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# A Review of Current Studies on Scallop Rake Modifications to Reduce Groundfish Bycatch in the Canadian Offshore Scallop Fishery on Georges Bank

# Revue des études actuelles consacrées à la modification des dragues à pétoncles en vue de réduire les prises accessoires de poissons de fond dans la pêche hauturière du pétoncle sur le banc Georges, au Canada

Stephen J. Walsh

Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2



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## ABSTRACT

The management of bycatch is fundamental to Canada's ecosystem based fishery conservation and management approach. In the Canadian sea scallop fishery on Georges Bank, the capture and mortality of yellowtail flounder, Atlantic cod and haddock, are measured and managed to bycatch limits for these stocks. The Canadian scallop fishery on Georges Bank is managed under Department of Fisheries and Oceans (DFO) Scotia Fundy Offshore Scallop Integrated Fisheries Management Plan (IFMP) that uses Total Allowable Catch (TAC) and meat counts as its two key management measures. This management plan includes a host of other control measures including Enterprise Allocations (EAs), bycatch quotas, dockside monitoring, regular observer coverage, satellite vessel tracking, etc. The industry have made efforts to manage their bycatch quotas by changing their fishing strategy, using acoustic seabed mapping to locate scallop beds and effectively fishing with reduced effort. However, because of seasonal movements and fluctuating changes in abundance of some groundfish species, it may be necessary to look at more than one conservation measure, or a combination of measures, to manage finfish bycatch in the Canadian scallop fishery on Georges Bank. Area/time closures are one conservation measure used to manage bycatch, and Canada has used this measure to manage the cod and yellowtail bycatch in the scallop fishery during cod spawning on Georges Bank. Gear based technical conservation measures can also be used to manage size and species bycatch, and, worldwide, have a long history in conservation research and management. Along with incentives and other management strategies, a key approach to managing bycatch of finfish and small scallops is to design and operate selective scallop rakes using knowledge of individual fish behaviour, including the target species, rake hydrodynamics and fishing practices.

Since the mid-1990s, both the Canadian and American scallop fishing industries have studied the engineering performance of scallop rakes (dredges) and potential modifications to reduce bycatch of finfish, while minimizing the loss of scallops. As a result, the 2004 USA management plan has regulated the mesh size in their twine top (equivalent of a Canadian rope back) panels to be set at 10 inch diamond or square mesh, and the ring size in the rake bags to be set at 4 inches. In Canada, there are no regulations pertaining to the construction or rigging of a scallop rake. Similar to American scallop fishers on Georges Bank, the Canadian scallopers generally fish twin New Bedford style rakes ranging in size from 14 feet on the wetfish vessels to 17 feet and, occasionally, a 20 feet rake on the factory freezer vessels. The ring size in the bag of rakes is mainly 3 inches, although some factory freezer vessels are using 4 inches. The wetfish trawlers and some freezer trawlers generally use a 5 or 6 inch diamond mesh rope back which may be hung square, while some factory freezer trawlers use 16 inch square mesh rope backs.

This report reviews and summarizes published and grey literature from Canada, the USA and the international community on gear modifications that have been proposed or used to reduce the bycatch of groundfish in scallop dredge fisheries. In the 11 major reports documenting trials to reduce finfish bycatch in the Canadian and American scallop rake fishery, there were some promising modifications to the frame (bale and bridle bars) of the rakes. The most encouraging modification to the rake frame was the use of a cookie sweep mounted just in front of the cutting bar. This appears effective at reducing catches of yellowtail, skates and other flatfish while increasing the catches of scallops, and works by scaring or herding fish out of the way before they enter the bag path. However, it may only be suitable on smoother substrates, and further testing is warranted. Overall, the most promising modifications to reduce finfish bycatch was an increase in mesh size of the rope back/twine top panel and an increase in ring size of the rake bags. Although most of the rope back/twine top mesh studies focused on diamond mesh panels,

there were some investigations into using panels where the diamond mesh was hung square, i.e., the diamond mesh netting was turned 45 degrees. This way of rigging the mesh panel is common among Canadian scallop fishers, while using regular diamond mesh in the top panel is common among American scallop fishers on Georges Bank. Round fish like cod and haddock should escape easier through either a square or a diamond mesh opening of sufficiently large size. The laterally compressed shape of flounders should favor escapement through elongated diamond meshes more so than through square meshes.

An attempt was made to combine the results from several disparate studies to look at trends in catches and bycatch reduction. Regression analysis was chosen to examine the form and significance of an overall relationship between bycatch reduction and mesh size increase in the rope back/twine top panel. Although it provided a quantitative method to combine the data sources and determine the direction of the effect, the results of the combined data from square and diamond mesh rope backs/twine top panel experiments should be considered equivocal; i.e., uncertain with respect to significance because of the varied nature (and quality) of the data extracted from the four reports used in the analysis. From these four reports, only one report gave any measure of uncertainty for estimates of percent reduction in mean catches. However, the individual experiments and the combined analysis do demonstrate a central tendency for a reduction in finfish bycatch with increasing mesh size in the rope back/twine top panels. Loss of scallops may become significant at larger mesh sizes. The question whether large square mesh rope backs retained or released more flatfish also could not be conclusively answered from the limited studies examined.

The overall conclusion from the synthesis of the experimental results in the individual reports on gear modifications and the regression analysis carried out on a limited data set is that increasing the mesh size in the top panel shows the greatest promise for large reduction in finfish bycatch. Other gains are expected in reducing catches of juvenile flatfish and scallops by increasing the ring size in the rake bag. A larger ring size should reduce fish mortality and improve yield from the scallop resource by promoting harvest of larger scallops with higher meat weights. The majority of the current Canadian scallop fleet fishing Georges Bank are using 5 and 6 inch diamond mesh size rope backs hung regular or on the square, and are using 3 inch ring size in the rake bags. The analysis suggests that these small mesh sizes in the diamond and square rope back and ring size in the rake bags may not be all that effective at releasing large amounts of finfish bycatch and small scallops. This may already be recognized by fishers because some Canadian factory freezer vessels have been and are currently fishing knotless 16 inch square mesh with a 4 inch ring size in their rake bags.

With the use of any conservation measures, whether it be area/time closures, bycatch quotas or gear based modifications, one should remember that temporal and spatial changes in the dynamics and abundance of groundfish species can shift the complexity of the problem thereby necessitating continuous adjustment in solving the problem. The various gear modifications examined vary in effectiveness depending on the dynamics and abundance of groundfish species and flexibility is required to deal with these fluctuations over time.

## RÉSUMÉ

Dans le cadre d'une approche écosystémique de la conservation et de la gestion des pêches du Canada, la maîtrise des prises accessoires est fondamentale. Dans la pêche canadienne du pétoncle géant sur le banc Georges, la prise et la mortalité de la limande à queue jaune, de la morue et de l'aiglefin sont évaluées et gérées en fonction de quotas de prises accessoires attribués pour chacun de ces stocks. La pêche canadienne du pétoncle géant pratiquée sur le banc Georges est gérée dans le cadre du plan de gestion intégrée de la pêche hauturière du pétoncle dans Scotia-Fundy du ministère des Pêches et Océans (MPO). Le total autorisé des captures (TAC) et le nombre de chairs sont les deux variables principales évaluées. Ce plan de gestion prévoit toute une série de mesures de contrôle supplémentaires, notamment : allocations d'entreprises (AE), quotas de prises accessoires, vérification à quai, présence régulière d'observateurs, surveillance des navires par satellite, etc. Pour gérer ces quotas de prises accessoires, les industries de la pêche ont produit des efforts, notamment en modifiant leurs stratégies de pêche, en utilisant la cartographie acoustique des fonds marins pour localiser les bancs de pétoncles, et en améliorant l'efficacité de la pêche tout en réduisant l'effort. Toutefois, compte tenu des mouvements saisonniers et de l'abondance variable de certaines espèces de poissons de fond, il pourra être nécessaire de mettre en place plus d'une mesure de conservation, ou une combinaison de mesures afin de gérer les prises accessoires de poissons à nageoires dans la pêche canadienne du pétoncle géant sur le banc Georges. La fermeture de pêches selon les périodes et les zones est l'une des mesures mises en place pour gérer les prises accessoires; le Canada s'est appuyé sur cette mesure pour gérer les prises accessoires de morue et de limande à queue jaune dans la pêche du pétoncle sur le banc Georges en période de fraie de la morue. Des mesures techniques de conservation s'appuyant sur des équipements peuvent également contrôler la taille et les espèces exposées aux prises accessoires. Ces types de mesures ont d'ailleurs fait l'objet de nombreuses recherches en conservation ailleurs dans le monde, où elles sont utilisées depuis longtemps pour la gestion des espèces. Outre des gratifications et autres stratégies de contrôle, l'un des principaux modes de gestion des prises accessoires de poissons à nageoires et de pétoncles de petite taille consiste à utiliser des dragues à pétoncles sélectives dont la conception s'appuie sur les connaissances du comportement des poissons, notamment des espèces ciblées, de l'aérodynamique des dragues et des pratiques de pêche.

Depuis le milieu des années 1990, les industries canadiennes et états-unienne de la pêche au pétoncle étudient les performances techniques des dragues à pétoncles, ainsi que d'éventuelles modifications qui permettraient de réduire les prises accessoires de poissons à nageoires tout en minimisant les pertes de pétoncles. En conséquence, le plan de gestion 2004 des États-Unis a entrainé la normalisation du maillage de la couverture filet des dragues (« dos » des dragues) : ouverture de maille carrée ou en losange limitée à 10 pouces, taille des anneaux composant les poches de la drague fixée à 4 pouces. Au Canada, la fabrication et l'amarrage des dragues à pétoncles ne sont encadrés par aucune législation spécifique. De même que les pêcheurs de pétoncles états-uniens, les dragueurs de pétoncles canadiens sur le banc Georges utilisent généralement des dragues de type New Bedford, dont la taille peut aller de 14 pieds sur les navires de pêche fraîche à 17 pieds, voire parfois 20 pieds sur les navires-usines congélateurs. La taille des anneaux de la poche est habituellement de 3 pouces, bien que certains navires-usines congélateurs soient équipés d'anneaux de 4 pouces. Les chalutiers de pêche fraîche et certains chalutiers congélateurs utilisent généralement des couvertures filets à maillage en losange avec une ouverture de maille de 5 ou 6 pouces pouvant être accrochées à l'équerre, alors que certains chalutiers-usines congélateurs utilisent pour leurs couvertures des filets à mailles carrées de 16 pouces.

Ce rapport présente une synthèse de la littérature publiée et de la littérature grise au Canada, aux États-Unis et dans le monde sur les modifications techniques envisagées ou mises en œuvre pour réduire les prises accessoires de poissons benthiques lors du dragage des pétoncles. Parmi les 11 principaux rapports faisant état de tentatives de réduction des prises accessoires de poissons à nageoires dans la pêche du pétoncle au râteau au Canada et aux États-Unis, certaines modifications de l'armature des râteaux (barre et pattes d'oie) apparaissent comme prometteuses. La modification la plus encourageante proposée pour l'armature de la drague a trait à l'utilisation d'une ligne témoin montée juste devant le racloir. Cette technique semble efficace pour réduire les prises de limande à queue jaune, de raie et d'autres poissons plats, tout en augmentant les prises de pétoncles : ce système permet d'effrayer ou de dégrouper les poissons du trajet de la drague avant qu'ils ne se trouvent engagés dans la poche. Toutefois, cette technique n'est adaptée qu'aux substrats les plus tendres et nécessite des tests supplémentaires. Dans l'ensemble, la modification la plus prometteuse en vue de réduire les prises accessoires de poissons à nageoires consiste en l'augmentation de la taille des mailles de la couverture filet, ainsi qu'en l'augmentation de la taille des anneaux de la poche de la drague. S'il est vrai que la plupart des études sur le maillage de la couverture filet se réfèrent principalement à des maillages en losange, certaines études ont porté sur l'utilisation de couvertures filets accrochées de sorte que les losanges soient disposés à l'équerre, c'est-à-dire tournés de 45 degrés par rapport à un filet classique. Si cette façon d'amarrer la couverture filet est courante chez les pêcheurs de pétoncles canadiens, les pêcheurs de pétoncles états-uniens en activité sur le banc Georges utilisent généralement des maillages en losange classiques. Les poissons ronds tels que la morue ou l'aiglefin devraient être en mesure de passer plus facilement à travers des mailles carrées ou des mailles en losange suffisamment larges. Quant aux limandes, leur gabarit aplati devrait leur permettre de s'échapper plus aisément par des mailles en losange allongées que par des mailles carrées.

On a essayé de combiner les résultats de plusieurs études disparates afin d'examiner les tendances en matière de prises et de réduction des prises accessoires. L'analyse de régression est la méthode qui a été choisie pour étudier la teneur et la portée d'une éventuelle corrélation globale entre la réduction des prises accessoires et l'augmentation de la taille des mailles des couvertures filets. Bien que l'utilisation de cette méthode quantitative ait permis de combiner les différentes sources de données et de dégager une tendance quant à l'effet produit, les résultats de la combinaison des données issues des expériences sur les couvertures filets à maillage carré et en losange doivent être considérés comme équivoques; il n'est pas certain qu'ils soient significatifs, compte tenu de la nature (et de la qualité) très diverse des données extraites des quatre rapports utilisés pour cette analyse. De ces quatre rapports, un seul fait état d'une mesure de l'incertitude concernant les estimations du pourcentage de réduction des prises moyennes. Toutefois, les expériences individuelles et l'analyse combinée de ces expériences permettent de dégager une tendance manifeste : l'augmentation de la taille des mailles des couvertures filets permettrait de réduire les prises accessoires de poissons à nageoires. Si l'on augmente encore la taille des mailles, les pertes de pétoncles pourraient devenir importantes. Le nombre limité d'études analysées n'a pas permis de répondre avec certitude à la question de savoir si les couvertures filets à larges maillages carrés contribueraient à augmenter ou à diminuer les prises accessoires de poissons plats.

La conclusion globale de la synthèse des résultats des expériences présentées dans les différents rapports portant sur les modifications techniques et de l'analyse de régression entreprise à partir d'une série limitée de données est la suivante : l'augmentation de la taille des mailles des couvertures filets semble la méthode la plus efficace pour réduire notablement les prises accessoires de poissons à nageoires. Par ailleurs, l'augmentation de la taille des anneaux de la poche de la drague devrait contribuer à réduire les prises des jeunes spécimens de poissons plats et de pétoncles. L'augmentation de la taille des anneaux devrait permettre de réduire la mortalité des poissons et d'améliorer la productivité des stocks de pétoncles en encourageant la récolte de pétoncles plus gros, donc dotés d'un poids de chair plus important. Actuellement, la majorité des navires de la flottille canadienne de pêche du pétoncle en activité sur le banc Georges utilisent des couvertures filets à maillages en losange avec une ouverture de maille de 5 ou 6 pouces accrochées de façon classique ou à l'équerre, et associées à des anneaux de 3 pouces de diamètre pour les poches des dragues. Les analyses indiquent que la petite taille de maillage de la couverture filet et des anneaux des poches ne permet sans doute pas de laisser s'échapper de grandes quantités de prises accessoires de poissons à nageoires et de jeunes pétoncles. Si l'on en juge par les maillages carrés avec une ouverture de maille de 16 pouces associés à des anneaux de 4 pouces de diamètre sur les poches des dragues actuellement utilisés sur certains navires-usines congélateurs, les pêcheurs ont peut-être déjà pris conscience de cet état de fait.

Concomitamment à toute mesure de conservation – qu'il s'agisse de fermetures selon les périodes ou les zones, de quotas de prises accessoires ou de modifications matérielles, il est indispensable de garder à l'esprit que les changements temporels ou spatiaux qui touchent la dynamique et l'abondance des espèces de poissons benthiques peuvent faire évoluer brutalement la complexité de la question et nécessitent dès lors une adaptation continue. L'efficacité des différentes modifications matérielles examinées dépendant de la dynamique et de l'abondance des espèces de poissons benthiques présentes, il est indispensable de faire preuve de souplesse afin de faire face à ces fluctuations sur le long terme.

# 1. Introduction

The management of bycatch is fundamental to any ecosystem based fishery conservation and management concept. In the Canadian sea scallop (*Placopecten magellanicus)* fishery on Georges Bank, the capture and mortality of yellowtail flounder (*Limanda ferruginea)*, cod (*Gadus morhua)* and haddock (*Melanogrammus aeglefinus)* are measured and managed to bycatch limits for these stocks (DFO 2007). Both Canadian and American scallop fisheries on Georges Bank, also capture a variety of skates (*Raja spp.),* monkfish (*Lophius americanus)* and other flounders, along with miscellaneous round fish and invertebrates. With the exception of monkfish, which may be retained, Canadian scallop fishers are required, since 1996, "to return to the water in a manner that causes the least possible harm all other species of fish caught incidentally while fishing for scallops" (DFO 2008: Interim 2008 offshore scallop fishing plan). In the US, the bycatch of commercial finfish can be landed. As part of the bilateral agreement between Canada and the US, bycatches of commercial finfish in the US and Canada scallop fisheries on Georges Bank are to be accounted for against their respective groundfish quotas; and mortality estimates of key bycatch species are used in the assessment of the stocks (DFO 2007).

Area/time closures are one conservation measure used to manage bycatch. For example, in 2006, Canada implemented an area/time closure during the cod spawning on Georges Bank to manage the cod bycatch in the scallop fishery (DFO 2007). However, because of seasonal movements and fluctuations in abundance of some groundfish species, it may be necessary to look at more than one technical conservation measure, or a combination of measures, to manage finfish bycatch. Gear based technical conservation measures can also be used to manage size and species bycatch, and have a long history in conservation research and management (Walsh et al. 2002). This engineering-based conservation research includes contributions to making fishing gears and fishing practices more selective for target species, reducing bycatch and discards and maintaining fishery impacts on the environment, within acceptable limits through technological development. The knowledge of fish behaviour underpins all successful examples of gear based technical measures development (Walsh et al. 2002; Walsh et al. 2003).

Since the mid-1990s, both the Canadian and American scallop fishing industries have studied the engineering performance of scallop rakes (dredges) and potential modifications to reduce bycatch of finfish (DuPaul et al. 1996). Unfortunately, modifications to rakes to reduce finfish bycatch can occur at the expense of loss of scallops. A large loss of scallops would necessitate the need for increased fishing time, and that could in turn mitigate some of the bycatch reduction benefits. Other losses associated with increases in fishing time, such as fuel cost, gear damage, habitat loss, etc., would also be impacted as a result.

This report reviews and summarizes published and grey literature from Canada, the USA and the international community on gear modifications that have been proposed or used to reduce the bycatch of groundfish in scallop dredge fisheries.

# 2. Materials and Methods

## 2.1 Gear Descriptions

The directed offshore scallop fishery on Georges Bank by Canada and the USA is prosecuted using a New Bedford style rake generally ranging in width from 13 feet to 17 feet and mostly fished as twin rigs. Figure 1 shows a generic representation of a scallop rake with the characteristic heavy metal frame, to which is attached a bag constructed of steel rings. There are a few differences in terminology for certain parts of this gear. In Canada, the gear is called a rake and in the USA, it is known as a dredge. The mesh panel on the top of the rake/dredge is called a rope back in Canada because it is made of rope. And a twine top in the USA because it is made of heavy twine.

In the American portion of Georges Bank, the scallop dredge is regulated by the National Marine Fisheries Services' (NMFS) Atlantic Sea Scallop Fishery Management Plan (Amendment 10) which also covers the fishery (NOAA 2004). The Georges Bank fishery is managed using a mix of minimum harvest size and effort controls as its two key management measures. The plan addresses the issue of reducing finfish bycatch by reducing days at sea, setting restrictions on the gear and establishing TACs for species of special concern such as yellowtail flounder. The regulated mesh size in the twine top panel is set at 10 inches (inside diameter) diamond or square mesh and the ring size in the bags is set at 4 inch (inside diameter). These regulations apply whether fishing inside or outside any of the US Closed Areas. In Canada, the scallop fishery on Georges Bank is managed under Department of Fisheries and Oceans Scotia Fundy Offshore Scallop Integrated Fisheries Management Plan that uses TACs and meat counts as its two key management measures, and which also includes ITQs, bycatch quotas and dockside monitoring. In this fishing plan, there are no regulated restrictions on any component of the scallop rake construction or design (DFO 2000). The industry have made efforts to reduce finfish bycatch by managing its bycatch quotas with reducing fishing effort. The industry utilizes acoustic seabed mapping to locate scallop concentrations which limits time the dredge is on bottom and, hence, should reduce bycatch (Kenchington 2000).

The present composition of the offshore Canadian fleet fishing on Georges Bank is 10 wetfish vessels and 6 factory freezer trawlers (Ginette Robert, Seafood Producers of Nova Scotia; personal communication). The New Bedford style rake size generally ranges from 14 feet on the wetfish vessels to 17 feet, and occasionally a 20 feet rake, on the factory freezer vessels and are generally fished as pairs. Ring size in the bag of different rakes is mainly 3 inches, although a few vessels are using 4 inches. Rings are held together with 3-4 links in the belly and 2 links in the top of the bag. The wetfish trawlers and some freezer trawlers generally use a 5 or 6 inch diamond mesh rope back which may be hung square in the top panels while some factory freezer trawlers use a full 16 inch knotless square mesh rope back. The rope backs are generally made of 1.5 inch polypropylene rope or 5/8 inch polysteel rope. The webbing is approximately 5 feet deep by 11-13 feet wide. On the larger rakes a pair of gooseneck rollers (wheels/discs) may be used to stop the nose from digging into the substrate. Towing speeds while fishing range from 3 to 5.5 knots and tow duration commonly ranges from 20 to 30 minutes. Tow duration mainly depends on bottom, catch-rates and weather. A 3 to 1 scope ratio is used while fishing in depths of 40-50 fathoms.

## 2.2 Data and Information Quality

None of the data and their analyses used in this review are published in the scientific literature. The information comes from technical reports that have not undergone the rigors of peer review typically associated with a primary publication in an international recognized scientific journal. Some may have undergone internal institute reviews which would come close to some of the demands of a journal. Some of the reports are noted as being preliminary or final, and the recipient of the report was often a funding agency, as is the case for most of the US reports. With the exception of the Kenchington (2000) report, the lead author and many of the co-authors were directly involved in designing the experiments, collecting the data and carrying out the analyses. With the exception of four reports, most analysis looked at mean differences in catch rates, and reported no measure of precision. In many cases, information on number of tows, towing speeds, tow duration, rake size, location of experimental rake (starboard or port side), size, location and twine diameter and knot construction of the rope back and bag ring size were missing. Most reports used catch rates that were standardized to distance, tow duration or area swept. In addition, the length frequency data of the individual bycatch species was missing from all reports except one. Size composition data is important information on the capture process and the selectivity of the dredge. Its absence, in many cases, made interpretation of the bycatch reduction results difficult. For example, if testing the modification of a dredge resulted in large reductions in one experiment or trip while a second repeat of the same experiment yielded little or no reductions in finfish bycatch, then the length frequencies could show if there was a size dependent component.

All reports were joint partnership between Industry and Science. The quality and reliability of the data and analyses from these reports must be judged on face value, as there is no way to provide validation.

## 2.3 Experimental Designs

The gear trials in most reports were designed around pair tows with a standard rake (often referred to as the control) on one side of the vessel and the experimental (modified) rake on the other side. Rarely during the experiments were the rakes switched from one side to the other to minimize any suspected bias in fishing power related to a side of the vessel or to the fishing practices such as turning only to one side during the tow. Tow durations and towing speeds were maintained within each experiment.

Within any one trip, multiple modifications may have been investigated simultaneously, which tends to result in not knowing which modification was responsible for the results observed. In other trips, more than one modification was investigated which may have resulted in a reduced number of paired tows and low statistical power.

Outside of the many modifications to the frame of the dredge, i.e., bail, cutting bar and pressure plate, most experiments concentrated on changing either the mesh size or mesh shape of the rope back panel. To denote the difference between a square mesh panel and one in which the diamond mesh is hung square, the term T45 mesh is used, which denotes a diamond mesh turned 45 degrees, i.e., the ‘run’ of the netting turned through 45 degrees.

## 2.4 Statistics

In most reports, the parametric match paired Student ‘t’ test for dependent samples was used to test whether the difference in mean catches in the experimental and control rakes were statistically significant. In two reports, the non-parametric match paired Wilcoxon signed rank tests were also given with the t-test results. Only in the Kenchington (2000) report is the match paired Wilcoxon signed rank test results solely used.

The assumption of the Student ‘t’ test is that the catches are normally distributed, which no report addressed or tested. If the sample size were 100 or more observations, then the sampling distribution can be assumed to be normal. Since in many cases, the bycatches were low, especially for cod, haddock, monkfish, yellowtail and barndoor skates, the catches are not expected to follow a normal distribution. With small sample sizes, there is no method to test the normality assumption. Hence, the non-parametric matched paired Wilcoxon signed rank test should have been the standard test used. Unlike the t-test which looks at the mean differences, the Wilcoxon test looks at the median differences in paired catches.

The null hypothesis tested is that the difference in mean (median) catches is zero, while the alternate hypothesis is that the difference in mean (median) catches is greater or less than zero. Since the modification to the dredge are expected to reduce the bycatch, a one-tail p value should be used, i.e., the larger mean catch is expected to be in the control (standard) rake. In these reports, a mixture of one and two tailed p values were used. A two-tailed test will calculate a larger p value when compared to the one-tail test. Choosing a one-tail p value can cause a dilemma, since if a large difference in the mean catches is observed with the experimental rake having the larger mean catch then, to be rigorous, it must be concluded that the difference is due to chance. Most statistical results appear to set alpha = 0.05 as the acceptable level for significance p value.

To standardize the interpretation of the data from all of the reports, the Smolowitz et al. (2001) method of calculating a percent bycatch reduction of mean catch rates effected by the experimental relative to the control gear (Control catch rate – experimental catch rate/control catch rate) was used for data from the Kenchington (2000), McIntyre et al. (2006), Henriksen et al. (1997), DuPaul et al. (1999), Smolowitz and Weeks (2006) and Smolowitz et al. (2006) reports. A negative percent reduction occurs when the experimental dredge catches more of a species and positive when it catches less of a species. Note that caution is needed in interpreting percent reductions, because in many cases catches are so low that percent reductions could be meaningless. Also note that with low bycatches very large number of tows could be needed before the modifications of the standard rake could emerge from the chance variations in catch data.

In some of the reports, the confidence intervals (CIs) were given for the mean difference. The calculation of confidence intervals is based on the assumption that the variable is normally distributed in the population. This estimate may not be valid if this assumption is not met, unless the sample size (number of pairs) is large, i.e., $n$=100 or more. In a few cases, the confidence interval statistic was considered. Also, some reports had other statistical tests and graphical results carried out, whose results confirmed the conclusions of the t-test statistic. These are not discussed here.

To standardize the interpretation of the results, only the statistical results reported from the Student t-test, which is the most common test reported, is used. For the Kenchington (2000) report, it is assumed that the statistical results would have been the same had the Student t-test been used. For the analysis of the Smolowitz and Weeks (2006) and Smolowitz et al. (2006) reports, statistical analysis was conducted on the preliminary data given in the report, and, for consistency with the analysis in other reports, the Student t-test[1] was used with a one-tail p value.

# 3. Synthesis of Canadian Research Efforts

The key results of both the Canadian and American investigations are summarized below, including the conclusions drawn by the original author(s). The summary of each report is followed by comments from the current author.

## 3.1 Kenchington, T.J. 2000. Finfish Bycatch Reduction in the Offshore Scallop Fishery. Technical Report for Offshore Scallop Operators Group. Gadus Associates, Musquodoboit Harbour, NS.

This reports summarizes bycatch reduction work in the scallop fishery undertaken by the Canadian Offshore Scallop Operators Group for the period 1995-1999. As the report notes, "these trials have not been conducted as scientific experiments but rather as industry-driven 'R&D' projects." Much of the information presented in the Kenchington (2000) report is incomplete, or only partial analysis of the data was conducted. In some trials, the author was able to carry out some statistical analysis using a non-parametric Wilcoxon matched paired signed ranks test ($\alpha$=0.05). The report also deals with the upgrade of the Industry's efforts in targeting of the fleet through development and use of high-precision charting of offshore banks and their habitats, and the use of subsequent developed charts by vessel captains to target scallop habit areas with less effort.

In the majority of trials, the vessels towed two dredges in a paired tow design with the control (standard) rake on one side and the modified one on the other side. Information on tow duration and towing speeds was not given. No standardization of the catch rates to time or distance traveled was used. Catches were analyzed as average catch per tow. In addition, total catches or percentage differences[2] in catches were also given.

### 3.1.1 The 1995 Trials

**Methodology**

The 1995 trials involved five commercial vessels, each with specific dredge modifications to be tested spread out over six trips.

Three major modifications were tested: 1) various designs of windows in rope backs at various locations; 2) tickler chains used on the towing frame ahead of the cutting bar; and 3) use of large mesh or square mesh rope backs.

[1] This is not endorsing the t-test as the acceptable statistic to use. Unless an analysis is carried out to see if the match pair catches are normally distribute, a match paired Wilcoxon signed rank test would be the preferred statistic.
[2] At times, it was not clear whether these were percentages of total catches or average catches.

### Results

Vessel 1 trials: There were four modifications to the standard dredge examined in these trials, which consisted of an increase in standard mesh size and, sometimes, shape (diamond versus square) in the rope back. Trial Gear refers to the configuration tested.

1) Nominal 5 inch (132 mm) diamond mesh rope back hung square (T45 mesh) versus standard 4 inch diamond rope back (Trial Gear #1).

*Trip #1* (32 tows): Finfish species with sufficient data for analysis included cod, haddock, winter flounder and yellowtail. There was a significant increase in the catch rates of scallops (5%) and cod (42%), and a non-significant increase in haddock (9%) and winter flounder (37%). There was a non-significant 9% reduction in yellowtail in the experimental rake, when compared to the control (standard) rake.

2) Nominal 6 inch (155 mm) T45 mesh[3] rope back versus standard 4 inch diamond rope back (Trial Gear #2).

*Trip #1* (35 tows): Finfish species with sufficient data for analysis included cod, haddock and winter flounder. There was a significant increase in the catch rates of cod (72%) and winter flounder (121%), and a non-significant increases in scallops (3%) catch rates in the experimental rake, when compared to the control (standard) rake. There was a non-significant 11% reduction in haddock catch rates in the experimental rake, when compared to the control (standard) rake. One yellowtail was caught.

*Trip #2* (15 tows): There was a non-significant reduction in catch rates of scallops in the 6 inch square mesh, when compared to the control rake, representing a 3% difference in total catches (kg). There was a non-significant 39% reduction in average catch of cod within the 6 inch square mesh rake, when compared to the 4 inch diamond mesh control rake. There was a 17% increase in average catches of winter flounder rake and a 13% reduction in average catches of yellowtail in the 6 inch mesh rope back, when compared to standard.

Here is a case where the same rigging was tested on the same vessel during two different trips and the results were almost opposite each other, with the exception of winter flounder results.

3) Nominal 5 inch (135 mm) T45 mesh[4] rope back versus standard 4 inch diamond rope back (Trial Gear #3).

*Trip #1* (21 tows)*:* Finfish species with sufficient data for analysis included cod, haddock, winter flounder and yellowtail. There was a significant increase in the catch rates of scallops (5%) and cod (106%), and a non-significant increase in winter flounder (21%) and haddock (24%) catch rates in the 5 inch square mesh experimental rake, when compared to the control (standard) rake. There was a non-significant 13% reduction in yellowtail in the experimental rake, when compared to the control (standard) rake.

4) Nominal 5 inch (132 mm) diamond mesh rope back hung square (T45 mesh) versus nominal 6 inch (155 mm) T45 mesh rope back. (Trial Gear #1 versus Trial Gear #2).

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[3] It was unclear whether this mesh is square or diamond hung square. It was assumed to be T45 mesh.
[4] It was unclear whether this mesh is square or diamond hung square (T45 mesh). It was assumed to be T45 mesh.

*Trip #1* (approximately 21 tows)*:* There was a significant 12% increase in the catch rates of scallops in the 5 inch T45 mesh rake, when compared to 6 inch square mesh rope back rake. There were non-significant increases in catches of cod (119%) and yellowtail (24%), and no difference for winter flounder in the 5 inch T45 mesh rake, when compared to the 6 inch square mesh rope back rake (note catch amounts for reduction were not specified).

5) Vessel side: Port and starboard comparison of catch rates using 4 inch standard rope back.

*Trip #2:* There was a 2% increase in scallop catches in the starboard rake, and a 21% (a marginally significant, $p<0.05$) decrease in cod catch rates in port rake.

<u>Vessel 2 trials:</u> There were two modifications to the standard dredge examined in these trials which consisted of using escape windows in the rope back.

1) Nine-6 inch openings were arranged around the trailing (aft) edge of the 4 inch diamond rope back of a modified rake versus 4 inch diamond rope back standard rake (106 tows) (Trial Gear #4).

No statistical analysis was carried out due to unavailability of raw data. No data on scallops were given. There was a 36% reduction in total finfish caught in the experimental rake, when compared with the standard rake. In the next 34 tows, the holes of the experimental rake were sown over. There was a 16% increase in total finfish catch in the experimental rake when compared with the standard rake.

2) Four openings (windows) were arranged in the centre of the 4 inch diamond rope back of a modified rake versus 4 inch diamond rope back standard rake (48 tows) (Trial Gear #5).

No statistical analysis were carried out due to unavailability of raw data. No data on scallops were given. There was a 16% increase in total finfish caught in the experimental rake, when compared with the standard rake.

<u>Vessel 3 trials:</u> There were two modifications to the standard dredge examined in these trials, which consisted of using tickler chains on the towing frame.

1) Twelve 60 cm lengths of chain dangling from the nose, bridle bars, and an additional crossbar fitted half way between nose and cutting bar of a 5 inch diamond mesh rope back dredge on starboard side versus 4 inch diamond rope back standard rake on port side (unspecified number of tows) (Trial Gear #6).

No statistical analysis was carried out due to unavailability of raw data. No data on scallops were given. There was a 34% and 18% reduction in the total catch (kgs) of cod and haddock, respectively, and an 8% increase in the total catch (kgs) of yellowtail in the experimental rake, when compared to the standard rake.

2) Vessel side comparison.

An additional small number of trials were conducted to look at whether the scallop catches of a rake that turned during a tow were different from a rake that did not turn during the tow. The conclusion was that there was no difference in the catches. A study of the effects of day and night on bycatches of cod and haddock concluded that higher catches were taken at night, with a greater difference seen in the daytime catches with the tickler chains, when compared to the standard rake.

Vessel 4 trials: There was one modification to the standard dredge examined in these trials, which consisted of using escape window in the rope back panel.

1) A 240 mm (9.5 inch) to 300 mm (11.8 inch) wide window, which extended across the entire width of the rake, was inserted at the midpoint of the 4 inch diamond rope back of a modified rake on the starboard side versus 4 inch diamond rope back standard rake on the port side (13 tows) (Trial Gear #7).

The escape window also had ¼ inch strengthening ropes crossing it every 250 to 300 mm from a fore to aft direction creating a series of windows. A flap was used to cover opening during shooting which was suppose to stay open during the tow.

There was a significant reduction in scallop catch rates (22% of total catch) and yellowtail catch rates (38% of total catch[5]) in the experimental rake with the escape window. There was a 6% increase in catches of winter skate in the experimental rake. Catches of cod and haddock were too low to be meaningful.

Vessel 5 trials: There was one modification to the standard dredge examined in these trials, which consisted of using netting between the pressure plate and cutting bar to block the opening.

1) A panel of 120 mm (4.7 inch) mesh netting was attached between the pressure plate and cutting bar in a 4 inch diamond rope back modified rake versus 4 inch diamond rope back standard rake (13 tows) (Trial Gear #8).

There was a 3% reduction in total catches of flounders and a 30% reduction in total catches of cod, and a 26% increase in the total catches of haddock in the experimental rake, when compared to the standard rake. The differences were statistically non-significant. No data on scallops available.

### Conclusions of Kenchington Report

Vessel 1 trials: Large mesh rope backs hung square sometimes took more scallops, cod and flatfish, and sometimes less.

Vessel 2 trials: Escape holes (windows) along the aft edge of rope back in a standard rake showed promise as a finfish bycatch reduction device.

### Comments

Vessel 1 trials: Kenchington's analysis showed that 5 inch T45 mesh, and one of the two trips using 6 inch T45 mesh, resulted in an increase in the catches of scallops, gadoids and most flounders. The second trip, with a 6 inch T45 mesh rope back, found opposite results with the exception of winter flounder catches. A direct comparison between a 5 inch T45 mesh (Trial Gear #1) and 6 inch T45 mesh (Trial Gear #2) showed that there was an decrease in catches of scallops, cod and yellowtail, and no difference in winter flounder in the 6 inch T45 mesh, when

[5] Kenchington was not sure if the numbers of finfish used were counts of individuals or weights.

compared to that seen in the T45 mesh. Kenchington noted that groundfish bycatch was scarce throughout these trials and were confined to a few cod and haddock. In the literature on flatfish mesh selection studies, where bottom trawl codends of the same mesh size, but with either diamond or square mesh, are compared, more flatfish are retained in square mesh and more codfish in diamond mesh codends; in particular, juvenile and mid-size fish (Walsh et al. 1992; Halliday et al. 1999; He 2007). Using 5-6 inch T45 mesh could result in increases in the catches of flounders when compared to standard 4 inch diamond mesh because of the geometry of the mesh opening.

Vessel 2 trials: The location of escape windows may influence the finfish bycatch results in either direction.

Vessel 3 trials: 1) Yellowtail flounder on the Grand Bank have shown the same day and night pattern in bottom trawl catches, when tickler chains were either used or not attached (Walsh 1988). This suggests that vision plays a role in increase in herding of fish by the chains. 2) In these trials, there were two modifications to the experimental rake and it may be difficult to attribute the reduction in catch rates to the use of chains, the 5 inch mesh rope back, or to both.

Vessel 4 trials: These results contrast somewhat with those from Vessel 2 Trial #2, in which the escape windows across the centre of the rope back resulted in an increase in finfish bycatch. Here no results were given for scallops.

Vessel 5 trials: Flounders seem to be mainly passing underneath cutting bar and avoiding the mesh panel. It is likely that cod may be passing over the pressure plate. Haddock catch rates increased in the experimental rake, which could indicate they were being forced underneath the cutting bar. It is difficult to explain these results here, which may be due to low catches of cod and haddock in both rakes. Smolowitz et al. (2001) used excluder rings (two sets of two bag rings strung together) to block passage between the strut openings between cutting bar and pressure plate, and found that scallop catch rates were reduced.

Overall: Bycatch of cod, haddock and flounders were reduced when some escape windows were used in the rope backs. When data was given for scallops it showed substantial impact on scallop catches. Tickler chains showed some promise for gadoids and large mesh or square mesh tops showed mixed results.

Kenchington's analysis showed that two trials of the 5 inch T45 mesh, and one of the two trips using 6 inch T45 mesh resulted in an increase in the catches of scallops, gadoids and most flounders; most of which were non-significant. The second trip with a 6 inch T45 mesh rope back found opposite results, with the exception of winter flounder catches; but all differences were non-significant. Lack of abundance of groundfish, low numbers of pair tows and absence of critical data could have confused the interpretation of some of the results.

### 3.1.2 The 1996 Trials

#### Methodology

The 1996 trials involved only one trip by a single commercial vessel to tested a series of large mesh rope backs: 7 inch (178 mm - Trial Gear #9), 11 inch (280 mm - Trial Gear #10), and 5 inch (127 mm - Trial Gear #11). The modified rake was always on port side. Although not stated, it is assumed that the mesh size in the rope back panel was four inches.

**Results**

5 inch rope back (4 tows - Trial Gear #11): No statistical analysis. There was a 7% increase in the catch rate of scallops and a 2% increase in catches of yellowtail in the experimental rake, when compared with the control rake.

7 inch rope back (26 tows - Trial Gear #9): There was a highly significant reduction (19%) in scallop catch in the experimental rake, when compared with the control rake. Significant reductions in catch rates of cod (65% of total) and monkfish (73% of total), and a non-significant 15% reduction in yellowtail ($p>0.1$) in the experimental rake, when compared with the control rake. Insufficient catches of haddock, sole and catfish could not be analyzed.

11 inch rope back (6 tows - Trial Gear #10): There was a marginally significant reduction (62%: $p=0.05$) in scallop catch in the experimental rake, when compared with the control rake. There was a non-significant 12% reduction in catch rates of yellowtail in the experimental rake, when compared with the control rake. Insufficient catches of haddock, cod and monkfish could not be analyzed.

**Conclusions**

Large mesh rope backs can reduce the bycatch at a cost of substantial reduction of scallop catches. The loss of scallops is so severe that bycatch per ton of scallops in the 11 inch showed an increase.

**Comments**

Both 5 inch and 11 inch rope back trials had a small number of tows and low bycatches, and the results here should be interpreted with caution. The 7 inch rope back showed good reductions in finfish catches at the expense of a loss of scallops.

### 3.1.3 The 1997 Trials

**Methodology**

The 1997 trials involved five commercial vessels each with specific dredge modifications to be tested during 35 trips and approximately 10,000 tows.

Two major modifications were tested: 1) rakes made up of 3.5 inch rings against the standard 3.0 inch rings; and 2) rakes made up of 3.5 inch rings, an 8 inch extension to the pressure plates, 4 inch rings in the wings of the bag, a rope back made up of 3.5 inch rings and a rope back made up entirely of 4 inch rings against the standard rake. Three vessels carried out testing of modification #1, and 2 vessels carried out testing of modifications #2.

Simple results summaries of the catch data were provided to Kenchington; finfish were not identified.

**Results**

1) Rakes made up of 3.5 inch rings against the standard 3.0 inch rings (Trial Gear #13). Not all tows were pairs.

Average catch rates of scallops were higher in rakes with 3.5 inch (6.1 bushels/tow), when compared with standard rake (5.7 bushels per tow). Average finfish weights were approximately 7.0 lbs per tow in both rakes. Larger rings gave a 6% lower bycatch ratio of fish per bushel of scallops.

2) Rakes made up of 3.5 inch rings, an 8 inch extension to the pressure plates, 4 inch rings in the wings of the bag, a rope back made up of 3.5 inch rings and a rope back made up entirely of 4 inch rings against the standard rake (Trial Gear #14).

Average catch rates of scallops were slightly higher in the modified rakes (5.7 bushels/tow), when compared with the standard rake (5.6 per tow). Average catch rates of finfish were slightly lower in modified rakes (10.0 lbs per tow), when compared with standard rake (10.5 lbs per tow).

**Conclusion**

Larger rings offer a small reduction in bycatch at the expense of a minimum reduction in scallops.

**Comments**

Analysis of the larger raw data set might have proven to be more useful had it been available. When there are too many modifications made to the rake in the same testing, then interpretation of results are confounded.

### 3.1.4 The 1998 Trials

**Methodology**

The 1998 trials involved 8 commercial vessels each with specific dredge modifications to be tested, spread out over 125 trips and approximately 10,000 tows. Much of this work was a continuation of the 1997 trials with many of the same vessels involved.

Five major modifications were tested:1) rakes made up of 3.5 inch rings against the standard 3.0 inch rings [Trial Gear #13]; 2) rakes made up of 3.5 inch rings, an 8 inch extension to the pressure plates, 4 inch rings in the wings of the bag, a rope back made up of 3.5 inch rings and a rope back made up entirely of 4 inch rings against the standard rake [Trial Gear #14]; 3) comparison of port and starboard catches using only the 3.0 inch ring-standard rakes; 4) comparison of port and starboard catches using only the 3.5 inch ring-standard rakes; and 5) rakes made up of 3.5 inch rings and an 8 inch extension to the pressure plates with a normal rope (Trial Gear #13) back against a 3.5 inch ring rake as the control ( standard).

Only a summary of the catch data for modification #2 was provided; finfish were not identified.

**Results**

2) Rakes made up of 3.5 inch rings, an 8 inch extension to the pressure plates, 4 inch rings in the wings of the bag, a rope back made up of 3.5 inch rings and a rope back made up entirely of 4 inch rings against the standard rake (3 vessels - 36 trips). (Trial Gear #14)

Summary notes and observations were only available for 3/36 trips on scallop catches and combined finfish catches. There was a 7% improvement in total catches of scallops and a highly significant (67% total catch) reduction in finfish daily totals in the experimental rake, when compared with the standard rake. It was thought that most of the reduction was contributed to escapement of cod and haddock, but not flatfish, from the modified rake.

In mid-June, one vessel carried out nine tows with several modifications: 1) 3 inch excluder rings between pressure plate and bridle bar to close off some of the space a above cutting bar (1 tow), addition of tickler chains on bridle bars which lay just behind cutting bar ( 2 tows), use of an 8 inch rope back (1 tow), addition of 10 tickler chains hanging from the bridle bars (1 tow), a rake with two 18 x 10 inch rubber wheels fitted to the nose of the towing bar (1 tow), and a rake with two 18 x 10 inch rubber wheels fitted to the nose of the towing bar with short chains dangling from the bridle bars and rings extending the pressure plate (1 tow). The final tow used a rake with two kinds of tickler chains, the two 18 x 10 inch rubber wheels fitted to the nose of the towing bar, and rings extending the pressure plate. Data for these tows were not available.

There was one trip which made 121 paired tows that has some observer data. The modified rake had two kinds of tickler chains (22 short chains on bridle bars and longer chains by the cutting bar) and two 18 x 10 inch rubber wheels fitted to the nose of the towing bar. It is unknown if it used rings to extend the pressure plate.

From the observer's records, the modified rake took 4% less scallops, 10% less skate, 5% less yellowtail, and 4% less other finfish when compared to the standard rake.

**Comments**

The 1998 trials, like the 1997 trials, resulted in many modifications to the standard dredge being tested, but unfortunately very little raw data was available to Kenchington to carry out detail analyses. With so many changes to the frame, it would be difficult to pick out any one change that would be responsible for the differences in catch rates. The increase in ring size from 3 to 3.5 inches resulted in a lower catch ratio of scallops to finfish.

### 3.1.5 The 1999 Trials

The 1999 trials focused on improving the targeting of scallop dragging and not on gear modifications.

The industry adopted the use of 3.5 inch rings into the construction of the rake bag.

**Comments**

Presently most of the industry is using 3 inch rings with a few factory freezer trawlers using 4 inch ring bags. None are using 3.5 inch rings (Seafood Producers Association of Nova Scotia; personal communication).

### 3.1.6 General Conclusions

Kenchington noted that "insufficient time was given to the testing of any one idea for conclusive results to be found." No one rake modification was successful in reducing finfish bycatch while minimizing loss of scallops. Large mesh rope backs and exit windows in rope backs reduced bycatch of finfish and scallops, while moderately large square mesh rope backs had little success in reduction of bycatch. Tickler chains and the use of 3.5 inch rings had some effect. The effects of extended pressure plates and use of 4 inch rings may have been confounded because they were always being tested with other modifications. The last trial in 1998 with its modifications of tickler chains and nose wheels offered some promise, but did not produce dramatic results.

### 3.1.7 General Comments

This report appears to chronicle many testing of modifications to the standard rake over time, with the hopes of coming up with a good bycatch reduction rake. Many of these trials were more successful in releasing roundfish, such as cod and haddock, than flatfish and skates. Differences in swimming behaviour and reaction times to the gear are obvious factors that would contribute to understanding the successes or failures of any modification. Large mesh rope backs were successful in reducing finfish bycatch, with varying loss of scallops, especially in rope backs of 11 inches. Diamond hung square mesh (T45 mesh) rope backs mainly showed increases in finfish bycatch and scallop catches. The success of using escape windows in the rope back depended on location. The use of tickler chains dangling from the frame bars also appeared to reduce finfish bycatch. In many cases, the success of a modification was negated by too few tows, low catche and other modifications being simultaneously tested.

There was a lot of data collected during these trials, especially the 1997 and 1998 trials, that remain unanalyzed. These data could contribute a lot of knowledge to the capture efficiency and behaviour of scallops in dredges, as well the effects of variables such rake fullness, weather, towing speeds, tow duration, and fish densities could have on bycatch efficiency. Kenchington also noted that fishing conditions and practices can have a great effect on success rate of any rake modification.

## 3.2 McIntyre, T.M., R. Cunningham, G. Robert, and B. Branton. 2006. Gear Trial Experiment to Reduce Groundfish Bycatch in the Offshore Scallop Fishery on Georges Bank. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2745.

#### Methodology

Modified frame and the use of light and sound experiments were carried out during six trips from 6-21 September 2005, using one commercial vessel fishing two 15 foot wide New Bedford style dredges on Canadian side of Georges Bank. Both the experimental and control dredges had identical bag construction using 3.5 inch rings joined by 2 links on the back and 3 links on the belly. The rope back panel was constructed of 6 inch square mesh. The control rake was fished on the starboard side and the experimental rake on the port side. Tow duration was standardized to 30 minutes using tow speeds ranging from 4.5- 5.5 knots.

Two tows using two standard dredges without modifications were used to investigate the effect of choice of vessel side, and day and night comparison on catches of all species categories.

Four modifications were tested, one dealing with the frame and three dealing with use of light and sound instruments as fish scaring devices attached to the frame: 1) a series of deflector panels were constructed to fix behind the pressure plate to deflect fish upwards behind the pressure plate towards escape openings along the top of the pressure plate. These movable panels could be positioned into 3 positions: high (space below panel was at its maximum), low (space below panel was at its minimum) and closed (same position as low, but closing off the opening above the pressure plate); 2) four intensity lights mounted on the pressure plate of a standard dredge and shining ahead; 3) two strobe lights mounted on the tow bars ahead of the pressure plate of a standard dredge and shining ahead; and 4) high frequency pingers mounted near the centre of the tow bars on the dredge.

Catch data from 125 modified dredge paired tows were analyzed using a one tail matched paired t-test and a matched paired Wilcoxon signed ranks test on standardized data. Catch rates (in numbers for fish and bushels for scallops) were standardized to catch per 4 km.

Species encountered with sufficient data for statistical analysis were scallops, cod, haddock, yellowtail flounder, monkfish, flounder (not specified – referred to as flatfish in the rest of this review) and skates (not specified).

**Results** (see Table 1)

Vessel Side and Day and Night Comparisons

Comparison of catch rates between the port and starboard sides did not detect any significant differences for all species. No significant difference was found between day and night catches for all species (p>.05). Data is not in tables.

Deflector Panel Dredge Modification

*High position and Low position*: An increase in catch rates of all finfish species was found in the experimental dredge, when compared to control dredge; most were statistically non-significant. There was a significant increase in catch rates of yellowtail (121%, 153% respectively) and flatfish (64%, 54% respectively) in both positions. A significant 32% increase in catch rates monkfish was estimated for the panel in the high position, but only a 4% increase was evident in the low position. A highly significant 54% reduction in scallop catch rates was evident when the panel was in the high position, and a non-significant 19% reduction was seen with the panel in the low position (actually, it was marginally significant in the Wilcoxon test). Skate gave the largest catches. There were non-significant reductions in the skate catch rates with the panel in the top (3%) and low positions (29%), when compared to the control rake.

*Closed position:* Non-significant reductions in catch rates in yellowtail (31%) and flatfish (6%) were estimated in the experimental dredge, when compared to control dredge. Non-significant increases in catch rates of skate (7%), monkfish (26%) and scallops (0.4%) were estimated in the experimental dredge when compared to control dredge.

Lights Mounted on Standard Dredge

*High intensity lights*: Lower catch rates were found in the experimental dredge for cod (63%), yellowtail (23%), flatfish (42%), and skate (7%) when compared to control dredge. Only the 23% reduction in yellowtail catch rates was significant. There was a marginally significant (p=.540) 42% reduction in flatfish in the experimental trawl, when compared to the control trawl. Non-significant increases in the catch rates of monkfish (3%), haddock (2%), and scallops (6%) were evident in the experimental dredge when compared to the control trawl.

*Strobe lights*: Non-significant reduction in catch rates were estimated for yellowtail (11%), flatfish (16%), cod (18%) and monkfish (9%) in the experimental dredge, when compared to control dredge. Haddock showed a significant 72% reduction in the experimental dredge. There was a significant 10% increase in the catch rates of scallops, and a non-significant 5% increase in the catch rates of skates in the experimental dredge, when compared to control dredge.

<u>Sound/Acoustic Pingers Mounted on Standard Dredge</u>

There was a non-significant reduction in the catch rates of yellowtail (58%), haddock (28%) and monkfish (7%) in the experimental dredge, when compared to control dredge. There was a significant 39% reduction in the catch rates of flatfish in the experimental dredge, when compared to control dredge. Non-significant increases in the catch rates of skates (11%) and cod (96%) were evident, along with a significant 12% increase in the catch rates of scallops in the experimental dredge, when compared to control dredge.

### Conclusions of the Report

The deflector rake often caused an increase in catch rates of finfish. Light and sound gave mixed results. Low catches of cod and haddock were evident.

### Comments

<u>Deflector panel dredge modification:</u> Although catches of cod and haddock were taken, they were too low to be derived meaningful results and, hence, are not cited here but are found in Table 1.

<u>*Lights mounted on standard dredge*</u>: Catches of cod and haddock were low and results may not be meaningful.

<u>Sound/acoustic pingers mounted on standard dredge:</u> Catches of yellowtail, cod, and haddock were low and results may not be meaningful.

<u>General:</u> The use of lights and sound to startle and cause flight in the finfish encountered, offer some promise for further investigations for reduction of flounder catches, but may result in the increase in skate catches. Both strobe lights and acoustic pingers resulted in an increase in catch rates of scallops, which would be a bonus. Pol and Carr 2002 reported that bay scallops, *Argopecten irradians*, swam up vertically in response to the passing of an outboard engine in shallow water. Scallops do not have sensory organs for hearing, but the authors surmised that the mechanoreceptors could be sensitive to pressure caused by different sound frequencies. The authors tried to repeat these results with bay and sea scallops in a control setting without success. Sound is known to initiate the capture process in fish (Wardle 1983). Fishes are mainly sensitive to sound of frequencies below 0.5 to 1 kHz range, and flatfish, because they have no swim bladder, are relatively insensitive to sound (see review by Wahlberg and Westerberg 2005). The acoustic pingers used here operate on a frequency of 10 KHz ±2Khz , which is not in the sensitive zone for detection by most fish. This may explain why there was only some difference in catch rates of finfish, which have bladders, along with low catches overall. Nevertheless, in further studies the combined use of light and sound should be investigated (Popper and Carlson 1998).

# 4. Synthesis of East Coast American Research Efforts

## 4.1 Henriksen, S., E. Welch, S. Therrien, R.J. Smolowitz, P.J. Struhsaker, C.A. Goudy, and H. Kite-Powell. 1997. Results of Gear Modification Tests to Reduce Bycatches of Commercial Finfish in Sea Scallop Dredges. August, 1997. Final Report, NOAA Award No. NA66FD0026, NMFS, NE Region Office, Gloucester, MA.

### Methodology

Twine top and modified frame experiments were carried out during six trips from 11 November 1996 to 29 March 1997, using two commercial vessels, each fishing two 15 foot wide New Bedford style dredges off Cape Cod on Georges Bank. The control (standard) and experimental dredges were occasionally switched between sides. Average tow durations ranged from 61 to 72 minutes at an average tow speed of 4.5 knots.

Four modifications were tested: 1) Trips #1-3, a 10 inch (254 mm) loosely hung diamond mesh twine top experimental dredge was compared with a standard 6 inch (152 mm) diamond mesh twine top dredge; 2) Trip #4 used a gooseneck roller on a the standard 6 inch (152 mm) diamond mesh twine top dredge tested against a standard dredge without a roller; and 3) Trip #s 5-6, an 8 inch diamond mesh (203 mm) hung square (T45 mesh) twine top experimental dredge was compared with a standard 6 inch (152 mm) diamond mesh twine top dredge; and 4) Trip #6A, an 8 inch diamond mesh (203 mm) hung square (T45 mesh) twine top experimental dredge, also fitted with a pressure plate on the towing bail, was compared with a standard 6 inch (152 mm) diamond mesh twine top dredge.

In addition, at four stations during Trip #6, large holes were cut in the 8 inch T45 mesh top webbing next to the apron (the aft part of the twine top where it attaches to the steel rings) of the experimental trawl. Large reductions in total numbers of yellowtail (61%) and other flats (51%) were noted. A 7% loss in scallop numbers was also recorded. No further tows or analysis were conducted because the authors felt that they could not separate whether the 8 inch square mesh or the holes were contributing to escapement.

Catch data from 140 paired tows during six trips involving two vessels were analyzed using a two-tail paired t test on raw data and on square root transformed data. Catch (in numbers) rates were standardized to catch per hour. Minor differences in t-test results between untransformed and transformed data were evident, so only t-test results on untransformed data will be discussed here. Yellowtail was principal species, but sufficient data was collected on combined flatfish (called flatfish), skates (not specified), monkfish, cod and ‘other fish’ for analysis.

**Results** (see Table 2)

Detailed statistical analysis were reported for yellowtail, other flatfish, skates, and scallops (Table 2). Catches of monkfish and cod were small, and some analysis was attempted.

<u>10 Inch Diamond Versus 6 Inch Standard Diamond Mesh Twine Tops (49 Tows in Trips #1-3)</u>

Highly significant reduction in experimental dredge catch rates of yellowtail in 3/3 trips, 1/3 trips for skate, 3/3 trips for other flatfish and 2/3 trips for scallops of all sizes (1/3 trips for sizes >90 mm, and 2/3 trips for sizes <90 mm shell height). Percent reduction in mean catches for yellowtail ranged from 30-62%, 14-23% for skate, 20-61% for other flatfish and 1-49% for scallops (4 -35% large, 40-53% for small sizes).

For monkfish, there were only sufficient data for t-test analysis for Trips #1-2. Significant reduction in bycatch occurred in experimental dredge for one (p=.0007) out of two trips. For Trip #3, there was little difference in the pooled catches (110 experimental versus 114 control). No percent reductions were calculated because of the absence of raw catch data.

For cod, there was only a total of 16 cod taken, 3 in experimental and 13 in controls, which resulted in a 77% reduction (not listed in Table 2).

<u>Gooseneck Roller Mounted on a 6 Inch Diamond Twine Top Dredge Versus 6 Inch Standard Diamond Mesh Twine Top Dredge (18 Tows in Trip #4)</u>

A non-significant 17% increase in yellowtail catch rates was measured in the experimental dredge. There were non-significant reductions in catch rates for skates (12%) and flatfishes (5%). There were minor differences in scallop catch rates, ranging from a 3% increase to a 5% decrease in the experimental dredge, when compared to the control dredge.

<u>8 Inch T45 Mesh Twine Top Dredge Versus 6 Inch Standard Diamond Mesh Twine Top Dredge (69 Tows in Trips #5-6)</u>

Highly significant reduction in the catch rates of the experimental trawl for skates (average 27-47%) and flatfish (average 41-46%). In Trip #5, there was a significant 34% reduction, and in Trip #6, a significant 37% increase in yellowtail catch rates in the T45 mesh when compared to the control mesh top. There was a non-significant 6% increase and a 3% reduction in combined scallop catch rates. However, when looking at the two size groups separately, a highly significant 13% increase in the catch rates of large scallops was evident in the experimental trawl in Trip #5, and a non-significant 5% decrease in catch rates in Trip #6. For small size scallops, there was a non-significant reduction (0 to 13%) in catch rates in the experimental trawl, when compared to the control dredge.

For monkfish, pooled catches indicated little differences between the two dredges. No cod was taken in experimental dredges, while 23 and 50 cod were taken in the control dredges in Trip #s 5 and 6, respectively. No statistical analysis was available.

<u>Pressure Plate on Towing Bail - 8 Inch T45 Mesh Versus 6 Inch Standard Diamond Mesh Twine Top Dredge (9 Tows in Trip #6A)</u>

A highly significant reduction in the catch rates of yellowtail (average 41%), a marginally significant large reduction (average 61%) in flatfish, and a non-significant moderate reduction (average 34%) in skate catch rates in the experimental dredge, when compared to the control dredge. There were no significant difference in scallop catch rates for any category; however, there was an average range of 8-13% percent reduction in catch rates in the experimental dredge.

Catches of monkfish and cod were too low for any meaningful analysis.

### Conclusions of the Report

Modifying the dredge by using an 8 inch diamond mesh twine top panel hung on the square had the most effect on reducing catches of finfish and little reduction on catches of scallops. Increasing to 10 inch diamond mesh would also significantly reduce finfish bycatch, but with a significant loss of scallops. A gooseneck roller on the bail of the standard dredge (6 inch diamond mesh twine top) had little influence on reducing catch rates of finfish and scallops.

### Comments

No differences in the t-test results for transformed and untransformed data were detected and 'F' ratio tests of variance results produced similar findings. Encouraging results were seen in the 8 inch T45 mesh; however, the use of an additional pressure plate on the bail of this dredge showed a similar effect on the outcome, although the number of tows (9) were too low to be conclusive. The use of gooseneck rollers seem to have little effect on finfish bycatch and scallop catches.

The authors note that the abundance of finfish and scallops was low in comparison with what they would expect had they been given access to carry out their studies in the Closed Areas on Georges Bank, and are unsure if there results would hold for tows in high density areas.

An economic analysis was attempted to find out what loss of profitability would be suffered by the fleet for reduction in some of the profitable finfish. The analysis showed that the proposed modification would not have an impact on fishing vessel income.

## 4.2 DuPaul, W.D., D.B. Rudders, and D.W. Kerstetter. 1999. Results of Modifications to Sea Scallop Dredge Twine Tops to Facilitate the Reduction of Finfish Bycatch: Georges Bank Closed Area II Experimental Fishery September–October 1998. VIMS Marine Resource Report No. 99-4.

### Methodology

Two twine top experiments were carried out from 17 September to 1 October 1998, using one commercial vessel fishing two New Bedford style dredges (unspecified widths-assumed 15 foot wide dredges). The control dredge was on the starboard size, and it was rigged with the standard 8 inch diamond mesh twine top. The experimental twine top was on the port dredge, and used a diamond mesh turned 45 degrees[6] (T45 mesh); i.e., hung square. In Experiment #1, 224 tows in the Georges Bank Closed Area II had the control twine top constructed of 65 mesh x 12 mesh panel of 8 inch diamond mesh and the experimental twine top with an 8 inch T45 mesh. Tow duration ranged from 1-27 minutes. In Experiment #2, 34 tows adjacent to the boundary of Closed Area II had the control twine tops constructed of 65 mesh x 12 mesh panel of 8 inch diamond mesh and the experimental twine top had the a 12 inch T45 mesh panel. Tow duration ranged from 1-70 minutes. Towing speeds were not specified in both experiments. Ring size was not stated but assumed to be 3.5 inches.

A two tailed paired t-test was used to test for statistical difference in average (in numbers) catch per tow for all tows, and also for only those tows in which fish of a particular species was

[6] In the report, it said the diamond mesh was rotated 90 degrees; however, Bill DuPaul clarified that the diamond mesh was actually rotated 45 degrees (B. DuPaul, VIMS 2008; personal communication).

caught. Species analyzed were scallops (>70 mm size class), yellowtail, blackback, and windowpane flounders, monkfish and barndoor skates.

**Results** (see Table 3)

Experiment #1: 8 Inch T45 Mesh Twine Top Dredge Versus 8 Inch Standard Diamond Mesh Twine Top Dredge

There was a non-significant increase in catch rates for yellowtail (12%) and a 42% increase in catch rates for barndoor skates (although the catches of the latter were low), and a non-significant reduction in blackback flounder (3%), monkfish (7%) and scallops (1%). A highly significant 21% reduction in catch rates of windowpane flounder was estimated in the experimental dredge when compared to the control dredge.

Experiment #2: 12 inch T45 Mesh Twine Top Dredge versus 8 inch standard Diamond Mesh Twine Top Dredge

A non-significant 46% reduction in the catch rates of yellowtail was evident in the experimental dredge. Highly significant reductions in the catch rates of blackback flounder (65%), windowpane flounder (63%), and scallops (16%). A marginally significant 51% reduction in monkfish (p=.04) catch rates was also found. There were insufficient data for barndoor skate analysis.

**Conclusions of the Report**

In Experiment #1, 8 inch T45 mesh twine top had little effect on escapement of most species, except windowpane flounder, when compared to catch rates for the 8 inch diamond mesh. The length frequency for the three flatfish showed that the square mesh was generally retaining more numbers at length for yellowtail and blackback flounder than the diamond mesh, typical of mesh selection studies in codends of bottom trawls using the same mesh size but different mesh shape (Walsh et al. 1992; He 2007). Differences in body shape may account for the decrease in windowpane flounder catches, when compared to the other flounders. In Experiment #2, although average catch rates of yellowtail (46% reduction) were lower but not significant, the experimental dredge with 12 inch T45 mesh twine top gave a substantial reduction in both flatfish and scallops, when compared to 8 inch diamond mesh twine top. The authors noted that large between tow variability in the yellowtail catches may have influenced the lack of statistical significance.

Percent reductions in catch rates of blackback and windowpane flounders in the experimental dredge fitted with a T45 mesh twine top were 65% and 63%, respectively, and for scallops, it was 23% for combined size group and 16% for larger scallops. This would be a substantial commercial scallop loss. The difference in scallop densities inside and outside Closed Area II could have an effect on the escapement of scallop.

**Comments**

Large catches of skates were taken in each experiment but not analyzed. In Experiment #1, there were 30 skate per tow for both control and experimental dredges; i.e., 0% reduction in experimental trawl. In Experiment #2, catch rates were 45 and 29, respectively, representing a 35% reduction in the experimental trawl. Catch rates of barndoor skates in Experiment #1 were low and these results are suspect. Length frequencies of all species analyzed showed that both dredges were sampling the same length distribution.

## 4.3 Smolowitz, R.J., P.J. Struhsaker, and W. DuPaul. 2001. Dredge Modifications to Reduce Incidental Groundfish Catches in the Northwest Atlantic Sea Scallop Fishery. Final Report. NMFS, NE Region Office, Gloucester, MA.

**Methodology**

Modified frame dredge experiments were carried out during three trips from December 2000 to October 2001, using two commercial vessels, each fishing two 15 foot wide New Bedford style dredges in two closed areas (NLSA[7] and CA I) on Georges Bank. Average tow durations ranged from 30-33 minutes. Average tow speed was not stated.

The experimental dredge frame was lightened by being constructed of round stock to test a habitat protection concept (Smolowitz et al. 2004). A standard commercial dredge was used as a control, and both twine tops had 10 inch diamond mesh panels. The latter was the regulated mesh size to fish inside the closed areas. Two modifications were tested: 1) a cookie fish sweep was rigged across the entire width of the experimental dredge in front of the cutting bar for trips #1-2; and 2) two sets of excluder rings welded between pressure plate and cutting bar between each strut[8] were used along with the cookie fish sweep in the experimental trawl, and the control trawl also used another lighter frame dredge for Trip #3 (see Figure 2).

Catch data from 67 paired tows during three trips in the closed areas involving two vessels were analyzed using a two tail paired t-test on raw data. Catch rate data was standardized per hectare and represented mean catch in numbers for the fish and mean bushel per hectare for scallops. Several supplementary graphics were given for examination of dredge performance and catches on a tow by tow basis. The summarized analysis presented here will focus on the t-test results. The authors also included percent reductions in catch rates between the experimental and control dredges with 95% confidence intervals.

Yellowtail, combined flatfish (flatfish), skates (not specified), monkfish and scallop catches had sufficient data to carry out the statistical analyses.

**Results** (see Table 4)

<u>A Fish Sweep Rigged on a Lighter Dredge Frame versus a Standard Dredge (40 Tows in Trips #1-2). Both Dredges had 10 inch Diamond Mesh Twine Tops</u>

There was a highly significant 37% reduction and a marginally significant (p=.045) 38% reduction in catch rates of yellowtail in the experimental dredge for trips #1 and 2, respectively. Skates showed a highly significant 29% reduction and a non-significant 10% reduction in trips #1 and 2, respectively. Catch rates for flatfish showed a similar pattern as seen in yellowtail and skate, with a significant 26% reduction in catch rates in Trip #1, and a non-significant 31% reduction in Trip #2. The catch rates of monkfish and scallops increased in the experimental dredge when compared to the control dredge. Both increases in scallop catch rates were highly

[7] Nantucket Light Ship Area: CA = Closed Area
[8] A half link was welded at the cutting bar, then a small piece of dog chain, a link, a ring, another link, a second ring, then dog chain to another welded half link to the leading edge of the pressure plate. There were two rows of this arrangement between each strut ( Ron Smolowitz, Coonamesett Farm, USA; personal communication).

significant (11% and 22% respectively), while only Trip #2 had a significant increase in catch rates for monkfish (10% and 80%, respectively) in the experimental dredge, when compared to the control dredge.

A Fish Sweep and Excluder Rings Rigged on a Lighter Dredge Frame versus a Control Lighter Dredge (27 Tows in Trip #3). Both Dredges had 10 inch Diamond Mesh Twine Tops

A highly significant 40% reduction in yellowtail, 40% in skate and 48% in other flatfish catch rates were seen in the experimental dredge. There was no significant difference in catch rates of monkfish (3%) and scallops (3%). The authors felt that there was one anomalous high scallop catch rate in one tow in the experimental dredge and when it was dropped, there was a highly significant 7% reduction in scallop catches in the experimental dredge, thereby, demonstrating that the excluder rings were affecting scallop catches.

**Comments**

A fish sweep rigged on a lighter dredge frame versus a standard dredge: The authors felt that low and variable catches may have contributed to the differences in results for the finfishes between Trips #1 and 2. Monkfish catches were very low. The cookie sweep rigged in front of the cutting bar may have been effective in herding finfish out of the way of the cutting bar while digging out more scallops.

A fish sweep and excluder rings rigged on a lighter dredge frame versus a control lighter dredge: Although the design of the excluder rigs was based on flexibility, as a rigid “blocking” in this area does not work well; it obviously affected scallop catches. The cookie sweep worked well on some bottoms and not well on others; i.e., was very variable. Figure 2 shows two wheels/rollers between nose and cutting bar, but this was not mentioned in the text.

Overall: In this analysis, the authors provided 95% CI for the percent reduction (as well for mean difference) in catch rates. The width of the CI depends on the sample size and on the variation of data value. Showing the CIs, illustrates that you cannot solely rely on percent differences in judging the performance of the dredge modifications. In this analysis, it is seen that that for Trip #2, yellowtail and other flatfish catch rates, and trips #1-2 for monkfish, had wide CIs (see Table 4). The authors noted that sample sizes in Trip #2 in January were low. It may simply be the case that some finfish species are seasonally moving in and out of the closed areas. This needs to be taken into account when planning experiments; i.e., to address the seasonal component. In some of the analysis, outliers were identified by graphics and dropped. No attention was paid to these, since in many cases the results did not change or outlier detection method did not seem to be equally applied.

The authors admit in the report that because of the mixture of changes to the experimental dredge and the control dredge in Trip #3, that they are unable to determine if any one modification contributed to the changes; i.e., lighter frame-fish sweep or lighter frame-fish sweep-excluder rings. One can speculate that the using a sweep ahead of the cutting bar along with excluder rings blocking the opening between the cutting bar and pressure plate is effective in herding finfish out of the way. Only the later might have an effect on scallop catches.

### 4.4 DuPaul, W.D. 2002a. Performance of a 4 inch Ring Scallop Dredge in Context of an Area Management Strategy. Award No. NA16FM1002 Closed Area II: Research TAC Set-aside Georges Bank Scallop Exemption Program Closed Areas Access. Final Contract Report. VIMS Marine Resource Report No. 2002-05, May 2002.

This report summarizes comparative performance of 3.5 inch and 4 inch ring bags on catches of scallops, finfish bycatch and trash (invertebrates and shells only-no rocks).

**Methodology**

The experiments were carried out during three trips from July 2000 to September 2001 using one commercial vessel fishing two 15 foot wide New Bedford style dredges side by side. The control dredge was the 3.5 inch ring bag dredge, and both were assumed rigged with the standard 10 inch diamond mesh twine tops. With the exception of the ring size, all other riggings and fishing practices were kept close to identical as possible. No details given.

Finfish bycatch is given for three trips in Closed Area II, two in Closed Area I and one in Hudson Canyon Closed Area. Percent reductions are given for total catches. The data and descriptions of the trips are found in DuPaul (2002a and b) and DuPaul et al. (2002). No statistical analysis is available for the catch rates, and the reader should keep in mind that the results refer to totals catches by area only.

Species analyzed were scallops, yellowtail, plaice, witch, blackback, fourspot and windowpane flounders, monkfish and skates, and other demersal dwelling fish.

**Results** (see Table 5)

There was a 5.6% increase in the efficiency of the 4 inch ring for scallops (area efficiencies ranged from 0.5% to 14.4%), when compared to the 3.5 inch ring dredge. The relative performance of both sizes is about equal for scallops in the 110-115 mm size range, but the 4 inch dredge was slightly more efficient at harvesting scallops greater than 110 mm. Reductions in the time on bottom per basket of scallops harvested was estimated by the author as ranging from 0.5% to 18.6%, as a result of using a larger ring size in the dredge bag.

The 4 inch ring dredge fished 'cleaner' than the 3.5 inch ring dredge, with large reductions in trash ranging from 21% to 40%.

There was a 53% reduction in the catches of small flounders in the 4 inch ring dredge, but no reduction in the catches of large yellowtail. The combined flatfish catches consisting of plaice, witch, blackback, windowpane and fourspot flounders, showed an overall 28% reduction in catches in the 4 inch ring dredges. It is noteworthy that there was less than 1% difference in the catches of skates between 3.5 and 4 inch ring dredges. In addition, roundfish catches showed large reductions (red hake, 28%; silver hake, 22%; sculpins, 39%; and sea ravens, 30%) in the 4 inch dredge, when compared to the 3.5 inch dredge.

**Comments**

It is apparent that small flatfish can wriggle out through larger ring size dredges. Although no roundfish were reported, it is likely that any reduction in roundfish catches may also be size dependent. Although smaller scallops are escaping through the larger 4 inch rings, it appears the 4 inch ring dredge is more efficient for larger scallops. As the ring size is increased, then the retained scallops are older and heavier. This may have something to do with the flow dynamics in large ring dredges. Morse (2005) reported on field trials of 4 inch ring dredge compared with 3.5 inch ring bags in the scallop dredges used in the inshore Gulf of Maine area. He found that there was a 3% loss of legal scallops (101.6 mm shell height) and a 26% reduction in sub-legal scallops.

## 4.5 DuPaul, W.D., and D.B. Rudders. 2004. A Comparative Evaluation of a 3.5 inch Ring Dredge versus a 4.0 inch Ring Sea Scallop Dredge Equipped with Sea Turtle Excluder Chains. VIMS Marine Resource Report No. 2004-05, April 2004.

This preliminary report summarizes comparative performance of 3.5 inch and 4 inch ring bags on catches of scallops, finfish bycatch and trash (invertebrates and shells only-no rocks).

### Methodology

The experiments were carried out during three trips from September to October 2003, using two commercial vessels in the Hudson Canyon Closed Area and consisted of 79 tows. One vessel fished two 15 feet wide and the other vessel fished two 13 feet wide New Bedford style dredges side by side. The control dredge was the 3.5 inch ring dredge and both were assumed rigged with the standard 10 inch diamond mesh twine top. The 4 inch ring dredges were fitted with a set of turtle chains, whose configuration of varying numbers of rock chains and tickler chains being a function of dredge width. With the exception of the ring size all other riggings and fishing practices were kept close to identical as possible.

### Results

No details of the catches were given in this report. Figure 4 from the report showed that the 3.5 inch ring dredge caught smaller scallops up to 105 mm when compared to the 4 inch dredge. There is little difference in the efficiency in both dredges for scallops larger than 115 mm.

### Comments

This is a very preliminary report and, as such, should be treated with caution. It is interesting to note that the 4 inch ring dredge caught fewer small scallops under 105 mm than the 3.5 inch ring dredge which was not seen in report 4.4 above (DuPaul 2002). The turtle chain mats may improve the efficiency of the 4 inch dredge in catching less smaller scallops.

## 4.6 Smolowitz, R.J., D. Rutecki, P.J. Struhsaker, and W. DuPaul. 2004. Comparison of Ten Inch versus Six Inch Twine Tops to Reduce Discard of Bycatch in the Sea Scallop Fishery. Final Report. NMFS, NE Region Office, Gloucester, MA.

### Methodology

Twine top and modified frame dredge experiments were carried out during 4 trips from October 1–28, 2003 using two commercial vessels each fishing two 15 foot wide New Bedford style dredges in the open and closed areas of Georges Bank. Average tow durations ranged from 7 to 52 minutes at an average tow speed of 3.8 to 4.5 knots.

A standard commercial dredge was used as a control with 6 inch diamond mesh (80 meshes wide and 15 meshes deep) twine top and the experimental dredge had 10 inch diamond mesh (40 meshes wide by 8.5 meshes deep) twine top panel. Hanging ratio was 1 to 1, i.e., 1 mesh per ring for the experimental dredge and 2: 1 for the control dredges. The depth of the two twine tops were rigged so that the aft end of the twine top was hung just aft of the centre of the sweep chain. New installation techniques intended to minimize scallop catch reduction were also tested. Two vessels were used and their dredges were slightly rigged differently. Vessel 1 dredges ( control and experimental) used 6 ticklers and 9 up and down rock chains and Vessel 2 dredges used 3 ticklers and 5 rock chains and two 24”x8” wheels on the bails. The ring size on all dredges was 3.5 inches.

Modifications were tested in open and closed areas: 1) Vessel 1 carried out comparison of 10 inch twine top versus 6 inch standard top as control (on starboard side) in 3 different areas; 2) Vessel 1 carried out comparison of 10 inch twine top vs. 6 inch standard top as control (on port side) in 3 different areas with 6 extra tows conducted with 6 inch mesh cover covering the lower third of the 10 inch twine top; 3) Vessel 1 carried out a comparison of 10 inch twine top vs. 6 inch standard top as control (on port side) in 3 different open areas with 11 extra tows conducted with 6 inch mesh cover covering the lower third of the 10 inch twine top; and 4) Vessel 2 carried out comparison of 10 inch twine top vs. 6 inch standard top as control (on starboard side) in 4 different areas with 13 extra tows conducted with 6 inch mesh cover covering the lower third of the 10 inch twine top.

Catch data from 162 paired tows (16 tow series) during 4 trips in both open and closed areas on Georges Bank involving two vessels were analyzed using a parametric two-tail paired t-test and a non-parametric match paired Wilcoxon signed rank test on raw data. Catch data was standardized as catch per hectare and represented mean catch in numbers for the fish and mean bushel per hectare for scallops. Similar to Smolowitz et al. 2001 report, several supplementary graphics were given for examination of dredge performance and catches on a tow by tow basis. In addition, the overall percent reductions for median and mean catch rates for each species were calculated along with their associated probabilities for the t-test and Wilcoxon tests. The summarized analysis presented here will focus on the t-test results (in 4/5 incidents, the Wilcoxon test gave a non-significant result when compared to the significant result obtained from the t-test method), and percent reductions in catch rates between the experimental and the control dredges were given with 90% confidence intervals. In Smolowitz et al. 2001, 95% CI were estimated.

Yellowtail, combined flatfish (flatfish), skates (not specified), barndoor skates, monkfish, and scallop catches had sufficient data to carry out the statistical analyses.

**Results** (see Table 6)

A total of 15[9] series of paired tows during the 4 trips were carried out by two vessels with Vessel 1 conducting 3 of the 4 trips. The species specific results from the 12 series of non-

9 Data from Vessel #2, Trip #1 (Series 4.1) is not included because three pairs of tows had identical data included due to a sorting problem between the two dredges.

covered rope back tests will be discussed separately from those 3 series completed with a cover over the lower third of the 10 inch mesh twine top.

Yellowtail flounder: Twelve out of 12 non-cover series showed reductions in catch rates, of which 8 were significant (6 highly and 2 marginally) reductions in the experimental dredge when compared to the control dredge. Percent reductions in the catch rates ranged from 19% to 97% (11/12 series had averages greater than 30%-see Table 6).

With the use of the cover in 3/15 series there was one highly significant 53% reduction and one non-significant 34% reduction in catch rates. There was also a non-significant 19% increase in the catch rates of the experimental trawl.

Overall median and mean reductions in the experimental dredge when compared to the control dredge ranged from 52.5% to 56.5% at associated probabilities of 0.003-0.004 for the median and mean reductions, respectively.

Skates: Eleven out of the 12 non-cover series showed reduction in catch rates, of which 10 were highly significant reductions, in the experimental dredge, when compared to the control dredge. Percent reductions ranged from 15% to 66%. One series showed a non-significant 11% increase in catch rates in the experimental dredge when compared to the control dredge.

All 3/15 of the series cover results showed highly significant reductions (15-47%) in the catch rates in the experimental dredge, when compared to the control dredge.

Overall median and mean reductions in the experimental dredge, when compared to the control dredge, ranged from 47.7% to 38.4% at an associated probabilities of 0.0005-0.0009 for the median and mean reductions, respectively.

Barndoor skates: Sufficient numbers of skates were taken to carry out statistical analysis for 9/15 series: 6 non-cover series and 3 cover series.

Five out of the 6 non-cover series showed significant reduction in catches in the experimental dredge when compared to the control dredge, of which only two were highly significant. *Note*: one of the significant (p=.02) results was non-significant in the Wilcoxon test. Percent reductions in catch rates ranged from 27%-87%. In 1/5 non-cover series there was a non-significant 4% increase in catch rates in the experimental trawl.

In 2/3 cover series there were non-significant reductions (12-27%) in catch rates and 1/3 showed a non-significant (100%) increase in the experimental catches, when compared to the control dredge.

Overall median and mean reductions in the experimental dredge, when compared to the control dredge, ranged from 55.7% to 15.9% at associated probabilities of 0.025-0.043 for the median and mean reductions, respectively.

Flatfish: Twelve out of the 12 non-cover series showed reduction in catch rates, of which 11 were significant (5 had p values ranging from .01 to 0.4), in the experimental dredge when compared to the control dredge. Percent reductions in catch rates ranged from 16% to 66% (8/11 series had percent reductions greater than 30% - Table 6).

For the cover series results, all three showed reduction in the catch rates, of which 2 were significant, in the experimental dredge when compared to the control dredge. One of these was marginally significant (p=.05) and non-significant (p=.06) in the Wilcoxon test. Percent reduction in catch rates ranged from 4-34%.

Overall median and mean reductions in the experimental dredge, when compared to the control dredge, ranged from 39.1% to 44.8% at associated probabilities of 0.01-0.002 for the median and mean reductions, respectively.

<u>Monkfish:</u> Eight out of the 12 non-cover series showed reductions in catch rates, of which 6 were significant (3/6 were highly significant), in the experimental dredge, when compared to the control dredge. Percent reductions in catch rates ranged from 0.4% to 35%. *Note:* One of six significant (p=.03) series would have been non-significant (p=.06) in the Wilcoxon test. Four series showed non-significant increases, ranging from 4-66%, in the catch rates in the experimental dredge when compared to the control dredge.

For the cover series results, 2/3 showed non-significant increases; ranging from 2-13%, in the catch rates, and one showed a non-significant 8% reduction in the catch rates in the experimental dredge, when compared to the control dredge.

Overall median and mean reductions in the experimental dredge, when compared to the control dredge, ranged from 11.4% to 8.5% at associated probabilities of 0.033-0.049 for the median and mean reductions, respectively.

<u>Scallops:</u> Eight out of the 12 non-cover series showed reductions, of which three were significant (one was highly significant), in the experimental dredge, when compared to the control dredge. Percent reductions in the catch rates ranged from 2-33%.

Three out of the 12 non-cover series showed increase in catch rates, of which two were moderate to marginally significant (p ranged from .02 to .04), in the experimental dredge, when compared to the control dredge. Percent increase in the catch rates ranged from 1-18%.

All three cover series showed a reduction in catch rates, but only one was significant (p=.01). Percent reductions in catch rates ranged from 2 to 15%.

Overall median and mean reductions in the experimental dredge when compared to the control dredge, ranged from 6.0% to 6.7% at associated probabilities of 0.128-0.05 for the median and mean reductions, respectively.

**Comments**

<u>Barndoor skates:</u> In many incidences, the catches were small and the variability around the mean catch was often high with wide confidence limits. So caution is warrant in interpreting these results. The overall 16% percent reduction in mean catch rates of the combined data is only marginally significant.

<u>Monkfish:</u> In many incidences, the catch rates of monkfish were highly variable showing wide confidence limits. So caution is warrant in interpreting these results. The overall 9% percent reduction in mean catch rates of the combined data is only marginally significant.

Scallops: Loss of scallops was evident in 8/15 series ranging from 1 to 33%, while 3/15 series showed an increase in catch rates with a 10 inch twine top. This probably reflects the differences in fishing conditions, difference in dredge riggings between the two vessels and general escapement of scallops through the larger mesh. The overall percent reduction in mean catch rates of the combined trip data would indicate a non-significant 7% reduction.

General: The results indicate that a 10 inch diamond mesh twine top hung on a 1 to 1 ratio was significantly effective in reducing the overall catch rates of yellowtail by 53%, skates by 38%, and other flatfishes by 45%. Marginally significant reduction in barndoor catch rates was estimated at 16%. Non-significant reductions in monkfish (9%) and scallops (7%) were estimated. Lower estimates of reductions in barndoor skates and monkfish may have been influence by low population numbers, in particular, barndoor skates (median reduction was estimated as 56% at a probability of 0.03). This report is the first and only example of analyzing combined trip data. It derives the probabilities associated with the overall means (or medians) in testing the null hypothesis that mean percent reductions in catch rates equal zero.

The cover seems to have little effect on the overall results, indicating that most of the escapement occurs in the upper two thirds of the twine top.

The authors argue that previous trials testing the standard 6 inch twine tops against 10 inch tops produced notable reductions in bycatch of finfish along with large reductions in scallops (up to 51%) as reported in Smolowitz 2002 (unpublished[10]). The authors concluded the overall small reduction in scallop catches estimated here was due to the installation techniques for mounting the twine top panel.

## 4.7 Smolowitz, R., and M. Weeks. 2006. Turtle-scallop Dredge Interaction Study. Final Report. NMFS, NE Region Office, Gloucester, MA.

*Note:* This report includes some bycatch data on finfish caught in a modified New Bedford style dredge developed to exclude loggerhead turtles, but its focus was on turtle bycatch. Average catch rates, average percent reductions and one tailed paired t-test were calculated from the raw data given. The reader is asked to treat these data and interpretations with caution. For the moment, they are meant to be illustrative of another type of change to the frame of the dredge, which resulted in bycatch reduction.

### Methodology

Modified frame dredge experiments were carried out during two trips from 20 August to 14 September 2005 using one commercial vessel fishing two 13 foot wide dredges off New Jersey. Average tow durations ranged from 36-44 minutes. Average tow speed was 4.5 knots.

The experimental dredge was a significant departure from existing designs in that the cutting bar was moved forward of the pressure plate, so that instead of confronting a vertical structure, fish, scallops and turtles can encounter a sloping structure. The design extends the struts, at 12 inch spacing, between the pressure plate and the forward positioned cutting bar (see Figure 4). The modified dredge had 4 of the 6 bail support bars removed. A double wheel system was used on the bail.

A standard New Bedford style commercial dredge was used as a control and both dredges had

[10] Report was not complete at the time of publication.

the regulated 10 inch diamond mesh twine top panels and 4 inch ring bags.

Catch data from 48 paired tows during 2 trips involving the same vessels were analyzed using a one-tail paired t-test on raw data. Catch rate data were not standardized to tow duration or distance traveled and represents mean catch in numbers per tow for the fish and mean bushel per tow for scallops. The summarized analysis presented here will focus on the t-test results, and average percent reductions in the experimental dredge. No confidence intervals were calculated.

Although several species of flatfish were caught and catch data collected for windowpane, fourspot, blackback, and yellowtail flounders were given, they were all combined into one category because of low numbers, (called flatfish) to have sufficient data for this preliminary analysis. Skates (not specified), monkfish and scallop catches also had sufficient data to carry out the statistical analyses.

**Results** (see Table 7)

Trip #1 (34 tows) showed marginally significant 11% reduction in skate catch rates (p=.04), and highly significant 39% reductions in monkfish catch rates. Non-significant 7% reduction in flatfish and 3% reduction in scallop catch rates were estimated in the experimental dredge when compared to the control dredge.

Trip #2 (14 tows) showed a significant 33% increase in skates, 88% increase in monkfish and 24% increase in scallop catch rates in the experimental dredge. There was a non-significant 2% reduction in other flatfish catch rates. The authors explained the increases were due to the forward cutting bar of the experimental dredge being higher off the bottom than in Trip #1. No explanation was given as to why this had occurred. Was it a rigging difference or a difference in substrate? Cameras were used on both experimental dredges and this may have been where the conclusion came from.

**Comments**

Little information is given about the standard (control) dredge except to say both bags were identical. The vessel used in these experiments was vessel 2 in the Smolowitz et al. (2004) study. In that study, the vessel used two 24”x8” wheels on the bails of the control dredge. It is unclear whether this is the case for this study although there are two similar wheels on the bails of the experimental dredge. This could affect results especially the difference between trips 1 and 2. If the increases in catch rates in Trip #2 were due to the forward cutting bar of the experimental dredge being higher off the bottom than in Trip 1 as a result of substrate differences, then this would illustrate that substrate can plays a key role in catchability.

## 4.8 Smolowitz, R., W. DuPaul, and R. Enoksen. 2006. Turtle-excluder Dredge for the Sea Scallop Fishery. Performance Report Two. NMFS, NE Region Office, Gloucester, MA.

*Note:* This report includes some bycatch data on finfish caught in a modified New Bedford style dredge developed to exclude loggerhead turtles, but its focus was on turtle bycatch. Average catch rates, average percent reductions and one tailed paired t-test were calculated from the raw data given. This is a preliminary report, and the reader is asked to treat these data and interpretations with caution. For the moment, they are meant to be illustrative of another type of change to the frame of the dredge which resulted in bycatch reduction.

**Methodology**

Modified frame dredge experiment was carried out during one trip in August 2006 using one commercial vessel fishing two 13 foot wide dredges off Panama City. Average tow durations and average tow speeds were not stated.

The experimental 15 foot wide dredge described in Smolowitz et al. (2006) was further modified. Steel angle iron was added to the cutting bar to eliminate the flat forward facing surface. Also added was round bar to the struts to come down and wrap around the bottom of the cutting bar. All but the center bail bars have been removed to facilitate escapement of any turtle or large fish entrapped under the bail during a tow (see Figure 4). The turtle excluder device was deigned to act as a wedge and eject turtles over the top of the dredge.

A standard commercial dredge was used as a control and both had 10 inch diamond mesh twine tops panels.

For this analysis, the combined catch data from 48 paired tows were analyzed using a one tail paired t-test. Catch rate data were not standardized to tow duration or distance traveled and represents mean catch in numbers per tow for the fish and mean bushel per tow for scallops. The summarized analysis presented here will focus on the t-test results, and percent reductions in catch rates in the experimental dredge. No confidence intervals were calculated.

Although several species of flatfish were caught and catch data collected for windowpane, fourspot, blackback, and yellowtail flounders, they have been combined into one category (called flatfish) to have sufficient data for this preliminary analysis. Skates (not specified), monkfish and scallop catches also had sufficient data to carry out the statistical analyses. Catches of barndoor skates were low in numbers for statistical analysis.

**Results** (see Table 7)

There was a significant 37% reduction in catch rates of skates, a significant 51% reduction in other flatfish and a non-significant 14% reduction in monkfish catch rates in the experimental dredge, when compared to the control dredge. There was a non-significant 3% reduction in scallop catch rates in the experimental dredge, when compared to the control dredge. Catches of barndoor skates were too low in numbers for statistical analysis, but average catches showed a 13% reduction in the experimental dredge, when compared to the control dredge.

**Comments**

These are preliminary data from the authors, and the statistical analysis has been conducted for this review should also be considered preliminary and illustrative. Smolowitz indicated that he was so impressed by the finfish bycatch reduction in the turtle excluder dredge that he was awaiting new funding to optimize this design for a new and improve scallop dredge (*pers. comm.*).

### 4.9 Goudey, C., M. Pol, O. Free, L. Williams, and P. Tasha. 2006. Sea Scallop Harvest using Flow Control. 2006 ICES Symposium on Fishing Technology in the 21st Century: Integrating Fishing and Ecosystem Conservation.

This is a novel approach to harvesting scallops without the leveling action of the cutting bar thereby, reducing habitat impacts associated with current scallop dredging methods. The idea is to lift scallops from the seabed to facilitate capture by use of jets of water deflected from suitably shaped lifting surfaces. After considerable testing at MIT's towing tank, a 7 foot 'Hydrodredge' prototype (see Figure 5) was built and tested in 2006.

**Methodology**

The following excerpt from an interview with Cliff Goudey was taken off the Massachusetts Institute of Technology website and is printed here (MIT News 2007: with permission from C. Goudey). "The dredge was fitted with four 11 inch hollow hemispheres positioned close to the seabed and mounted on pivots so that if it hit something on the bottom they could deflect out of the way. The hemispheres produce a downward directed jet of water that seems to have a profound effect on scallops when they hit it. Goudey notes "that most mobile creatures near the dredge can escape its path. Essentially the scallops start spinning up in the water high enough so they are suspended in the water when the chain bag comes by." One day fishing trials revealed the dredge is easy to deploy and tow, and caught 30-50% of a nominal conventional dredge catch. It included the regulated 10 inch twine top.

**Results**

In April 2007, preliminary trials of the hydrodredge were carried out in the Isle of Man (Sheppard et al. 2007). Trials included comparison with Newhaven spring toothed dredges (see description under International Bycatch Initiatives below), and showed promising success for queen scallop (*Aequipecten opercularis*) which sits on the seabed, like sea scallops, in eastern North American waters, but less success for the burying king scallop, *Pecten maximus.* The hydrodredge performed better on smooth grounds then on rough bottoms. The focus of this testing was on maintaining catch rates of scallops and reducing habitat impact. Very little finfish bycatch was evident.

**Comments**

Further engineering developments are expected to continue in 2008, which will see the final version scaled up to commercial size for an offshore scallop vessel. In the new trials, scallop catch rates and bycatch rates will determined. If successful, this novel dredge has the possibility of reducing finfish bycatch and bottom impact, while maintaining catch rates of the target species.

# 5. International Bycatch Reduction Initiatives

## 5.1 European

In 2000, a large scale EU-Brussels funded project called ECODREDGE was started. The project involved researchers from UK, Ireland, France, Italy and Portugal. This project aimed to study the interactions between shellfish dredges, affected species and the marine environment.

The work was oriented towards the goals of improving selectivity, understanding and reducing incidental mortality and undesirable environmental effects.

The project investigated both laboratory and field studies in scallop and clam dredge fisheries in European waters; scallop species (UK, France) *Pecten maximus*, *Aequipecten opercularis;* clam species (Italy; N. Adriatic) *Chamelea gallina;* and clam species (Portugal) *Spisula solida*, *Donax trunculus, Callista chione*. Selectivity measures and dredge design were examined for their consequences in terms of environmental effects. Studies included physical, chemical, and biological effects both at individual and community level, and selectivity of dredging.

For scallops, two main dredge designs in common use were investigated: 1) spring toothed dredges for king scallops, *Pecten maximus*, and queen scallops, *Aequipecten opercularis*, commonly used in UK, Isle of Man, Ireland, and France; and 2) fixed toothed dredges using dive plates, commonly called French dredges, and used for king scallops in France and UK and queen scallops in France.

The following dredge descriptions were taken almost verbatim from the ECODREDGE report with permission from senior author, Bill Lart, CEFAS:

<u>Spring tooth bar 'Newhaven' Scallop dredge:</u> The dredge used commonly in UK, Isle of Man, Ireland and France to catch king scallop (*Pecten maximus*). The dredge, typically 0.8 m by 1.4 m (2.6 x 4.6 feet) and 350 kg (772 lbs) employs a sprung-toothed digging blade (approx. 0.7 m [2.3 feet] wide) and collecting bag made from steel rings (74-85 mm [2.9-3.4 inches] internal diameter) and, usually, mesh netting. Features considered most likely to influence selectivity are the teeth and ring configuration.

<u>Fixed tooth bar 'Queenie' dredge:</u> The dredge used mainly to catch 'black and white' queen scallops, *Chlamys varia* and *Aequipecten opercularis*, in France. The dredge, which measures 1.8 m by 3.2 m (5.9 x 10.5 feet) and weighs 120 kg (365 lbs), employs a fixed digging blade (max 0.66 m [2.2 feet] wide) and collecting bag made from steel rings (42 mm [1.7 inches] diameter) and mesh netting. Features considered most likely to influence selectivity are the blade and ring configuration. Small vessels work up to 6 dredges, whereas large vessels can operate up to 24 dredges.

In the England and Wales king and queen scallop fisheries, the main bycatch is sole (*Solea solea),* angler fish (*Lophius sp*), and plaice (*Pleuronectes platessa).* In Scotland, the bycatch in the king scallop fishery is crabs *(Cancer pagarus)* and angler (monk) fish *(Lophius spp*.), and in the queen scallop fishery, it is a small proportion of commercial flatfish species (e.g. *Solea).* In France, the bycatch in king scallops fishery is flatfish in Bay of Seine (plaice, sole, brill), while the bycatch in the Queen scallops (*Chlamys varia* and *Aequipecten opercularis*) is sea urchins.

Investigations into alternates to teeth on scallop dredges were made, which included 3 designs to lift king scallops off the seabed (only a water-jet/hydraulic dredge showed any promise), and the replacement of the tooth bar with a tickler chain and mounting the dredge on a pair of ski-like skids. These innovations focused on maintaining capture efficiency for the target species, and, in some cases, minimizing bycatch of the other scallops, while minimizing the environmental effects. None of these investigations talked about fish bycatch.

### Comments

Several researchers in the EU area were contacted to see if fish bycatch was a problem. The ECODREDGE project leader, William Lart at Seafish Industry Authority in Hull, England, indicated that fish bycatch is generally not a problem in toothed dredge fisheries in UK waters in spring; however, in fixed toothed dredges using diving plates (French dredges), it has been a problem with boats effectively fishing for Dover sole in inshore waters, where they are not allowed to trawl. Dave Palmer at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in Lowestoff, England, clarified that it was not that the dredge itself was the problem, but the modification employed by some fishers which consisted of lacing twine through the steel rings of the bags to retain more sole. The French dredges have been banned in UK waters since 1999 as a result, much to the upset of those who were legitimately targeting scallops with them. Palmer also confirmed that fish bycatch is not a concern and is limited mainly to the English Channel scallop fishery area.

## 5.2 USA West Coast

The weathervane scallop, *Patinopecten caurinus*, fishery occurs in the Gulf of Alaska, Bering Sea and Aleutian Islands, in depths of 37-229 m on sand, silt and clay substrates (Woodby et al. 2005). The gear regulations limit vessels to using no more than 2 x 15 feet (4.5 m) dredges, except in Cook Inlet, where vessels are limited to using a single 6 foot (1.8 m) scallop dredge. The offshore fishery uses one or two New Bedford style dredge. Ring size is regulated at 4 inches (102 mm), and chafing gear to protect the bottom of the bag is prohibited. There is no regulation for mesh size in twine tops (J. Barnhart, Alaska Dept. of Fish and Game; personal communication).

Observers collect data on crab and halibut bycatch. Crab bycatch limits are imposed to protect stocks of king, Tanner and snow crabs. All halibut are to be returned unharmed to the sea. Bycatches of other fishes are not estimated by the managers. Estimated bycatch of halibut totaled 1,165 in 1999/2000 fishery, 631 in 2000/2001 fishery and 663 in 2001/2002 fishery (Barnhart and Rosenkranz 2003). Fish bycatch species in sampled dredges for the 1999-2002 seasons include 11 species of flatfish, lingcod, pacific cod, pollock, dogfish and skates, of which catches of skates were the highest. Harrington et al. (2005) using data from the Barnhart and Rosenkranz 2003 report on observer collected data, estimated discards up to 21 mt for yellowfin sole, 35 mt for big skate, and 20 mt for longnose skate, among the many bycatch species during the 1999-2002 weathervane scallop fishery.

### Comments

The estimated 2000 fishery data were used from the tables in the Harrington et al. (2005) paper for Georges Bank and Alaska fisheries for scallops to calculate bycatch ratios. It is assumed that the Georges Bank fishery used a mixture of 8 inch and 10 inch in closed areas and that Alaska used 6 inch twine tops, and that both used the then regulated ring size of 3.5 inches. In the US sea scallop fishery on Georges Bank, the bycatch ratio was 0.07 tons of finfish bycatch for every ton of scallops landed. In the weathervane scallop fishery off Alaska, the bycatch ratio was 0.17 tons of finfish bycatch for every ton of scallops landed. Some of this difference may be accounted for by differences in twine top mesh sizes and ring size. Bycatch of fish is not considered a problem in the Alaska weathervane scallop fishery and, as a result, no modifications have been made (or investigated) to the gear by researchers (J. Barnhart, Alaska Dept. of Fish and Game; personal communication).

### 5.3 Argentina

The Patagonian scallop, *Zygochlamys patagonica*, fishery off Argentina, is prosecuted solely by otter trawls with a scallop legal size limit of 55 mm in shell height. Two trawl nets are operated on each side of the vessel. The mesh size of the body is 100 mm, while that of the codend is 10 mm. Benthic bycatch (not specified) and catches of small scallops appears to be the only bycatch problem, and it is recommended that the use of square mesh codends be investigated to reduce this bycatch (Pottinger et al. 2007).

### 5.4 Australia

In southern Australia, the fishery for Tasmanian scallop, *Pecten fumatus*, occurs in New Sound Wales, Victoria and Tasmania (Bass Strait Central Zone). Tasmanian scallops are found in Australia's southern waters from mid New South Wales down and around to mid Western Australia, at depths of at least 120 m over bare, soft sand or mud substrates. They are generally caught using a rigid mesh box-shaped mud dredge on skids. The dredge has a forward mounted plate, stabilizing fins and teeth or a cutting bar that penetrates the substrate. It is typically 1.7 m long, 3.3 m wide and 0.38 m wide (5.6 x 10.9 x 1.3 feet) (Lart 2003). The level of bycatch is low in the higher scallop density areas consisting mainly of mollusks and other bivalves, and very small quantities of fish are taken (Semmens et al. 2000). Bycatch of fish is not considered a problem and, as a result, no modifications have been made to the gear by researchers (J. Semmens, University of Tasmania; personal communication).

In the northern area of Australia the fishery for Queensland scallops (also called saucer scallop) *Amusium japonicum balloti*, is carried out using otter trawls. Both turtle excluder devices (TEDs) and square mesh codends are used together in the scallop trawls to reduce bycatch of other benthic invertebrates (crabs, cuttlefish, sea urchins, etc.), sharks and turtles, and small scallops (Courtney and Campbell 2007; OceanWatch Australia 2007).

## 6. Summary of Research Efforts

### 6.1 Canadian, American and International Research Efforts to Reduce Bycatch of Finfish

The two Canadian reports used different approaches to address the bycatch issue: 1) the Kenchington (2000) report summarized many industry “R&D” modifications to the towing frame to minimize finfish entering the rake, and once in front of the sweep chain changes in the rope back panel to encourage finfish to escape up through the meshes; and 2) the McIntyre et al. (2006) report exploited different techniques to stop finfish from entering the rake, including attempts to manipulate fish behaviour by scaring them away from the dredge with the use of light and sound. In terms of standing up to scientific rigor, the industry initiatives lack some structure in experimental design and data collection. While fishers will be the first to admit they are not scientists, many are continuously trying the improve the efficiency of their rakes by tweaking this or that component using the common scientific method of ‘trial and error’. Kenchington noted that there was a lot of data collected but not analyzed, which could have yielded more insight into the performance of the various modifications tested.

The American reports mainly chronicle the work begun in 1994 by Ron Somolowitz, a commercial fishing gear engineer who has worked with industry, MIT Sea Grant and Virginia

Institute of Marine Science on testing modifications to the standard New Bedford style dredge to reduce finfish bycatch. Until 2004, the yellowtail bycatch issue was the initial focus (they do not encounter much cod or haddock in their scallop fisheries on Georges Bank), and later the protection of endangered species such as barndoor skates. The Henriksen et al. (1997) and Smolowitz et al. (2001) reports described the results of the modifications to the towing frame to herd or frighten finfish away from the cutting bar area, and changes made to the twine top panels. During the early 2000s, Bill DuPaul and colleagues at Virginia Institute of Marine Science (VIMS) began examining the effect of increasing ring size in the bag from 3.5 inches to 4 inches. Their research showed that there was a reduction in the bycatch of small flatfish that can wriggle out through larger ring size of the bag. No catches of roundfish were reported, and it is possible that escapement through the rings may also be size dependent. Although some small scallops are escaping through the larger 4 inch rings, it appears the 4 inch ring dredge is more efficient for larger scallops. The new minimum ring size is intended to improve yield from the scallop resource by promoting harvest of larger scallops with higher meat weights. Based on a decade of research, many regulated changes in key components of the dredge used in the USA east coast scallop fisheries have been implemented. Dave Rudders of VIMS (personal communication) provided a chronology of changes: In 1994, New England Fisheries Management Council (NEFMC) set a minimum mesh size of 5.5 inches on twine tops. The following year, NEFMC noticed that scallop fishers were attaching the twine top to run the entire length of the dredge so it stretched closed during use and presumably prevented escapement. As a result in 1995, NEFMC specified the minimum number of rows of rings between the twine top and the club stick to stop the practice. In 1999, when Framework Adjustment 11 granted limited access to Closed Area II on Georges Bank, twine top mesh size was set at 10 inches in the Exemption Area and 8 inches outside it. As additional access areas were created, similar dual mesh size requirements were established. It was not until 2004, that Amendment 10 increased twine top mesh size to 10 inches in all areas (NOAA 2004). At that time the regulated ring size in the bags was increased from 3.5 inches to 4 inches, inside diameter.

After 2004, the research focus shifted to developing a turtle excluder scallop dredge to minimize encounters with loggerhead turtles, *Caretta caretta*, mostly found in the mid-Atlantic scallop fishery areas. Good success with reduction in finfish bycatch and a low reduction in scallop catches with this redesigned sloping front frame (cutting bar is ahead of pressure plate) will lead to improvements being made to the standard New Bedford dredge (Ron Smolowitz, Coonamessett Farm, USA, personal communication).

One notable modification, for which no data on finfish were available, was Goudey et al.'s (2006) hydrodredge. Although the focus in this development was primarily on reducing bottom impacts by scallop dredges, it may show promise in reducing finfish bycatch. It may take similar 'thinking outside of the box' innovations to bring finfish bycatches close to zero, with minimal loss of scallops. In addition, the turtle excluder scallop dredge design, with its cutting bar ahead of the pressure plate also appears to reduce finfish bycatch even further than the standard 10 inch twine top dredge, while minimizing the loss of scallops.

On the international scene, finfish are caught in various amounts in most dredges used in scallop fisheries; however, it is not recognized as a problem elsewhere. There has been no recent related research focusing on finfish bycatch reduction in scallop dredges. In EU countries, there is a large amount of effort being directed towards studying habitat impact of dredges. In two areas where bottom trawls are used, bycatch has been identified as a problem and investigations are ongoing using square mesh codends to minimize the problem.

## 6.2 Scallop and Fish Capture Process in a Scallop Dredge

There seems to be little published information about the reaction behaviour of scallops and finfish to a scallop dredge. Catching efficiency and selectivity are real-world manifestations of finfish and shellfish behaviour, and a better understanding of this behaviour is fundamental to designing selective fishing gears and fishing practices (Walsh and Bjordal 2004). From the available information, some descriptions of the behaviour reactions of scallops and finfish to scallop dredges have been assembled. Pol and Carr (2002) described the scallop swimming behaviour in reaction to disturbance by a towed rake. The capture process is thought to be initiated when scallops swim up vertically in reaction to, or are lifted vertically by, the hydrodynamic effect of the cutting bar. The cutting bar of the rake usually rides at or just above the sea floor depending on substrate and scallops can pass under the bar, collide with the bar and tumble over or swim over it (Smolowitz and Weeks 2006). Some of the scallops entrained in the water turbulence may passed out through the open meshes of the twine top. The sweep chain, which forms the leading edge of the ring bag, passes beneath the scallops when they rise and the scallops fall into the bag and are captured. Tickler and rock chains mounted ahead of the sweep chain or in front of the cutting bar, may also cause some vertical swimming reaction. Scallops smaller than the inside diameter of the rings that comprise the bag may pass through them.

Small scallops less than 100 mm can easily swim up from the bottom when disturbed but scallops greater than 100 mm have a reduced swimming capability (Caddy 1968) and movement in both size groups is primarily an escape response (Posgay 1981). The ability to swim vertically as an escape response to scallop dredges is evident in queen scallops, *Aequipecten opercularis,* < 68 mm shell height, in UK waters. These scallops have been found caught in a top net (see Figure 6) sitting over toothed scallop dredge indicating they were swimming in advance of the arrival of the gear and avoid capture, especially during the period June to mid-autumn. At that time of the year scallop fishers in the Irish Sea switch to trawls to catch them (Lart 2003). Pol and Carr (2002) also reported that bay scallops, *Argopecten irradians*, swam up vertically in response to the passing of an outboard engine in shallow water. Using video cameras mounted on the bail of a scallop dredge, Smolowitz and Weeks (2006) noted that many scallops ahead of the dredge were seen swimming upward or forward in response to disturbance (maybe to the nose wheel), and some scallops were swimming for a few minutes. Scallops were also seen swimming over the dredge’s pressure plate.

Smolowitz and Weeks (2006) used video cameras on their turtle excluder scallop dredge and gave the following observations about fish. Skate often sit on bottom till the last minute before reacting to the cutting bar. Either the cutting bar will pass over them or they turn and swim under the bar and into the bag. Sometimes they were caught (stuck) to the cutting bar for several minutes of the tow before passing under the bar or over the pressure plate. Large skate can out swim the approaching dredge, or swim up or laterally away from the tow path.

Observations using video and still cameras of reaction of skate to the footgear of bottom trawls have shown almost identical behaviours (see for example, Walsh and Hickey 1993). These observations also showed flounders sitting on the bottom for long periods of time, often partially buried, and like skate exhibit similar reactive behaviours to the footgear (Main and Sangster 1981; Walsh and Hickey 1993). It is expected that flounders will react the same way to the scallop dredge. Although the behaviour reactions of cod and haddock to bottom trawls (see for example: Main and Sangster 1981; Walsh and Hickey 1993; Godø 1994) are well known, no observations of reactions have been reported for scallop dredge. Small cod and haddock will pass underneath the ground gear of a bottom trawl, while older cod swim into the trawl close to the lower bellies and older haddock often rise off the bottom to pass into the trawl generally above mid-height. Large cod and haddock can avoid capture by swimming out of the tow path or in the case of haddock over the top of the trawl. Similar reactive behaviours to scallop dredges may happen. Small and medium-sized cod, haddock and other roundfish are likely to pass underneath the cutting bar or swim through the space between the pressure plate and cutting bar or over the top of the dredge. No descriptions of how finfish, once pass the cutting bar, escape before and after entering the dredge bag are known to have been reported. The speed of the tow and bottom substrate in many cases will have an influence on behaviour reactions of fish to towed gears and their reactions are often size and density dependent (Walsh and Godø 2003).

## 6.3 Experimental Design, Data Collection and Statistical Analysis

It was clear that the experimental setup, data collection and statistical analysis varied among the reports examined. Field trials dedicated to investigate modifications to the dredge to reduce finfish bycatch and minimize scallop loss need to be conducted with scientific rigor and attention to detail. What was missing from the many reports was the use of individual fish and scallop behaviour, rake hydrodynamics and fishing practices necessary to design and operate selective scallop rakes. The McIntyre et al. 2006 report showed a promising first step in using fish behaviour. Instrumentation, including acoustic, still and video cameras and ROV technologies should be investigated and the data collected and analyzed quantitatively. The first step towards changing the efficiency of the dredge is to measure the hydrodynamics of the dredge with field and/or flume tank studies. The ECODREDGE report should provide guidelines (Lart 2003). Also there is simulation software created by IFREMER in France that may be adapted to model the effect of changes in dredge design and flow dynamics.

Differences in fishing powers of the dredges need to be investigated. During the experiments rakes should be switched from one side to the other on a random basis to minimize any bias in fishing power attributed to one dredge always being on the same side of the vessel, or to fishing practices such as turning only to one side during the tow. This can be investigated in a separate experiment (see McIntyre et al. 2006), or one can assume that it occurs and adopt a randomized switching routine into the experiment. Information on turning the vessel around during the tow should be noted separately from those that do not and its effect on catchability should be determined in a separate experiment. In conducting field trials, it is important not to test more than one modification to the dredge or fishing practice simultaneously. Plan separate experiments for each modification.

Low bycatches of key species will necessitate many paired tows to derive meaningful statistical results, so that the difference in catch rates are reflective of the real world and not the result of chance. Length frequency of both scallops and bycatch species must be collected and analyzed to interpret changes in selectivity with changes in modifications. Many of the reports concluded that their results may be different if the densities of finfish and bycatches were higher, and experimental designs should account for density effects. The effect of high densities of skates on escapement of other finfish should be investigated along with the effect bag fullness has on dredge efficiency. Changes in tow duration and towing speeds need also to be investigated. Mesh opening and shape selection of the rope back/twine top such as diamond versus T45 square mesh of the same mesh size should also be investigated. Mesh bags could be designed to mount over the rope back to collect all escaping species for a true measure of selectivity (see Figure 6 for an example). Attention should be also paid to investigating rope back/twine top panel dimensions, including twine and rope sizes, location in relation to sweep chain and pressure plate and hanging ratios. A multiplicative model of the effects of many of these variables on scallop catch rates and also on bycatch reduction should be developed. Other variables for which data could be collected include wind speed, sea state, substrate type, water depth and temperature. The ICES Manual of Methods of Measuring the Selectivity of Towed Fishing Gears offers excellent guidance in experimental design and types of data to collect (Wileman et al. 1996).

Non-parametric match paired Wilcoxon signed ranked test should be used as the appropriate statistical model. Confidence intervals are needed for difference in median catch rates. A method of outlier detection is necessary for examining catch data. Graphical representation of data can help one understand between tow variability (see Smolowitz et al. 2004 for examples). Another effective measure of the change in efficiency of the experimental dredge relative to standard dredge, would be estimate the ratio of the experimental catch /experimental + control catch which can be applied to both total catches and catches at length, i.e., selectivity (Millar and Walsh 1992; Wileman et al. 1996). Should a standardized dredge or dredges be agreed upon then a scallop size selectivity curve should be experimentally derived for use by stock assessment biologists to calculate biological parameters such as yield per recruit, reproductive output and mortality, along with extrapolation of age/size catch information from the fishery (see Yochum (2006) for an example).

## 6.4 Influence of Tow Duration, Skate Densities and Bag Fullness on Efficiency of Scallop Dredges

It is well known in studies of codend mesh selection that tow duration and catch size are some of the factors that can affect selectivity, and hence, catchability, of fish in bottom and beam trawls (Wileman et al. 1996). What generally has not been well publicized is the masking effect of some species in codends of bottom trawls. Skate, for example, when abundant in a bottom trawl, can block meshes in the codend and hence, influence escapement of other species (Enrique de Cárdenas, Instituto Español de Oceanografía, Santander, personal communication). Exploratory analyses was carried out here to gain some insight into the effects of these variables on catchability of a scallop dredge.

The extensive Smolowitz et al. (2004)'s standardized mean catch per hectare data were examined for scallops, skate, yellowtail flounder, flatfish and monkfish by trip from the tables given in report. The intent was to look at whether 1) tow duration had an effect on catch rates of individual species, 2) increasing catches of skate had an effect on catch rates of other finfish, and 3) increasing catch rates of scallops had an effect on catch rates of finfish, i.e., fullness of the bag.

Average tow duration in minutes were given for each of the 4 trips and 15 series, and varied widely from 7 to 64 minutes The objective of the original experiments was to compare the catching efficiency of a 10 inch diamond mesh twine top experimental dredge against the control 6 inch diamond mesh twine top dredge. An unweighted least squares linear regression model was used to examine trends in the data.

### Results

Figure 8 shows the catch rates of scallops and individual finfish species. There were highly significant downward trends in the catch rates of scallops, flatfishes, and skate with increasing tow duration ($p<.01$, $df=14$). Model fits, $r^2$, ranged from .38 to .54. There was no linear relationship seen in yellowtail and monkfish catch rates with tow time. The results of all analyses were similar for both the experimental and control dredges. Fifas et al. (2004) also found a reduction in scallop catches with increased tow duration in scallop dredges in UK waters due to overfilling of the bag.

Figure 9 shows the relationship between skate catch rates and those of yellowtail, flatfish, and monkfish. There was a highly significant linear relationship between the catch rates of skate and flatfish in the control (p=.0000; $r^2$=.88, df=14) and experimental dredge (p=.0000; $r^2$=.94, df=14). No such relationship existed for yellowtail and monkfish, which may be due to low catches of both species. One interpretation of this linear trend could be that skate were blocking the twine top meshes and reducing escapement of flatfish, as observed in bottom trawl codends. The dynamics of what influences escapement of fish up through the rope back meshes or out through the meshes of a codend may not be the same. Another explanation is that there may be a strong spatial correlation in the abundance of both species. Skate catches were by far the dominant finfish catch, with total trip catches (in numbers) in the control dredge ranging from 315 to 4024 and in the experimental dredge ranging from 188 to 2789.

Figure 10 shows the relationship between scallops catch rates and those of skate, yellowtail, flatfish, and monkfish. In both dredges, there were highly significant increasing trends in the catch rates of skates and flatfish, but not in the catch rates of yellowtail or monkfish, with increasing catch rates of scallops indicating that as the catch rates of scallops increased there was no drop off in the catch rates of finfish bycatch. The relationship for skate and flatfish were highly significant (p=.0000, df=14) and model fits ($r^2$ ranged from 0.81 to 0.88) were very high. The lack of a drop off in catch rates probably would have been more evident if total catches were used instead of average catches because the latter would not be indicative of bag fullness. Again these relationships could also mean a strong spatial correlation in the occurrence of these finfish with scallops. To determine which variables were most influential on scallop catchability all of these variables should be entered into a multivariate analysis.

### Conclusion

The investigation of this data is meant to be illustrative, and no estimate of uncertainty is given due to the varied nature and unknown quality of the data. Results could differ if catch and tow duration data were available on a tow by tow basis and not aggregated by trip, as was done in the Smolowitz et al. (2004) report and presented here. Large catches of skate dominated the finfish catches in the McIntyre et al. (2006) report and dominated most of the USA experiments cited. The poor swimming ability of skate may affect reductions in catches of other finfish, especially when they occur in high densities. Given that the simple aim of the regression analysis was to look for directional trends, the results suggest that the effect of variables such as tow duration, scallop catches (fullness) and skate catches should be considered in any investigation into catchability (capture or escapement) of finfish.

## 7. Synthesis of Mesh Size in Rope Back/Twine Top Experiments

There were some promising modifications to the frame of the rakes and dredges that resulted in reductions to finfish bycatch. Lengths of chain hanging from the bridle bars showed promise in reducing catch of cod and haddock, and had no effect on scallop catch rates. However, the addition of a tickler chain just behind the cutting bar seemed to have little effect on reducing cod, haddock and flatfish catches. The most promising modification was the use of a cookie sweep mounted just in front of the cutting bar. It appears effective at reducing catches of yellowtail, skates and other flatfish, while increasing the catches of scallops. The latter may be a good example of scaring fish out of the way before they enter the bag path. Although it may more suitable to smoother bottom, further use should be investigated.

Modifications to the rope back/twine top panel were the most numerous modification investigated. Large escape windows in the rope back often led to a reduction in bycatch of cod, haddock, flatfish, and scallops depending on their location and size. The most promising modification to reduce bycatch was to increase the mesh size of the rope back/twine top panel. In sections of Kenchington (2000) and Henriksen et al. (1997) reports, and all of DuPaul et al. (1999) report, an alternate mesh shape was investigated, in which the diamond mesh was hung square, i.e., the netting was rotated 45 degrees and was denoted here as T45 mesh to distinguish it from a square mesh panel. Figure 7 shows an example of the two orientations.

Since many of the experiments listed in the reports compared modified mesh size/shape against a standard mesh size in use at the time, a linear regression analysis was conducted to investigate the effect of increasing mesh size on percent reduction in catch rates in the modified (experimental) rake in relation to the control rake.

Selection criteria for this regression analysis was simple: select experimental results where the mesh size in the rope back was the only modification being tested, and treat all trip results as individual experimental results. The data were assembled into a table which included results from the 1995 and 1996 Canadian industry trials in Kenchington (2000), Henriksen et al. (1997), DuPaul et al. (1999), and Smolowitz et al. (2004) (see tables 8 and 9). The only statistic used was the percent reduction in catch rates of the experimental rake when compared to the control rake. Since the amount of trial results is low, outlier detection was not used to remove questionable data. Data were assembled on cod, haddock, yellowtail flounder, flatfish, monkfish, skates and scallops. Cod and haddock data were sparse and only appeared in Kenchington's and Henriksen et al.'s[11] (cod only) reports. Although total catches of skate data was tabled in DuPaul et al. (1999), it was not included in his statistical analysis; however, the number of tows were given and, therefore, the percent differences in catch rates to be used in this analysis were calculated. There were no skate data in the Kenchington (2000) report, but it is likely that some were caught, which means there is little skate data for smaller mesh sizes/shapes. Catches of monkfish are listed, but were generally too low and only available from a limited number of mesh experiments. This species is not included in this analysis. The data were used in two ways: 1) the differences of the experimental and the control mesh sizes were calculated and used in a regression analysis with percent reduction in mean catch rates of individual species; and 2) the experimental mesh size was used alone in a regression analysis with percent reduction in mean catch rates of individual species. Neither accounted for differences in mesh shape and the data set was too small to exclude the T45 mesh results. The second analysis does not account for any information on the control mesh and is meant to be illustrative with less weight given to the results. In the first analysis, DuPaul et al.'s 8 inch T45 mesh versus 8 inch diamond control was excluded in the first regression because the mesh size difference would have been zero and not appropriate for the analysis. This data set was included in the second analysis. The cover-rope back experimental results in the Smolowitz et al. (2004) report were not used. The statistical significant level for the regression analyses was set at 0.05.

[11] In the comparison of 10 inch versus 6 inch twine tops, there were 3 cod in experimental and 13 in control. These are not listed in Table 2 because the numbers are so low for 38 tows to consider any meaningful statistic analysis.

### Data Quality

The quality of the data in the regression analysis could be affected by several factors. The data on cod and haddock was limited to the Kenchington (2000) report and cod only to the Henriksen et al. (1997) report. The data for both species were combined in the same analysis, assuming that the escapement of both species through the rope back/twine top is equal. Halliday et al. (1999) found little difference between cod and haddock in shape of the selectivity curves from codend mesh selection studies of diamond and square meshes, and this was seen as a sufficient reason to combine them. Standardization of catch rates may be an issue affecting some results: Henriksen catch rates were standardized to catch per hour, Smolowitz catch rates were standardized to catch per hectare, DuPaul catch rates were catch per tow and Kenchington used catch per tow or total catches. However, using percent reduction as the catch rate variable should negate most of these differences in standardization; however, only one out of the four reports give any measure of uncertainty around this catch rate. Smolowitz et al. (2004) data consisted of 12 experimental results for the same mesh size, and the between trip variability would have large influence on any linear modeling. Low catches in the initial data sets could greatly influence the reliability of estimates of percent reduction in catch rates. All catch reduction estimates were given equal weight.

### Results

Figure 11 shows the graphical representations of the data from all experiments considered with trend lines fitted to the data. Overlaid on these plots are the calculated overall mean percent reduction in catch rates in the experimental rake, when compared to the control rake, a positive value indicates a reduction and a negative value indicates an increase in the catch of the experimental dredge (see Table 9).

There was a significant linear relationship in percent reduction in catch rates, with increasing mesh size differences for flatfish ($r^{2=}.63$; p=.0000, df=20) and scallops ($r^{2=}.37$; p=.0012, df=24), but not for the other species (Table 10). Both yellowtail (r=.48, p=.0812, n=23) and cod/haddock (r=.56, p=.0711, n=10) showed moderate, non-significant correlations of percent reduction in catch rates with increasing mesh size differences. Skate showed no correlation between the two variables which may be due in part to the low number of mesh results less than 10 inches (Figure 11; Table 10). The correlation coefficient determines the extent to which values of two variables are "proportional" to each other. Proportional means linearly related; that is, if the correlation is high then it can be approximated by a straight line (sloped upwards or downwards). Here the yellowtail and the cod/haddock correlations suggest a linear trend in percent reductions in catch rates, with increasing mesh differences.

Increasing mesh size differences in Figure 11 are a proxy for increasing experimental mesh size relative to the control mesh. Based on the regression analysis of yellowtail, flatfish and scallops, for which there are more mesh size information, the intersection of the mean percent reduction in catch rates line and the trend line was observed to occur between 3.4-3.5 inches. In the cod/haddock category, it was approximately 1.7 inches and there was no trend for skate. Since the majority of the Canadian scallop fleet are currently using 5 and 6 inch mesh sizes in their rope backs, the results suggest that an increase in mesh size to 9 inches (a midpoint of 3.4 inches mesh size differences gives a range of 8.4-9.4 inches in mesh size) could result in average target reductions of approximately 42% in yellowtail, 30% in flatfishes, 10% in scallops

(Figure 11). The illustrative Figure 12[12] also suggested a mesh size of 9 inches for all species except cod/haddock (see Table 11 for regression output). It is expected that most small to medium-sized cod and haddock (approximately 75%) would escape through a 9 inch mesh size. For skate, which had the worst model fit, target reductions would probably be under the average 35%. There were no reported experimental trials testing 9 inch mesh rope back/twine tops to compare with the regression model results; however, results existed for 8 inch, and 10 inch to 12 inch meshes.

### Discussion

These upward trends in percent reductions in catch rates with increasing mesh size do not take into account that there is a combination of mesh shapes in the data. For example, T45 mesh data account for 6/24 results for yellowtail, 7/25 results for scallops, 9/11 results for cod/haddock, 6/21 results for flatfish and 3/18 results for skates. The results suggests that a minimum mesh size of 9 inches in the rope backs should give promising results in reducing finfish bycatch while minimizing the loss of scallops. Much of the T45 mesh data comes from the Kenchington (2000) report and suggests that for smaller mesh sizes using T45 mesh could lead to increase catches of bycatch. However, larger T45 mesh and diamond mesh sizes results both showed reductions in bycatch (Table 8). This current analysis does not resolve the mesh shape question, i.e., would a 9 inch diamond mesh rope back give the same efficiency/selectivity results as 9 inch T45 square mesh rope back? Knotted diamond mesh rope backs hung normally or hung on the square (T45) comprise the majority of the Canadian fleet fishing Georges Bank. A few vessels are using full knotless square mesh rope backs which avoids the problem of knots slippage common in knotted twines and ropes as they age.

Results on mesh selection in codend studies that compare selectivity of diamond and square meshes of the same size, showed square meshes will be more selective for cod and haddock (Halliday et al. 1999) in 5-6 inch sizes, but not in larger meshes of 7 inches where selectivity of both shapes were found to be the same (He 2007). On the contrary, diamond mesh sizes of 5 – 7 inches were found to be more selective for flatfish (Walsh et al. 1992; He 2007). Both Walsh et al. (1992) and He (2007) showed that to achieve the equivalent selectivity for flatfish in diamond and square mesh codends the size of the square mesh would have to be at least 1 inch larger. The success of using large diamond meshes to reduce the catches of flounders was recently demonstrated by Milliken and DeAlteris (2004), who inserted 16 inch diamond mesh panels in a small mesh trawl codend in the New England silver hake (*Merluccius bilinearis)* fishery and reduced flounder catches by 78%.

Although the dynamics inside bottom trawl codends which allow fish to escape through a mesh are not expected to be the same for fish escaping up through the rope back/twine top panel there may be some similarities in how fish perceive and pass through a mesh. Based on this literature discussion on codend mesh selection, both a T45 mesh and a knotless square mesh rope back having the same mesh size are likely to retain more small and medium sized flatfish when compared to a diamond mesh panel of the same size. A sufficiently large mesh size of any shape should have similar selectivity for cod and haddock, i.e., promote more escapement.

Dredge efficiency for large scallops has been reported to increase with increased diamond mesh size because of an increase in the hydrodynamic flow through the larger meshes (Fifas et al. 2004). The mesh of conventionally rigged diamond netting twine top can be closed by using

[12] This regression analysis does not account for any information on the control mesh size used and is meant to be illustrative with less weight given to the overall results.

the wrong hanging ratio; for example, if a 6 inch mesh size is hung 3 meshes to 1 ring in a 3 inch ring bag, the meshes will be bunched together creating a very narrow mesh opening and restricting water flow. This restriction could reduce the escapement of finfish and scallops. By using T45 or square mesh netting, there is a mesh resistance to closing (see Figure 7). Although a diamond mesh hung square (T45) has the same bar lengths as a regular diamond mesh of the same size, it now has a mesh opening that is 29% smaller which can, in some cases, negate the success of an increase in mesh size especially for some flounders. For example, Kenchington's (2000) results for mesh sizes of 5 inch and 6 inch diamond (bar lengths of 2.5 and 3.0 inches, respectively) mesh hung square would have had an approximate 3.6 inch and 4.3 inch mesh opening, respectively, which effectively makes the mesh opening similar to a 4 inch diamond mesh (bar length of 2 inches) opening in the control rake. Although roundfish like cod and haddock should escape more easier through T45 and full square meshes because the escape opening is larger and suited to their elliptical shape, the laterally compressed shape of flounders would favor escapement through the elongated diamond meshes (Clark, 1963; Robertson and Stewart 1988; Simpson 1989). Large T45 or square mesh rope backs of the same mesh size may allow more scallops that are entrained in the turbulence underneath the rope back to easily pass out through the open meshes[13].

### Conclusion

The amount of finfish bycatch was reduced with increasing mesh size in the rope back/twine top analyses. Table 12 represents a summary of key results on the effect of an increase in mesh size on finfish and scallop reduction from experiments using rope backs/twine tops with mesh sizes of 8 and 10 inches to compare to the results from the regression estimate for a 9 inch mesh. Density of species and the number of tows in each of the test areas when the data were collected may play a role in the interpretation of results. Henriksen et al. (1997) T45 mesh results, based on low number of tows in the area outside the closed areas, showed good reductions in catch rates of finfish with an 8 inch T45 mesh; however, DuPaul et al. (1999) results suggest that an 8 inch diamond mesh hung square increases the catch rates of yellowtail flounder while reducing the catches of other flatfish when compared to a an 8 inch diamond mesh. DuPaul et al. (1999) also showed that a 12 inch T45 mesh gave larger reductions in all finfish catch rates when compared to an 8 inch diamond mesh twine top. Kenchington (2000) analysis of the small T45 mesh rope back results generally showed increases in catch rates of gadoids and flatfish, but not yellowtail. Square mesh panels of certain mesh sizes may retain more flounders, like yellowtail, than diamond mesh panel of the same size because these square meshes have a 29% smaller mesh opening. Both Henriksen et al. (1997) and Smolowitz et al. (2004) study of a 10 inch diamond mesh size suggests that better reductions can be achieved for yellowtail cod, skate, and flatfish, with average loss of scallops of ranging from 8-28%. From the regression analysis, which considered all suitable data sets, a mesh size of 9 inches should reduce bycatch of yellowtail and flatfish, species for which there were sufficient data, by an average of 30-36%, with a minimal average loss of 10% for scallops.

Regression analysis was chosen to examine the form and significance of an overall relationship between bycatch reduction and mesh size increase in the rope back/twine top panel from the several disparate studies. Although it provided a quantitative method to combined the data sources and determine the direction of the effect, the results should be considered equivocal, i.e., uncertain with respect to significance, because of the varied nature and quality of the data extracted from the four reports. For example, from these four reports, only Smolowitz et al.

[13] Ron Smolowitz suggests this is why no USA scallop fisher on Georges Bank uses square mesh (2008; personal communication).

(2004) gave any measure of uncertainty for estimates of percent reduction in mean catches. Although parameter estimates are presented in the regression analysis of the combined data, true variability is probably underestimated given that no measure of uncertainty from the studies are incorporated into the analysis. However, the individual experiments and the combined analysis do demonstrate a central tendency for a reduction in finfish bycatch with increasing mesh size in the rope back/twine top panels, as evident in Table 12. Loss of scallops may become significant at larger mesh sizes. The question whether large square mesh rope backs retained or released more flatfish also could not be conclusively answered from the limited studies examined.

The majority of the current Canadian scallop fleet fishing Georges Bank are using 5 and 6 inch diamond mesh size rope backs hung regular or on the square (T45). Based on the regression analysis's central tendency of increasing bycatch reduction with increasing mesh size, the escapement of finfish is not expected to be high at these lower mesh sizes.

## 8. Further Research on Dredge Modifications and Fishing Practices

Within the USA east coast research on twine top modifications, Smolowitz et al. (2004) identified several important elements in the construction of the rope back/twine top which would influence bycatch reduction. They noted that a host of variables linked with installing a twine top on a dredge could impact scallop and flatfish catch and stressed the need for a much stronger understanding of these factors. They stated that the most important parameters are associated with how the twine top was hung and listed the following: 1) changing the width and length of the twine top alters both scallop and flatfish retention; 2) decreasing the number of rows of meshes in the width allow more scallops and fish to escape; and 3) hanging the twine too tight then gear efficiency is loss, i.e., escapement does not occur[14]. They emphasized that the length of the twine top was also very important for scallop retention; key factors being the twine top location relative to the sweep chain and the tension in the meshes. The twine top should end just above the center of the sweep and if the twine top ends further aft more scallops are lost by going out through the meshes, and that if it is further forward, the dredge opening is closed down forcing scallops under the sweep and reducing catch.

In Smolowitz's recent 2005-2007 studies on developing a turtle excluder scallop dredge, he again emphasized that twine top hanging ratios, overall size and position of twine top relative to the sweep, in addition to mesh size, were important[15] (Ron Smolowitz 2008, Coonamessett Farm, personal communication). He also mentioned that changes in certain fishing practices such as tow duration, towing speed and scope ratios could also affect efficiency of the dredge. My analysis of tow duration, scallop and skate densities reported in Section 6.4 also suggest that bycatch reduction can be affected by fishing practices and fish behaviour. Smolowitz (personal communication) felt that hanging a 10 inch diamond on the square (T45 mesh) would result in loss of scallops with this more opened mesh shape.

[14] There are two directions the twine top can be too tight. If the hanging ratio is 1:1 and the twine top does not have enough meshes across, it can pull up on the side pieces lifting the corners of the sweep. The other problem is if it is cut too short in length, it can pull on the ring bag which can negatively impact the sweep. Too tight a mesh can also impact fish escapement (Ron Smolowitz; personal communication).

[15] Since the US regulation on mesh size in the twine top does not specify a hanging ratio, there have been several reports of fishers using 3-4 meshes to a ring, which closes up the mesh opening.

Although the efficiency of the current east coast USA New Bedford scallop dredge for scallops has been estimated to range from 20-55%, on average of 46% (Gedame et al. 2004; Walter et al. 2007), the Canadian industry feel that the efficiency of their dredge is closer to the lower estimate (Seafood Producers Association of Nova Scotia 2008; personal communication). This range in dredge efficiencies suggest that spatial differences related to water depth, bottom substrate and scallop size or abundance may be influencing the estimates. Spatial differences may also contribute to variable bycatch reduction in the current Canadian scallop dredge fisheries. Similarly, the efficiency of toothed scallop dredges used in UK waters has been also estimated to be low, ranging from 24-30% (Beukers-Stewart et al. 2001). The fish and scallop capture process in dredges appears to be poorly understood, and this has probably hindered, and even slowed, progress in developing a more efficient and selective dredge. Even the leading engineering dredge expert, Ron Smolowitz, who has worked on dredge modifications since 1994, says that further work is needed. This not meant to be a criticism, but illustrates the complexity of the problem.

In summary, when reviewing both east coast Canadian and American research, there were differences in the rigging of the New Bedford style scallop rake which could impact the escapement of finfish and scallops through the top panels. Should further research be carried out in Canada on changes to scallop rakes then they should include: 1) the use of rope made versus twine made top panels; 2) the use of longer top panels with fore attachment point one ring row from pressure plate versus shorter panels which are attached several rings away from pressure plate; 3) the use of diamond or square meshes in the top panels; and 4) the effect of hanging ratios on mesh opening in diamond mesh rope back panels.

# 9. General Conclusions

Along with incentives and other management strategies, a key approach to managing bycatch of finfish and small scallops is to design and operate selective scallop rakes using knowledge of individual fish behaviour, including the target species, rake hydrodynamics and fishing practices. Modifications to the scallop rake/dredge tested to reduce finfish bycatch and minimize loss of scallops have been numerous as cited in the many reports listed here. Most studies have not extensively considered fish and scallop behaviors nor the hydrodynamics of the rake/dredge in the capture process. Wide variation in some of the mesh size results listed in this report were due to low catches, short number of tows, more than one modification being tested simultaneously, changes in efficiency due to spatial and temporal changes density and changes in efficiency due to substrate types, among other things. Analysis of efficiency/catchability data in other towed gears such as bottom and beam trawls and static gears, such as pots and gillnets, are generally modeled by either pooling all data to derive the an overall gear efficiency or, if data permits, estimating a mean efficiency from individual tows (and taking between tow variation into account) for a particular mesh size or gear component (Wileman et al. 1996). The overall success of a particular efficiency change can be judged by various measures of variability around the estimate and model fits. Only Smolowitz et al. 2004 carried out such analysis. What was critically lacking in most reports was a comparative analysis of length data of scallops and major bycatch species from both paired dredges. Length data is imperative to understanding and estimating gear efficiency, when modifications are made to the control dredge.

The overall conclusion from this synthesis of the many reports reviewed and the exploratory regression analyses carried in this document is that there is a greater tendency to reduce finfish bycatch by increasing the mesh size in the rope back/twine top panel, when compared to the other technical modifications listed. Again, it has to be stated that although regression analysis provided a quantitative method, to combine the data sources and determine the direction of the effect the results should be considered equivocal, i.e., uncertain with respect to significance, because of the varied nature and quality of the data. However, the individual experiments and the combined analysis do demonstrate a central tendency for a reduction in finfish bycatch with increasing mesh size in the rope back/twine top panels as evident in Table 12. The majority of the current Canadian fleet fishing Georges Bank are using knotted 5 and 6 inch diamond mesh size rope backs hung regular or on the square (T45), and the results suggest that increasing the mesh size up to 4 inches should effect good reductions in finfish bycatch while minimizing the loss of scallops. A few vessels are using 16 inch full knotless square mesh rope back panels in their rakes. There is some evidence that the common practice of hanging a diamond mesh rope back on the square may result in an increase in the bycatch of some finfish, especially at smaller mesh sizes. The laterally compressed shape of flounders would favor escapement through the elongated diamond meshes, when compared to square mesh of the same size which also has a 29% smaller mesh opening.

Additional ways of improving reduction in finfish bycatch and the bycatch of small scallops have also been tested in various experiments. Earlier reports concluded that ring sizes of 3-4 inches in the bags would not facilitate the escapement of juvenile finfish (DuPaul et al. 1996); however, recent experimental evidence has contradicted that conclusion. Increasing the ring size in the ring bag from 3.0 inches to 3.5 inches was shown to lower the bycatch ratio without loss of scallops in the Kenchington (2000) analysis of Canadian industry data. Increasing the ring size from 3.5 to 4.0 inches as shown by the DuPaul (2002a, b) and DuPaul et al. (2002, 2004) reports should reduce bycatch of small flatfish (no roundfish caught) with minimal loss of commercial scallops. Most of the Canadian industry are presently using 3 inch ring bags in their rakes.

With the use of any conservation measures, whether it be area/time closures, bycatch quotas or gear based modifications, one should remember that temporal and spatial changes in the dynamics and abundance of groundfish species can shift the complexity of the problem thereby necessitating continuous adjustment in solving the problem.

## 10. Recommendations

In the Canadian scallop offshore fishery, an increase in rope back panel mesh size and in rake bag ring size, should be considered if other conservation measures such as bycatch quotas and effort reduction are not fully resolving the bycatch problem. Based on this synthesis of available information four recommendations are made:

1. Consider increasing the mesh size of the rope back panel from the current 5 or 6 inches to at least 9 inch diamond or square mesh.

2. Consider increasing the ring size of the bags at 4.0 inches (inside diameter). This ring size should reduce the bycatch of small flatfish.

3. Consider conducting ongoing field trials to allow for the testing of other modifications to the scallop rake and rope back under a joint science and industry agreement to ensure success

and scientific rigor. Included in this research should be the use of rope versus twine in top panel, hanging ratios, increasing overall panel length, and mesh shape.

4. In planning future field trials, consider involving researchers in the USA. A first step would be share information via a workshop.

## 11. Acknowledgements

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*Table 1. Data analysis results from Canadian scallop dredge research. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per 4 km tows using numbers for fish and bushels for scallops.*

| | | | | | | Yellowtail | | | | Skates | | | | Flatfish | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Study | Modification | Mean Tow time | Mean Tow speed (Kt) | Area | No. of tow pairs | Control Mean catch | Exp. Mean Catch | % reduce | Sign. | Control (#tows) | Exp. Mean Catch | % reduce | Sign. | Control (#tows) | Exp. Mean Catch | % reduce | Sign. |
| McIntyre et al. 2006 | Deflector plates | 30 | 4-5 to 5.5 | G.B. | | | | | | | | | | | | | |
| | Top position | | | | 24 | 4.58 | 10.12 | -120.9 | ***0.0002*** | 23.18 | 23.84 | -2.8 | 0.3700 | 1.67 | 2.73 | -63.6 | ***0.0270*** |
| | Low position | | | | 22 | 2.70 | 6.82 | -153.0 | ***0.0080*** | 25.13 | 32.50 | -29.3 | 0.0700 | 3.93 | 6.06 | -54.4 | ***0.0410*** |
| | Closed position | | | | 19 | 0.81 | 0.56 | 31.4 | 0.1250 | 23.05 | 24.60 | -6.8 | 0.2000 | 2.95 | 2.78 | 5.6 | 0.3920 |
| | Lights | | | | 20 | 15.07 | 11.60 | 23.0 | ***0.0130*** | 24.42 | 22.83 | 6.5 | 0.2130 | 4.73 | 2.77 | 41.5 | 0.0540 |
| | Strobes | | | | 20 | 5.77 | 5.15 | 10.6 | 0.1990 | 17.27 | 18.06 | -4.6 | 0.3290 | 2.36 | 1.98 | 15.8 | 0.2320 |
| | Sound | | | | 20 | 0.81 | 0.34 | 58.0 | 0.0860 | 14.62 | 16.25 | -11.1 | 0.1710 | 3.05 | 1.87 | 38.7 | ***0.0040*** |

| | Monk fish | | | | Cod | | | | | Haddock | | | | | Scallops Combined | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Modification | Control (#tows) | Exp. Mean Catch | % reduce | Sign. | Control (#tows) | Exp. Mean Catch | % reduce | Sign. | Comment | Control (#/tow) | Exp. Mean Catch | % reduce | Sign. | Comment | Control (#bushels /tows) | Exp. Mean Catch | % reduce | Sign. |
| Deflector plates | | | | | | | | | | | | | | | | | | |
| Top position | 3.59 | 4.73 | -31.7 | ***0.0190*** | 0.04 | 0.11 | -208.3 | 0.2100 | small catches | 0.00 | 0.11 | | 0.0930 | small catches | 12.31 | 5.63 | 54.3 | ***0.0000*** |
| Low position | 3.94 | 3.96 | -0.4 | 0.4900 | 0.09 | 0.12 | -42.5 | 0.3520 | small catches | 0.00 | 0.19 | | ***0.0113*** | small catches | 8.56 | 6.91 | 19.3 | 0.0890 |
| Closed position | 3.23 | 4.08 | -26.4 | 0.1550 | 0.34 | 0.30 | 11.6 | 0.3980 | small catches | 1.36 | 0.91 | 33.0 | 0.1300 | small catches | 9.20 | 9.24 | -0.4 | 0.4750 |
| Lights | 5.25 | 5.41 | -3.1 | 0.4290 | 1.56 | 0.58 | 62.7 | 0.0620 | Sign. in Wilcoxon | 0.23 | 0.23 | -2.2 | 0.4880 | small catches | 9.08 | 9.59 | -5.6 | 0.1570 |
| Strobes | 3.25 | 2.94 | 9.4 | 0.3630 | 0.46 | 0.38 | 17.7 | 0.3560 | small catches | 0.52 | 0.14 | 72.4 | ***0.0090*** | small catches | 5.90 | 6.50 | -10.2 | ***0.0344*** |
| Sound | 4.63 | 4.29 | 7.3 | 0.3020 | 0.18 | 0.36 | -95.1 | 0.1120 | small catches | 0.67 | 0.49 | 27.8 | 0.2950 | small catches | 5.11 | 5.72 | -11.9 | ***0.0180*** |

Signif. = Significance
Exp. = Experimental

*Table 2. Data analysis for east coast USA scallop dredge research (Henriksen et al. 1997). Numbers of non-zeros in brackets. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per hour using numbers for fish and scallops.*

| | | | | | | Yellowtail | | | | | Skates | | | | Flatfish | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **Modification** | **Mean Tow time (min)** | **Mean Tow speed (Kt)** | **Area** | **No. of tow pairs** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** |
| **Henriksen et al 1997/ 2 vessels used** | | | | off C. Cod | | | | | | | | | | | | | | |
| **Trip 1 vessel 1** | **10" Dia. mesh vs 6" Dia. mesh** | 63.2 | 4.5 | off C. Cod | 14 | 9.9 | 3.7 | 62.6 | ***<.001*** | | 87.3 | 73.1 | 16.3 | >.05 | 31 | 19.2 | 38.1 | ***0.0245*** |
| **Trip 2** | | 61.3 | 4.5 | off C. Cod | 24 | 8.6 | 4.3 | 50.0 | ***<.001*** | | 40.2 | 34.4 | 14.4 | >.05 | 16.5 | 6.5 | 60.6 | 0.0344 |
| **Trip 3** | | 67.1 | 4.5 | off C. Cod | 11 | 19.3 | 13.5 | 30.1 | ***0.0059*** | | 184.1 | 142.1 | 22.8 | ***0.00*** | 33.3 | 26.8 | 19.5 | ***0.0046*** |
| **Trip 4-vessel 2** | **10" Dia. mesh with roller on bail vs 6" Dia. mesh** | 67.2 | 4.5 | off C. Cod | 18 | 10.4 | 12.5 | -20.2 | 0.053 | **Better catch Exp.** | 55.4 | 48.9 | 11.7 | >.05 | 25.6 | 24.3 | 5.1 | >.05 |
| **Trip 5** | **8" (T45) vs 6 " Dia.mesh** | 69.0 | 4.5 | off C. Cod | 30 | 16 | 10.5 | 34.4 | ***<.001*** | | 178.4 | 131.0 | 26.6 | ***<.001*** | 109.9 | 64.2 | 41.6 | ***<.0010*** |
| **Trip 6** | | 71.5 | 4.5 | off C. Cod | 39 | 18.5 | 11.6 | 37.3 | ***<.001*** | | 47.7 | 25.4 | 46.8 | ***<.001*** | 70.4 | 38.0 | 46.0 | ***<.0010*** |
| | | | 4.5 | | | | | | | | | | | | | | | |
| **Trip 6a** | **8" T45)+ pressure plate on bale vs 6" Dia mesh** | 71.1 | | off C. Cod | 9 | 24.4 | 14.3 | 41.4 | ***0.011*** | | 37.9 | 25.0 | 34.0 | >.05 | 82 | 56.9 | 30.6 | ***0.0430*** |

Signif. = Significance
Exp. = Experimental

*Table 2. Continued; Henriksen et al. (1997).*

| | Scallops Combined | | | | | > 90 mm large Scallops | | | | | <90 mm Small Scallops | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Modification** | **Control Mean catch (#s)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean catch (#s)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean catch (#s)** | **Exp. Mean Catch** | **% reduce** | **Signif.** |
| **10" Dia. mesh vs 6" Dia. mesh** | 347.9 | 226.9 | 34.8 | ***0.0215*** | | 151.1 | 137.6 | 8.9 | >.05 | | 395.8 | 194.9 | 50.8 | ***0.0250*** |
| | 903.2 | 465.5 | 48.5 | ***<.0010*** | | 176.3 | 114.3 | 35.2 | ***<.0010*** | | 872.2 | 413.1 | 52.6 | ***<.0010*** |
| | 201.2 | 198.6 | 1.3 | >.05 | | 192.5 | 200.2 | -4.0 | >.05 | **Better catch Exp.** | 33.4 | 19.9 | 40.4 | >.05 |
| **10" Dia. mesh with roller on bail vs 6" Dia. mesh** | 423.2 | 418.8 | 1.0 | >.05 | | 213.7 | 220.7 | -3.3 | >.05 | **Better catch Exp.** | 249.3 | 237.2 | 4.9 | >.05 |
| **8" (T45) vs 6 " Dia.mesh** | 351.6 | 372.1 | -5.8 | 0.1300 | **Better catch Exp.** | 251.6 | 284.2 | -13.0 | ***0.0024*** | **Better catch Exp.** | 101.2 | 88.5 | 12.5 | 0.0960 |
| | 328.1 | 319 | 2.8 | >.05 | | 265 | 252.6 | 4.7 | >.05 | | 66.7 | 66.4 | 0.4 | >.05 |
| **8" T45)+ pressure plate on bale vs 6" Dia mesh** | 293.1 | 255.9 | 12.7 | >.05 | | 248.6 | 215.1 | 13.5 | >.05 | | 44.3 | 40.7 | 8.1 | >.05 |

Signif. = Significance
Exp. = Experimental

*Table 3. Data analysis for east coast USA scallop dredge research (DuPaul et al. 1999). Numbers of non-zeros in brackets. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per tow using numbers for fish and bushels for scallops.*

| | | | | | | Yellowtail | | | | | Skates | | | | Barndoor skates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Study | Modification | Mean Tow time (min) | Mean Tow speed (Kt) | Area | No of tow pairs | Control Mean catch (#tows) | Exp. Mean Catch | % reduce | Signif. | Comment | Control Mean Catch (#tows) | Exp. Mean Catch | % reduce | Signif. | Control Mean Catch (#tows) | Exp. Mean Catch | % reduct. | Signif. | Comment |
| DuPaul et al. 1999/ 1 vessel | | | | | | | | | | | | | | | | | | | |
| Experiment # 1 | 8"Sq (T45) mesh vs 8" Dia mesh | range 1-27 mins | N.D. | CA II | 224 | 3.48 | 3.9 | -12.1 | 0.2330 | Better catch Exp. | 6744* | 6628* | | | 0.12 | 0.17 | -41.7 | 0.2390 | Better catch Exp. |
| Experiment # 2 | 12"Sq (T45) mesh vs 8" Dia. mesh | range 1-70 mins | N.D. | Adjacent to CA II | 34 | 6.44 | 3.47 | 46.1 | 0.0820 | | 1524* | 983* | | | N.D. | N.D. | | | |

| | Flatfish | | | | Monkfish | | | | | Scallops Combined | | | | | > 70 mm large Scallops | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Modification | Control Mean Catch (#tows) | Exp. Mean Catch | % reduce | Signif. | Control Mean Catch (#tows) | Exp. Mean Catch | % reduce | Signif. | Comment | Control Mean Catch (#bushels/ tows) | Exp. Mean Catch | % reduce | Signif. | Comment | Control Mean Catch (#bushels/t ows) | Exp. Mean Catch | % reduce | Signif. |
| 8"Sq (T45) mesh vs 8" Dia mesh | 2.09 (2.93)** | 2.01 (2.31) | 3.8 (21.2) | 0.6700 (***.0000***) | 0.78 | 0.72 | 7.7 | 0.5030 | | 433.8 | 425.8 | 1.8 | 0.7690 | | 428.9 | 421.2 | 1.8 | 0.7740 |
| 12"Sq (T45) mesh vs 8" Dia. mesh | 13.97 (2.26) | 4.85 (0.82) | 65.3 (63.7) | ***0.0040 (.0030)*** | 4.26 | 2.11 | 50.5 | ***0.0410*** | | 85.6 | 66.1 | 22.8 | ***0.0000*** | | 82.9 | 69.6 | 16.0 | ***0.0000*** |

Signif. = Significance
Exp. = Experimental
*Total catch of skates – no statistical analysis
** Flatfish catches were done by species: Blackback flounder and windowpane flounder in brackets
CAI = Closed Area I
CAII = Closed Area II
NLSA = Nantucket Light Ship Area

*Table 4. Data analysis for east coast USA scallop dredge research (Smolowitz et al. 2001). Numbers of non-zeros in brackets. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per hectare using numbers for fish and scallops.*

| | | | | | | Yellowtail | | | | | Skates | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **Modification** | **Mean Tow time (min)** | **Mean Tow speed (Kt)** | **Area** | **No of tow pairs** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** |
| **Smolowitz et al. 2001/2 vessels used but** | | | | | | | | | | | | | | |
| Trip 1 | **Lighter frame plus fish sweep/10" Dia. mesh vs standard/10" Dia. mesh** | 32.5 | N.D. | NLSA | 16 | 4.83 (16)** | 3.02 | 37.4±16.8*** | ***0.0003*** | | 12.73 (16) | 9.08 | 28.7±14.2 | ***0.0006*** |
| Trip 2 | | 29.8 | N.D. | CA1 | 24 | 1.81 (14) | 1.12 | 38.0±37.0 | 0.0450 | | 38.68 (15) | 34.86 | 9.9±12.7 | 0.1147 |
| Trip 3 | **Lighter frame Plus excluder rings and fish sweep/10" Dia. mesh vs lighter frame** | 33.0 | N.D. | CA1 | 27 | 10.87 (22) | 6.58 | 39.5±25.8 | ***0.0045*** | unsure of control setup | 54.18 (27) | 32.3 | 40.4±15.3 | ***0.0001*** |

| | Flatfish | | | | Monkfish | | | | | Scallops Combined | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Modification** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean Catch (#bushels/tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** |
| **Lighter frame plus fish sweep/10" Dia. mesh vs standard/10" Dia. mesh** | 3.97 (16) | 2.95 | 25.7±19.4 | 0.013 | 0.85 (16) | 0.94 | -10.3±39.4 | 0.5800 | **Better catch Exp.** | 12.63 (16) | 13.99 | -10.8±7.98 | ***0.0110*** | **Better catch Exp.** |
| | 4.27 (15) | 2.96 | 30.8±41.4 | 0.133 | 1.58 (14) | 2.83 | -79.5±60.8 | ***0.0144*** | **Better catch Exp.** | 13.79 (24) | 16.8 | -21.8±15.4 | ***0.0075*** | **Better catch Exp.** |
| **Lighter frame Plus excluder rings and fish sweep/10" Dia. mesh vs lighter frame** | 6.72 (25) | 3.51 | 47.8±22.8 | 0.0002 | 9.79 (27) | 9.54 | 2.58±12.0 | 0.6620 | | 8.05 (27) | 7.8 | 3.2±8.75 | 0.4600 | |

Signif. = significance; Exp. = Experimental
% reduce has 95% Confidence Intervals
CAI = Closed Area I; NLSA = Nantucket Light Ship Area

*Table 5. Comparison of total catches by area from 3.5 inch ring versus 4.0 inch ring dredges. A negative percent reduction means the 4 inch ring bag caught more while a positive values indicates the 4 inch ring bag caught less than the 3.5 inch dredge. Catches were standardized to catch per tow using numbers for fish and baskets for scallops*

| | 3.5 inch | | | | | | 4 inch | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | CAII | CAII | CAII | CA1 | HC | Total Catch | CAII | CAII | CAII | CA1 | HC | Total Catch | Percent reduction |
| Scallops | 636 | 191 | 543 | 2023 | 1898 | 5291 | 727 | 217 | 454 | 2284 | 1906 | 5588 | -5.6 |
| Ytail | 1069 | 1118 | 788 | 39 | 0 | 3014 | 998 | 1131 | 830 | 43 | 0 | 3002 | 0.4 |
| Ytail<30cm | 54 | 194 | 66 | 2 | 0 | 316 | 22 | 76 | 41 | 3 | 0 | 142 | 55.1 |
| Witch<35cm | 4 | 2 | 11 | 0 | 1 | 18 | 1 | 0 | 6 | 0 | 0 | 7 | 61.1 |
| Plaice<35cm | 13 | 4 | 14 | 0 | 5 | 36 | 5 | 0 | 18 | 0 | 3 | 26 | 27.8 |
| Flatfish<35 cm | 71 | 200 | 91 | 2 | 6 | 370 | 28 | 76 | 65 | 3 | 3 | 175 | 52.7 |
| Other Flatfish | 309 | 472 | 407 | 169 | 55 | 1412 | 195 | 356 | 272 | 167 | 31 | 1021 | 27.7 |
| Monkfish | 87 | 157 | 147 | 40 | 111 | 542 | 132 | 159 | 138 | 34 | 148 | 611 | -12.7 |
| Skates | 740 | 4103 | 1711 | 607 | 1086 | 8247 | 744 | 4083 | 1672 | 584 | 1103 | 8186 | 0.7 |

CA = Closed Area
HC = Hudson Canyon
Ytail = yellowtail
Flatfish<35 cm = sum of Yellowtail, plaice and witch catches for which small fish size was broken out

*Table 6. Data analysis for east coast USA scallop dredge research (Smolowitz et al. 2004). Numbers of non-zeros in brackets. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per hectare using numbers for fish and scallops.*

| | | | | | | Yellowtail | | | | | Skates | | | | | Barndoor skates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **Modification** | **Mean Tow time (min)** | **Mean Tow speed (Kt)** | **Area** | **Number of tow pairs** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signf.** | **Comment** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signf.** | **Comment** | **Control Mean catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signf.** | **Comment** |
| **Smolowitz et al. 2004/two vessels used** | | | | | | | | | | | | | | | | | | | | |
| **Trip 1.1 Vessel 1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 7.4 | 4.0 | NLSA | 12 | 10.60 (10) | 5.90 | 44.1±50.5 | 0.0720 | | 148.1 (12) | 78.9 | 46.7±38.7 | ***0.0270*** | | | | | | |
| **Trip 1.2** | | 21.0 | 4.0 | | 22 | 11.00 (21) | 2.70 | 75.1±52.3 | ***0.0060*** | | 44.7 (22) | 19.6 | 56.1±9.21 | ***0.0000*** | | | | | | |
| **Trip 1.3** | | 63.7 | 4.0 | | 22 | 44.10 (22) | 24.80 | 43.6±10.3 | ***0.0000*** | | 51.3 (22) | 36.2 | 29.6±9.3 | ***0.0000*** | | 0.80 (16) | 0.82 | -3.5±30 | 0.4100 | small catches |
| **Trip 2.1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 5.8 | 4.0 | NLSA | 13 | 6.30 (11) | 5.10 | 19.2±37.1 | 0.1800 | | 193.9 (13) | 160 | 17.5±24.3 | 0.1100 | | | | | | |
| **Trip 2.2** | | 19.8 | 4.0 | | 11 | 3.18 (11) | 1.21 | 62.0±35.6 | ***0.0050*** | small catch | 47.9 (11) | 25.5 | 46.6±11.1 | ***0.0000*** | | | | | | |
| **Trip 2.3** | | 50.2 | 4.0 | | 17 | 1.01 (10) | 0.21 | 79.1±20.9 | ***0.0000*** | small catch | 27.2 (17) | 9.31 | 65.7±20.8 | ***0.0000*** | | 0.43 (8) | 0.14 | 68.1±55.2 | ***0.0200*** | small catches/N.S. Wilcoxon |
| **Trip 2.4** | **Cover used** | 51.7 | 4.0 | | 6 | 0.57 (6) | 0.68 | -18.7±75.7 | 0.3200 | small catch | 22.8 (6) | 17.7 | 22.5±10.9 | ***0.0040*** | | 0.13 (5) | 0.62 | -100±100 | 0.0900 | small catches |
| **Trip 3.1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 27.3 | 4.0 | Cultivator Shoals & CA I | 12 | 1.72 (7) | 0.06 | 96.8±95.9 | 0.0500 | Small Catches Sig/Wilcoxon | 69.4 (12) | 77.1 | - 11.1±18.4 | 0.1500 | **Better catch Exp.** | 1.16 (6) | 0.15 | 86.8±64.1 | ***0.0200*** | small catches |
| **Trip 3.2** | | 46.1 | 3.9 | | 17 | 1.16 (15) | 0.41 | 65.1±33.4 | ***0.0000*** | small catch | 43.8 (17) | 25.3 | 42.3±20.9 | ***0.0000*** | | 0.96 (15) | 0.29 | 69.8±33.6 | ***0.0000*** | small catches |
| **Trip 3.3** | **Cover used** | 40.9 | 3.8 | | 11 | 1.77 (11) | 1.16 | 34.3±45.8 | 0.1000 | small catch | 45 (11) | 30 | 33.5±13.2 | ***0.0000*** | | 0.65 (9) | 0.57 | 12.1±92.4 | 0.4100 | small catches |
| **Trip 3.4** | | 7.0 | 3.8 | | 19 | 8.67 (16) | 3.41 | 60.7±34.8 | ***0.0000*** | | 134.2 (19) | 113.6 | 15.4±8.19 | ***0.0000*** | | | | | | |
| **Trip 4.1 Vessel** | **3 Tickler-5 rock chains/10" Dia. mesh vs standard/6" Dia. mesh with 2 wheels on bale** | 7.6 | 4.5 | NLSA | 23 | | | | | | | | | | | | | | | FAUTLY DATA |
| **Trip 4.2** | | 14.4 | 4.5 | | 10 | 4.04 (10) | 1.79 | 65.7±58.5 | ***0.0350*** | | 49.4 (10) | 21.1 | 57.2±15.2 | ***0.0000*** | | | | | | |
| **Trip 4.3** | | 31.5 | 4.5 | | 14 | 1.60 (11) | 0.47 | 70.8±22.4 | ***0.0001*** | small catch | 55.5 (14) | 26.4 | 52.4±16.3 | ***0.0000*** | | 0.89 (13) | 0.25 | 71.6±38.5 | ***0.0030*** | small catches |
| **Trip 4.4** | **Cover used** | 27.9 | 4.5 | | 13 | 3.01 (13) | 1.44 | 52.2±31.2 | ***0.0060*** | small catch | 73.1 (13) | 38.2 | 47.7±14.8 | ***0.0001*** | | 2.03 (11) | 1.47 | 27.4±58.7 | 0.2100 | small catches |
| **Trip 4.5** | | 31.5 | 4.4 | | 8 | 2.97 (8) | 1.93 | 35.1±40.8 | 0.0730 | small catch | 65.2 (7) | 32.7 | 49.9±29.7 | ***0.0090*** | | 1.94 (8) | 1.42 | 27.1±64.0 | 0.2200 | small catches |

Signif. = significance; Exp. = Experimental
% reduce has 90 Confidence Intervals
CAI = Closed Area I;
NLSA = Nantucket Light Ship Area
Trip 4.1 had some faulty data mixed into the table and I choose not to include results here.

*Table 6. Continued; Smolowitz et al. (2004)*

| Study | Modification | Flatfish: Control Mean catch (#tows) | Exp. Mean Catch | % reduce | Signf. | Comment | Monkfish: Control Mean catch (#tows) | Exp. Mean Catch | % reduce | Signf. | Comment | Control Mean Catch (#bushels/tows) | Exp. Mean Catch | % reduce | Signf. | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Smolowitz et al. 2004/two vessels used** | | | | | | | | | | | | | | | | |
| **Trip 1.1 Vessel 1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 22.90 (11) | 12.8 | 44.0±17.5 | ***0.0005*** | | 1.55 (7) | 1.90 | -22.7±175 | 0.4000 | **Better catch Exp.** | 123.20 (12) | 120.40 | 2.2±8.9 | 0.3300 | |
| **Trip 1.2** | | 7.23 (22) | 2.96 | 59.0±16.9 | ***0.0000*** | | 10.6 (22) | 7.00 | 34.1±15.4 | ***0.0002*** | | 24.10 (21) | 19.00 | 21.5±8.9 | ***0.0001*** | |
| **Trip 1.3** | | 5.56 (22) | 2.98 | 46.5±24.4 | 0.0007 | | 5.05 (22) | 4.40 | 12.9±12.0 | ***0.0300*** | N.S./Wilcoxon | 3.71 (22) | 3.76 | -1.3±6.5 | 0.3600 | |
| **Trip 2.1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 22.90 (13) | 19.30 | 15.8±54.6 | 0.3100 | | 4.61 (9) | 4.79 | -3.9±89.4 | 0.4700 | **Better catch Exp.** | 226.80 (13) | 247.10 | -9.0±7.53 | 0.0280 | |
| **Trip 2.2** | | 5.40 (11) | 2.20 | 58.9±35.9 | ***0.0070*** | | 11.50 (11) | 7.60 | 34.0±20.6 | ***0.0070*** | | 18.60 (11) | 15.60 | 16.4±13.1 | ***0.0210*** | |
| **Trip 2.3** | | 2.42 (17) | 0.82 | 66.0±26.3 | ***0.0001*** | | 6.46 (17) | 4.17 | 35.4±17.1 | ***0.0010*** | | 3.50 (17) | 3.24 | 7.58±25.3 | 0.2800 | |
| **Trip 2.4** | **Cover used** | 2.30 (6) | 2.21 | 3.85±58.4 | 0.4500 | small catches | 6.43 (6) | 7.24 | -12.6±28.5 | 0.2100 | **Better catch Exp.** | 8.45 (6) | 8.28 | 2.0±12.5 | 0.3800 | |
| **Trip 3.1** | **6 Tickler-9 rock chains/10" Dia. meshvs standard/6" Dia. mesh** | 14.10 (12) | 7.61 | 46.2±43.9 | ***0.0400*** | | 7.13 (11) | 8.25 | -15.6±40.2 | 0.2500 | **Better catch Exp.** | 13.30 (12) | 15.70 | -17.8±16.8 | ***0.0400*** | |
| **Trip 3.2** | | 4.19 (17) | 2.55 | 39.1±29.2 | ***0.0100*** | | 5.02 (17) | 4.88 | 2.85±30.2 | 0.4300 | | 2.09 (17) | 1.79 | 14.1±19.7 | 0.0900 | |
| **Trip 3.3** | **Cover used** | 4.80 (11) | 3.18 | 33.7±26.2 | ***0.0200*** | | 4.53 (11) | 4.17 | 7.89±28.0 | 0.3100 | | 1.45 (11) | 1.24 | 14.8±9.66 | ***0.0100*** | |
| **Trip 3.4** | | 21.3 (19) | 12.10 | 43.0±30.4 | ***0.0100*** | | 2.20 (16) | 3.64 | -65±81.1 | 0.0700 | **Better catch Exp.** | 196.60 (19) | 204.10 | -3.88±6.4 | 0.1300 | |
| **Trip 4.1 Vessel** | **3 Tickler-5 rock chains/10" Dia. mesh vs standard/6" Dia. mesh with 2 wheels on bale** | | | | | | | | | | | | | | | FAUTLY DATA |
| **Trip 4.2** | | 5.91 (10) | 3.03 | 48.8±37.7 | ***0.0210*** | | 10.4 (10) | 6.02 | 42.2±23.0 | ***0.0040*** | | 23.90 (10) | 18.90 | 20.6±32.0 | 0.1300 | |
| **Trip 4.3** | | 5.25 (14) | 1.86 | 64.6±19.5 | ***0.0000*** | | 3.45 (14) | 2.23 | 35.3±24.7 | ***0.0130*** | | 1.33 (14) | 0.89 | 33.4±13.0 | ***0.0003*** | Small Catches |
| **Trip 4.4** | **Cover used** | 4.72 (13) | 3.38 | 28.5±28.6 | 0.0510 | N.S./Wilcoxon | 3.88 (13) | 3.95 | -1.77±30.2 | 0.4600 | **Better catch Exp.** | 1.40 (13) | 1.34 | 4.5±9.17 | 0.2000 | |
| **Trip 4.5** | | 6.81 (8) | 4.38 | 35.7±22.9 | ***0.0110*** | | 3.31 (8) | 3.31 | 0.04±30.2 | 0.5000 | | 1.50 (8) | 1.41 | 6.1±9.26 | 0.1300 | |

*Table 7. Data analysis from the US turtle excluder scallop dredge. Numbers of non-zeros in brackets. Significant reductions at the p=0.05 level are bold and italicized. A negative percent reduction means the experimental dredge caught more. Catches were standardized to catch per tow using numbers for fish and scallops. Data is preliminary.*

| | | | | | | Skates | | | | | Barndoor skates | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **Modification** | **Mean Tow time (min)** | **Mean Tow speed (Kt)** | **Area** | **Number of tow pairs** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** |
| **Smolowitz & Weeks2006 Trip 1 & 1 vessel** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | 44.1 | 4.6 | ? | 34 | 165.07 (29) | 147.1 | 10.9 | ***0.0444*** | | 1.14 (14) | 1 | 12.5 | 0.3494 |
| **Trip 2** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | 36.2 | 4.6 | | 13 | 72.69 | 96.54 | -32.8 | ***0.0013*** | **Better catch Exp.** | | | | |
| **Smolowitz et al. 2007, 1 vessel** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | N.D. | N.D. | Off Panama city | 14 | 10 (14) | 6.29 | 37.1 | ***0.0245*** | | | | | |

| | | Other flatfish | | | | Monkfish | | | | | Scallops Combined | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **Modification** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Control Mean Catch (#tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** | **Control Mean Catch (#bushels/tows)** | **Exp. Mean Catch** | **% reduce** | **Signif.** | **Comment** |
| **Smolowitz & Weeks2006 Trip 1 & 1 vessel** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | 9.90 (29) | 9.24 | 6.6 | 0.2189 | 2.50 (30) | 1.53 | 38.7 | ***0.0089*** | | 5.26 (34) | 5.1 | 3 | 0.1865 | |
| **Trip 2** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | 7.15 | 7 | 2.2 | 0.4535 | 1.92 | 3.62 | -88.0 | ***0.0243*** | **Better catch Exp.** | 4.08 | 5.08 | -24.3 | ***0.0129*** | **Better catch Exp.** |
| **Smolowitz et al. 2007, 1 vessel** | **Turtle excluder/10" Dia. Mesh vs standard10"dia. mesh** | 11.57 (14) | 5.71 | 50.6 | ***0.0115*** | 24.71 (14) | 21.36 | 13.6 | 0.1189 | | 36.64 | 35.54 | 3.02 | 0.3362 | |

Signif. = significance; Exp. = Experimental

*Table 8. Data selection for the analysis of relationship between mesh size and percent reduction in catch rates. Each column of % reduction represents an individual trial. A negative percent reduction means the experimental dredge caught more than the control. A blank means that species was not caught or the data not clearly indicated. Mesh sizes are in inches. Ytail = yellowtail flounder. T45 mesh is a diamond mesh netting hung square.*

| Study | Species | Control mesh size_ | Mesh shape | Experimental mesh size_ | Mesh shape | % Reduction | % Reduction |
|---|---|---|---|---|---|---|---|
| **Kenchington** | ytail | 4 | diamond | 5 | T45 | 9 | |
| **2000** | skates | 4 | diamond | 5 | T45 | | |
| | flatfish | 4 | diamond | 5 | T45 | -37 | |
| | monkfish | 4 | diamond | 5 | T45 | | |
| | cod | 4 | diamond | 5 | T45 | -42 | |
| | haddock | 4 | diamond | 5 | T45 | -9 | |
| | scallops | 4 | diamond | 5 | T45 | -5 | |
| | | | | | | | |
| | ytail | 4 | diamond | 6 | T45 | | 13 |
| | skates | 4 | diamond | 6 | T45 | | |
| | flatfish | 4 | diamond | 6 | T45 | -121 | -17 |
| | monkfish | 4 | diamond | 6 | T45 | | |
| | cod | 4 | diamond | 6 | T45 | -72 | 39 |
| | haddock | 4 | diamond | 6 | T45 | 13 | |
| | scallops | 4 | diamond | 6 | T45 | -3 | 3 |
| | | | | | | | |
| | ytail | 4 | diamond | 5 | T45 | 11 | |
| | skates | 4 | diamond | 5 | T45 | | |
| | flatfish | 4 | diamond | 5 | T45 | -21 | |
| | monkfish | 4 | diamond | 5 | T45 | | |
| | cod | 4 | diamond | 5 | T45 | -106 | |
| | haddock | 4 | diamond | 5 | T45 | -24 | |
| | scallops | 4 | diamond | 5 | T45 | -5 | |
| | | | | | | | |
| | ytail | 4 | diamond | 5 | diamond | -2 | |
| | skates | 4 | diamond | 5 | diamond | | |
| | flatfish | 4 | diamond | 5 | diamond | | |
| | monkfish | 4 | diamond | 5 | diamond | | |
| | cod | 4 | diamond | 5 | diamond | | |
| | haddock | 4 | diamond | 5 | diamond | | |
| | scallops | 4 | diamond | 5 | diamond | -7 | |
| | | | | | | | |
| | ytail | 4 | diamond | 7 | diamond | 15 | |
| | skates | 4 | diamond | 7 | diamond | | |
| | flatfish | 4 | diamond | 7 | diamond | | |
| | monkfish | 4 | diamond | 7 | diamond | 73 | |
| | cod | 4 | diamond | 7 | diamond | 65 | |
| | haddock | 4 | diamond | 7 | diamond | | |
| | scallops | 4 | diamond | 7 | diamond | 19 | |
| | | | | | | | |
| | ytail | 4 | diamond | 11 | diamond | 22 | |
| | skates | 4 | diamond | 11 | diamond | | |
| | flatfish | 4 | diamond | 11 | diamond | | |
| | monkfish | 4 | diamond | 11 | diamond | | |
| | cod | 4 | diamond | 11 | diamond | | |
| | haddock | 4 | diamond | 11 | diamond | | |
| | | | | | | | |
| | scallops | 4 | diamond | 11 | diamond | 62 | |

*Table 8. Continued.*

| Study | Species | Control mesh size_ | Mesh shape | Experimental mesh size_ | Mesh shape | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | % Reduction | MEAN | S.D. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Henriksen** | | | | | | | | | | | | | | | | | | | |
| **1997** | ytail | 6 | diamond | 10 | diamond | 63 | 50 | 30 | | | | | | | | | | | |
| | skates | 6 | diamond | 10 | diamond | 16 | 14 | 23 | | | | | | | | | | | |
| | flatfish | 6 | diamond | 10 | diamond | 38 | 61 | 20 | | | | | | | | | | | |
| | monkfish | 6 | diamond | 10 | diamond | | | | | | | | | | | | | | |
| | cod | 6 | diamond | 10 | diamond | 77 | | | | | | | | | | | | | |
| | scallops | 6 | diamond | 10 | diamond | 35 | 49 | 1 | | | | | | | | | | | |
| | ytail | 6 | diamond | 8 | T45 | 34 | 37 | | | | | | | | | | | | |
| | skates | 6 | diamond | 8 | T45 | 27 | 47 | | | | | | | | | | | | |
| | flatfish | 6 | diamond | 8 | T45 | 42 | 46 | | | | | | | | | | | | |
| | monkfish | 6 | diamond | 8 | T45 | | | | | | | | | | | | | | |
| | cod | 6 | diamond | 8 | T45 | 100 | 100 | | | | | | | | | | | | |
| | scallops | 6 | diamond | 8 | T45 | -6 | 3 | | | | | | | | | | | | |
| **DuPaul** | ytail | 8 | diamond | 8 | T45 | -12 | | | | | | | | | | | | | |
| **1999** | skates | 8 | diamond | 8 | T45 | 0 | | | | | | | | | | | | | |
| | flatfish | 8 | diamond | 8 | T45 | 4 | 21 | | | | | | | | | | | | |
| | monkfish | 8 | diamond | 8 | T45 | 8 | | | | | | | | | | | | | |
| | scallops | 8 | diamond | 8 | T45 | 2 | | | | | | | | | | | | | |
| | ytail | 8 | diamond | 12 | T45 | 46 | | | | | | | | | | | | | |
| | skates | 8 | diamond | 12 | T45 | 35 | | | | | | | | | | | | | |
| | flatfish | 8 | diamond | 12 | T45 | 65 | 64 | | | | | | | | | | | | |
| | monkfish | 8 | diamond | 12 | T45 | 51 | | | | | | | | | | | | | |
| | scallops | 8 | diamond | 12 | T45 | 23 | | | | | | | | | | | | | |
| **Smolowitz** | ytail | 6 | diamond | 10 | diamond | 44 | 75 | 44 | 19.2 | 62 | 79.1 | 97 | 65 | 34 | 66 | 71 | 35 | **57.6** | **22.5** |
| **2004** | skates | 6 | diamond | 10 | diamond | 47 | 56 | 30 | 17.5 | 46.6 | 65.7 | -11 | 42 | 16 | 57 | 52 | 49 | **39.0** | **21.9** |
| | flatfish | 6 | diamond | 10 | diamond | 44 | 59 | 47 | 16 | 59 | 66 | 46 | 39 | 43 | 49 | 65 | 36 | **47.4** | **14.0** |
| | monkfish | 6 | diamond | 10 | diamond | -23 | 34 | 13 | -4 | 34 | 35 | -16 | 3 | -66 | 42 | 35 | 0 | **7.3** | **32.0** |
| | scallops | 6 | diamond | 10 | diamond | 2.2 | 22 | -1 | -9 | 16 | 8 | -18 | 14 | -4 | 21 | 33 | 6 | **7.5** | **14.5** |

*Table 9. Data summary of percent reductions and mesh size in the experimental dredge for Figure 11 (DuPaul et al. 1999) results for 8 inch T45 experimental dredge versus 8 inch control dredge have been deleted. A negative percent reduction means the experimental dredge caught more.*

| Species | Control mesh size (inches) | Mesh shape | Experimental mesh size (inches) | Mesh shape | % Reduction | Mesh Difference |
|---|---|---|---|---|---|---|
| ytail | 4 | diamond | 5 | T45 | 9 | 1 |
| ytail | 4 | diamond | 6 | T45 | 13 | 2 |
| ytail | 4 | diamond | 5 | T45 | 11 | 1 |
| ytail | 4 | diamond | 5 | Diamond | -2 | 1 |
| ytail | 4 | diamond | 7 | Diamond | 15 | 3 |
| ytail | 4 | diamond | 11 | Diamond | 22 | 7 |
| ytail | 6 | diamond | 10 | Diamond | 63 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 50 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 30 | 4 |
| ytail | 6 | diamond | 8 | T45 | 34 | 2 |
| ytail | 6 | diamond | 8 | T45 | 37 | 2 |
| ytail | 6 | diamond | 10 | Diamond | 44 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 75 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 44 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 19.2 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 62 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 79.1 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 97 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 65 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 34 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 66 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 71 | 4 |
| ytail | 6 | diamond | 10 | Diamond | 35 | 4 |
| ytail | 8 | diamond | 12 | T45 | 46 | 4 |
| **MEAN** | | | | | **42** | |
| scallops | 4 | diamond | 5 | T45 | -5 | 1 |
| scallops | 4 | diamond | 6 | T45 | -3 | 2 |
| scallops | 4 | diamond | 6 | T45 | 3 | 2 |
| scallops | 4 | diamond | 5 | T45 | -5 | 1 |
| scallops | 4 | diamond | 5 | diamond | -7 | 1 |
| scallops | 4 | diamond | 7 | diamond | 19 | 3 |
| scallops | 4 | diamond | 11 | diamond | 62 | 7 |
| scallops | 6 | diamond | 10 | diamond | 35 | 4 |
| scallops | 6 | diamond | 10 | diamond | 49 | 4 |
| scallops | 6 | diamond | 10 | diamond | 1 | 4 |
| scallops | 6 | diamond | 8 | T45 | -6 | 2 |
| scallops | 6 | diamond | 8 | T45 | 3 | 2 |
| scallops | 8 | diamond | 12 | T45 | 23 | 4 |
| scallops | 6 | diamond | 10 | diamond | 2.2 | 4 |
| scallops | 6 | diamond | 10 | diamond | 22 | 4 |
| scallops | 6 | diamond | 10 | diamond | -1 | 4 |
| scallops | 6 | diamond | 10 | diamond | -9 | 4 |
| scallops | 6 | diamond | 10 | diamond | 16 | 4 |
| scallops | 6 | diamond | 10 | diamond | 8 | 4 |
| scallops | 6 | diamond | 10 | diamond | -18 | 4 |
| scallops | 6 | diamond | 10 | diamond | 14 | 4 |
| scallops | 6 | diamond | 10 | diamond | -4 | 4 |
| scallops | 6 | diamond | 10 | diamond | 21 | 4 |
| scallops | 6 | diamond | 10 | diamond | 33 | 4 |
| scallops | 6 | diamond | 10 | diamond | 6 | 4 |
| **MEAN** | | | | | **10** | |
| cod | 6 | diamond | 10 | Diamond | 77 | 4 |
| cod | 6 | diamond | 8 | T45 | 100 | 2 |
| cod | 6 | diamond | 8 | T45 | 100 | 2 |
| cod | 4 | diamond | 5 | T45 | -42 | 1 |
| cod | 4 | diamond | 6 | T45 | -72 | 2 |
| cod | 4 | diamond | 5 | T45 | 39 | 1 |
| cod | 4 | diamond | 5 | T45 | -106 | 1 |
| cod | 4 | diamond | 7 | diamond | 65 | 3 |
| haddock | 4 | diamond | 5 | T45 | -9 | 1 |
| haddock | 4 | diamond | 6 | T45 | 13 | 2 |
| haddock | 4 | diamond | 5 | T45 | -24 | 1 |
| **MEAN** | | | | | **13** | |

| Species | Control mesh size (inches) | Mesh shape | Experimental mesh size (inches) | Mesh shape | % Reduction | Mesh Difference |
|---|---|---|---|---|---|---|
| flatfish | 4 | diamond | 5 | T45 | -37 | 1 |
| flatfish | 4 | diamond | 6 | T45 | -121 | 2 |
| flatfish | 4 | diamond | 6 | T45 | -17 | 2 |
| flatfish | 4 | diamond | 5 | T45 | -21 | 1 |
| flatfish | 6 | diamond | 10 | diamond | 38 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 61 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 20 | 4 |
| flatfish | 8 | diamond | 12 | T45 | 65 | 4 |
| flatfish | 8 | diamond | 12 | T45 | 64 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 44 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 59 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 47 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 16 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 59 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 66 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 46 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 39 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 43 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 49 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 65 | 4 |
| flatfish | 6 | diamond | 10 | diamond | 36 | 4 |
| **MEAN** | | | | | **30** | |
| skates | 6 | diamond | 10 | diamond | 16 | 4 |
| skates | 6 | diamond | 10 | diamond | 14 | 4 |
| skates | 6 | diamond | 10 | diamond | 23 | 4 |
| skates | 6 | diamond | 8 | T45 | 27 | 2 |
| skates | 6 | diamond | 8 | T45 | 47 | 2 |
| skates | 6 | diamond | 10 | diamond | 47 | 4 |
| skates | 6 | diamond | 10 | diamond | 56 | 4 |
| skates | 6 | diamond | 10 | diamond | 30 | 4 |
| skates | 6 | diamond | 10 | diamond | 17.5 | 4 |
| skates | 6 | diamond | 10 | diamond | 46.6 | 4 |
| skates | 6 | diamond | 10 | diamond | 65.7 | 4 |
| skates | 6 | diamond | 10 | diamond | -11 | 4 |
| skates | 6 | diamond | 10 | diamond | 42 | 4 |
| skates | 6 | diamond | 10 | diamond | 16 | 4 |
| skates | 6 | diamond | 10 | diamond | 57 | 4 |
| skates | 6 | diamond | 10 | diamond | 52 | 4 |
| skates | 8 | diamond | 12 | T45 | 35 | 4 |
| skates | 6 | diamond | 10 | diamond | 49 | 4 |
| **MEAN** | | | | | **35** | |

*Table 10. Regression parameters from the least squares model using mesh size differences and percent reduction in catch rates in the experimental gear. Numbers in brackets are standard errors for the estimate and p is the significance value of the model test for each parameter.*

| Parameters | yellowtail | scallops | cod/haddock | flatfish | skate |
|---|---|---|---|---|---|
| Model fit (r2) | 0.22 | 0.37 | 0.32 | 0.63 | 0 |
| Correlation | 0.48 | 0.61 | 0.56 | 0.80 | 0.03 |
| a | 11.06 (13.19) | -18.96 (8.55) | -60.13 (40.11) | -94.16 (22.50) | 39.27 (29.24) |
| b | 9.08 (3.56) | 8.63 (2.34) | 40.12 (19.61) | 35.11 (6.14) | -1.13 (7.64) |
| p [a] | 0.411 | 0.0368 | 0.1681 | 0.0005 | 0.1981 |
| p [b] | 0.0812 | 0.0012 | 0.0711 | 0.0000 | 0.8840 |

*Table 11. Regression parameters from the least squares model using experimental mesh and percent reduction in catch rates in the experimental gear. Numbers in brackets are standard errors for the estimate and p is the significance value of the model test for each parameter.*

| Parameters | yellowtail | scallops | cod/haddock | flatfish | skate |
|---|---|---|---|---|---|
| Model fit (r2) | 0.40 | 0.21 | 0.54 | 0.69 | 0.03 |
| Correlation | 0.64 | 0.45 | 0.73 | 0.83 | 0.16 |
| a | -39.56 (20.77) | -29.97 (15.57) | -179.73 (61.76) | -142.78 (25.79) | -2.11 (53410 |
| b | 8.87 (2.26) | 4.27 (1.71) | 30.26 (9.41) | 18.54 (2.74) | 3.61 (5.43) |
| p [a] | 0.0695 | 0.0851 | 0.0173 | 0.0000 | 0.9690 |
| p [b] | 0.0007 | 0.0198 | 0.0106 | 0.0000 | 0.5163 |

*Table 12. Key results on the effect of an increase in mesh size on finfish and scallop reduction from experiments that had used 8 and 10 inches mesh sizes in the rope backs/twine tops to compare with regression estimate for a 9 inch mesh size rope back/twine top.*

| Study | Mesh Size/shape | Yellowtail % mean reduction | Cod/haddock % mean reduction | Flatfish % mean reduction | Skate % mean reduction | Scallops % mean reduction |
|---|---|---|---|---|---|---|
| Henriksen 69 tows/2 trips outside Closed Areas | 8 inch T45 mesh vs. 6 inch mesh control | 36% | I.D. | 44% | 37% | -2% |
| DuPaul 224 tows/1 trip inside Closed Area | 8 inch T45 mesh vs. 8 inch mesh control | -12% | - | 13% | 0% | 2% |
| Figure 11 784 tows | 9 inch | 36% | 75% | 30% | <31% | 10% |
| Henriksen 49 tows/3 trips outside Closed Areas | 10 inch Dia. Mesh vs. 6 inch mesh control | 47% | 77% | 40% | 18% | 28% |
| Smolowitz 200 tows/4 trips in and outside 3 Closed Areas | 10 inch Dia. Mesh vs. 6 inch mesh control | 58% | - | 47% | 39% | 8% |

*1) Henriksen's estimates are averages of trips. 2) A negative value indicates an increase in the experimental trawl; 3) I.D. indicates insufficient data; 4) regression is estimated from the linear equation; 5) DuPaul's average estimates of flatfish are 4% for blackback and 21% for windowpane flounders 6) Figure 11 refers to this report; 7) Smolowitz estimates are overall means for the combined experiments; and 8) I.D. means insufficient data.*

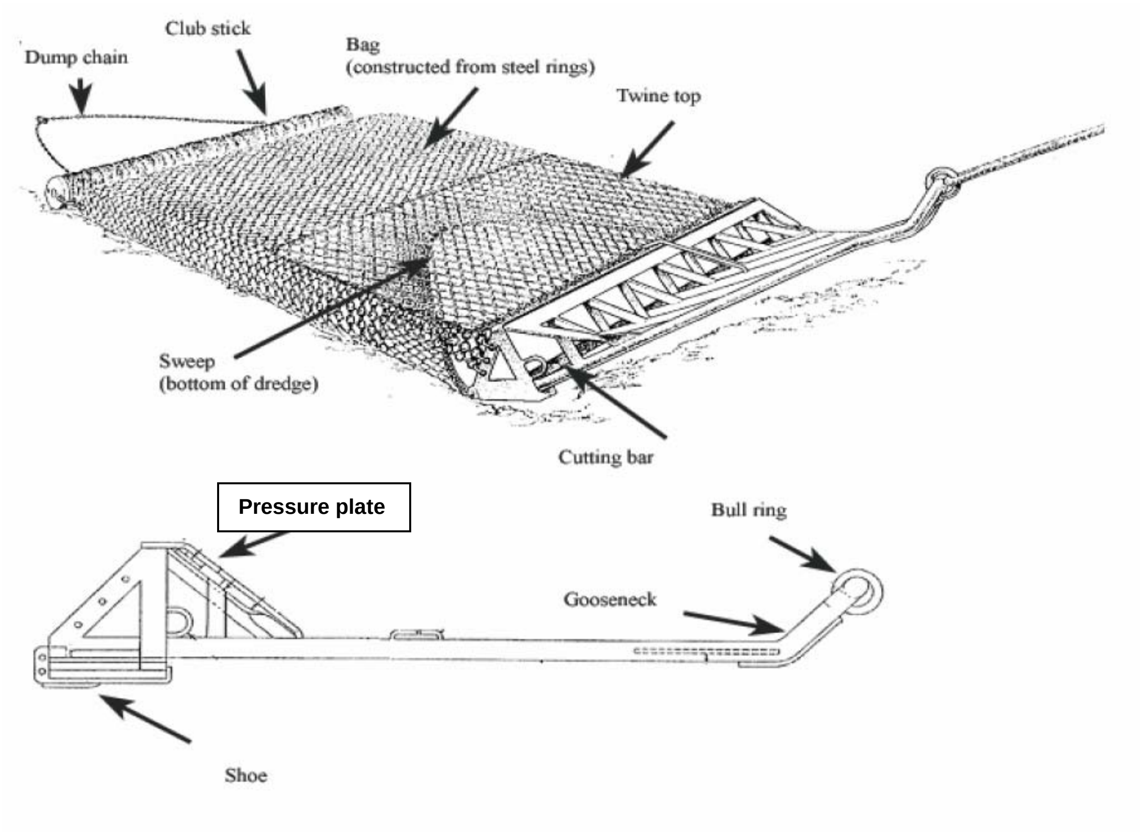



*Figure 1. A generic New Bedford style scallop dredge with components labeled.*


*Figure 2. The 2001 dredge frame design showing cookie sweep and excluder rings (Smolowitz et al. 2001, used with permission from R. Smolowitz, Coonamessett Farm.*

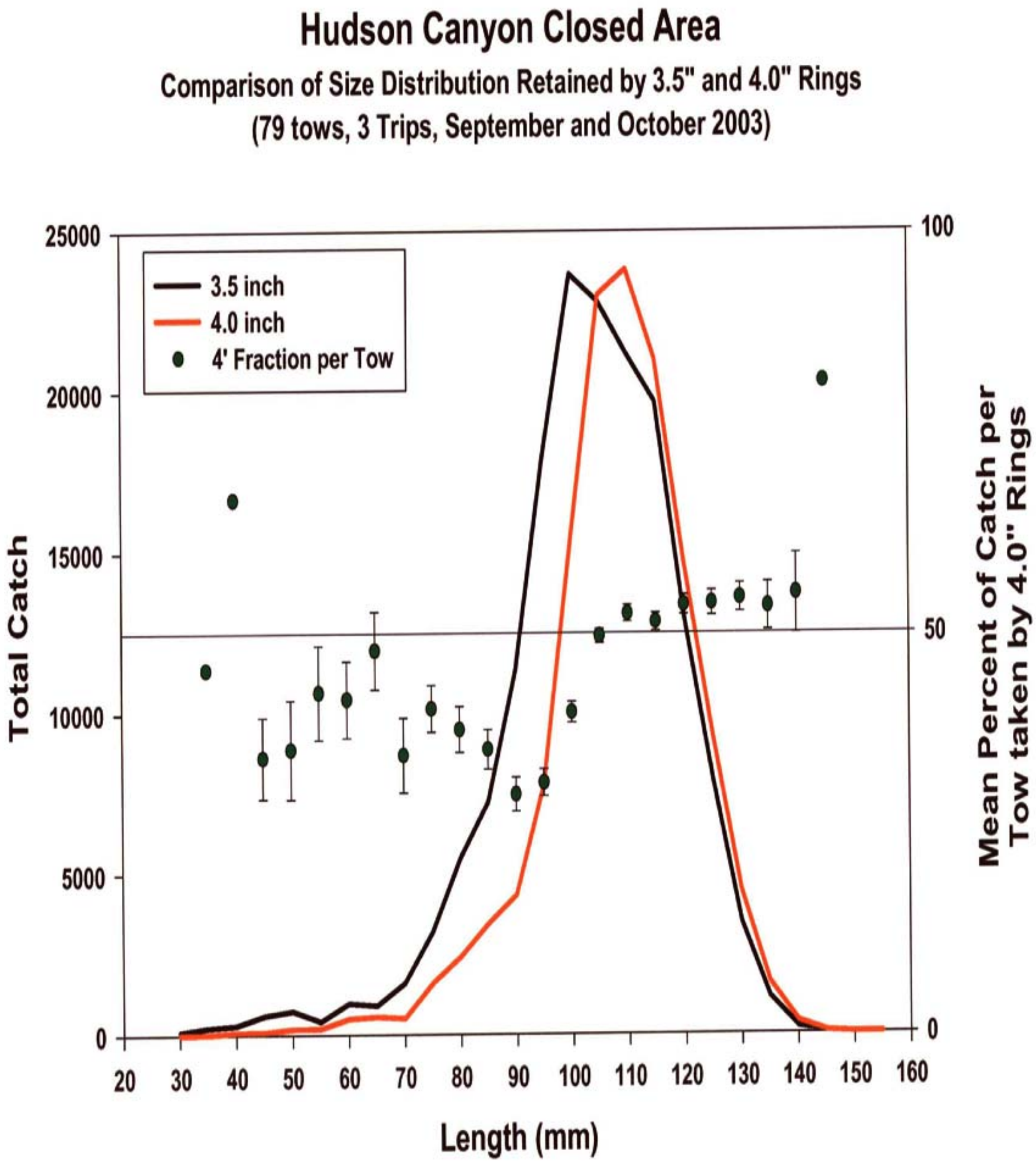



*Figure 3. Comparison of the efficiency of a 3.5 inch ring dredge and a 4 inch ring dredge with a turtle mat for scallops. (Adopted from DuPaul et al. 2004 with permission).*


*Figure 4. Turtle exclude scallop dredge frame design (with permission from R. Smolowitz).*


*Figure 5. Seven foot hydrodredge developed at M.I.T. (Goudey et al 2006; used with permission).*

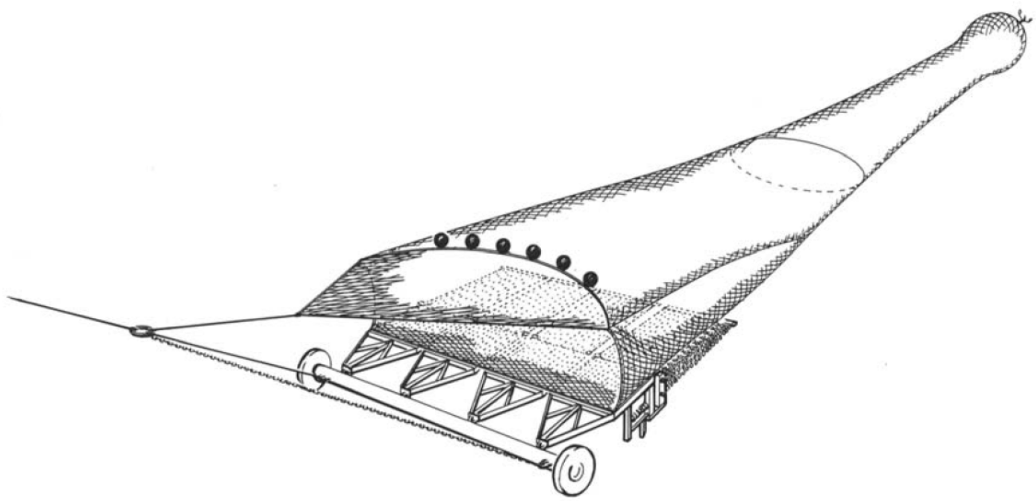


*Figure 6. Line drawing of the 'top net' in position over a gang of four queen dredges (ECODREDGE Report, Lart 2003 used with permission).*

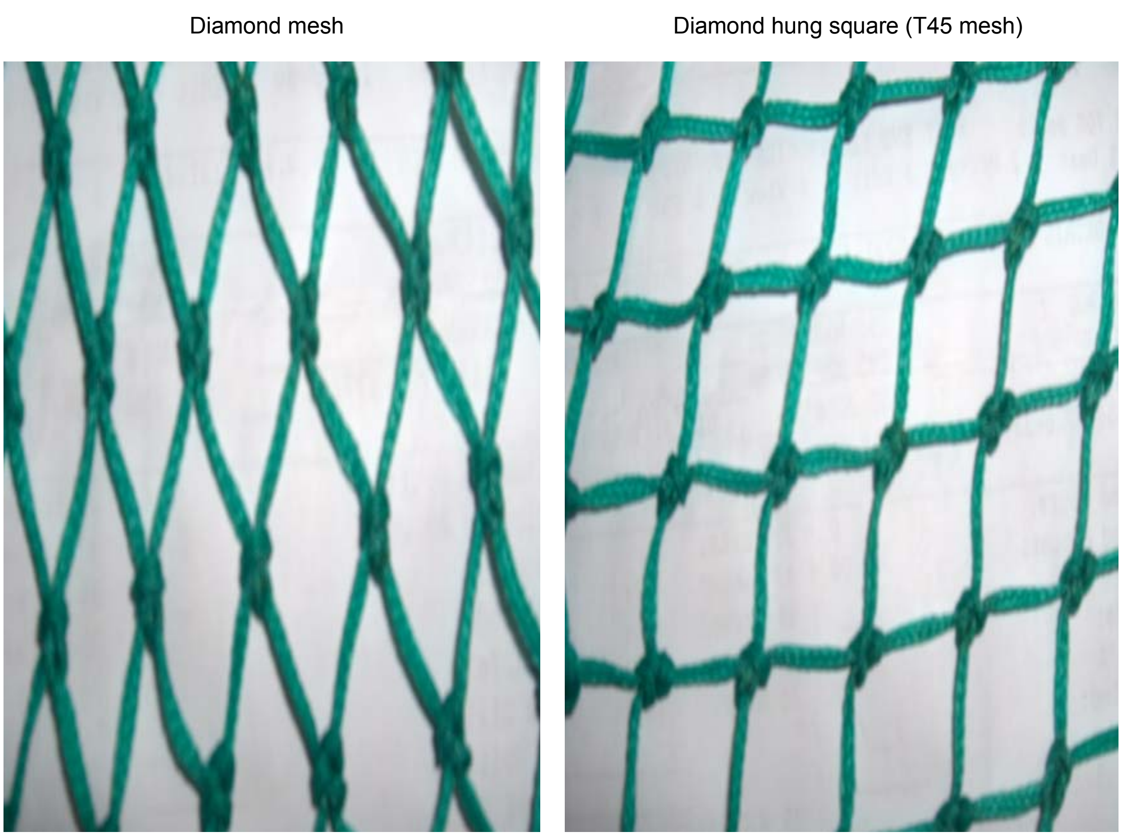



*Figure 7. Difference in mesh opening for the same netting. Left photo is normal knotted diamond mesh and right photo is a knotted diamond mesh hung square, i.e., rotated 45 degrees. The netting is not under load.*

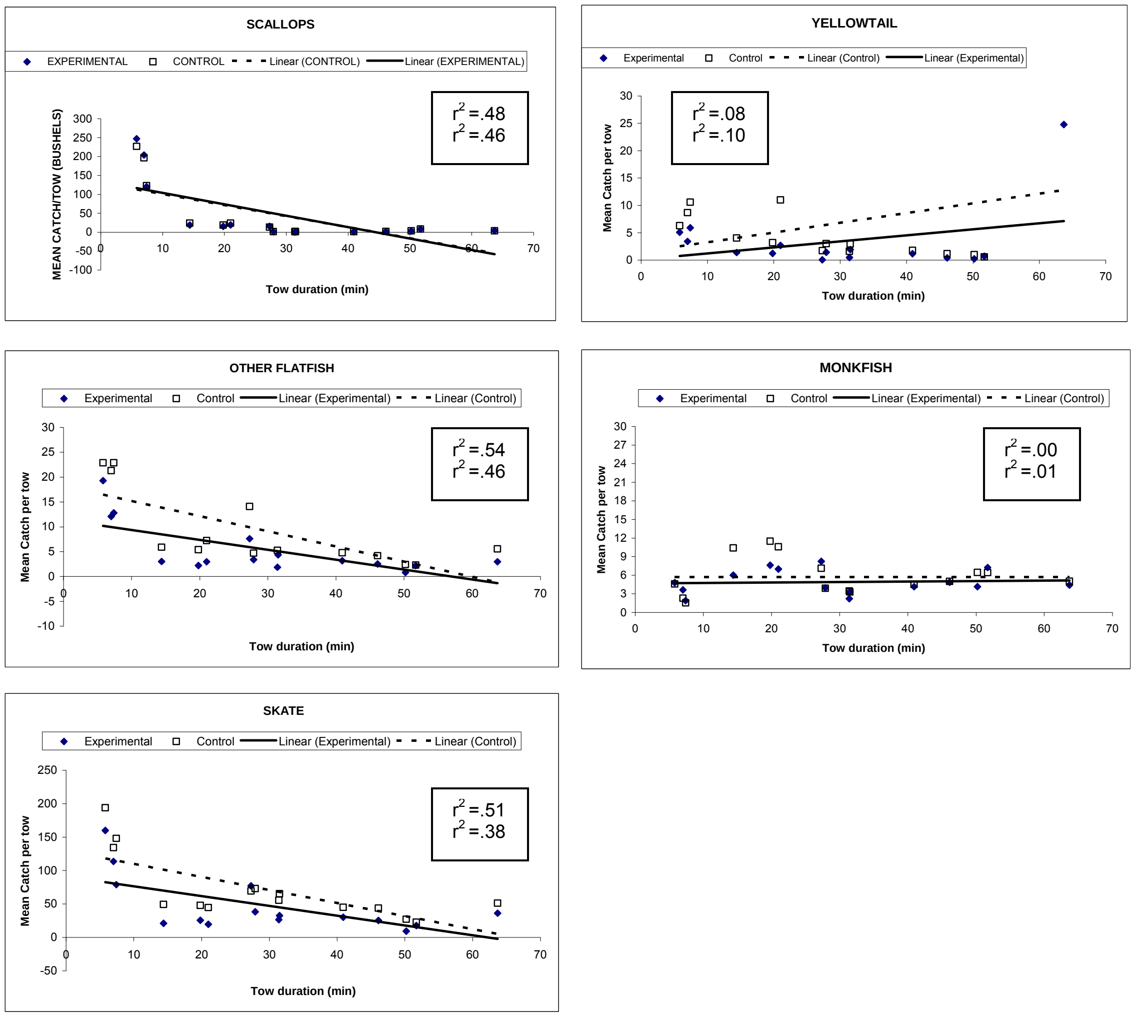



*Figure 8. The effect of tow duration on catch rates in the experimental and control dredges using data from Smolowitz et al. 2004. The first* ***'r²'*** *is the fit for the control dredge and the second one is the model fit for the experimental dredge.*

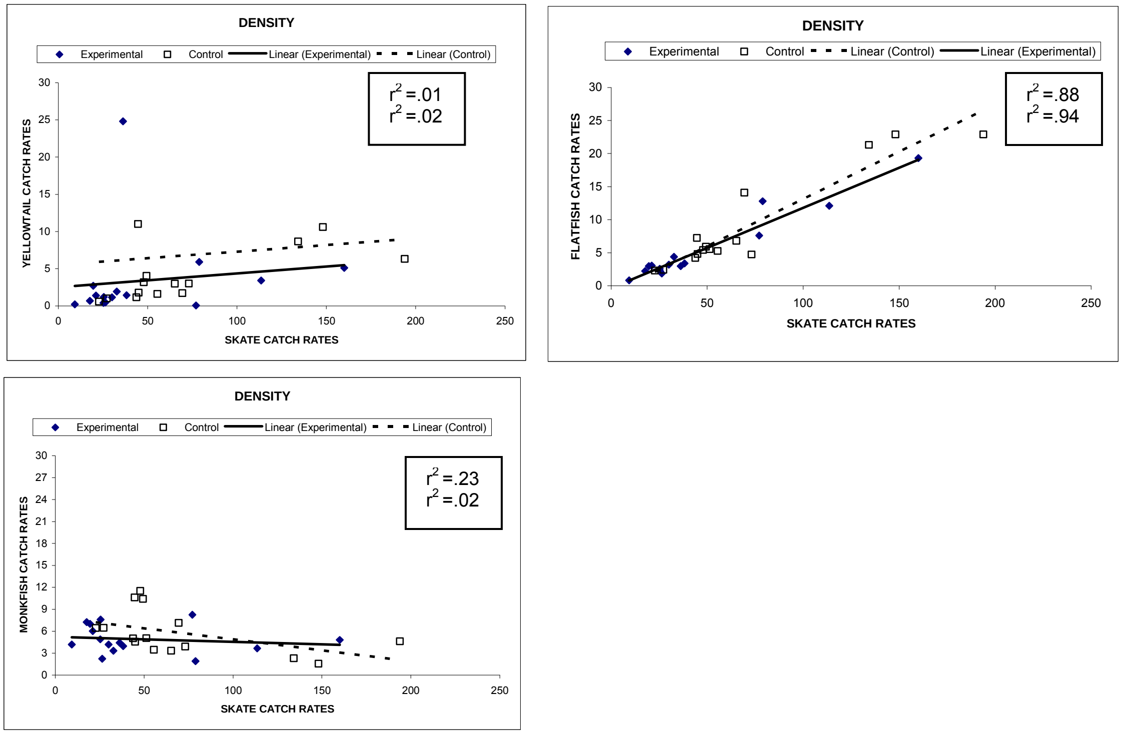



*Figure 9. The relationship between catch rates of yellowtail flounder, flatfish and monkfish with skate catch rates using data from Smolowitz et al. 2004. The first* ***'$r^2$'*** *is the fit for the control dredge and the second one is the model fit for the experimental dredge.*

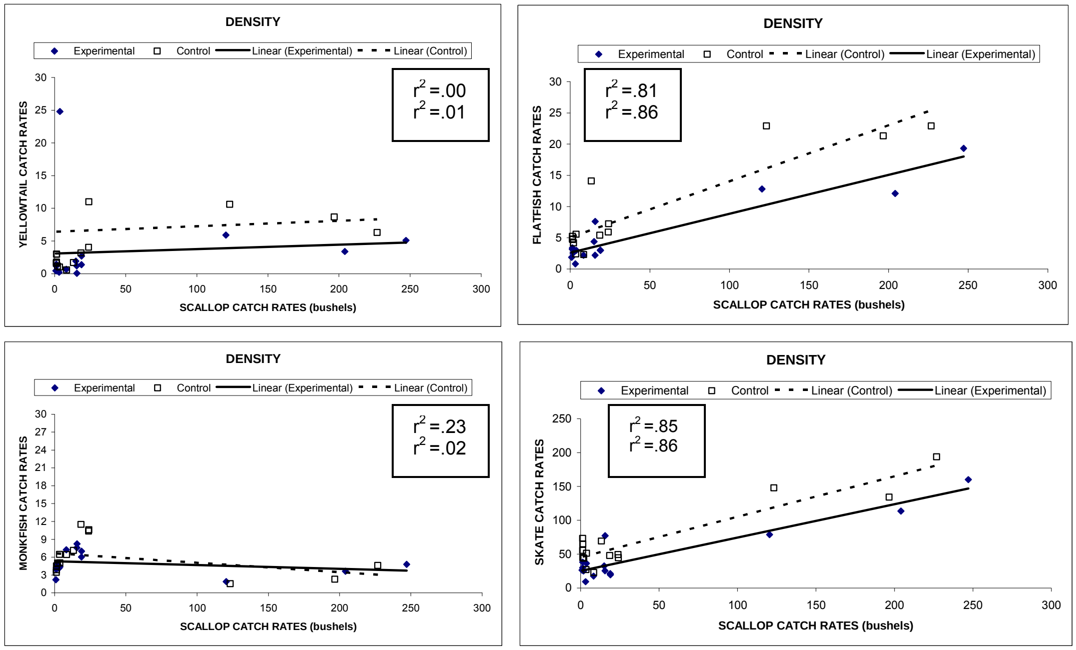



*Figure 10. The relationship between catch rates of yellowtail flounder, flatfish, skate and monkfish with scallop catch rates using data from Smolowitz et al. 2004. The first* ***'$r^2$'*** *is the fit for the control dredge and the second one is the model fit for the experimental dredge.*

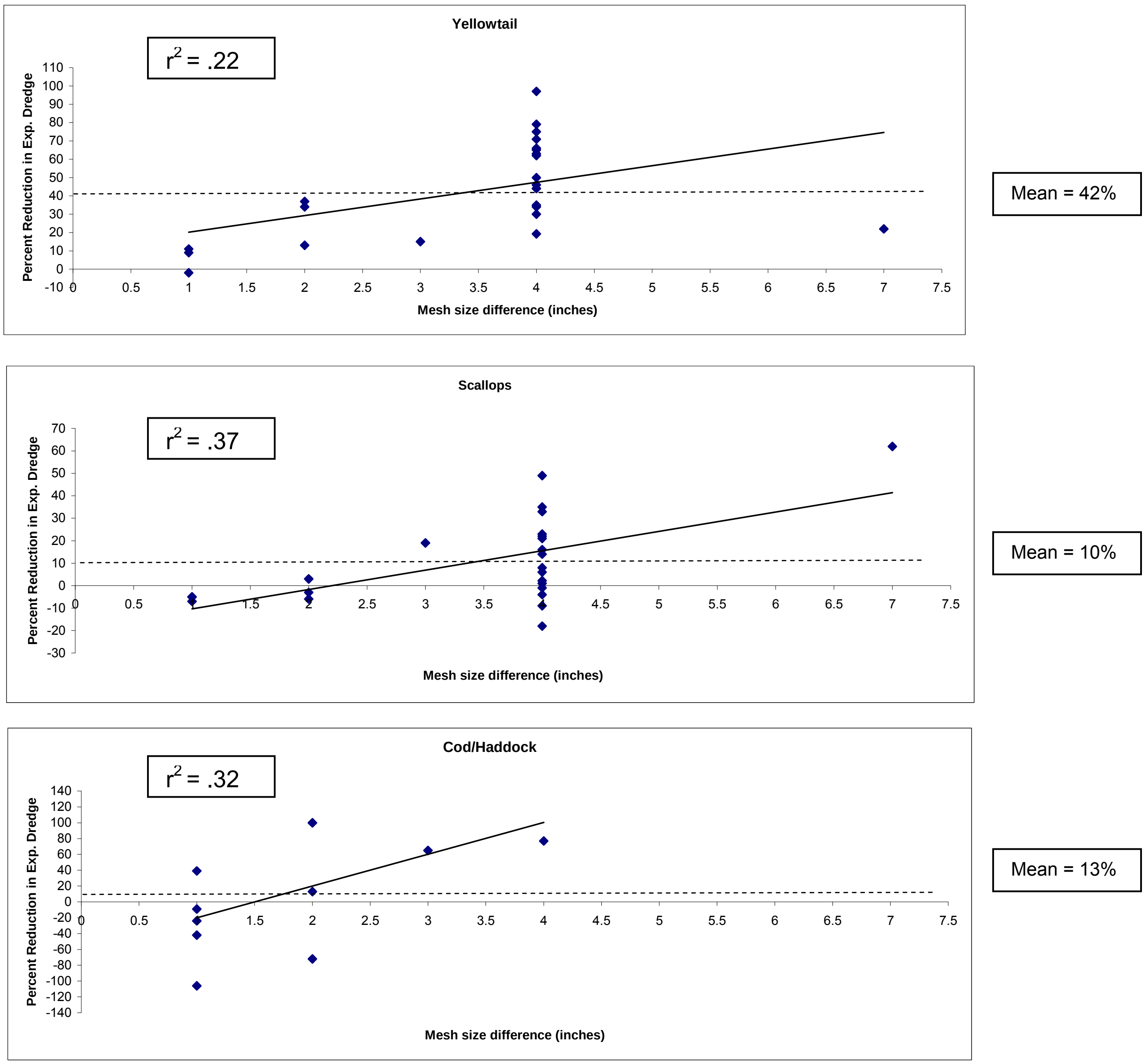
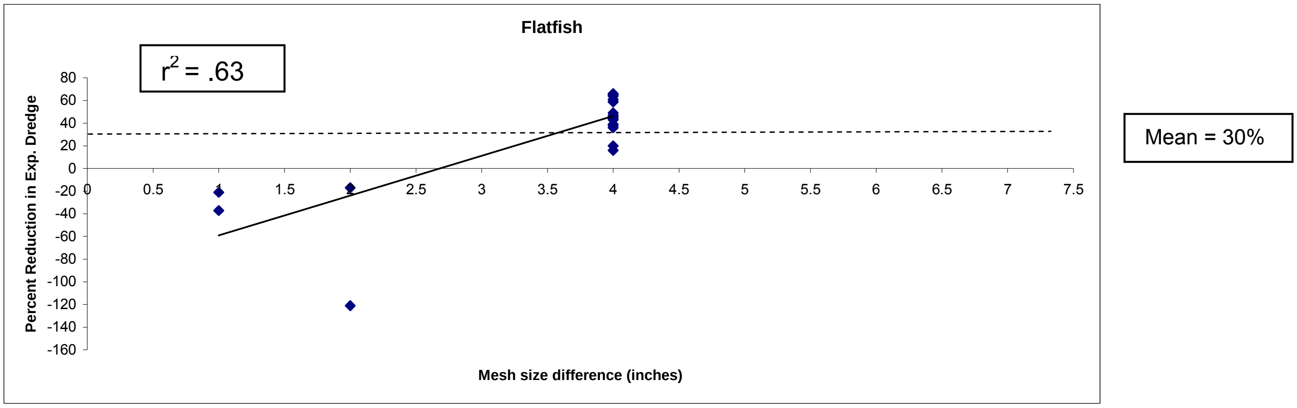



*Figure 11. The relationship between percent reduction in the experimental dredge catch rates for yellowtail flounder, scallops combined cod and haddock and skates and difference in mesh size (experimental-control). Dash line represents overall mean percent reduction from Table 9.*



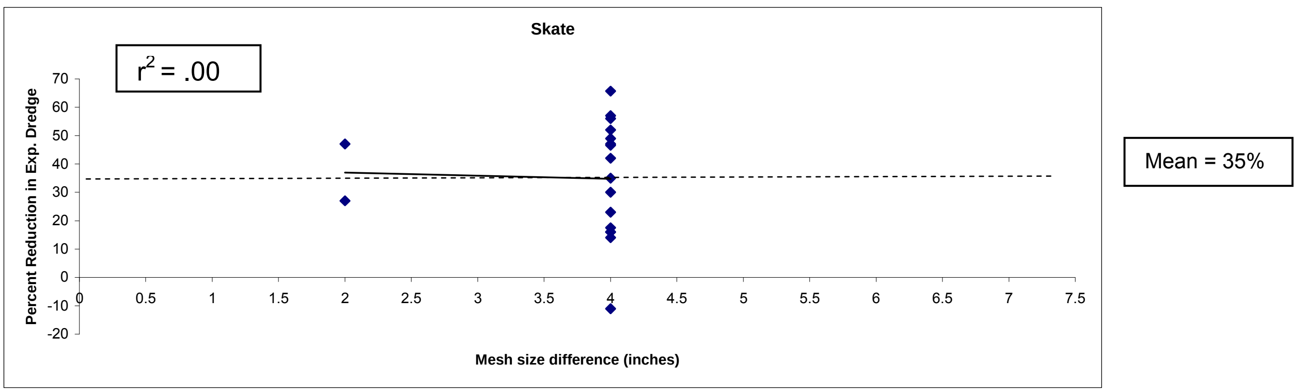




*Figure 11. Continued.*

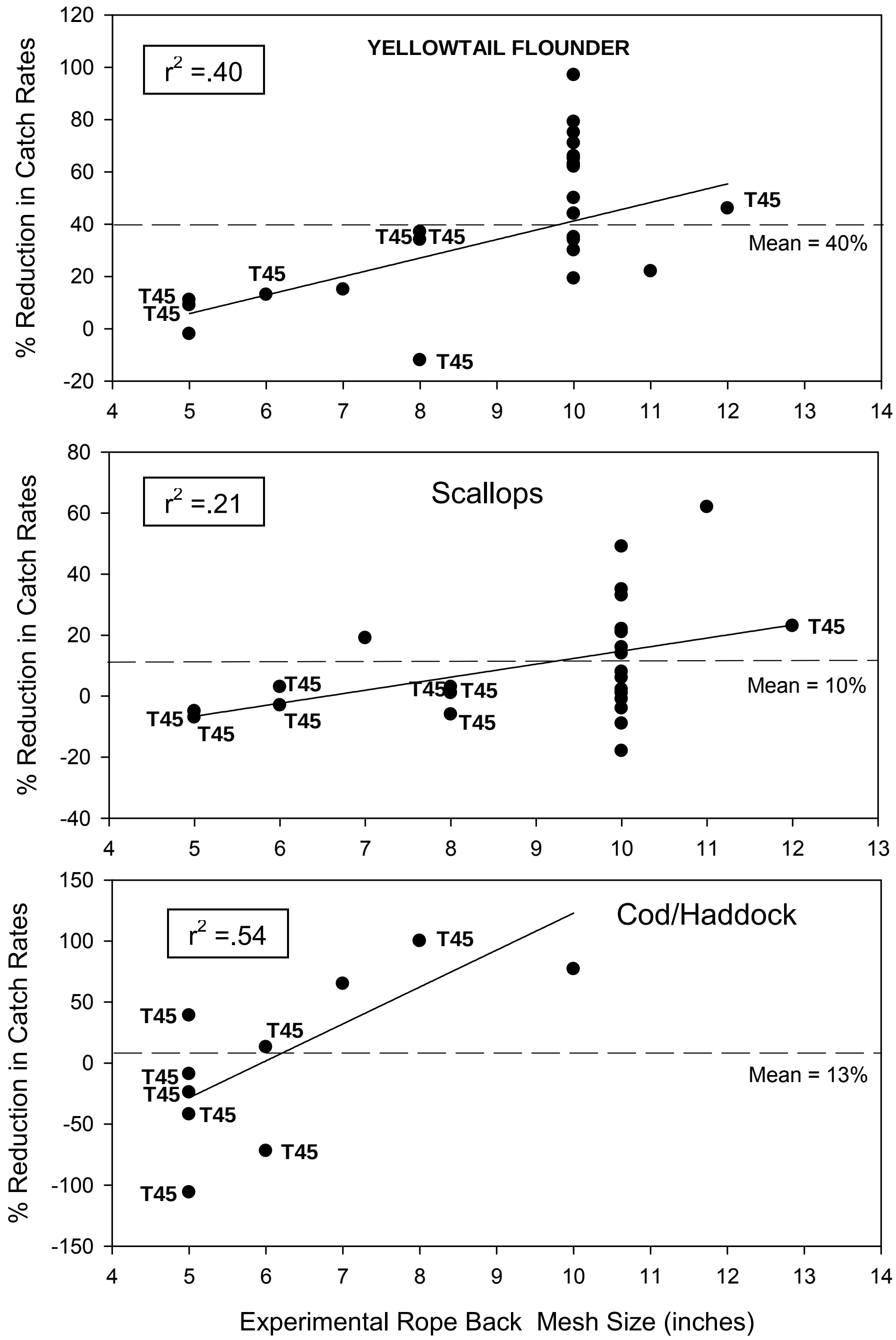



*Figure 12. The relationship between percent reduction in experimental dredge catch rates for yellowtail flounder, scallops, combined cod and haddock and skate. DuPaul et al. (1999) data for 8 inch T45 mesh are included which was deleted in Figure 11 and hence the mean percent reductions are slightly different. All T45 meshes are denoted to separate them from diamond mesh rope backs.*

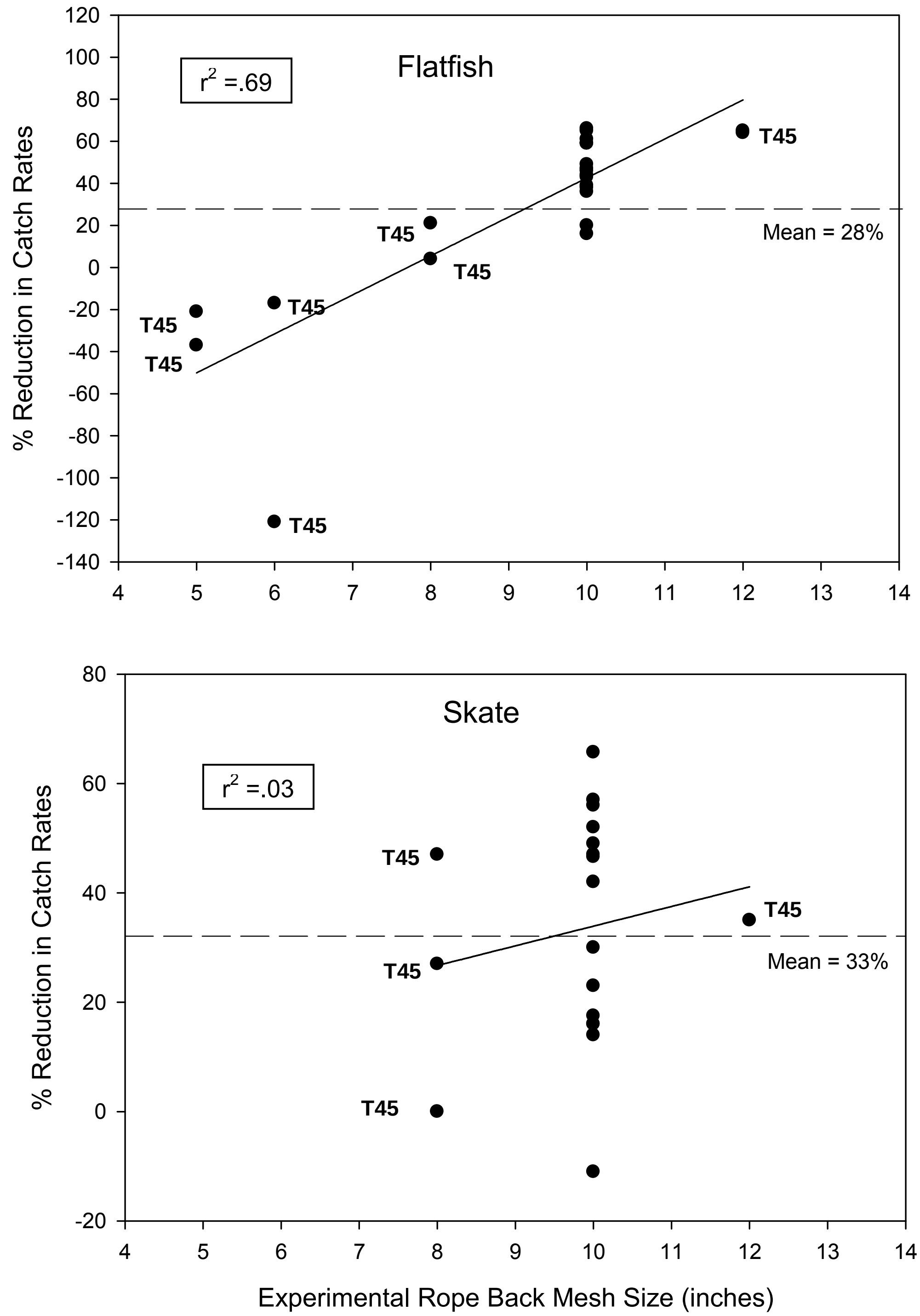



*Figure 12. Continued.*