mesh codends. Scottish Fisheries Bulletin 49:15-16.

Robertson, J.H.B., D.C. Emslie, K.A. Ballantyne, and C.J. Chapman. 1986. Square and diamond mesh trawl codend selection trials on *Nephrops norvegicus* (L). International Council for the Exploration of the Sea. C.M. 1986/B:12, Fish Capture Committee.

Rogers, J.B., and E.K. Pikitch. 1989. Life history characteristics of commercially important groundfish species off California, Oregon and Washington. NOAA Tech. Mem., NMFS F/NWC-166, 39 pp.

Scheffe, H. 1959. The analysis of variance. Wiley, New York.

Smolowitz, R.J. 1983. Mesh size and the New England groundfishery—applications and implications. NOAA Tech. Rept. NMFS SSRF-771.

Stewart, P.A.M., and J.H.B. Robertson. 1985. Small mesh codend covers. Scottish Fisheries Research Report No. 32.

Vaga, R.M., and E.K. Pikitch. 1988. West Coast groundfish mesh size study (Phase I). Final Report, Saltonstall-Kennedy Grant No. NA86ABH00035.

LIST OF TABLES

Table 1.—Experimental codend specifications.

Codend component	Specification	
Web	Diamond mesh: double strand polyethylene, 4-mm diameter Square mesh: Nichimo UC, 4-strand braided knotless, 480 ply	
Rib lines	Polydacron rope, 1-in diameter; seized to every third knot; four rib lines per codend	
Hanging ratio	Three percent with ribline tension at 500 lb in^2	
Codend size	3-in diamond:	112 meshes around x 142 meshes deep
	4.5-in diamond:	80 meshes around x 100 meshes deep
	5-in diamond:	72 meshes around x 90 meshes deep
	5-in square:	72 meshes around x 180 bars deep
Restraining straps	Polydacron rope, 1.5-in diameter, 12-ft length, placed 3 ft apart	
Chafing gear	Polypropylene rope, 0.5-in diameter, 12.5-in mesh, three of four panels covered	

Table 2.—List of species referred to in the report, giving the common usage, formal taxonomic name, and the abbreviations used in the tables.

Common usage	Taxonomic name	Abbreviation
Arrowtooth flounder	*Atheresthes stomias*	Arrowtooth
Canary rockfish	*Sebastes pinniger*	Canary
Darkblotched rockfish	*Sebastes crameri*	Darkblotch
Dover sole	*Microstomus pacificus*	Dover
English sole	*Parophrys vetulus*	English
Greenstripe rockfish	*Sebastes elongatus*	Greenstripe
Lingcod	*Ophiodon elongatus*	Lingcod
Longspine thornyhead	*Sebastolobus altivelis*	LST
Pacific cod, true cod	*Gadus macrocephalus*	Pacific cod
Pacific ocean perch	*Sebastes alutus*	POP
Pacific whiting, hake	*Merluccius productus*	Pac. whiting
Petrale sole	*Eopsetta jordani*	Petrale
Redbanded rockfish	*Sebastes babcocki*	Redbanded
Redstripe rockfish	*Sebastes proriger*	Redstripe
Rex sole	*Glytocephalus zachirus*	Rex
Rosethorn rockfish	*Sebastes helvomaculatus*	Rosethorn
Rougheye rockfish	*Sebastes aleutianus*	Rougheye
Rough scale grenadier	*Coryphaenoides acrolepis*	R.S. Grenadier
Sablefish, black cod	*Anoplopoma fimbria*	Sablefish
Sharpchin rockfish	*Sebastes zacentrus*	Sharpchin
Short spine thornyhead	*Sebastolobus alsacanus*	SST
Silvergray rockfish	*Sebastes brevispinis*	Silvergray
Slender sole	*Lyopsetta exilis*	Slender
Spiny dogfish	*Squalus acanthias*	S. dogfish
Splitnose rockfish	*Sebastes diplopora*	Splitnose
Spotted ratfish	*Hydrolagus colliei*	S. ratfish
Yelloweye rockfish	*Sebastes ruberrimus*	Yelloweye
Yellowmouth rockfish	*Sebastes reedi*	Yellowmth
Yellowtail rockfish	*Sebastes flavidus*	Yellowtl
Widow rockfish	*Sebastes entomelas*	Widow

Table 3.—Variance component estimates for the logarithm of tow cash value (in dollars per hour of tow time) in the flatfish and rockfish portions of the Pacific groundfish fishery (from Bergh et al. in press). See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies. These estimates are based on data (Pikitch 1986) from 139 fishing trips, with a total of 376 rockfish tows and 502 flatfish tows.

Variance	Rockfish	Flatfish
σ_T^2	0.391	0.170
σ_H^2	1.368	0.454

Table 4.—Variance component estimates for the mean total length (cm) for 8 species of importance in the Pacific groundfishery. M - males; F - females (from Bergh et al. in press). These estimates are based on data (Pikitch 1986) from 139 fishing trips, with a total of 376 rockfish tows and 502 flatfish tows. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

Species	Sex	Mean length	σ_T^2	σ_H^2
Arrowtooth	M	37.05	39.87	0.67
Arrowtooth	F	39.62	52.18	1.06
Petrale	M	32.58	9.48	3.84
Petrale	F	38.90	10.13	10.33
English	M	26.18	10.38	3.02
English	F	31.18	-	8.66
Dover	M	34.68	4.28	2.89
Dover	F	39.09	8.79	7.33
Sablefish	M	50.45	15.50	10.59
Sablefish	F	52.71	15.19	28.52
POP	M	37.32	3.65	0.82
POP	F	39.16	3.25	1.96
Widow	M	39.01	0.82	7.54
Widow	F	40.71	4.28	7.59
Yellowtl	M	42.78	2.44	3.72
Yellowtl	F	45.06	6.39	2.01

Table 5.—Number of vessel trips required to reject the null hypothesis "There is no mesh size effect," at $\alpha = 0.10$ (one-tailed) with a power of $(1\text{-}\beta) = 0.80$ for the logarithm of tow cash value, in the flatfish and rockfish portions of the Pacific groundfishery for Designs A and B (from Bergh et al. in press). See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies. It was assumed that there are 8 tows per trip for flatfish trips and 16 tows per trip for rockfish trips. The column headed "Magnitude of response" is the ratio $\frac{DPH_1}{DPH_2}$, where DPH_1 is the mean dollar per hour for the net with the larger gross cash value.

Magnitude of response	Design A	Design B
	Fishing strategy: Flatfish	
1.05	3,444	436
1.10	902	116
1.15	418	52
1.20	246	32
1.50	52	7
2.00	18	3
	Fishing strategy: Rockfish	
1.05	7,240	649
1.10	1,896	168
1.15	882	78
1.20	518	47
1.50	104	10
2.00	38	4

Table 6.—Number of trips required to reject the null hypothesis of no treatment effect at $\alpha = 0.10$ (one-tailed) with a power of $(1-\beta) = 0.80$ for the mean body length per tow of the species and sexes (M - male; F - female) indicated using Design A with 8 tows per trip (from Bergh et al. in press). P is the percentage change between two nets with different mesh size under the alternative hypothesis.

Species	Sex	P = 1%	2	3	4	5	6	7	8	9	10
Arrowtooth	M	10,528	2,632	1,168	658	420	292	214	164	130	104
Arrowtooth	F	12,054	3,012	1,338	752	482	334	246	188	148	120
Petrale	M	3,394	848	376	212	136	94	70	54	44	36
Petrale	F	2,730	682	302	170	108	78	58	44	36	30
English	M	5,676	1,418	630	354	226	156	116	88	72	58
English	F	-	-	-	-	-	-	-	-	-	-
Dover	M	1,394	348	154	86	58	40	30	24	20	16
Dover	F	2,296	574	254	142	92	66	48	38	30	24
Sablefish	M	2,390	596	264	148	96	68	50	40	32	26
Sablefish	F	2,440	610	270	152	98	70	52	40	32	26
POP	M	974	242	108	62	40	28	22	18	14	12
POP	F	824	206	92	54	34	24	18	14	12	10
Widow	M	418	104	48	28	18	14	10	8	8	6
Widow	F	1,140	284	126	72	48	34	26	20	16	14
Yellowtl	M	574	142	66	38	24	18	14	10	10	8
Yellowtl	F	1,182	294	130	76	50	34	26	20	16	14

Table 7.—Number of trips required to reject the null hypothesis "There is no change in mean length" $\alpha = 0.10$ (one-tailed) with a power of $(1-\beta) = 0.80$ for the mean body length per tow of the species and sexes (M - male; F - female) indicated using Design B with 8 tows per trip (four per treatment type) (from Bergh et al. in press).

Species	Sex	P = 1%	2	3	4	5	6	7	8	9	10
Arrowtooth	M	11	3	2	1	1	1	1	1	1	1
Arrowtooth	F	15	4	2	2	1	1	1	1	1	1
Petrale	M	81	20	9	4	3	2	2	2	1	1
Petrale	F	154	38	17	6	4	4	3	3	2	2
English	M	99	24	11	4	3	2	2	2	2	2
English	F	-	-	-	-	-	-	-	-	-	-
Dover	M	54	13	6	3	2	2	1	1	1	1
Dover	F	108	27	12	4	4	3	2	2	2	2
Sablefish	M	94	23	10	4	3	3	2	2	2	2
Sablefish	F	232	58	25	9	6	4	4	3	3	3
POP	M	13	4	2	1	1	1	1	1	1	1
POP	F	28	7	4	2	1	1	1	1	1	1
Widow	M	112	28	12	4	4	3	2	2	2	2
Widow	F	103	25	11	4	4	3	2	2	2	2
Yellowtl	M	45	11	5	2	2	2	1	1	1	1
Yellowtl	F	22	5	3	2	1	1	1	1	1	1

Table 8.—Definitions of aborted tows.

1. Catch weight less than 50 pounds
2. Doors cross and the time that the event occurred is unknown
3. Torn net or codend that may result in significant escapement
4. Catch weight composed of greater than 50% spiny dogfish shark (*Squalus acanthias*)

Table 9.—Summary of data collected during each trip and tow for the 1988 field study.

Vessel and gear specifications	Haul information	Catch information	Trip information
Trip number	Trip number	Trip number	Trip number
Engine type	Haul number	Estimated pounds retained by tow and by species (from the vessels log book)	Departure date
Engine horsepower	Sub-tow ID	Total pounds landed and ex-vessel prices (obtained from fish tickets by species)	Departure time
Winch type	Date		Port of departure
Cable diameter (in)	Time start		Return date
Cable length (ft)	Time finish		Return time
Trawl brand	Block number		Port of return
Net material	Vessel trawl gear used		Off-loading date
Headrope length (ft)	Fishing strategy		Fish plant name
Footrope length (ft)	Codend mesh size and type		Number of crew
Age of net	Identify reason for new tow location		Rank of trip target species in order of importance
# floats on headrope	Identify target species		List of processor requests
Diameter of floats	Intended location and duration of tow		Species limited by the processor
# rollers on footrope	Wind speed (knots)		Gross revenues needed for a successful trip
Diameter of rollers	Wind magnitude		Gross revenues needed to break even
Bridle length (ft)	Current magnitude		Rating of trip success
Net vertical opening (ft)	Bottom type		Basis of trip success rating
Length of mud gear (ft)	Position start		Reason(s) for ending the trip
Diameter of mud gear (in)	Position finish		Trip expenses
Mesh size of net body	Depth start (fm)		
Mesh size of net intermediate	Depth finish (fm)		
Intermediate circ. (# of meshes)	Average depth (fm)		
Door weight (lbs)	Length of wire out (fm)		
Door square area (m^2)	Average tow speed (knots)		
Plotter brand & model	Net performance		
Loran receiver brand & model			
Paper echosounder brand & model			
Video chromoscope brand & model			
Sonar brand & model			
Net sounder brand			

Table 9.—continued.

Catch species composition	Catch length frequency	Giller species composition	Giller length frequency	Timing of events
Trip number Haul number Date Estimated catch weight (weight of codend contents that were dumped on the deck Total sample weight Species name: Utilized weight Discarded weight Code to indicate whether the weights represent a sample of the catch or 100% of the catch Code to indicate whether the weights were estimated or represent actual measured weights Code to indicate the reason for discards Comments	Trip number Haul number Date Species name Total length (truncated, cm) Sex Disposition (utilized or discarded) Total weight of all measured fish by species	Trip number Haul number Date Estimated total giller weight Total giller sample weight Species name: Utilized weight Discarded weight Code to indicate whether the weights represent a sample of the gilled fish or 100% of the gilled fish Code to indicate whether the weights were estimated or represent actual measured weights Code to indicate the reason for discards Comments	Trip number Haul number Date Species name Total length (truncated, cm) Sex Disposition (utilized or discarded) Total weight of all measured fish by species	Trip number Haul number Giller picking time Catch sorting time Net mending time Codend changing time

Table 10.—Focus species selected for obtaining total length measurements in the field.

Flatfish	Rockfish	Other
Arrowtooth flounder	Bank rockfish	Lingcod
Dover sole	Canary rockfish	Longspine thornyhead
English sole	Chilipepper rockfish	Pacific cod
Petrale sole	Pacific ocean perch	Sablefish
	Redstripe rockfish	Shortspine thornyhead
	Widow rockfish	
	Yellowtail rockfish	

Table 11.—Number of vessels included on the 1988 experimental fishing permit, number of vessels sampled and number of experimental trips conducted.

Geographical location of vessels' home port	Permitted vessels	Vessels sampled	Experimental trips
Northern Washington	8	4	6
Southern Washington & northern Oregon	15	4	5
Central Oregon	14	8	10
Southern Oregon & northern California	8	3	3
Central California	3	2	2

Table 12.—Summary of completed tows and blocks listed by trip number. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Rockfish				Flatfish			
Trip no.	# of tows aborted	# of tows successful	Total tows	# of blocks completed	# of tows aborted	# of tows successful	Total tows	# of blocks completed
				3-diamond mesh codends				
1	3	13	16	3	0	11	11	3
2	5	21	26	7	1	1	2	0
3	4	24	28	8	2	8	10	2
4	1	6	7	2	0	0	0	0
5	1	4	5	1	0	13	13	4
6	0	0	0	0	0	11	11	3
				4 codends: 3-diamond & 1-square				
7	1	8	9	2	0	1	1	0
8	0	0	0	0	2	6	8	1
9	4	27	31	6	0	2	2	0
10	1	1	2	0	1	6	7	1
11	5*	2	7	0	0	0	0	0
12	0	0	0	0	0	6	6	1
13	11*	7	18	1	1	5	6	1
14	0	0	0	0	1	11	12	2
15	0	0	0	0	3	19	22	4
16	0	0	0	0	1	9	10	2
17	2	5	7	1	1	10	11	2
18	4	14	18	3	0	0	0	0
19	0	10	10	2	0	0	0	0
20	0	0	0	0	0	16	16	4
21	3	17	20	4	0	0	0	0
22	0	2	2	0	0	10	10	2
23	0	1	1	0	0	11	11	2
24	3	16	19	4	0	0	0	0
25	0	0	0	0	0	4	4	1
26	3	6	9	1	1	1	2	0
Total	51	184	235	45	14	161	175	35

*Indicates that at least one mid-water tow was conducted that was not part of the experiment.

Table 13.—Frequency distribution of non-aborted tows by INPFC area of tow location, fishing strategy, and month of fish delivery. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

INPFC Area	Strategy	Jul	Aug	Sept	Oct	Nov	Dec	Total
Vancouver	Rockfish	34	23	36	5			98
	Flatfish	12	8	7	16			43
Columbia	Rockfish		11	9	24		40	84
	Flatfish		24	19	28		12	83
Eureka	Rockfish							0
	Flatfish				21			21
Monterey	Rockfish						2	2
	Flatfish						14	14
Total		46	66	71	94	0	68	345

Table 14.—Frequency distribution of completed blocks by INPFC area of block location (designated by the first tow of each block), fishing strategy, and month of fish delivery. (A) Three-codend data set: 3"d, 4.5"d and 5"d. (B) Four-codend dataset: 3"d, 4.5"d, 5"d and 5"s. Note that the blocks enumerated for B represent a subset of blocks listed in A. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

INPFC Area	Strategy	Jul	Aug	Sept	Oct	Nov	Dec	Total
				-A-				
Vancouver	Rockfish	10	8	7	1			26
	Flatfish	3	2	1	3			9
Columbia	Rockfish		3	2	5		9	19
	Flatfish		7	3	7		2	19
Eureka	Rockfish							0
	Flatfish				4			4
Monterey	Rockfish							0
	Flatfish						3	3
Total		13	20	13	20	0	14	80
				-B-				
Vancouver	Rockfish			7	1			8
	Flatfish			1	3			4
Columbia	Rockfish			2	5		9	16
	Flatfish			3	7		2	12
Eureka	Rockfish							0
	Flatfish				4			4
Monterey	Rockfish							0
	Flatfish						3	3
Total		0	0	13	20	0	14	47

Table 15.—Management regulation limits (pounds) in effect during 1988.

Species	Effective dates	Regulation
Sablefish	01/01/88-08/02/88	6000 lb/trip, no more than 5000 pounds less than 22 inches total length, no more than two landings per week
	08/03/88-12/31/88	2000 lb/week
POP	01/01/88-12/31/88	5000 lb/trip or 20 percent (by round weight) of all legal fish on board, which ever is less No restrictions on landings less than 1000 pounds
Widow	01/01/88-09/20/88	30,000 lbs/week, no more than one landing per week above 3000 pounds
	09/21/88-12/31/88	3000 lbs/trip
Sebastes complex	01/01/88-12/31/88	North of Coos Bay, OR: 25,000 lbs/week of which not more than 7500 lbs may be yellowtail rockfish, <u>or</u> 50,000 lbs biweekly of which not more than 15,000 lbs may be yellowtail rockfish, <u>or</u> 12,500 lbs twice weekly of which not more than 3,750 may be yellowtail rockfish. No restrictions on landings less than 3000 lbs
	01/01/88-12/31/88	South of Coos Bay, OR: 40,000 lbs/trip, with no frequency or special limit on yellowtail

Table 16.—Experimental mesh size study trip deliveries (in pounds) to fish processing plants categorized by species or species groups managed by trip poundage limits. Asterisks (*) indicate those species or species groups that were caught in excess of trip limits.

Trip no.	Sablefish	Widow rockfish	POP	Yellowtail rockfish	Other rockfish	*Sebastes* complex	Total landing	Landing date
1[a]	82	2,769	5,394*	23,700*		23,700	66,693	07/14/88
2[a]	184	5,203	3,258	106,635*		106,635*	117,790	07/29/88
3[a]	5,406*		3,854	3,402	18,710	22,112	42,374	08/12/88
4		700		38,390*	1,400	39,790*	42,190	08/10/88
5	10,142*			9,367	6,892	16,259	47,198	08/20/88
6	4,784*	185			720	720	25,690	08/26/88
7	6,540*			42,605*	1,900	44,505*	57,210	09/06/88
8	8,775*				362	362	24,640	09/08/88
9[a]				100,354*	41,346	141,700*	142,578	09/15/88
10	3,627*	2,102			2,064	2,064	13,161	09/16/88
11	28	29,732[b]	356	2,728	3,084	5,812	33,890	09/19/88
12	8,721*				129	129	21,619	09/26/88
13	530	2,926	14,098*	26,556*	7,380	33,936*	56,571	09/27/88
14	13,795*				495	495	39,485	10/03/88
15	3,082*	195	8,024*		11,022	11,022	38,375	10/11/88
16	5,413*				1,534	1,534	46,211	10/10/88
17	4,413*		2,016	3,034	15,148	18,182	41,128	10/17/88
18	592	707	11	17,083*	4,569	21,652	24,769	10/21/88
19	356	2,293	1,258		15,463	15,463	20,200	10/30/88
20	19,272*		705		4,159	4,159	43,368	10/31/88
21	284	19,672*			19,625	19,625	42,286	12/03/88
22	10,558*				15,084	15,084	38,071	12/09/88
23	28,475*				2,008	2,008	45,665	12/11/88
24		69,060*		11,903*	14,745	26,648*	96,011	12/16/88
25	11,805*						20,661	12/19/88
26	192	3,230*			2,128	2,128	6,980	12/20/88
Total	147,056	138,774	38,974	385,757	189,967	575,724	1,194,820	
Amt. over quota	114,808	82,962	12,516	262,226		193,214		

[a] Two-week trip frequency declaration; otherwise, trip or weekly limits were in effect.
[b] Captured with vessel's midwater gear.

Table 17.—Number of length measurements recorded for non-gilled and gilled fish during 1988.

Species	Number measured Non-gilled	Gilled
Arrowtooth	2,612	820
Bank	202	66
Canary	3,661	86
Chilipepper	548	42
Dover	10,944	123
English	1,526	138
Lingcod	2,141	32
LST	995	297
Pacific cod	1,140	4
POP	3,573	1,490
Petrale sole	2,365	106
Redstripe	1,661	693
Sablefish	8,368	565
SST	3,919	344
Widow	3,841	1,405
Yellowtl	10,235	2,323
Total	57,731	8,534

Table 18.—Codend mesh size measurements (in inches) recorded at the conclusion of the 1988 field work. Meshes were stretched and measured diagonally (between knots) using a mesh measuring gauge ($\bar{x}$ = mean, S.D. = standard deviation, N = number of meshes measured). All diamond mesh codends of codend set A were towed during 12 experimental trips, whereas the square mesh codend of set A was towed during 11 trips. All diamond mesh codends of codend set B were towed during 8 experimental trips; the square mesh codend of set B was towed during 9 trips. The 4.5" and 5" diamond mesh codends of set C were towed during 6 experimental trips and the 3" diamond mesh codend of set C was towed during 4 trips . Codends within set D were not used during 1988.

	3" diamond			4.5" diamond			5" diamond			5" square		
Codend set	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N
A	3.49	0.13	82	4.62	0.13	64	5.25	0.08	56	5.12	0.12	28
B	3.17	0.10	82	4.62	0.11	57	5.22	0.14	49	5.14	0.11	54
C	3.39	0.17	79	4.60	0.11	58	5.33	0.10	49	---	---	---
D	3.27	0.09	89	4.70	0.11	56	5.21	0.11	56	---	---	---

Table 19.—Results of ANOVA to test the null hypothesis "There is no effect of codend type" on response variables invovling all species combined. Results are given for both the flatfish and rockfish sub-studies for both 3- and 4-codend datasets. In each case, N represents the number of complete blocks of data analyzed, and $p(F_{mesh})$ is the p-value of the F-statistic for the overall mesh effect resulting from the ANOVA. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Sub-study							
	Flatfish				Rockfish			
	3-codends		4-codends		3-codends		4-codends	
Response variable	N	$p(F_{mesh})$	N	$p(F_{mesh})$	N	$p(F_{mesh})$	N	$p(F_{mesh})$
Tow duration (hr)	35	0.975	23	0.188	45	<0.0005	24	0.040
Dollars per trawl hour (all species)	35	<0.0005	23	0.001	45	0.001	24	<0.0005
Giller picking time (in min):								
Without tow time as covariate	34	0.593	21	0.058	38	<0.0005	24	<0.0005
With tow time as covariate	34	0.581	21	0.121	38	<0.0005	24	0.066
Giller weight/total catch weight	35	<0.0005	23	<0.0005	45	<0.0005	24	<0.0005
Giller weight (lbs) per trawl hr	35	0.006	23	0.1141	45	<0.0005	24	<0.0005
Catch sorting time (in min):								
Without tow time as covariate	31	<0.0005	18	<0.0005	25	0.341	6	0.661
With tow time as covariate	31	<0.0005	18	<0.0005	25	0.166	6	0.689
Discard weight/total catch weight	35	0.078	23	0.516	45	0.884	24	0.649
Discard weight (lbs) per trawl hour	35	<0.0005	23	<0.0005	45	0.071	24	0.008

Table 20.—Adjusted mean responses by codend type for the flatfish sub-study for response variables involving all species combined. See text (pp. 11-12) for definition of flatfish sub-study. Means for the 3- and 4-codend datasets are reported separately. See text for further explanation of adjustments made.

	Flatfish sub-study						
	3-codends			4-codends			
Response variable	3"	4.5"	5"	3"	4.5"	5"	5" sq.
Tow duration (hr)	4.19	4.25	4.20	4.44	4.96	4.68	4.22
Dollars per trawl hr (all species)	310.8	246.4	155.2	276.8	204.1	108.6	115.4
Giller picking time (in min):							
Without tow time as covariate	8.77	7.61	7.26	10.29	8.11	6.30	4.80
With tow time as covariate	8.61	7.61	7.12	10.77	8.11	6.25	5.68
Giller weight/total catch weight	0.0093	0.0262	0.0429	0.0101	0.0309	0.0404	0.0419
Giller weight (lbs) per trawl hr	11.53	21.54	24.38	14.05	25.68	22.66	27.46
Catch sorting time (in min):							
Without tow time as covariate	109.81	68.36	43.76	102.99	67.40	35.01	32.61
With tow time as covariate	109.16	68.36	42.85	112.35	67.40	35.19	40.11
Discard weight/total catch weight	0.346	0.249	0.279	0.266	0.196	0.246	0.243
Discard weight (lbs) per trawl hr	498.7	242.6	179.4	311.6	141.1	106.5	114.7
Total catch weight (lbs)	186,923	128,341	127,839	122,450	80,548	52,950	62,173

Table 21.—Adjusted mean responses by codend type for the rockfish sub-study for response variables involving all species combined. See text (pp. 11-12) for definition of rockfish sub-study. Means for the 3- and 4-codend datasets are reported separately. See text for further explanation of adjustments made.

	Rockfish sub-study						
	3-codends			4-codends			
Response variable	3"	4.5"	5"	3"	4.5"	5"	5" sq.
Tow duration (hr)	1.23	1.57	1.47	0.98	1.32	1.40	1.17
Dollars per trawl hr (all species)	1,788.7	698.1	794.9	2,289.2	829.9	805.8	736.9
Giller picking time (in min):							
Without tow time as covariate	3.38	10.72	16.32	3.52	8.05	8.28	6.05
With tow time as covariate	3.67	10.72	16.61	3.57	8.05	8.30	6.10
Giller weight/total catch weight	0.0027	0.0684	0.1440	0.0047	0.0598	0.0995	0.0772
Giller weight (lbs) per trawl hr	11.80	112.90	284.40	25.40	115.80	157.03	112.32
Catch sorting time (in min):							
Without tow time as covariate	51.12	43.26	36.57	30.61	34.89	18.12	16.38
With tow time as covariate	56.73	43.26	36.42	31.16	34.89	18.66	17.31
Discard weight/total catch weight	0.220	0.222	0.258	0.196	0.247	0.162	0.131
Discard weight (lbs) per trawl hr	1,078.3	460.0	572.9	1,489.4	672.9	372.3	276.4
Total catch weight (lbs)	267,207	144,010	127,839	137,378	80,224	51,139	46,944

Table 22.—P-values from t-tests for all possible pairwise comparisons among codend types for response variables involving all species for the 3-codend dataset. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

Response variable	Sub-study	N	3"-4.5"	3"-5"	4.5"-5"	MSE
Tow duration	Rockfish	45	0.010	0.045	0.244	0.44
	Flatfish	35	0.474	0.419	0.444	1.19
Dollars per trawl hour	Rockfish	45	<0.0005	0.001	0.303	1.41
(all species)	Flatfish	35	0.076	<0.0005	0.003	0.44
Giller picking time:						
Without tow time as covariate	Rockfish	38	0.001	<0.0005	0.117	2.31
	Flatfish	34	0.229	0.163	0.403	0.61
With tow time as covariate	Rockfish	38	0.002	<0.0005	0.109	2.33
	Flatfish	34	0.25	0.151	0.359	0.56
Giller weight/total catch weight	Rockfish	45	<0.0005	<0.0005	0.005	2.114
	Flatfish	35	<0.0005	<0.0005	0.016	0.921
Giller weight per trawl hour	Rockfish	45	<0.0005	<0.0005	0.012	3.526
	Flatfish	35	0.006	0.002	0.303	0.988
Catch sorting time:						
Without tow time as covariate	Rockfish	25	0.233	0.075	0.231	0.634
	Flatfish	31	<0.0005	<0.0005	0.001	0.263
With tow time as covariate	Rockfish	25	0.116	0.028	0.222	0.61
	Flatfish	31	<0.0005	<0.0005	<0.005	0.233
Discard weight/total catch	Rockfish	45	0.39	0.311	0.415	4.13
weight	Flatfish	35	0.016	0.057	0.272	0.65
Discard weight per trawl hour	Rockfish	45	0.014	0.05	0.282	3.18
	Flatfish	35	<0.0005	<0.0005	0.064	0.65

Table 23.—P-values from t-tests for all possible pairwise comparisons among codend types for response variables involving all species for the 4-codend dataset. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

Response variable	Sub-study	N	3"-4.5"	3"-5"	3"-5"s	4.5"-5"	4.5"-5"s	5"-5"s	MSE
Tow duration	Rockfish	24	0.017	0.005	0.109	0.302	0.170	0.073	0.27
	Flatfish	23	0.076	0.256	0.260	0.212	0.022	0.100	1.40
Dollars per trawl hour (all species)	Rockfish	24	0.001	0.001	<0.0005	0.462	0.348	0.384	1.07
	Flatfish	23	0.053	<0.0005	<0.0005	0.001	0.002	0.37	0.38
Giller picking time:									
Without tow time as covariate	Rockfish	24	0.009	0.008	0.055	0.466	0.196	0.174	1.28
	Flatfish	21	0.201	0.046	0.006	0.186	0.037	0.17	0.81
With tow time as covariate	Rockfish	24	0.011	0.009	0.059	0.463	0.203	0.179	1.30
	Flatfish	21	0.156	0.03	0.015	0.176	0.104	0.366	0.79
Giller weight/total catch weight	Rockfish	24	<0.0005	<0.0005	<0.0005	0.089	0.248	0.245	1.89
	Flatfish	23	<0.0005	<0.0005	<0.0005	0.143	0.112	0.438	0.74
Giller weight per trawl hour	Rockfish	24	0.001	<0.0005	0.001	0.245	0.473	0.225	2.28
	Flatfish	23	0.027	0.061	0.017	0.339	0.412	0.263	1.019
Catch sorting time:									
Without tow time as covariate	Rockfish	6	0.427	0.236	0.211	0.188	0.166	0.464	1.403
	Flatfish	18	0.010	<0.0005	<0.0005	<0.0005	<0.0005	0.336	0.245
With tow time as covariate	Rockfish	6	0.438	0.244	0.215	0.201	0.176	0.459	1.443
	Flatfish	18	0.001	<0.0005	<0.0005	<0.0005	0.001	0.193	0.195
Discard weight/total catch weight	Rockfish	24	0.321	0.358	0.224	0.204	0.113	0.345	4.717
	Flatfish	23	0.078	0.346	0.329	0.149	0.16	0.481	0.849
Discard weight per trawl hour	Rockfish	24	0.065	0.006	0.001	0.127	0.046	0.281	3.089
	Flatfish	23	0.001	<0.0005	<0.0005	0.108	0.180	0.371	0.563

Table 24.—Estimates of the number of complete blocks needed to reject the null hypothesis "There is no difference in mean response among pairs of codend types" for all possible pairwise comparisons. Results are given for the 3-codend dataset for response variables involving all species combined. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies. Sample size estimation procedures are discussed in section 4.4.

Response variable	Sub-study	N	3"-4.5"	3"-5"	4.5"-5"	MSE
Dollars per trawl hour (all species)	Rockfish	45	21	27	1,038	1.41
	Flatfish	35	102	13	26	0.44
Giller picking time:						
Without tow time as covariate	Rockfish	38	22	13	162	2.31
	Flatfish	34	376	212	3,437	0.61
With tow time as covariate	Rockfish	38	26	14	151	2.33
	Flatfish	34	453	193	1,600	0.56
Giller weight/total catch weight	Rockfish	45	5	4	39	2.11
	Flatfish	35	12	7	44	0.92
Giller weight per trawl hour	Rockfish	45	11	6	52	3.53
	Flatfish	35	32	23	801	0.99
Catch sorting time:						
Without tow time as covariate	Rockfish	25	281	70	277	0.634
	Flatfish	31	15	6	17	0.263
With tow time as covariate	Rockfish	25	104	39	256	0.610
	Flatfish	31	14	5	14	0.233
Discard weight/total catch weight	Rockfish	45	3,570	1,133	5,944	4.13
	Flatfish	35	44	83	581	0.65
Discard weight per trawl hour	Rockfish	45	55	99	825	3.18
	Flatfish	35	16	10	89	0.65

Table 25.—Estimate of the number of complete blocks needed to reject the null hypothesis "There is no difference in mean response among pairs of codend types" for all possible pairwise comparisons. Results are given for the 4-codend dataset for response variables involving all species combined. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies. Sample size estimation procedures are discussed in section 4.4.

Response variable	Sub-study	N	3"-4.5"	3"-5"	3"-5"s	4.5"-5"	4.5"-5"s	5"-5"s	MSE
Dollars per trawl hour (all species)	Rockfish	24	14	14	12	15,837	956	1,681	1.07
	Flatfish	23	51	7	8	14	15	1,271	0.38
Giller picking time:									
Without tow time as covariate	Rockfish	24	24	23	55	20,323	196	162	1.28
	Flatfish	21	178	42	18	157	37	137	0.81
With tow time as covariate	Rockfish	24	25	23	57	16,839	209	169	1.30
	Flatfish	21	122	34	25	144	78	1,089	0.79
Giller weight/total catch weight	Rockfish	24	6	5	5	78	313	304	1.89
	Flatfish	23	9	7	6	120	92	5,757	0.74
Giller weight per trawl hour	Rockfish	24	14	10	14	305	31,535	252	2.28
	Flatfish	23	36	56	29	812	2,828	344	1.02
Catch sorting time:									
Without tow time as covariate	Rockfish	6	1,015	64	51	41	34	4,124	1.403
	Flatfish	18	18	5	5	9	8	617	0.245
With tow time as covariate	Rockfish	6	1,403	69	52	46	37	3,186	1.443
	Flatfish	18	14	5	5	9	13	181	0.195
Discard weight/total catch weight	Rockfish	24	670	1,101	250	211	97	917	4.72
	Flatfish	23	67	890	710	127	139	62,609	0.85
Discard weight per trawl hour	Rockfish	24	61	21	14	110	49	433	3.09
	Flatfish	23	13	8	9	89	163	1,273	0.56

Table 26.—Number of tows for which giller picking time fell into one of three time categories (0-5 min; 5-20 min; and 20+ min) by codend mesh type for the 3-codend dataset for (a) the rockfish sub-study and (b) the flatfish sub-study. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Mesh size(s)			
Giller picking time (min)	3"	4.5"	5"	All
a. Rockfish sub-study				
0-5	24	29	19	72
5-20	12	6	13	31
20+	2	3	6	11
All	38	38	38	114
b. Flatfish sub-study				
0-5	25	25	26	76
5-20	8	7	6	21
20+	1	2	2	5
All	34	34	34	102

Table 27.—Number of tows for which giller picking time fell into one of two time categories (0-10 min; 10+ min) by codend mesh type for the 4-codend dataset for (a) the rockfish sub-study and (b) the flatfish sub-study. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Mesh size(s)				
Giller picking time (min)	3"	4.5"	5"	5"s	All
a. Rockfish sub-study					
0-10	18	19	15	17	69
10+	6	5	9	7	27
All	24	24	24	24	96
b. Flatfish sub-study					
0-10	15	16	19	16	66
10+	6	5	2	5	18
All	21	21	21	21	84

Table 28.—Number of tows for which catch sorting time fell into one of three time categories by codend mesh type for the 3-codend dataset for (a) the rockfish sub-study and (b) the flatfish sub-study. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Mesh size(s)			
Catch sorting time (min)	3”	4.5”	5”	All
a. Rockfish sub-study				
0-30	11	8	14	33
30-60	8	8	6	22
60+	6	9	5	20
All	25	25	25	75
b. Flatfish sub-study				
0-5	6	2	14	22
5-20	10	4	10	24
20+	15	25	7	47
All	31	31	31	93

Table 29.—Number of tows for which catch sorting time fell into one of two time categories (0-30 min; 30+ min) by codend mesh type for the 4-codend dataset for (a) the rockfish sub-study and (b) the flatfish sub-study. See text (pp. 11-12) for definitions of rockfish and flatfish sub-studies.

	Mesh size(s)				
Catch sorting time (min)	3”	4.5”	5”	5”s	All
a. Rockfish sub-study					
0-30	2	3	4	4	13
30+	4	3	2	2	11
All	6	6	6	6	24
b. Flatfish sub-study					
0-30	2	1	9	7	19
30+	16	17	9	11	53
All	18	18	18	18	72

Table 30.—Adjusted mean responses for catch weight (lb) per trawl hour for selected species from the 3-codend dataset. N represents the number of complete blocks of data analyzed. $P(F_{mesh})$ is the p-value of the F-statistic for the overall mesh effect resulting from an ANOVA with blocks and mesh as main effects and tow depth as a covariate.

Species	N	3"	4.5"	5"	$p(F_{mesh})$
Canary	13	374.7	138.7	225.6	0.280
Yellowtail	27	4418.0	2377.6	1862.8	0.024
Widow	17	451.4	285.5	90.9	0.114
POP	11	57.5	68.0	10.3	0.017
Sharpchin	14	145.1	60.8	10.6	0.006
Dover	36	295.7	138.2	85.1	<0.0005
Rex	23	57.6	14.6	3.8	<0.0005
Sablefish	35	289.6	169.3	140.4	0.031
LST	7	792.4	531.9	267.5	0.262
SST	24	73.4	66.7	25.6	<0.0005

Table 31.—Adjusted mean responses for catch weight (lbs) per trawl hour for selected species from the 4-codend dataset. N represents the number of complete blocks of data analyzed. $P(F_{mesh})$ is the p-value of the F-statistic for the overall mesh effect resulting from an ANOVA with blocks and mesh as main effects and tow depth as a covariate.

Species	N	3"	4.5"	5"	5"s	$p(F_{mesh})$
Canary	4	77.7	198.5	93.3	107.1	0.7560
Yellowtail	11	3608.9	2340.6	715.6	1132.5	0.0115
Widow	7	5456.4	240.7	825.1	387.4	0.1356
POP	6	567.6	315.6	154.5	244.3	0.3983
Sharpchin	6	1536.5	123.5	7.6	16.8	0.0003
Dover	21	286.0	149.8	105.1	153.4	0.0045
Rex	13	36.7	10.8	3.3	7.6	0.0001
Sablefish	19	280.7	196.8	119.5	93.2	0.0132
LST	5	204.6	90.5	44.2	46.3	0.0602
SST	14	76.0	86.0	29.4	34.4	0.0011

Table 32.—P-values from the t-tests for catch weight per trawl hour for selected species from the 3-codend dataset.

Species	N	3”-4.5”	3”-5”	4.5”-5”	MSE
Canary	13	0.062	0.209	0.218	2.380
Yellowtl	27	0.029	0.005	0.222	1.330
Widow	17	0.257	0.016	0.057	4.030
POP	11	0.399	0.011	0.007	2.260
Sharpchin	14	0.130	0.002	0.017	3.850
Dover	36	<0.0005	<0.0005	0.012	0.760
Rex	23	<0.0005	<0.0005	<0.0005	0.810
Sablefish	35	0.030	0.006	0.250	1.340
LST	7	0.256	0.051	0.137	1.170
SST	24	0.346	<0.0005	<0.0005	0.690

Table 33.—P-values from the t-tests for catch weight per trawl hour for selected species from the 4-codend dataset.

Species	N	3”-4.5”	3”-5”	3”-5”s	4.5”-5”	4.5”-5”s	5”-5”s	MSE
Canary	4	0.179	0.425	0.370	0.226	0.267	0.443	1.641
Yellowtl	11	0.196	0.003	0.018	0.016	0.081	0.182	1.294
Widow	7	0.019	0.084	0.034	0.174	0.355	0.278	5.259
POP	6	0.229	0.065	0.149	0.186	0.371	0.280	1.648
Sharpchin	6	0.018	0.001	0.002	0.013	0.039	0.214	2.662
Dover	21	0.012	0.001	0.014	0.098	0.464	0.084	0.737
Rex	13	0.001	0.000	0.000	0.001	0.150	0.011	0.666
Sablefish	19	0.161	0.012	0.003	0.084	0.023	0.243	1.157
LST	5	0.091	0.017	0.019	0.116	0.130	0.467	0.695
SST	14	0.339	0.003	0.009	0.001	0.004	0.301	0.601

Table 34.—Post-hoc sample size estimates for catch weight per trawl hour for selected species from the 3-codend dataset. Sample size estimation procedures are discussed in section 4.4.

Species	N	3”-4.5”	3”-5”	4.5”-5”	MSE
Canary	13	31	115	125	2.38
Yellowtl	27	44	23	278	1.33
Widow	17	239	20	39	4.03
POP	11	1000	11	10	2.26
Sharpchin	14	64	9	16	3.85
Dover	36	17	8	41	0.76
Rex	23	7	4	8	0.81
Sablefish	35	58	32	466	1.34
LST	7	92	14	32	1.17
SST	24	928	10	11	0.69

Table 35.—Post-hoc sample size estimates for catch weight per trawl hour for selected species from the 4-codend dataset. Sample size estimation procedures are discussed in section 4.4.

Species	N	3”-4.5”	3”-5”	3”-5”s	4.5”-5”	4.5”-5”s	5”-5”s	MSE
Canary	4	24	609	198	36	54	1072	1.641
Yellowtl	11	86	8	14	13	31	77	1.294
Widow	7	44	19	11	44	288	115	5.259
POP	6	60	14	30	41	313	98	1.648
Sharpchin	6	7	3	4	6	10	52	2.662
Dover	21	23	11	24	74	15927	65	0.737
Rex	13	8	4	5	8	66	14	0.666
Sablefish	19	114	21	14	58	27	234	1.157
LST	5	14	6	6	18	20	4088	0.695
SST	14	486	10	14	8	11	307	0.601

Table 36.—Adjusted mean responses for the total lengths (cm) of selected species for the 3-codend dataset. N represents the number of complete blocks of data analyzed. $P(F_{mesh})$ is the probability associated with the F-statistic of the overall mesh effect resulting from an ANOVA with blocks and mesh as main effects and tow depth as a covariate.

Species	N	3"	4.5"	5"	$p(F_{mesh})$
Canary	9	47.57	48.42	49.47	0.690
Yellowtail	24	45.07	44.75	45.48	0.469
Widow	11	38.19	41.65	44.11	0.006
POP	7	35.73	37.92	39.29	0.527
Dover	28	35.56	37.98	39.67	<0.0005
Arrowtooth	21	46.38	49.23	52.29	0.071
Sablefish	25	50.73	51.23	53.06	0.119
LST	3	23.82	25.24	24.69	0.276
SST	15	28.73	34.63	35.27	0.002

Table 37.—Adjusted mean responses for the total lengths (cm) of selected species for the 4-codend dataset. N represents the number of complete blocks of data analyzed. $P(F_{mesh})$ is the probability associated with the F-statistic of the overall mesh effect resulting from an ANOVA with blocks and mesh as main effects and tow depth as a covariate.

Species	N	3"	4.5"	5"	5"s	$p(F_{mesh})$
Canary	3	41.72	47.77	47.85	44.61	0.630
Yellowtail	10	45.74	45.03	46.07	45.41	0.338
Widow	6	36.86	41.90	43.56	44.86	0.140
POP	5	37.14	38.01	38.65	39.97	0.923
Dover	16	35.63	37.81	39.62	39.65	<0.0005
Arrowtooth	11	52.11	52.09	56.46	54.46	0.476
Sablefish	17	50.54	51.20	53.66	55.04	0.007
LST	3	23.86	25.24	24.87	25.66	0.068
SST	12	29.13	35.56	36.56	39.37	<0.0005

Table 38.—P-values from t-tests for total lengths of selected species for the 3-codend dataset.

Species	N	3"-4.5"	3"-5"	4.5"-5"	MSE
Canary	9	0.303	0.130	0.261	11.26
Yellowtl	24	0.280	0.227	0.095	3.56
Widow	11	0.001	<0.0005	0.008	4.15
POP	7	0.116	0.035	0.219	9.78
Dover	28	0.004	<0.0005	0.026	9.75
Arrowtooth	21	0.016	<0.0005	0.011	16.16
Sablefish	25	0.280	0.006	0.021	9.04
LST	3	0.050	0.123	0.214	0.54
SST	15	0.002	0.001	0.363	24.15

Table 39.—P-values from t-tests for total lengths of selected species for the 4-codend dataset.

Species	N	3"-4.5"	3"-5"	3"-5"s	4.5"-5"	4.5"-5"s	5"-5"s	MSE
Canary	3	0.099	0.097	0.244	0.492	0.226	0.221	20.15
Yellowtl	10	0.198	0.347	0.343	0.112	0.323	0.215	3.26
Widow	6	0.007	0.002	0.001	0.150	0.045	0.205	6.43
POP	5	0.327	0.222	0.091	0.369	0.165	0.251	8.26
Dover	16	0.039	0.002	0.002	0.069	0.066	0.491	10.75
Arrowtooth	11	0.495	0.017	0.110	0.017	0.108	0.145	17.89
Sablefish	17	0.280	0.006	0.000	0.020	0.001	0.114	10.37
LST	3	0.118	0.179	0.075	0.361	0.340	0.230	1.31
SST	12	0.004	0.001	0.000	0.311	0.039	0.091	23.71

Table 40.—Post-hoc sample size estimates for total lengths of selected species for the 3-codend dataset. Sample size estimation procedures are discussed in section 4.4.

Species	N	3"-4.5"	3"-5"	4.5"-5"	MSE
Canary	9	195	39	126	11.26
Yellowtl	24	429	258	82	3.56
Widow	11	6	4	11	4.15
POP	7	26	12	65	9.78
Dover	28	22	9	43	9.75
Arrowtooth	21	26	8	22	16.16
Sablefish	25	446	21	34	9.04
LST	3	6	11	23	0.54
SST	15	11	9	731	24.15

Table 41.—Post-hoc sample size estimates for total lengths of selected species for the 4-codend dataset. Sample size estimation procedures are discussed in section 4.4.

Species	N	3"-4.5"	3"-5"	3"-5"s	4.5"-5"	4.5"-5"s	5"-5"s	MSE
Canary	3	9	9	31	43437	26	25	20.15
Yellowtl	10	79	376	361	38	277	93	3.26
Widow	6	5	4	4	30	11	48	6.43
POP	5	137	46	14	247	28	60	8.26
Dover	16	29	10	10	41	40	170752	10.75
Arrowtooth	11	460233	14	41	14	40	56	17.89
Sablefish	17	300	14	8	22	11	68	10.37
LST	3	11	17	7	122	91	27	1.31
SST	12	9	7	5	290	21	38	23.71

Table 42.—Gilled weight of a species divided by total catch weight of that species (X 100) for species commonly caught in the rockfish and flatfish sub-studies as a function of codend mesh type for the 4-codend data set.

	Species	N	3”	4.5”	5”	5”s
Rockfish	Canary	4	0.00	0.20	1.60	2.86
	Yellowtail	11	0.00	2.09	14.90	5.72
	Widow	7	0.00	7.69	16.82	11.61
	POP	6	1.01	7.47	7.23	13.25
	Sharpchin	6	5.90	16.08	7.34	4.24
Flatfish	Dover	21	0.10	0.19	0.29	0.00
	Rex	13	0.71	0.49	0.00	1.12
	Sablefish	19	0.00	2.22	1.70	2.63
	LST	5	1.89	1.26	1.26	0.37
	SST	14	0.44	0.92	0.48	0.54

Table 43.—Discarded weight of a species divided by total catch weight of that species (X 100) for species commonly caught in the rockfish and flatfish sub-studies as a function of codend mesh type for the 4-codend data set.

	Species	N	3"	4.5"	5"	5"s
Rockfish	Canary	4	0.00	0.00	0.00	0.00
	Yellowtail	11	0.00	0.26	0.11	0.08
	Widow	7	0.06	0.00	0.00	0.00
	POP	6	6.07	5.50	1.08	0.01
	Sharpchin	6	6.91	5.08	8.76	9.54
Flatfish	Dover	21	9.73	1.17	0.65	0.16
	Rex	13	23.78	19.46	22.43	4.51
	Sablefish	19	14.75	9.51	1.69	4.23
	LST	5	10.18	4.85	2.69	2.81
	SST	14	9.07	3.32	2.11	0.21

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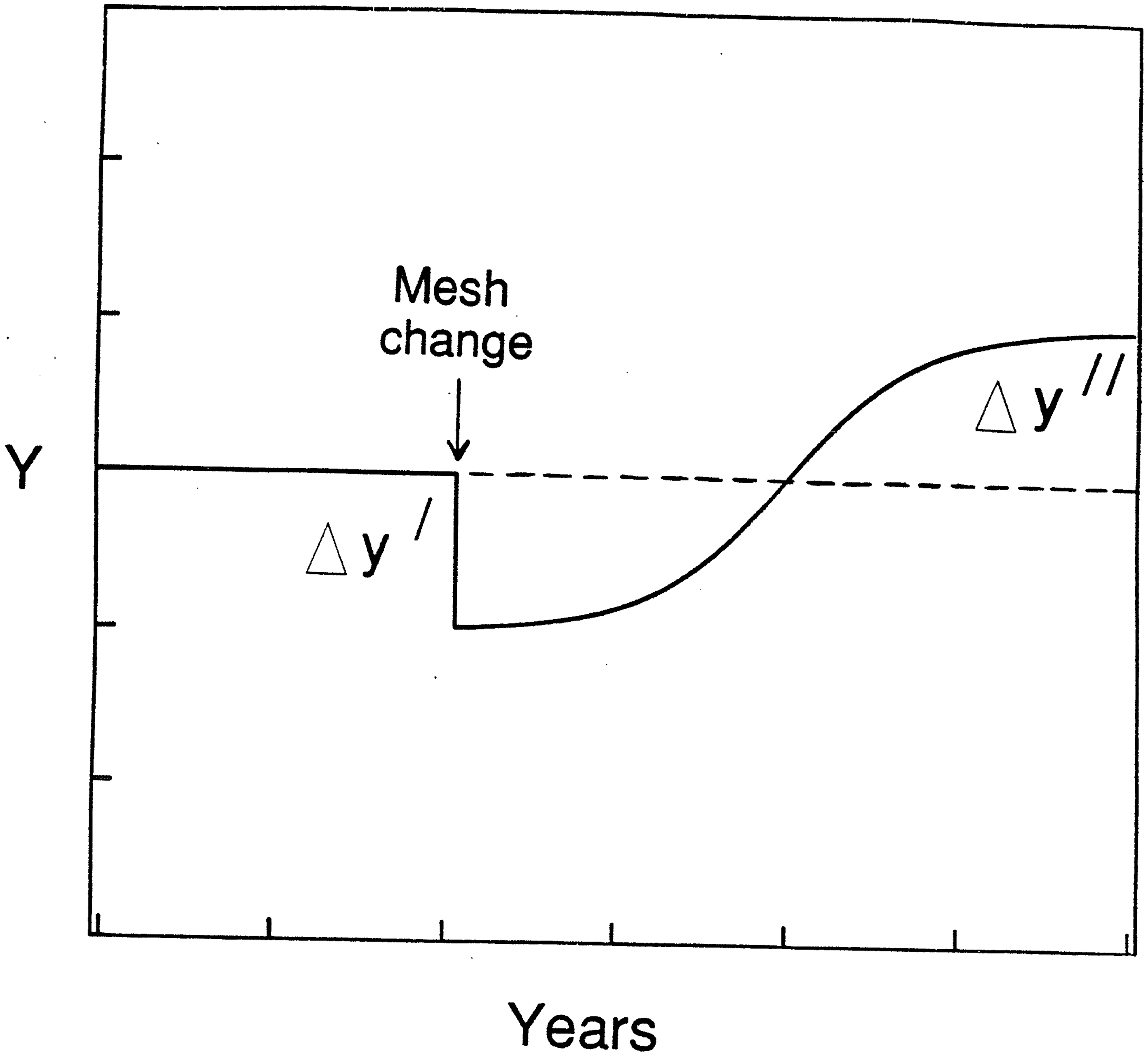

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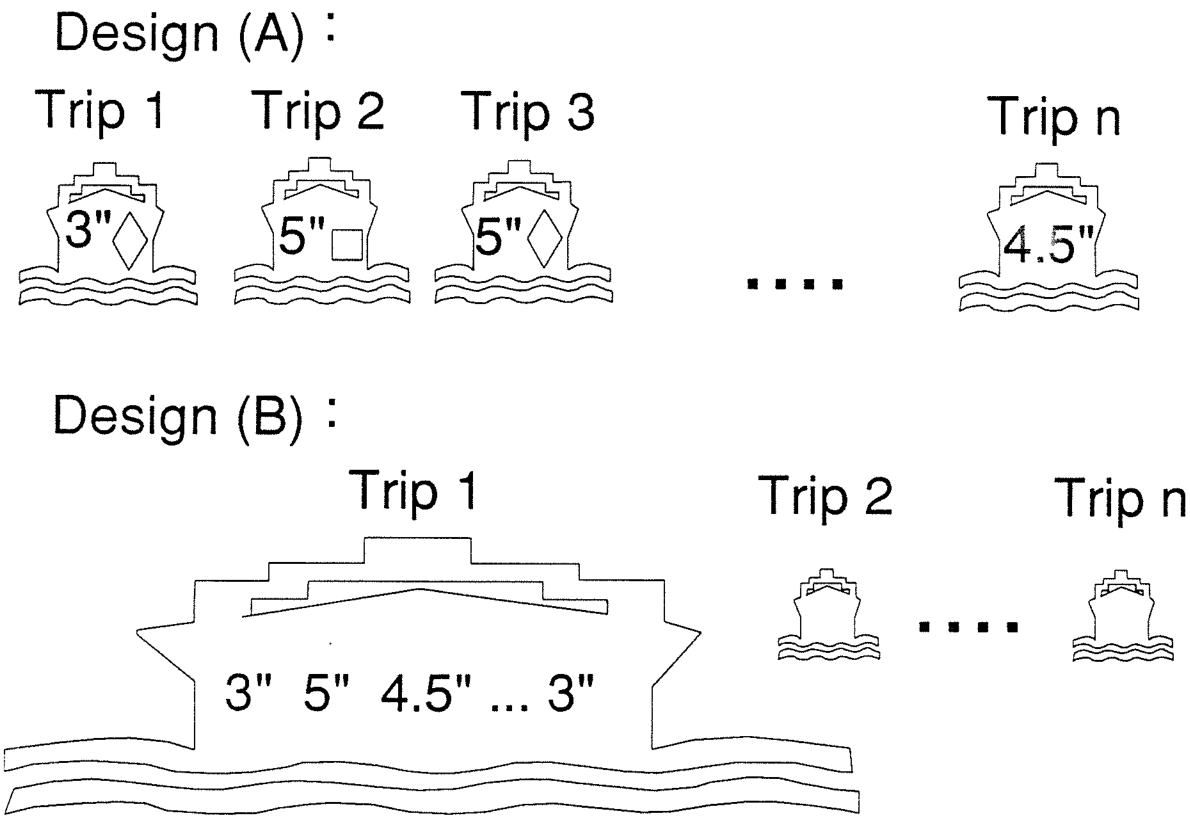
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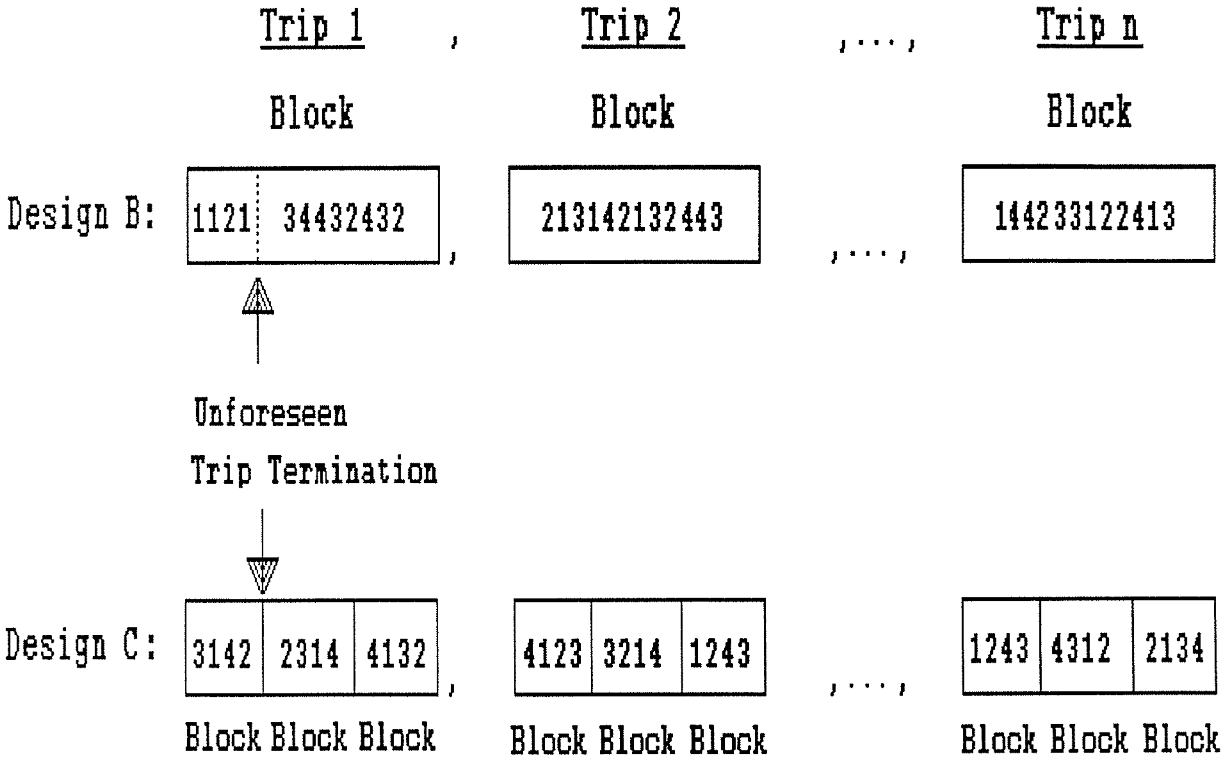
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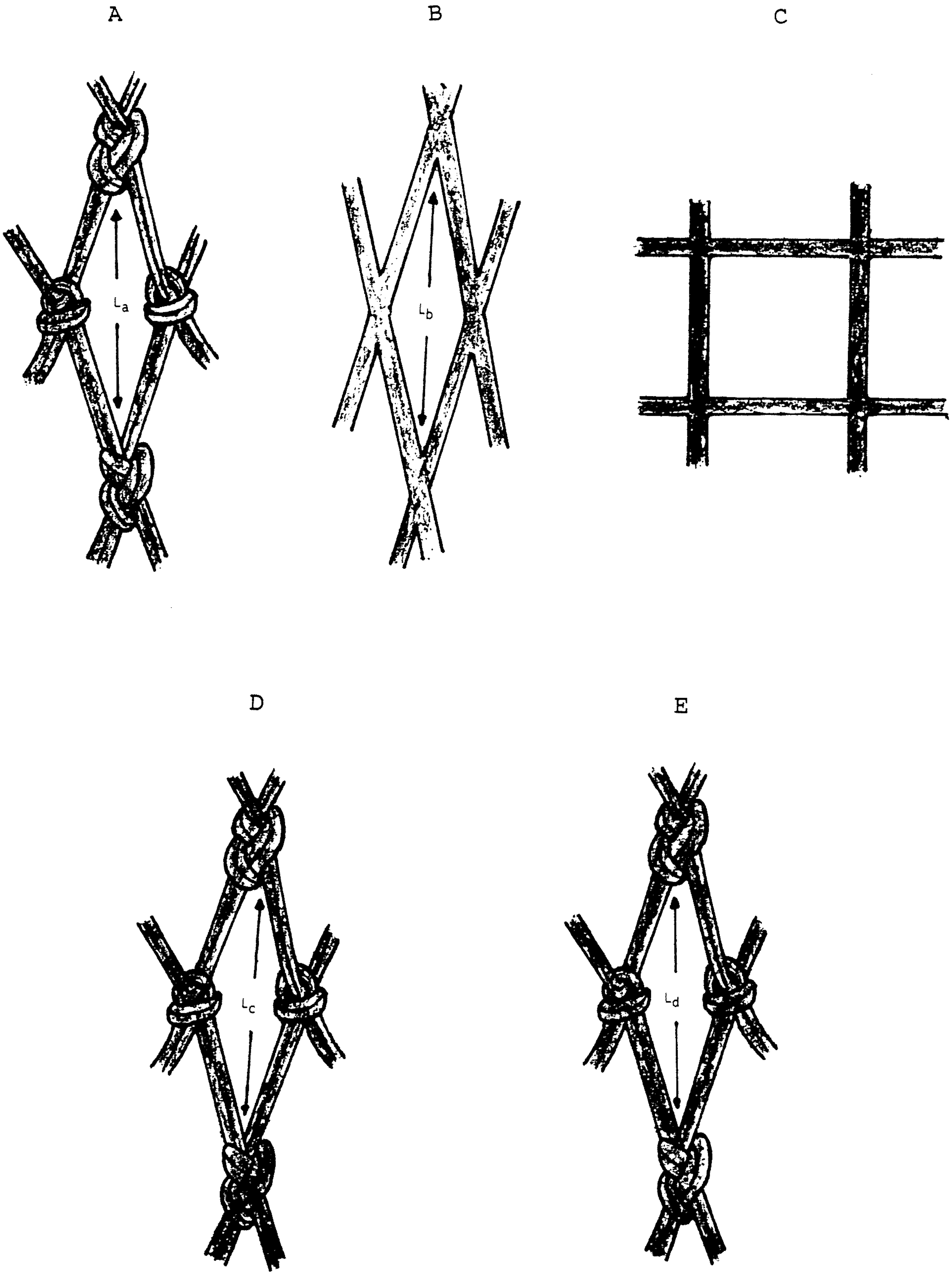

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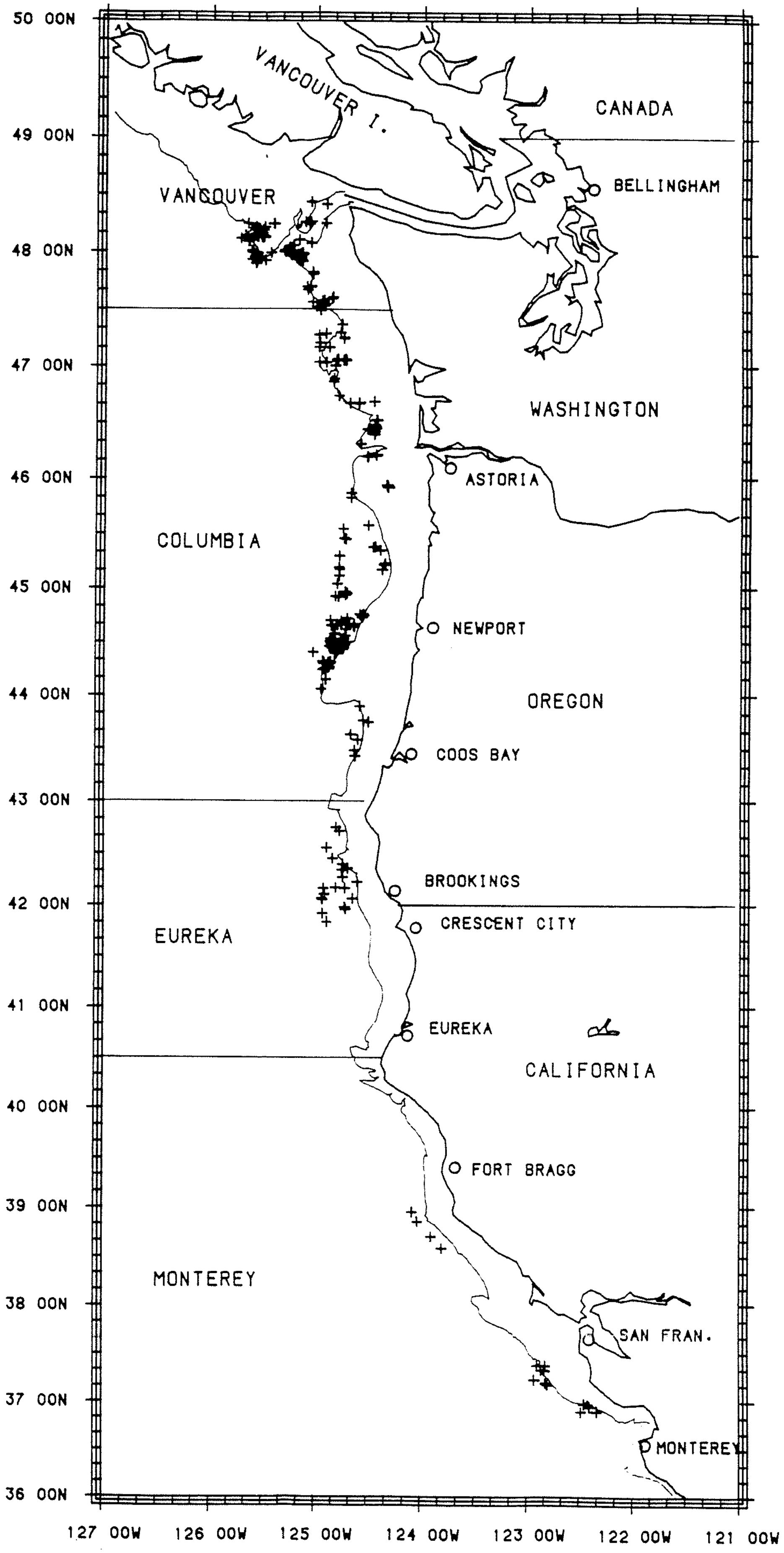
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WASHINGTON
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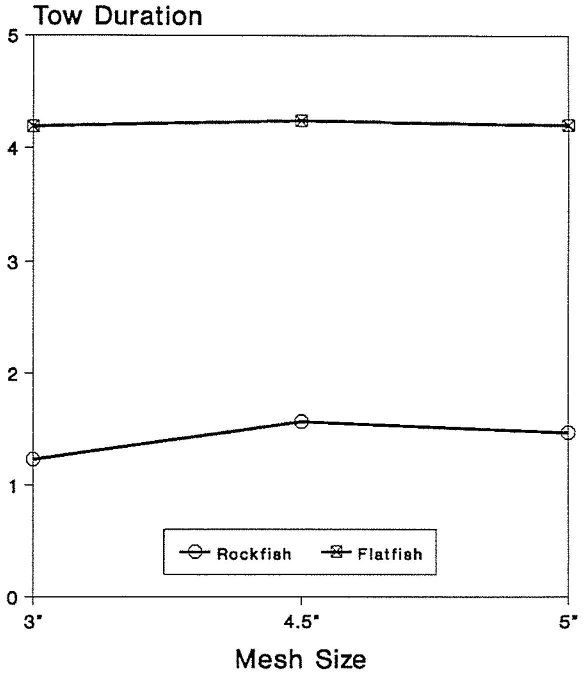

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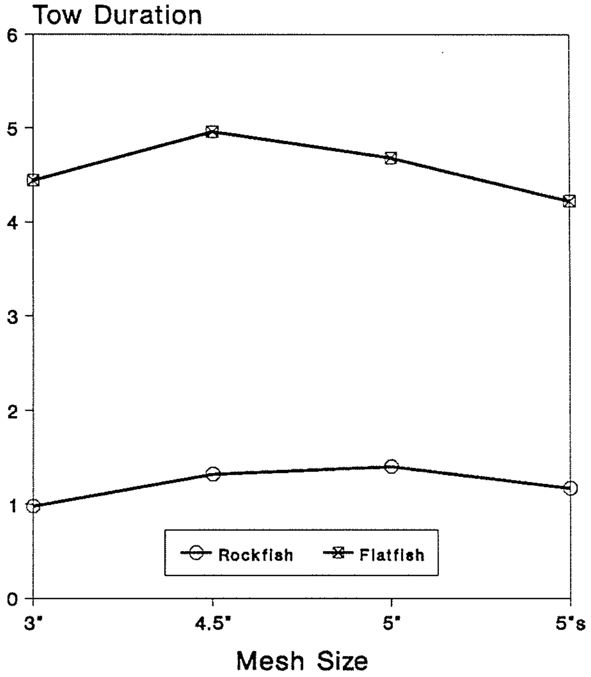

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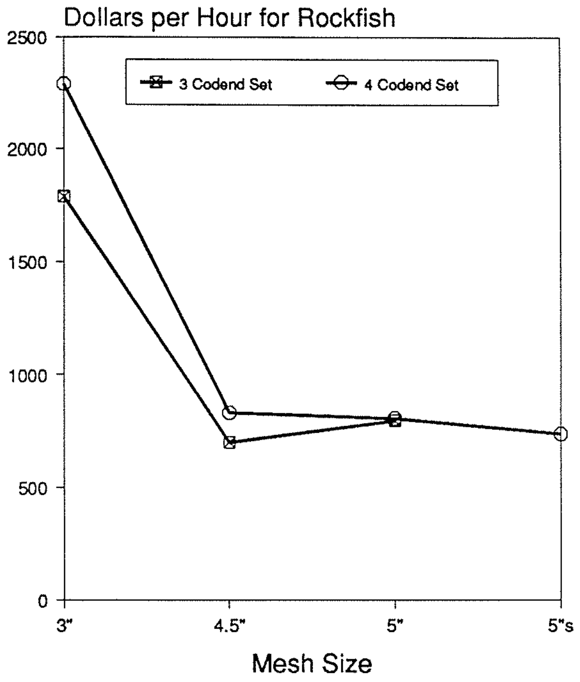

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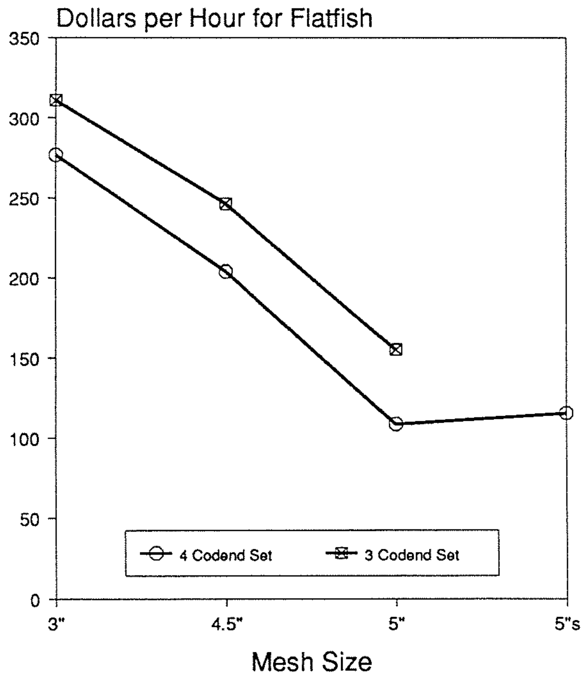

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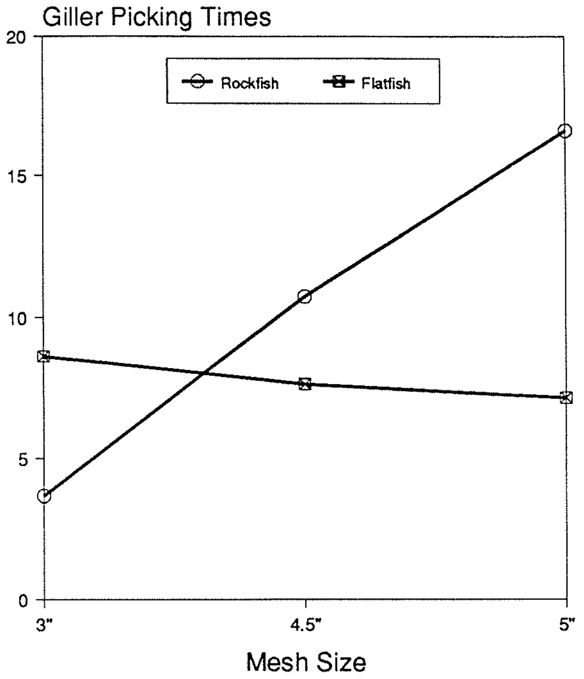

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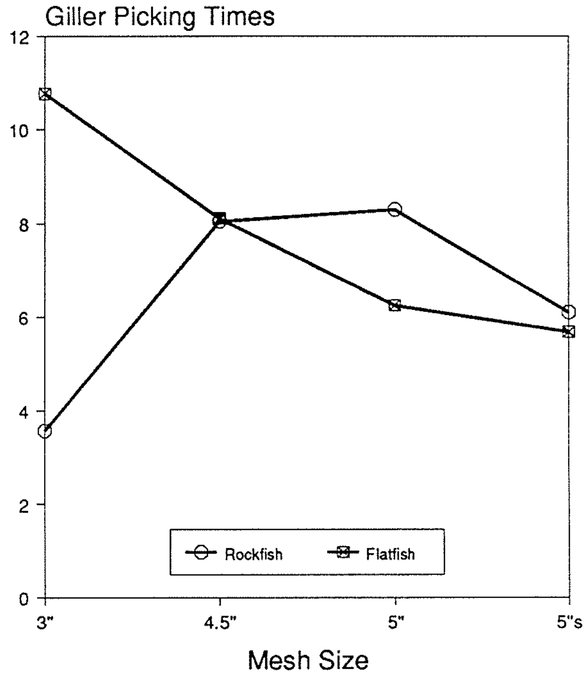

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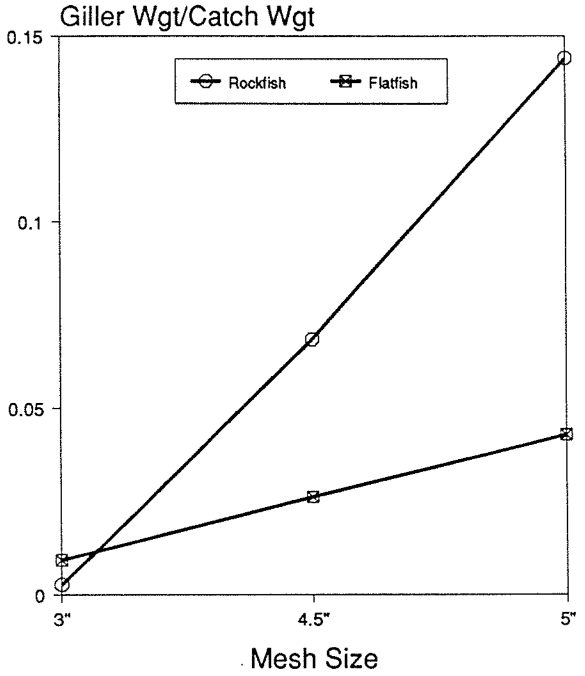

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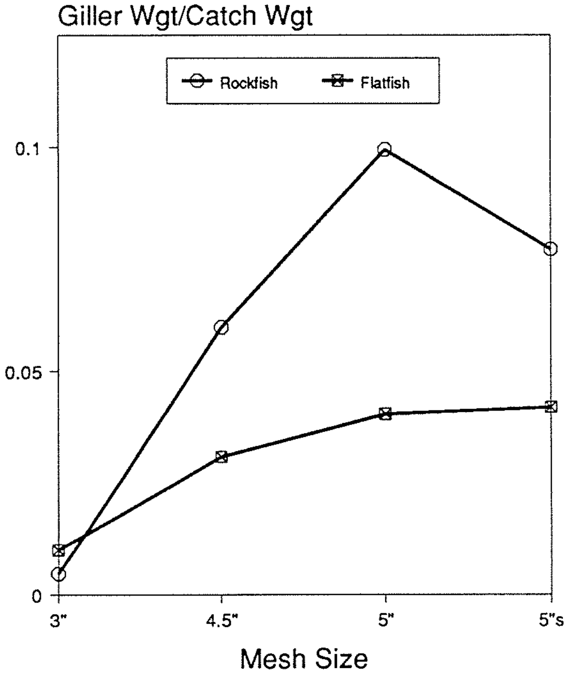

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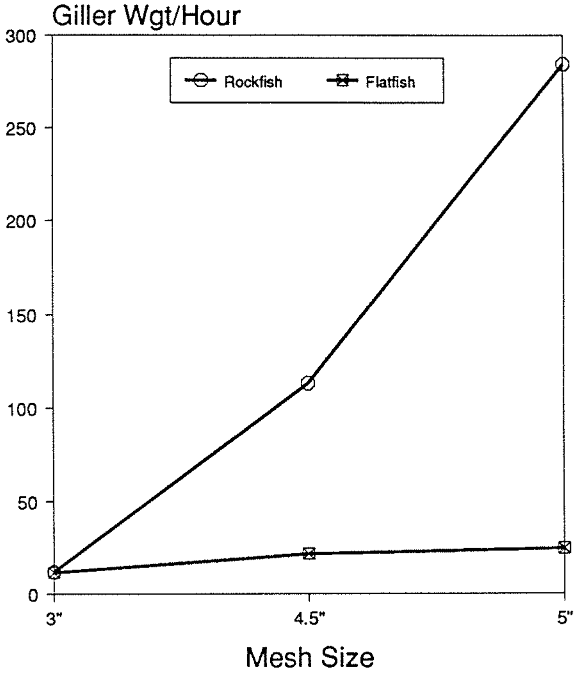

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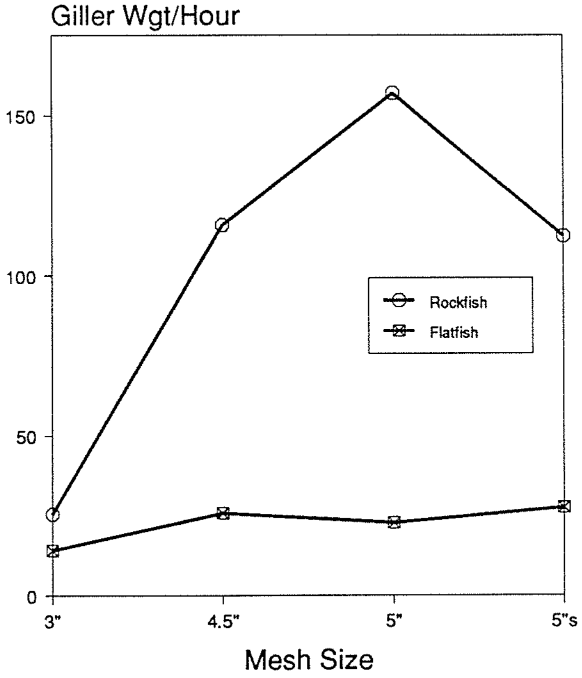

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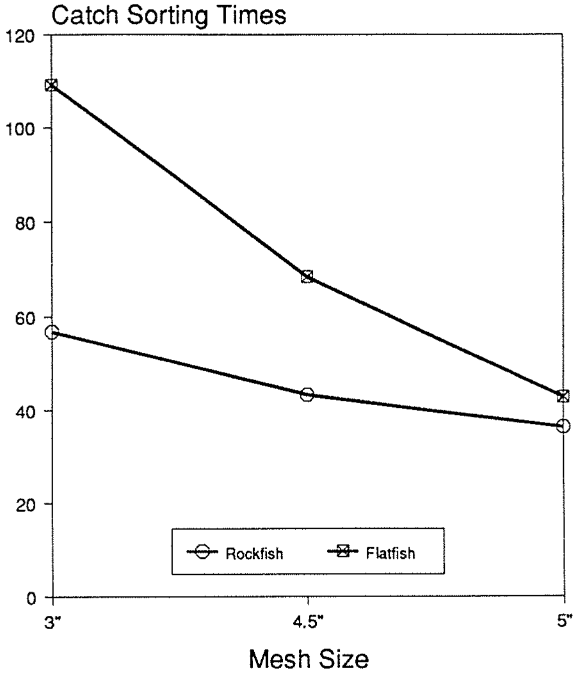

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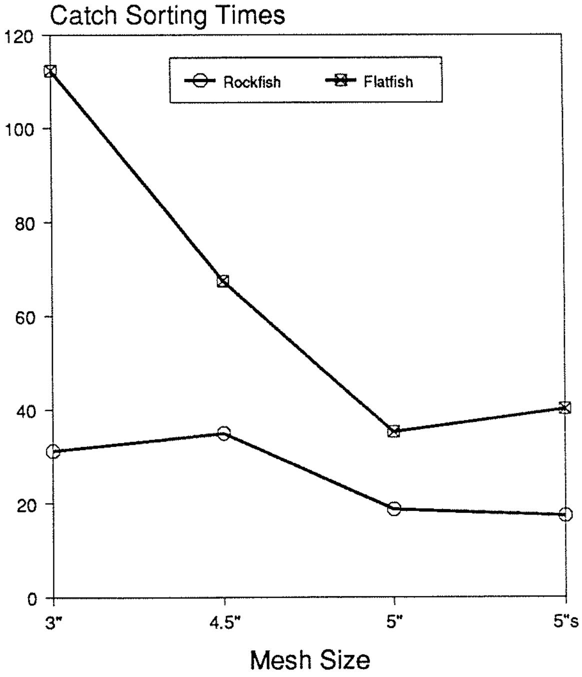

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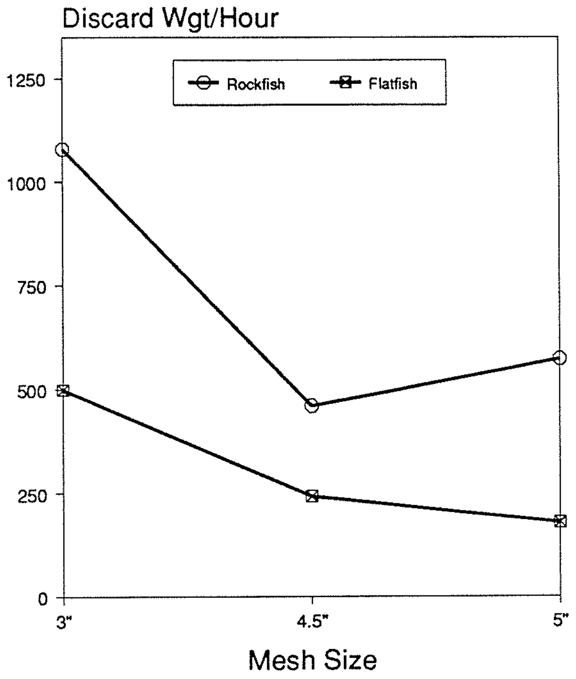

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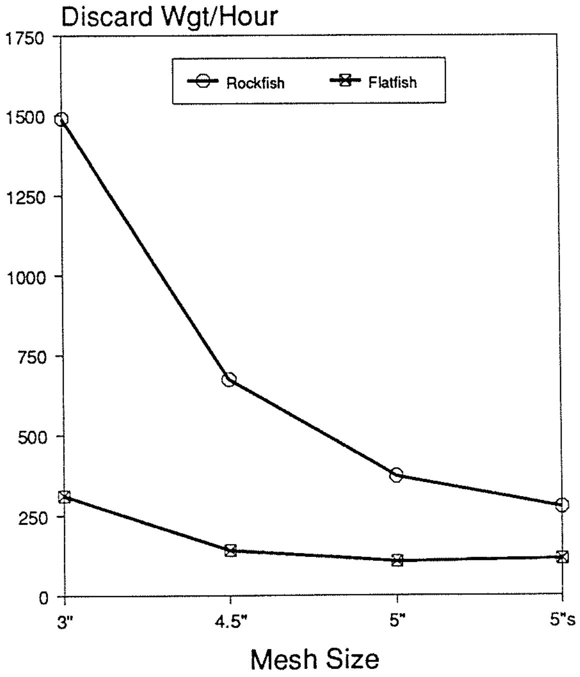

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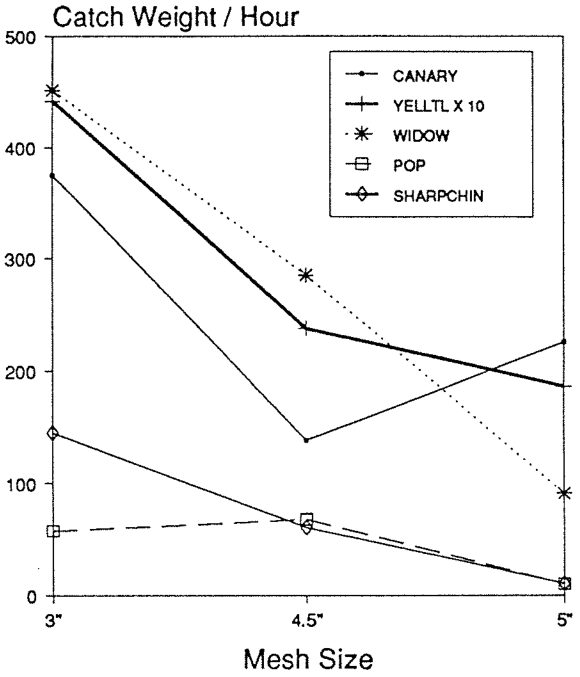

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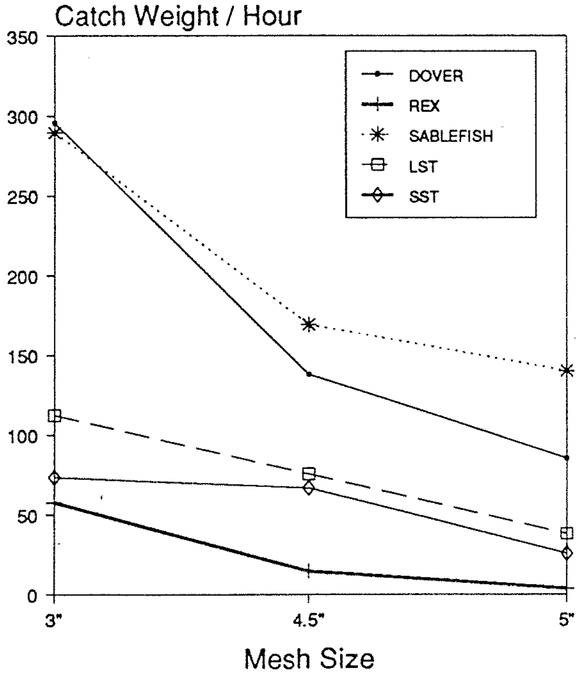

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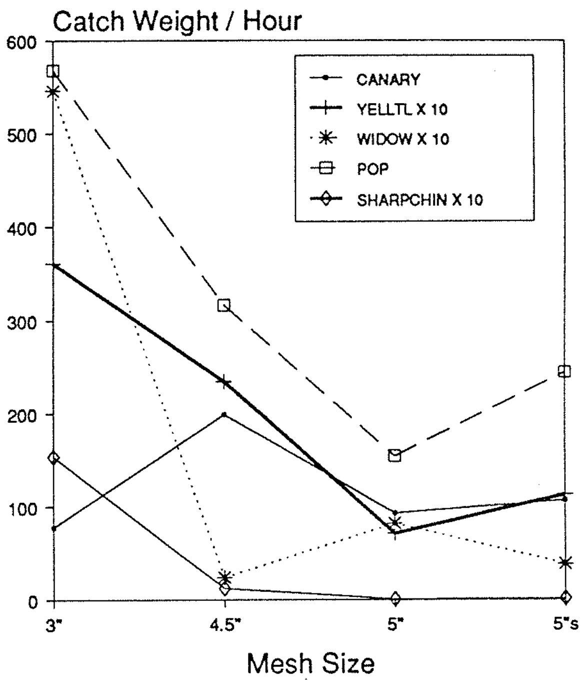

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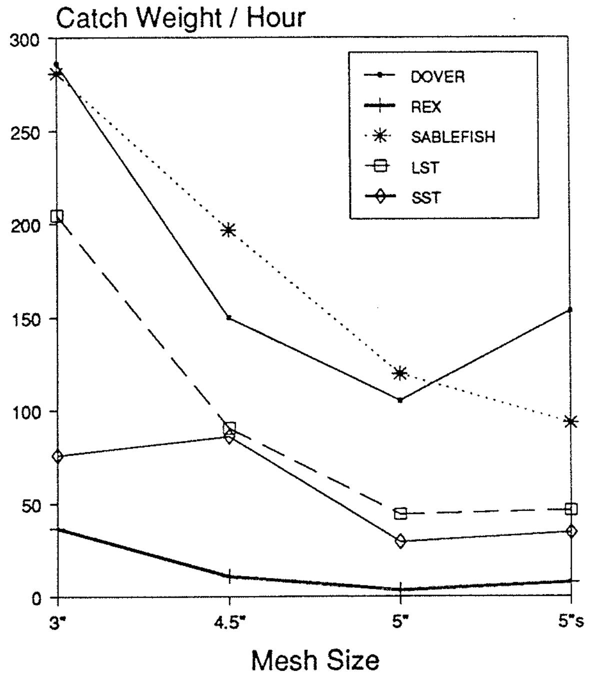

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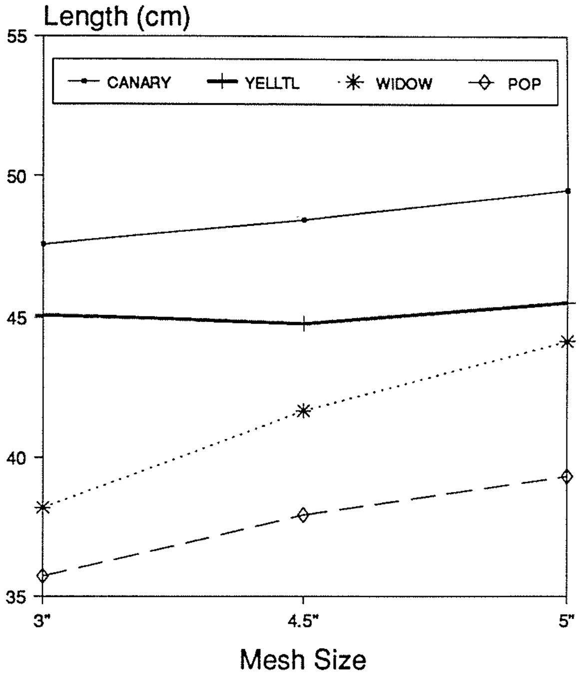

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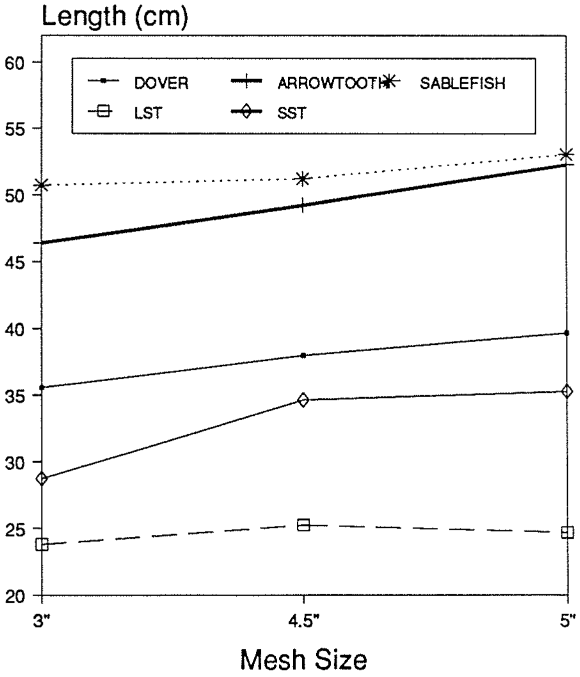

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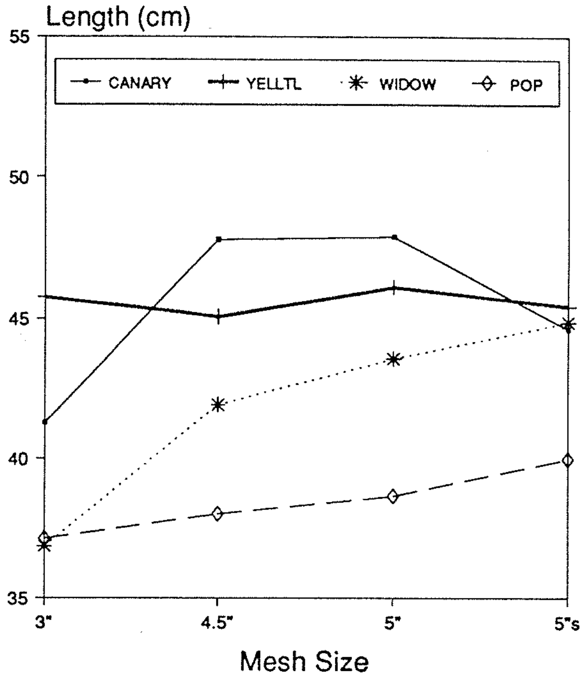

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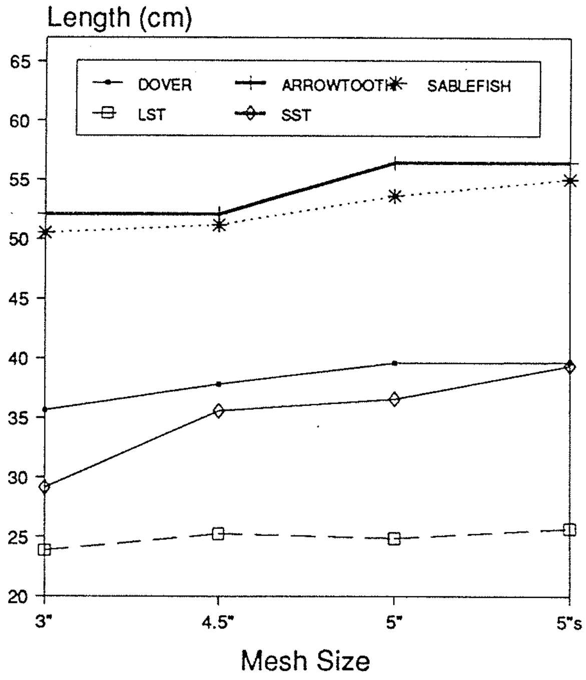

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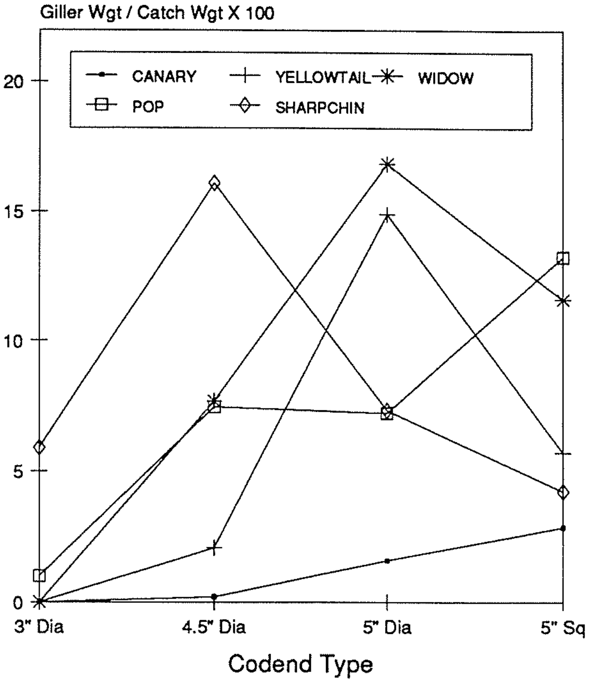

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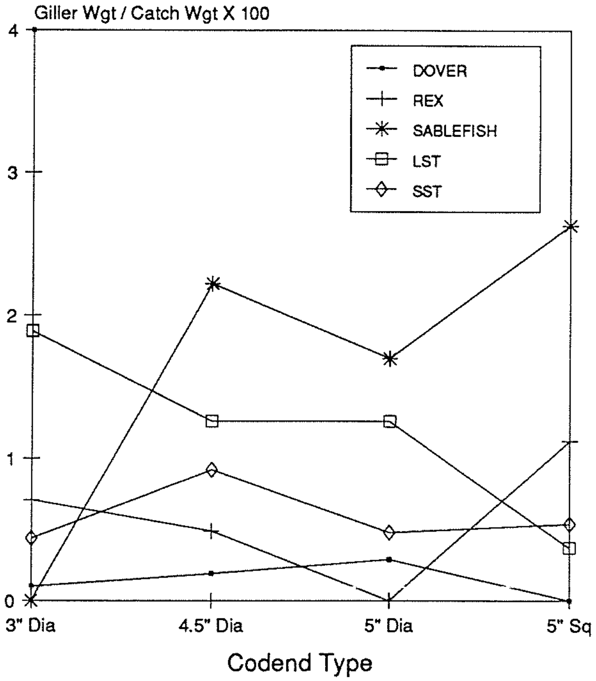

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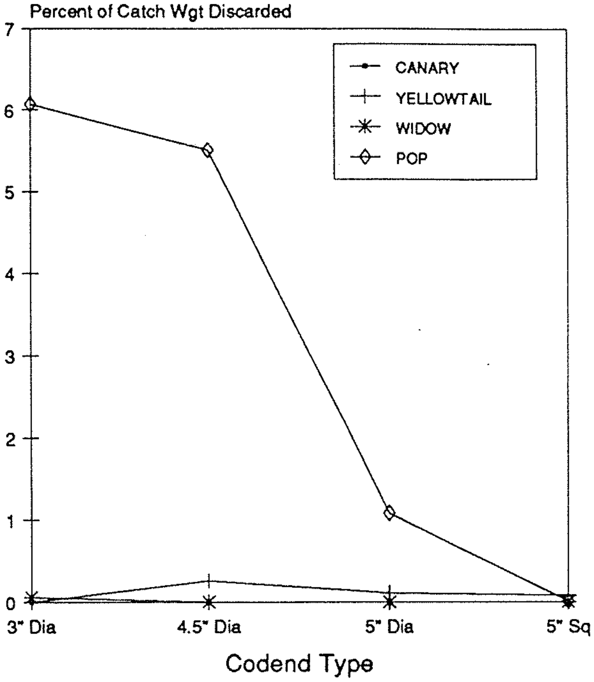

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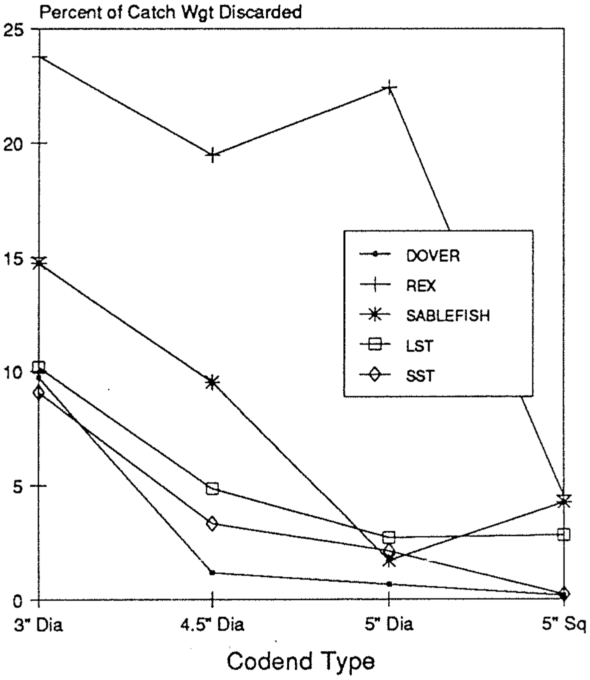

APPENDIX A. PROGRAM MANAGEMENT

Overall project manager was Donna Reed, of the West Coast Fisheries Development Foundation. Dr. Wes Silverthorne served as the S-K program officer for this project. Dr. Ellen Pikitch coordinated all the technical aspects of the project. Dan Erickson served as the field sampling coordinator, and had major responsibility for developing field sampling and data recording techniques, hiring, training and supervising field samplers, coordinating the development of codend design, procuring field supplies and equipment, and in coordinating industry participation in the project. Michael Bergh took the lead in the experimental design phase of the project, and also coordinated the contributions of other project staff (including E. Pikitch, J. Wallace, J. Skalski, and D. Erickson of UW) in this effort. John Wallace created a database management system for the data collected, oversaw the efforts of data entry personnel, and performed much of the data analysis in collaboration with other project staff. All of the UW personnel involved in the project made substantial contributions to the data analysis, interpretation of results, preparation of tables and figures, and writing of this final report.

In addition to project staff discussed above, members of the Mesh Size Advisory Group contributed to many aspects of the project, particularly to project planning and decision-making, and coordination of industry involvement. Members of the Mesh Size Advisory group involved in planning and/or implementing Phase II and their affiliations were:

Ralph Brown, Commercial Fisherman
Robert L. Demory, Oregon Department of Fisheries and Wildlife
Joseph Easley, Oregon Trawl Commision
Wayne Getz, University of California, Berkeley
Susan Hanna, Oregon State University
Peter Leipzig, Fishermen's Marketing Association
Bill Lenarz, National Marine Fisheries Service
Rich Marasco, National Marine Fisheries Service
Gary Stauffer, National Marine Fisheries Service
Ed Ueber, National Marine Fisheries Service
Bill West, Nor'Eastern Trawl Systems
Richard Young, Commercial Fisherman

APPENDIX B. EVALUATION

A. DESCRIPTION OF THE ORIGINAL PROJECT GOALS AND OBJECTIVES, AND THE CONTEXT IN WHICH THE PROJECT WAS TO BENEFIT THE FISHING INDUSTRY

The major goals of this projects were to perform and summarize the results of a small-scale field study, and to obtain a preliminary assessment of the effects of various trawl codend mesh types on gross revenues per trawling hour, and other responses of interest to the fishing industry. Specific objectives included: (1) Hire and train field samplers, procure supplies and equipment, coordinate industry participation; (2) Conduct sampling aboard commercial fishing vessels operating under production fishing conditions; (3) Summarize results of field investigations, and (4) Present summary and data to the PFMC, the industry, and scientific and management entities.

This project is part of a multiyear effort. The major product of this project was expected to be information. Specific information sought included: (1) an assessment of the feasibility of proposed data gathering procedures, (2) a preliminary assessment of the effects of codend mesh type on catch characteristics and other responses, (3) development of analytical techniques and collection of data needed to plan further field studies.

The goals and objectives were not modified during the course of the project, and all have been met to a large extent. It is difficult to quantify the degree to which some of the goals and objectives were met given the nature of these goals and objectives. For example, it was necessary to perform some initial fieldwork in order to determine the number of samplers needed per trip. It was therefore difficult to predict the number of trips that could be conducted. At the inception of the project the amount of donated vessel time that could be secured was not known. In addition, the possibility that long periods of bad weather or other unforseen events might occur made it difficult to predict the number of trips that could be conducted.

However, following the performance of the first two trips it was determined that two samplers would be needed per vessel. We then estimated that approximately 25 trips would be conducted during 1988. This estimate was fairly accurate, since 26 sampling trips were performed during the year.

As is clear from the contents of this report, (and discussed in more detail below) we succeeded in obtaining all the information that was sought. Specifically, we demonstrated that our data procurement procedures were feasible, analyses of the data demonstrate that codend mesh type has a significant effect on various aspects of catch and fishing operations when fishing occurs under production conditions, and the data collected in 1988 have already been used to plan further field work.

B. DESCRIPTION OF SPECIFIC ACCOMPLISHMENTS.

The major products of this research are:

1. Development of a general methodology for evaluating statistical designs for comparative fishing experiments.
2. Application of the methodology to data from the west coast groundfish fishery.
3. Results of the application were used to select a final experimental design for the 1988 field work.
4. Submittal of experimental fishing permits to conduct the experimental fieldwork, which were subsequently approved.
5. Development of experimental codend design.
6. Procurement of supplies and equipment necessary to conduct the fieldwork, and supervision of codend construction.
7. Field sampling and data recording procedures were developed.
8. Field samplers were hired, trained, and supervised throughout the duration of the field work.
9. Industry participation was solicited and secured.
10. A total of 26 experimental trips were conducted in 1988.
11. The feasibility of data procurement procedures was demonstrated.
12. Data obtained in the field were entered, edited and analyzed.
13. A preliminary assessment of the effects of codend mesh type on several response variables (including gross revenues per trawling hour, mean catch weight, catch sorting time, discarded catch weight, giller picking time, giller catch weight and mean length) was obtained.
14. Analytical techniques were developed to facilitate planning for future field studies.
15. The data collected in 1988 have already proved to be extremely useful in planning future studies.

The products of this research clearly meet, and in some respects exceed, the original project goals and objectives. Several of the products are not only of value to the industry and other persons interested in the west coast groundfish fishery, but are also valuable contributions to the scientific community at large (particularly items 1, 7, 11, 13 and 14).

C. DESCRIPTION OF HOW THE PROJECT BENEFITTED THE FISHING INDUSTRY

Industry representatives played an important advisory role, and were involved in decision-making throughout the course of the project. Preliminary results of the study were made broadly available on several occassions. For example, the special report prepared in February 1989 was distributed to members of the advisory group, the Groundfish Management Team, and other interested persons. Preliminary results were also discussed at several meetings of the advisory group and at a meeting of the Groundfish Management Team which took place in Portland, OR and Seattle, WA. These meetings were open to other interested persons, and several fishermen not on the advisory group attended some meetings. Data obtained during 1988 were distributed to two members of the advisory group (Pete Leipzig and Susan Hanna) during the early part of 1989 and to the program officer early in 1990.

This report constitutes the most comprehensive documentation of results of the 1988 study prepared to date. An earlier draft version was circulated to all members of the advisory group for their comments. We plan to publish the final version of this report as a NOAA Technical Memorandum and/or an FRI-UW Technical Report, which will be broadly distributed.

Results of this project will be used in conjunction with the results of previous and future phases of this study by a variety of persons. The major application of the results is anticipated to be use of the information obtained to provide a scientific basis for management decision-making, particularly with respect to formulation and modification of gear regulations. It is expected that the industry will extensively participate in such decision-making, and will make use of the results of this research in the process. In addition to the industry, the results will be used by the Pacific Fishery Management Council and its advisory bodies, other management agencies, scientists from other universities, and the scientific and management communities at-large.

D. DESCRIPTION OF SPECIFIC ECONOMIC OR OTHER BENEFITS

This project was never intended to produce immediate economic benefits. As described above, the major product of this research is information, which will be used as a basis for management decision-making. It is likely that the results of this research will be applied in a number of different ways for a large number of years. Based on the results on this phase and the previous phase, it is likely that the decisions made possible by this research will ultimately produce substantial economic and other benefits to the industry, which may include enhanced fishery production and yields, reduced discards, reduced severity of alternative management measures, increased operating flexibility, and reduced catch sorting time.

E. DESCRIPTION OF THE NEED FOR FEDERAL ASSISTANCE

The research activities performed during this project were clearly beyond the scope of any single entity within the fishing industry to undertake without government assistance. Given the fact that many of the benefits of this research will be accrued in the long run, and that short-term negative impacts may occur, it is particularly appropriate for federal assistance to support this effort.

APPENDIX C: ADJUSTED MEANS FOR LOGIT TRANSFORMED RESPONSES

Let the observed proportion be denoted as $P_{m,j}$, i.e., the proportion obtained using the mth treatment type in the jth block. The assumption is that $y_{m,j}$, where

$$y_{m,j} = \ln(\frac{P_{m,j}}{1-P_{m,j}}),$$

is normally distributed. An ANOVA model was fitted to the transformed values and the resulting gear factor estimates, α_m, were used to calculate untransformed adjusted mean proportions for giller weights and discard weights. To do this, the untransformed mean proportion for the 4.5-inch mesh type, $P_{4.5}$, is calculated from raw data, including all zero response levels in incomplete blocks in this calculation.

The relationship between the untransformed mean proportion for the 4.5-inch mesh type, the 4.5 gear factor and the adjusted mean and gear type estimate for another mesh type m is:

$$\ln\frac{P_m}{1 - P_m} - \ln\frac{P_{4.5}}{1 - P_{4.5}} = \alpha_m - \alpha_{4.5}$$

The unknown adjusted mean, P_m, is therefore

$$P_m = \frac{\frac{P_{4.5}}{1 - P_{4.5}} e^{\alpha_m - \alpha_{4.5}}}{1 + \frac{P_{4.5}}{1 - P_{4.5}} e^{\alpha_m - \alpha_{4.5}}}$$