Do Silent Ships See More Fish?

Comparisons of Walleye Pollock Backscatter Recorded by a Conventional and a Noise-Reduced Research Vessel in Alaska

by Alex De Robertis, Christopher D. Wilson and Neal J. Williamson

Figure 1. The NOAA ships *Miller Freeman* (left) and *Oscar Dyson* (right) in Dutch Harbor, Alaska. Although the ships are of similar length, the *Dyson* has approximately 30% more displacement and approximately 40% more horsepower. Photo by Alex De Robertis.

It has been widely reported that, under some circumstances, fish detect and avoid approaching vessels. A sizeable body of work has demonstrated that fish respond to vessels by diving towards the seafloor or by moving horizontally out of the vessel's path. These reactions are often initiated well before the vessel passes over the fish. Such vessel-induced avoidance behavior is potentially a major source of error in surveys of fish populations; this has led to concern that vessel avoidance will bias survey results used in fish stock assessments. Acoustic surveys estimates are thought to be particularly vulnerable to vessel avoidance as only those fish directly below the vessel are enumerated, and the intensity of the acoustic return from a fish is strongly dependent on the orientation of the fish.

Avoidance behavior appears to be variable, with a given species exhibiting strong avoidance reactions to vessels in some cases and no response in others. For fish to avoid a vessel at a distance, the stimulus triggering avoidance must propagate away from the vessel in order to be detected by the fish before the vessel arrives. Given that sound propagates a long distance in water and that fish are generally most sensitive to sound in the frequency range at which the underwater sound radiated from ships is most intense (10–500 Hz), the stimulus for this avoidance behavior is thought to be auditory.

The concern that vessel noise induces fish avoidance led to the formulation of recommendations for maximum underwater-radiated noise levels produced by research vessels. These recommendations, developed by the International Council for the Exploration of the Seas (ICES), include guidelines for low frequency noise limits to minimize fish avoidance reactions and also higher frequency limits intended to maximize the performance of acoustic instruments. The specifications for radiated noise were based on the hearing capabilities of Atlantic herring (*Clupea harengus*) and Atlantic cod (*Gadus morhua*), two species with sensitive hearing; the recommendation is therefore expected to minimize noise-induced vessel avoidance for other species as well. In practice, the recommendations for cod and herring at a vessel speed of 11 knots (hereafter referred to as the ICES recommendation) have been used as a contractual benchmark for specification and construction of new research vessels.

Several vessels have been constructed to comply with the ICES radiated-noise limits. Specialized vessel designs, including quiet hull designs, diesel-electric propulsion, and fixed-pitch propellers have resulted in substantial reductions in noise levels over a wide frequency range (10–50,000 Hz). Although several nations have invested in vessels conforming to the ICES recommendation for radiated noise, there has only been a single study directly evaluating the effectiveness of a noise-reduced vessel in terms of reducing fish avoidance. This recent study compared avoidance reactions

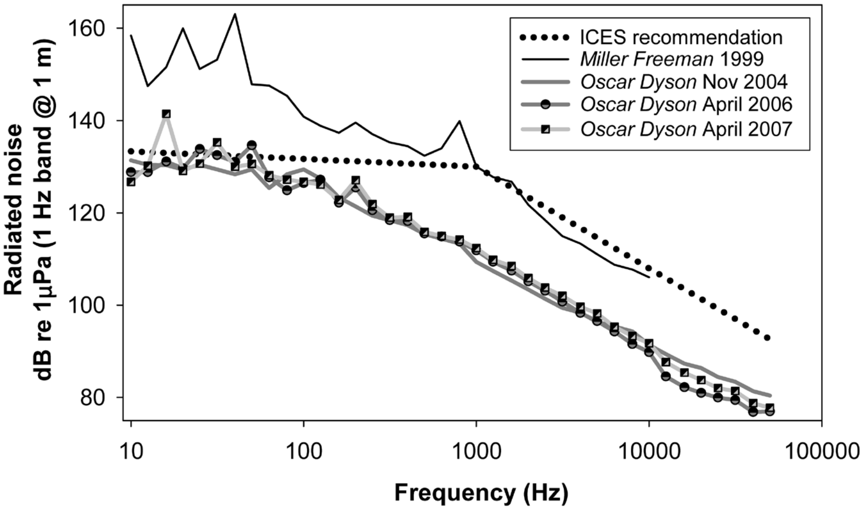

Figure 2. Underwater radiated-noise signature of the NOAA ships *Miller Freeman* and *Oscar Dyson* at speeds of 11 knots plotted along with the ICES recommendation for noise emission by research vessels.

of Norwegian over-wintering herring to a conventional research vessel with avoidance reactions to a larger but much quieter noise-reduced research vessel. The study revealed that although echosounders aboard both vessels detected similar amounts of herring backscatter, the herring performed stronger diving responses when approached by the noise-reduced vessel. This unexpected finding indicates that the stimuli causing vessel avoidance and, therefore, the efficacy of noise-reduction in minimizing avoidance responses under survey conditions remain poorly understood.

The National Oceanic and Atmospheric Administration (NOAA) is building four noise-reduced fisheries research ships of a single design that are intended to conform to the ICES recommendations for underwater radiated noise. The first of these, the NOAA ship *Oscar Dyson*, operates in the North Pacific, where it is scheduled to replace the conventional (i.e., not noise-reduced) NOAA ship *Miller Freeman* as the primary vessel used to continue a long time-series of acoustic-trawl assessment surveys of walleye pollock (*Theragra chalcogramma*) in Alaska. Because the *Oscar Dyson* is a noise-reduced vessel whereas the *Miller Freeman* is not, there is concern that biomass indices derived from the two vessels will differ. To ensure consistent results as the acoustic surveys transition to the *Dyson*, the Alaska Fisheries Science Center's (AFSC) Midwater Assessment and Conservation Engineering (MACE) program has undertaken a series of field experiments designed to establish if walleye pollock differentially avoid the two ships. Four different acoustic surveys of walleye pollock are routinely conducted by the AFSC: a summer survey of the eastern Bering Sea, and winter surveys of prespawning fish in the vicinity of Bogoslof Island in the Bering Sea, and Shelikof Strait and the Shumagin Islands in the Gulf of Alaska. The potential for differential vessel avoidance has been evaluated separately in each survey area as the walleye pollock in these surveys differ markedly in their depth distribution, age-structure, reproductive state, and environmental conditions.

Methods

Vessels: The *Oscar Dyson* and *Miller Freeman* are stern trawlers built for fisheries research (Fig. 1). The Dyson was designed with noise-control measures such as diesel-electric propulsion, a large fixed-pitch propeller, and sound-dampening material to meet the ICES noise specification maxima. The *Miller Freeman* was built with more conventional geared diesel propulsion but was retrofitted with a new propeller, which reduced the radiated noise signature, particularly at high frequencies.

The *Freeman* exceeds the ICES recommendation at frequencies less than 2,000 Hz, which are thought to cause avoidance reactions by fish, but it meets the ICES recommendation at the higher frequencies specified to maximize echosounder performance (Fig. 2). The *Dyson* met the ICES recommendation for radiated noise when it was delivered in 2004 but exceeded the recommendation at several low-frequency bands when measured in 2006 and 2007 (Fig. 2). The changes in these repeated measurements highlights the challenges of maintaining the noise signature of noise-reduced research vessels over time. Given the temporal variability in radiated noise produced by the *Dyson* and the fact that the radiated noise produced by the *Freeman* has likely changed since noise measurements were last made in 1999, these noise signatures should be viewed as approximate. Despite the uncertainty in the exact noise signature of the vessels during the comparison, it is clear that the *Oscar Dyson* is much quieter than the *Miller Freeman* over a broad frequency range.

This difference in radiated noise may have important consequences for walleye pollock responses to the vessels. The method used to generate the ICES recommendation predicts that walleye pollock will avoid the *Miller Freeman* at a range of approximately 75 m and the *Oscar Dyson* at a range of approximately 20 m, based on radiated noise levels at approximately 100 Hz when the vessels are moving at 11 knots. Although there are several assumptions inherent in these calculations, the predictions illustrate the potential for walleye pollock to exhibit differential avoidance responses to the two vessels due to differences in underwater radiated-noise levels produced by the vessels.

Study Design: Experiments comparing acoustic estimates of walleye pollock abundance observed by the *Oscar Dyson* and *Miller Freeman* were conducted concurrently with established MACE assessment surveys of walleye pollock. Five experiments were conducted in the four distinct areas where walleye pollock are surveyed (Fig. 3). Two experiments were conducted on nonspawning walleye pollock during the summer on the eastern Bering Sea shelf (3-13 July 2006 and 26-31 July 2008). In addition, experiments during surveys targeting prespawning walleye pollock were conducted in the Gulf of Alaska in the vicinity of the Shumagin Islands (6-15 February 2008) and Shelikof Strait (11-24 March 2007) and in the Bering Sea in the vicinity of Bogoslof Island (1-9 March 2007).

The experiments followed a two-part design where the vessels 1) were arranged side by side during the survey transects (side-by-side transects), or 2) conducted a series of transects in which one vessel led and the other followed behind the leading vessel (follow-the-leader transects). During the side-by-side transects, one vessel con-

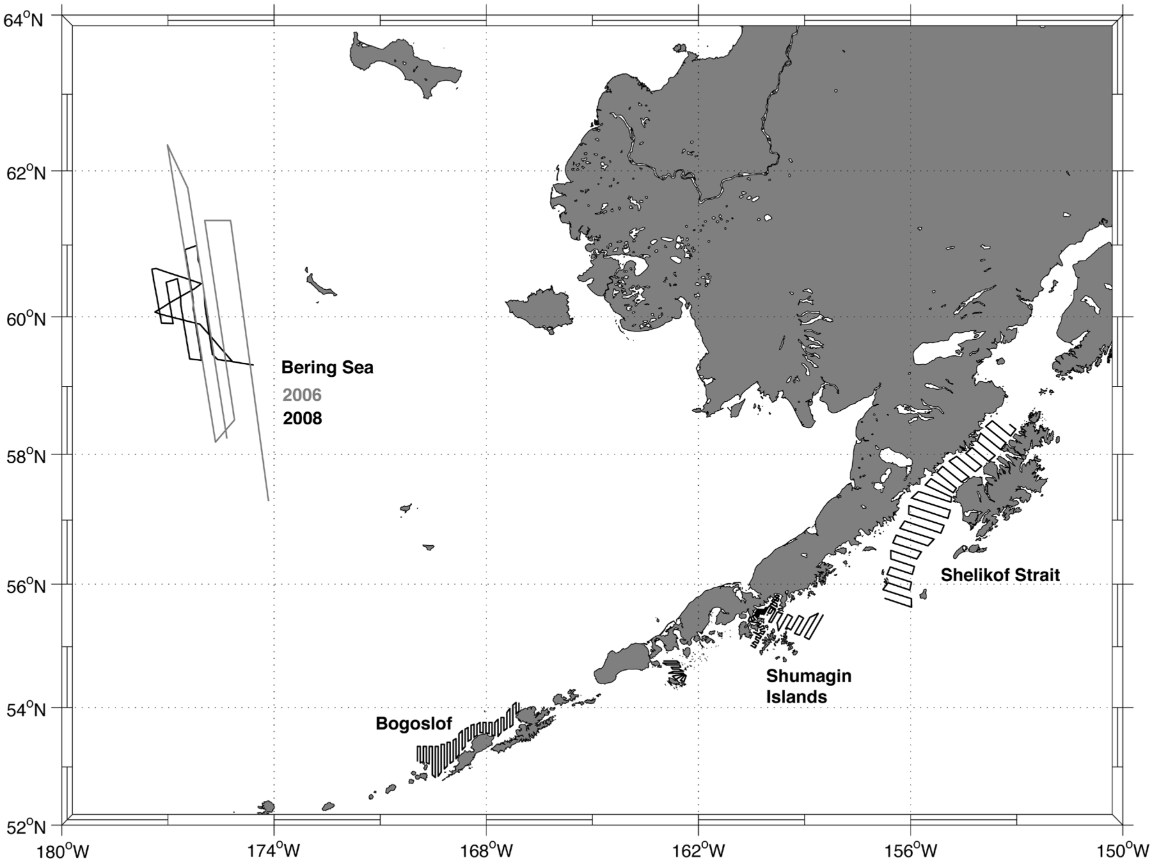

Figure 3. Map showing side-by-side transects conducted as part of the vessel comparison experiments.

ducted an acoustic survey using standard protocols along equally spaced transects. The accompanying vessel was laterally displaced by 0.5 or 0.7 nautical miles (nmi) to the side of the survey vessel (Fig. 4A). The 0.5 nmi separation was chosen based on the difference in vessel's radiated noise such that fish in the vicinity of one vessel are unlikely to be influenced by auditory stimuli produced by the accompanying vessel. For the Bogoslof and Shelikof surveys, which are conducted in deep water, the separation was increased to 0.7 nmi to eliminate acoustic interference between echosounders. The direction of the displacement of the accompanying vessel (i.e., left or right) was selected at random for each survey transect. The side-by-side transects were periodically interrupted to conduct a series of 5-nmi-long follow-the-leader transects oriented in an east/west direction and spaced 0.5 nmi apart. For each transect, the lead vessel was assigned randomly. The other vessel followed at a distance of 1 nmi and was offset to starboard by 0.1 nmi (Fig. 4B). The paired acoustic data from both the side-by-side and follow-the-leader transects were analyzed in 5 nmi segments to compute the mean and 95% confidence interval of the vessel ratio (s_A, DY/s_A, MF), where s_A is a linear measure of acoustic backscatter from walleye pollock *Oscar Dyson* (DY) and *Miller Freeman* (MF).

During the Shumagin Islands survey, a dedicated experiment using an echosounder mounted in a free-floating buoy was conducted to characterize the behavioral responses of walleye pollock as they were approached and then passed by the *Dyson* and the *Freeman* (Fig. 4C). The vessels took turns passing the buoy at 15 min intervals. Each vessel approached the buoy from a distance of 1 nmi at survey speed (12 knots), passed within 10 m of the buoy, and then continued along a straight path for 1 nmi.

Results

Vessel Ratio*:* The side-by-side vessel ratio exhibited strong contrasts among study areas (Fig. 5). In the eastern Bering Sea where the fish were the shallowest (< 120 m), there was no significant difference in vessel ratio (i.e., the 95% confidence interval includes 1.0) in 2006 and 2008. This suggests that acoustic estimates from the *Dyson* and the *Freeman* were not different in this area. This was also the case for the Bogoslof area, where walleye pollock were distributed between 400 and 700 m.

However, significant differences were observed in the Shumagin Islands and Shelikof Strait, where the 95% confidence intervals did not include a vessel ratio of 1.0. The mean vessel ratio during the Shumagins experiment was 1.31, which indicates that acoustic abundance estimates from the *Dyson* were on average 31% higher. In Shelikof Strait, the mean vessel ratio was 1.13, indicating that acoustic backscatter estimates from the *Dyson* were 13% higher than those from the *Freeman*. The discrepancies in vessel ratio were greater for shallower fish, which is consistent with the expectation of a stronger response for fish closer to the vessels. The vessel ratios for the follow-the-leader transects were equivalent to those measured with the vessels side by side (results not shown).

Depth Distribution*:* Analysis of the observed depth distribution of walleye pollock backscatter revealed that the depth distribution of walleye pollock differed between the vessels. In all cases, when the *Dyson* led during the follow-the-leader experiments, the *Dyson* detected walleye pollock to be

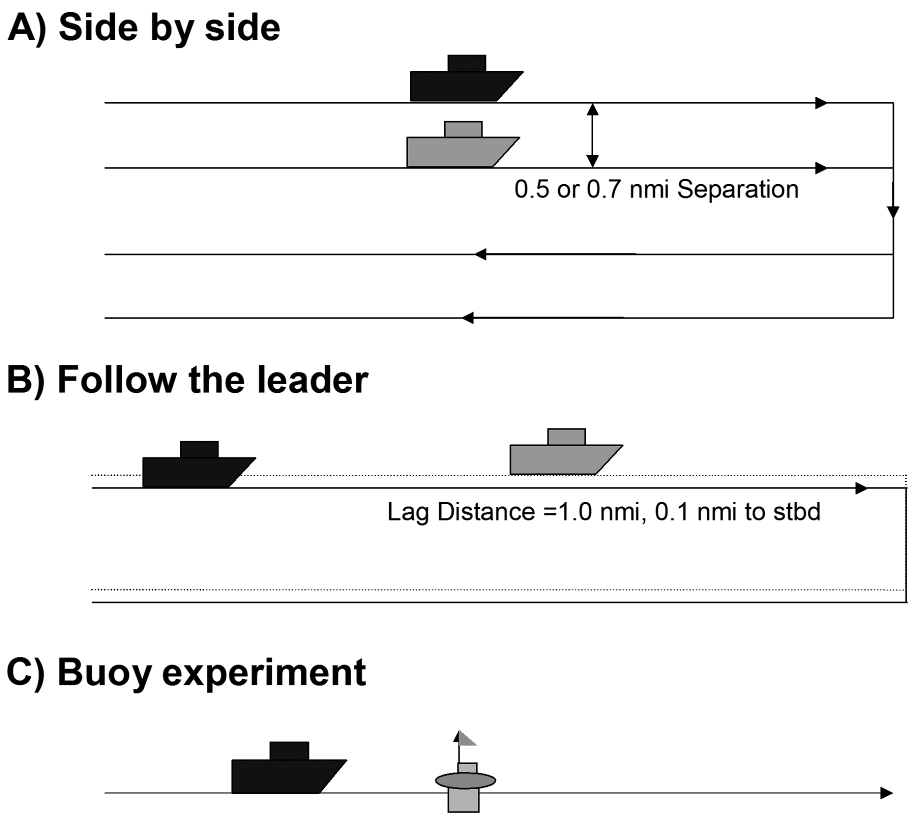

Figure 4. Vessel configurations used in the vessel comparison experiments. A) Side-by-side configuration for paired vessel measurements; B) Follow-the-leader configuration for paired vessel measurements; and C) Buoy experiment in which vessels sequentially pass a free-drifting buoy used to monitor fish behavior.

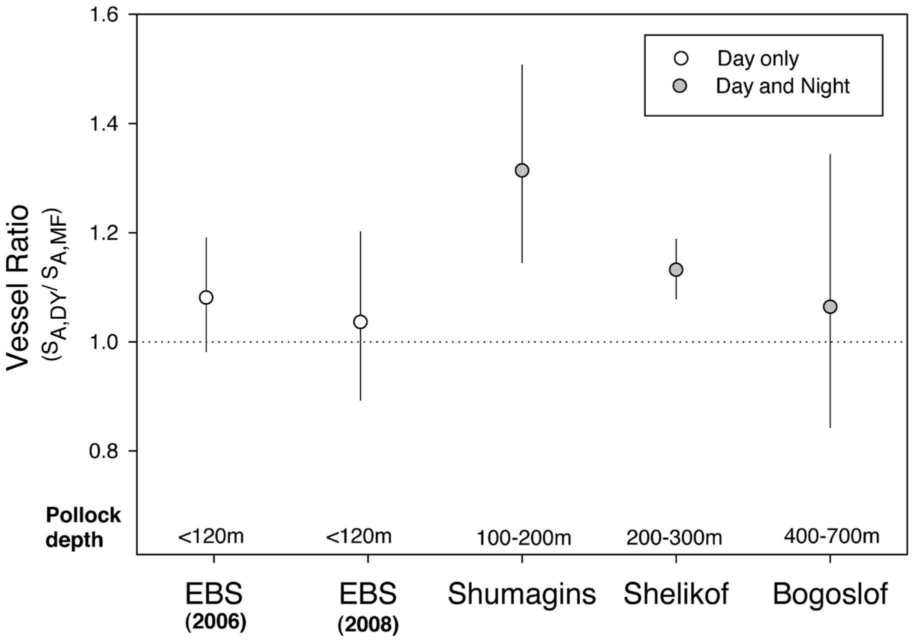

Figure 5. Estimated vessel ratios (*Oscar Dyson*/*Miller Freeman*) with 95% confidence intervals for the side-by-side transects from each experiment. A vessel ratio >1 indicates that the *Oscar Dyson* detected more walleye pollock backscatter than the *Miller Freeman*. Cases in which the 95% confidence interval does not include 1 imply a significant difference between vessels. Daytime measurements are shown for the eastern Bering Sea (EBS) survey, which is conducted during daytime hours only, whereas the other surveys are conducted both day and night. The approximate depth range of most of the walleye pollock in each study area is noted.

shallower than those observed in the corresponding observations from the *Freeman* (e.g., Fig. 6). The observations in other vessel configurations were not consistent among the study areas. Although the results do not suggest a simple explanation for the exact cause of the observations, the key points are that there are vessel differences in walleye pollock depth estimates in at least one of the side-by-side and follow-the-leader vessel configurations and that these depth differences become weaker with depth. This provides additional evidence that walleye pollock exhibit differential behavioral responses to the vessels, as one would expect no differences in vertical distribution if responses to the vessels were equivalent.

Buoy Observations: The acoustic records from the buoy confirmed that walleye pollock exhibited a stronger avoidance response to the *Miller Freeman* than to the *Oscar Dyson* in the Shumagin Islands. When the *Freeman* approached the buoy, the fish, particularly in shallower strata, began to dive prior to the vessel's arrival at the buoy (Fig. 7A). This response to the *Freeman* was greater than when the *Dyson* approached and passed the buoy (Fig. 7B). The averaged response for all buoy passes indicates that in this situation, when the *Dyson* approached the buoy, there was a smaller reduction in backscatter strength at the closest point of approach (CPA) compared to the case where the *Freeman* passed the buoy (Fig. 7C). In the upper 125 m, where the reaction is more evident, walleye pollock backscatter at the time the *Dyson* passed the buoy was reduced by an average of 15% compared to a reference period prior to arrival, while backscatter dropped by an average of 29% when the *Freeman* passed (Fig. 7C). The reduction in backscatter over the entire water column was 7% for the *Dyson* and 13% for the *Freeman*. For both depth intervals, the *Freeman* exhibited a significant difference ($p < 0.05$) between the reference period and vessel passage while the *Dyson* did not ($p > 0.05$). There was also a small (mean = 2.1 m) but significant increase in overall pollock depth from the reference period when the *Freeman* passed ($p < 0.05$), but not when the *Dyson* passed.

Discussion

This study demonstrates that a noise-reduced vessel designed to minimize fish avoidance detected more fish than a conventional (i.e., non-noise reduced) vessel under some survey conditions. Specifically, more walleye pollock backscatter was observed aboard the *Oscar Dyson* than aboard the *Miller Freeman* in the Shumagin Islands and Shelikof Strait in paired and spatially randomized transects. The mean difference was estimated as 31% higher backscatter for the *Dyson* in the Shumagins and 13% higher in Shelikof Strait, and the 95% confidence intervals of the vessel ratio excluded 1.0 in both cases. In addition, the vessel ratio tended to be higher for the shallowest walleye pollock in a given area, which is consistent with a reaction to a stimulus that is stronger for fish closer to the vessel. In replicate experiments in the Bering Sea as well as in the Bogoslof area, no significant differences in vessel ratio were observed, which suggests that acoustic backscatter measurements of walleye pollock conducted aboard either vessel were equivalent there.

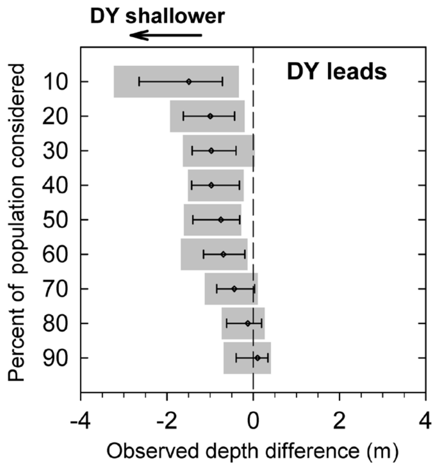

Figure 6. Example of differences in walleye pollock depth distribution observed in Shelikof Strait when the *Oscar Dyson* (DY) leads during the follow-the-leader transects. The bars and confidence intervals show the median and 95 % confidence interval of the observed difference in walleye pollock depth (i.e., Depth_{DY}-Depth_{MF}), while the gray boxes show the 25th and 75th percentile of observations. The depth difference is presented for the depth at which increasing proportions of the population are found starting from the surface. For example, the first bar indicates that the minimum depth at which the shallowest 10% of walleye pollock backscatter is found approximately 1.5 m shallower for the *Oscar Dyson* than for the *Miller Freeman*. The *Dyson* consistently detects walleye pollock as shallower than the *Freeman* in this vessel configuration, and the discrepancy decreases as greater (and thus deeper) proportions of the population are considered.

Analysis of walleye pollock depth distribution supports the inference of differential fish avoidance to the *Oscar Dyson* and the *Miller Freeman*. Although the differences in walleye pollock depths observed by the *Dyson* and the *Freeman* were not uniformly consistent among the study areas, we observed vessel-specific differences in depth distribution in all cases. These differences in depth distribution reinforce the inference from the analysis of vessel ratios that walleye pollock responded differently to the vessels.

The differential vessel avoidance observed during the Shumagins experiment was independently confirmed by an experiment conducted using a buoy-mounted echosounder. When the *Miller Freeman* passed the buoy, larger decreases in backscatter intensity and an increased diving response were observed compared to when the *Oscar Dyson* passed. This suggests a stronger avoidance response to the *Freeman*, which is consistent with the results of the Shumagin paired-transect comparison. In addition, these buoy observations indicate that in an absolute sense, walleye pollock responses to the *Dyson* are small. This work is a key complement to the vessel comparison approach, as vessel comparison can only be used to estimate relative differences. For example, vessel comparison cannot be used to distinguish between the cases where there is a large but equivalent avoidance response to both vessels or no response to both vessels.

In locations where discrepancies in walleye pollock backscatter measurements were observed, they tended to be associated with fish depth. For example, if one considers the prespawning surveys in isolation, the discrepancy between vessels was highest in the Shumagin Islands area where the walleye pollock are relatively shallow, intermediate for Shelikof Strait where the fish are deeper, and no difference was observed in Bogoslof where walleye pollock are found at depths greater than 400 m. Additionally, in the case of Shumagins and Shelikof where significant differences were detected, the discrepancy was larger for the shallower portions of the population. However, the results in the eastern Bering Sea where pollock are found at relatively shallow depths (< 120 m) make it clear that depth is not the only explanatory factor as there was no significant difference in backscatter between vessels.

Although little is known about the factors that influence how fish react to perceived vessel stimuli, it is clear that many factors modulate how fish and other organisms respond to predators. These factors may be related to environmental conditions or the internal state of the fish, such as feeding history, maturity state, or exposure to predators. For example, feeding history and recent history of encounter with predators are well known to affect anti-predator behavior—hungry organisms and those with little recent exposure to predators tend to be less risk averse and less vigilant. Reactions to vessels are likely a response to a sensory stimulus perceived as a threat, and responses to vessels could also be modulated by these factors.

The vessel comparisons reported here were conducted under different environmental conditions, with walleye pollock of different ages, sizes, and reproductive condition, which likely had different histories of feeding and exposure to predators, vessel traffic, and commercial fishing. All of these factors may have influenced the likelihood that walleye pollock will respond to the approaching research vessels. It is possible, for example, that differences in reproductive state may partially explain the difference between the summer and winter walleye pollock observations, as walleye pollock are not in spawning condition during the summer. However, the vessel ratio exceeded 1.0 in areas of the Shumagin Islands where immature age-1 walleye pollock were dominant, which suggests that reproductive condition alone is insufficient to explain the observed differences. It is clear that vessel avoidance is a complex process that remains difficult to predict, and that directed efforts will be required to identify the factors that elicit vessel avoidance and the factors that influence how fish respond to the stimuli they perceive.

This study is the first explicit demonstration that noise-reduction can reduce vessel avoidance compared to a conventional vessel. From previous studies, it is clear that vessel avoidance behavior is variable, and current understanding of the processes influencing the behavior is insufficient to accurately predict the cases in which vessel avoidance will occur and to predict the strength of the response. The study was not designed to identify the stimuli which triggered walleye pollock to respond. However, radiated noise is an obvious candidate as the *Oscar Dyson* was built to conform to

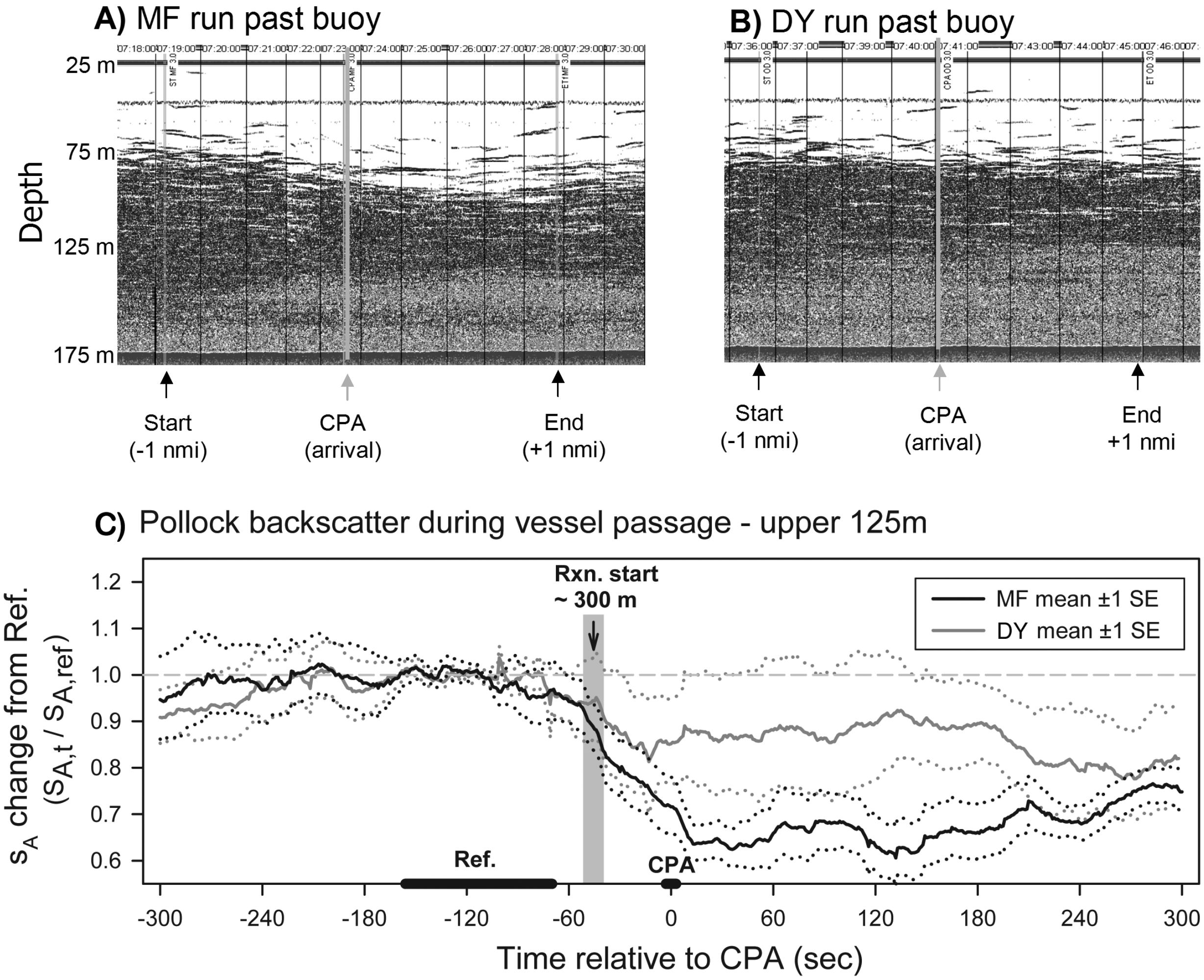

Figure 7. Observations of walleye pollock abundance from the buoy-mounted echosounder as vessels sequentially approach the buoy from a distance of approximately 1 nautical mile (nmi) until reaching the closest point of approach (CPA) to the buoy (~10 m) then continue this course until approximately 1 nmi away from the buoy. A) Example echogram as the *Miller Freeman* (MF) runs past the buoy. B) Example echogram as the *Oscar Dyson* (DY) runs past the buoy. The *Freeman* can be seen to disturb the shallowest walleye pollock prior to arrival, while this is not clear for passage of the *Dyson*. C) Averaged response for all buoy passes (MF n = 7, DY n = 6) showing changes in backscatter from a reference period as the vessels approach and pass the buoy. Results are shown for walleye pollock at depths of less than 125 m. The gray bar shows that the fish begin to respond about 45 sec prior to vessel passage, which is approximately 300 m prior to CPA.

the ICES recommendation and is substantially quieter than the *Miller Freeman* over a broad frequency range, including the range where pollock have sensitive hearing. Although this is a reasonable working hypothesis, other factors such as near-field particle acceleration or infrasound, which have been suggested as potential stimuli, should not be discounted. The vessel-specific differences in acoustic survey results have implications for management of walleye pollock, which form the basis of a considerable fishery. In the case of the Shumagin Islands and Shelikof Strait abundance surveys, the acoustic estimates of abundance from the *Oscar Dyson* are expected to be higher than those conducted by the *Miller Freeman*. This result illustrates that there may be a 'vessel effect' and that differential biases can be introduced into a time series by switching vessels, particularly in the case where the change involves a noise-reduced vessel designed to minimize avoidance such as the newest generation of NOAA fisheries research ships.

Acknowledgments

This work resulted from the collaborative efforts of many dedicated people. V. Hjellvik from the Institute of Marine Research, Norway helped develop much of the statistical methodology. All the members of the MACE group made tangible contributions to this work, particularly S. Furnish, R. Towler, D. Twohig, M. Guttormsen, S. Stienessen, and P. Ressler. The officers and crew of the NOAA ships *Miller Freeman* and *Oscar Dyson* are thanked for their contributions and ship handling in what were often challenging conditions. This work would not have been possible without those who prepared the vessels for sea, including M. Bancroft, members of the Pacific Marine Center, and the U.S. Navy Carderock Division.