# Cooperative Research to Reduce the Effects of Bering Sea Flatfish Trawling on Seafloor Habitat and Crabs

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CONSERVATION ENGINEERING, as it relates to fisheries science, is the research and development process to bring new and innovative techniques to commercial fishing operations that reduce bycatch and other unintended effects on non-target components of the marine ecosystem. For more than 50 years, conservation engineering has been part of the mission of the Alaska Fisheries Science Center (AFSC) and its predecessors. Continuing those efforts, scientists from the Resource Assessment and Conservation Engineering (RACE) Division have actively collaborated with the Bering Sea flatfish fishing industry to develop fishing gear changes that reduce effects of flatfish trawling on seafloor habitats of the eastern Bering Sea shelf.

These conservation engineering efforts originally focused on modification to flatfish trawl gear to reduce impacts to benthic habitat. The techniques, however, also showed promise to reduce mortality rates of crabs that slip under the gear without being caught (unobserved mortality). The issue of unobserved trawl effects on crab has stirred controversy between flatfish trawlers and crabbers for years because of concern that unobserved crab mortalities reduced the abundance of crabs available to the crab fishery. Rates of unobserved mortalities would also be a key factor for crab stock assessment scientists to take into account in assessing factors affecting crab populations. Accordingly, a project to estimate unobserved, trawl-caused crab mortalities was funded by the North Pacific Research Board beginning in 2007.

During a 2002-05 analysis (NMFS 2005) of the effects of fishing on the essential fish habitat (EFH) of Alaska groundfish and subsequent considerations of mitigation actions, fishing industry representatives offered that gear modifications be considered as another management option for reducing trawl effects as an alternative to further area closures. As research was required to develop and test proposed modifications, the North Pacific Fishery Management Council (NPFMC) included support for such research in its initial EFH actions, agreeing to review the results and consider them during analyses of protections for Bering Sea EFH. In May 2005, John Gauvin, a long-time industry organizer of collaborative research projects, convened captains of Bering Sea bottom trawlers and gear manufacturers to meet with RACE Division scientists to plan the research and to propose specific modifications for development and testing. This was the first of many such meetings throughout the duration of the project to update members on results and obtain feedback and suggestions for continued work.

Bering Sea commercial flatfish fisheries, the largest in the world, are pursued almost exclusively with demersal otter trawls. These otter trawls use cables, herein called sweeps (Fig. 1), which connect the trawl net to spreading devices (doors) and skim the seafloor ahead and to both sides of the net, herding flatfish from those areas into the path of the net for capture. To increase efficiency, Alaska flatfish fishermen have used progressively longer sweeps to increase the width of their gear and, hence, the area from which flatfish are captured. Because 2-in diameter cable sweeps have proved to be effective for herding flatfish, their use has allowed fuel-cost savings relative to the use of bigger nets to sweep the same area. The use of cable sweeps is so widespread that sweeps now account for the overwhelming majority of the seafloor area swept by these trawlers. While these sweeps greatly increase flatfish catches with greater fuel efficiency, this dominance of the fished area also makes sweeps the most important trawl component for potential negative effects of flatfish trawling on the seafloor.

At the initial planning meeting in spring 2005, participants discussed alternative gear modifications to reduce habitat effects of Bering Sea flatfish fisheries. For initial study,

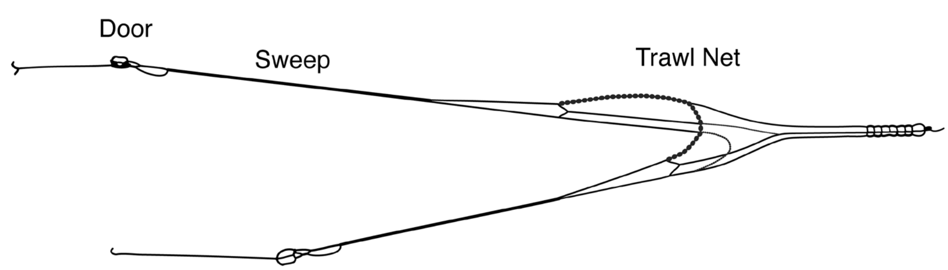


Figure 1. Diagram showing a typical otter trawl system.

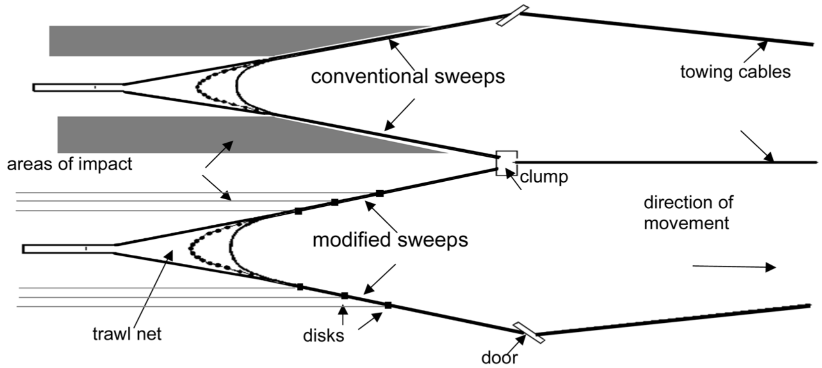


Figure 2. Schematic representation (not to scale) of the twin trawl system used to investigate modified sweeps. Shaded areas indicate bottom contact by sweeps.

the group settled on the concept of raising the sweeps slightly above the seafloor, allowing the relatively small and flexible animals that are typical of the Bering Sea shelf, as well as other habitat structure, such as sand ripples, to pass safely beneath. Successful modifications had to 1) not substantially reduce catch rates of target flatfish to the extent that increased trawling effort could cancel habitat benefits, 2) reduce damage to non-target seafloor animals, particularly those that form habitat structure or support other fisheries, and 3) not cause substantial handling problems or gear damage.

## Effects on flatfish catch rates

To test whether the sweep modifications affected their ability to herd flatfish, we applied twin trawling (Fig. 2). A twin trawl system towed two separate trawls, including sweeps, simultaneously behind the same vessel on parallel, adjacent tracks. This minimized any differences in the fish encountered by the trawls, allowing catch differences to be attributed to differences in gear. The only difference between the two adjacent trawls in the experiment was the use of elevating disks on the sweeps of one side. These results summarize a paper published in the April 2010 issue of *Fishery Bulletin*.

Field experiments were conducted during September 2006 in the eastern Bering Sea onboard the F/V *Cape Horn*, a 47-m trawler processor active in the mixed groundfish fisheries of the Bering Sea and equipped for twin trawling. Towing sites were selected to provide commercial catch rates of a mixture of the four principal flatfish species of the Bering Sea shelf: yellowfin sole (*Limanda aspera),* northern rock sole, (*Lepidopsetta polyxystra*), flathead sole (*Hippoglossoides elassodon*), and arrowtooth flounder (*Atheresthes stomias)*.

The sweeps were composed of combination rope constructed of steel cable covered with polyethylene fiber. This is the most common sweep material currently used in U.S. Bering Sea flatfish fisheries. In the field study, elevating devices, composed of short clusters of disks, were attached onto the experimental sweeps at 9-m (30 ft) intervals (Fig. 2). The disks were either 15, 20, or 25 cm (6, 8, or 10 in) in diameter attached to 5-cm (2 in) diameter sweeps, creating nominal clearance between the cables and the seafloor of 5, 7.5, and 10 cm (2, 3, and 4 in), respectively. Nominal clearances are those immediately adjacent to a disk when resting on a hard surface. The disks pressing into the seafloor and sagging of the sweeps between elevating devices would affect actual clearances. They were fixed in position with a combination of clamps and rope seizings, which were run through the sweep cable to prevent slippage. Test tows were made with modified sweeps on one net and unmodified sweeps on the other. Halfway through each experiment, the sides were switched to account for any differences in catchability between sides.

Catches from each trawl were kept separate throughout the sampling process. As catches entered the sampling area, they passed across a motion-compensated flow scale to determine total catch weight. All individuals of four flatfish species—yellowfin sole, northern rock sole, flathead sole, and arrowtooth flounder—and two gadids—Pacific cod (*Gadus macrocephalus)* and walleye pollock (*Theragra chalcogramma*)—were sorted into separate holding bins. These are the principal flatfish and gadid species commercially fished from the eastern Bering Sea shelf. Fish from each bin were then run across a second flow scale to measure the weight of each of those species.

The use of 15-cm disks on the sweeps did not cause significant differences in catch rates for any of the six species, and only the pollock catch rate changed (12% increase) with the 20-cm disks (Fig. 3). Northern rock sole and flathead sole catches both decreased significantly (-11% and –5%,

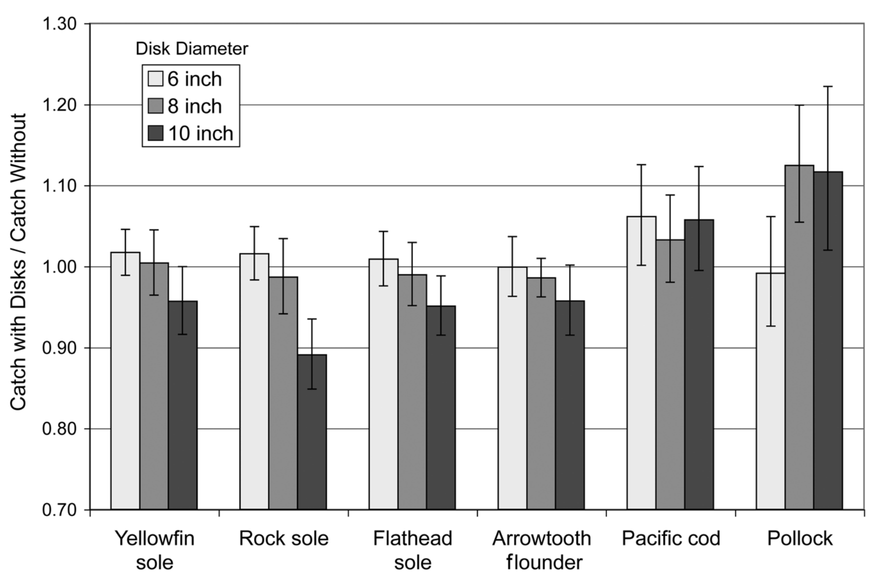


Figure 3. Ratios of catch rates of trawls with and without 15, 20, 25 cm (6, 8, 10 in) diameter disk clusters placed at 30-ft spacing on sweeps to raise sweeps off the seafloor.

respectively) when the 25-cm disks were used, while pollock catch increased again (+12%). A consistent decrease in the mean relative catch with increasing disk size for all of the flatfish species, while only significant for the largest disks, suggests that smaller effects may have occurred for the smaller disks that could not be statistically detected in our experiment. Pacific cod catches did not change significantly with any of the modifications. For evaluating the likelihood of substantial losses of catch, the confidence intervals reveal insights beyond those provided by the means and significance tests. For example, the lower confidence bounds for the effects of 20-cm disks on flatfish catches leave only a 2.5% (1 of 40) probability that catch losses would exceed 4%–6%. Corresponding "worst case" losses for the 15-cm disks were even smaller. Therefore, a trawler could implement one of these modifications with little expectation of catching fewer flatfish.

## Effects on seabed

We used a high-resolution, rapid-update sonar (SoundMetrics DIDSON, dual-frequency identification sonar) to observe how the sweep modifications affected seafloor contact. This unit was mounted in a protective sled, which was towed both behind the sweeps, showing interactions between the sweeps and the seafloor, and independently across the track of a previous haul, showing marks left on the seafloor. These observations were only made on sweeps with the 20-cm disks. The sled was towed across existing tracks and was also equipped with a video camera for detailed imagery.

Sonar imagery during towing showed that unmodified sweeps produced a continuous cloud of disturbed sediment due to seafloor contact. Variation in the density of that cloud appeared to result from contact with high and low spots on the seafloor, and rapid oscillation of strong and weak cloud intensity appeared to be due to vibration of the sweeps. In contrast, the sediment cloud from the modified sweep appeared directly behind the disk cluster. The only clouds from the sweeps themselves were brief puffs after contact with high spots on the seafloor. Areas covered by the modified sweeps showed marks from the disk clusters approximately 10 cm wide separated by seafloor indistinguishable from unaffected areas (Fig. 4A). This disk cluster mark was approximately 5% of the 2-m interval between marks. This spacing is much shorter than the 9-m spacing along the cable because sweeps are sharply angled relative to their direction of movement (angle of attack). Images of such tracks from the video (Fig. 4B) showed a flattening of very low-profile surface textures.

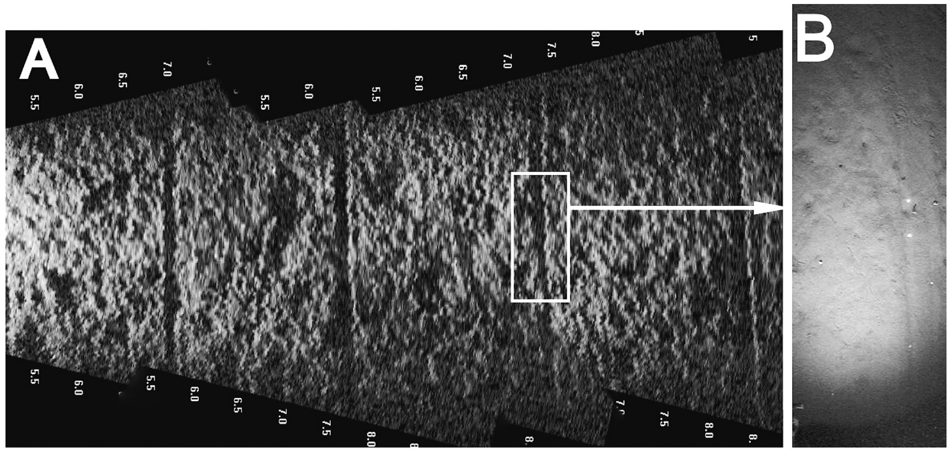


Figure 4. Sonar and video imagery of seafloor after passage of modified trawl sweeps.

## Effects on sessile seafloor animals

While the above results demonstrated that the disks reduced seafloor contact, it remained to examine whether the gear modifications reduced damage to the structure-forming seafloor animals found on the flatfish grounds. The following results focus on sea whips (*Halipterus* sp.), slender colonial octocorals that anchor themselves vertically in soft substrates. Compared to other sessile animals on these substrates, sea whips are considered to be highly vulnerable to trawling due to their high profile, commonly more than 1 m high. Our experiments consisted of creating parallel trawl tracks with a conventional, single flatfish trawl, including both modified and conventional sweeps. A seafloor sled with both sonar and video sensors was then towed across the parallel trawl tracks at several points to compare the condition of seafloor animals in areas affected by these different gears, and in control areas between tracks (Fig. 5). Areas covered by different gear components were identified using sonar imagery, and sea whip conditions were assessed from video images. The proportions of damaged sea whips in affected areas were compared with those in control areas immediately outside of the trawl tracks, as well as between those of the conventional and modified sweeps. Observer and VMS (Vessel Monitoring System, which records locations of fishing vessels) records were

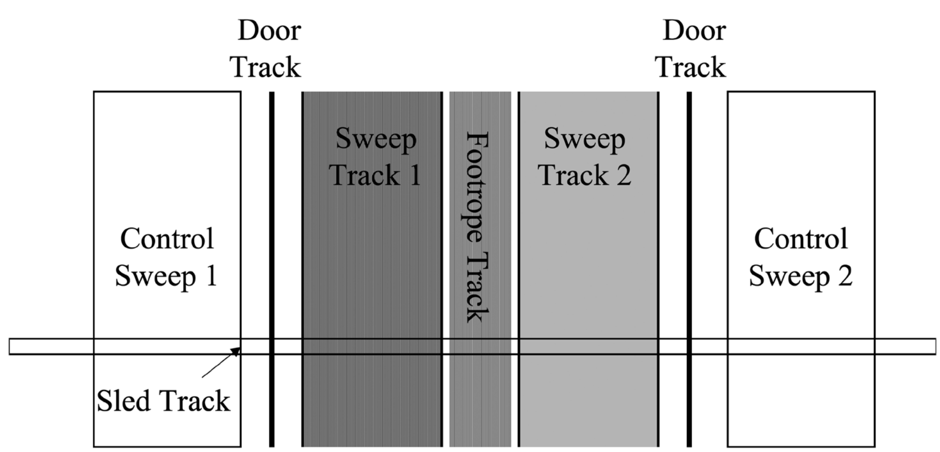


Figure 5. Illustration of the sled sampling across the track of a single trawl with different sweeps installed on each side. Sled had sonar and video cameras to detect position relative to tracks and condition of seafloor animals.

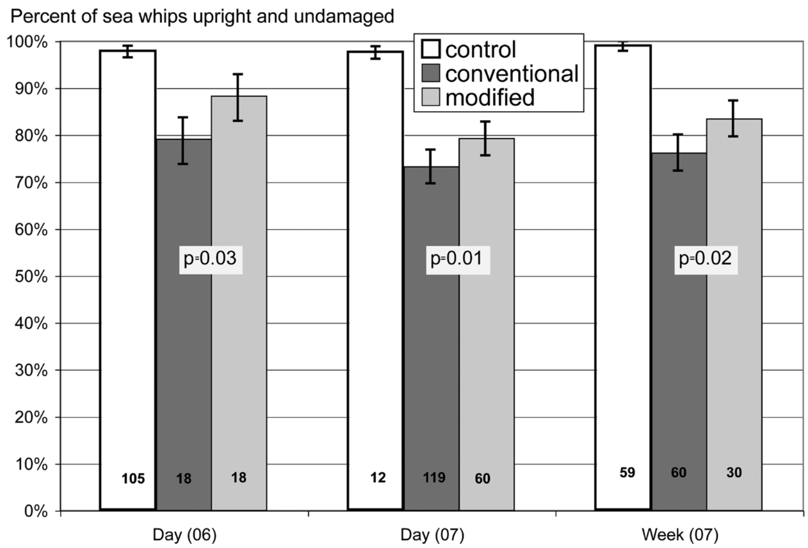


Figure 6. Percentage of normal sea whips after passage under modified and unmodified trawl sweeps (compared to control area) with significance test results between bars (n.s.—p > 0.05). Bare rods were **not** included in counts.

examined to select a study area where trawling had not occurred for at least 15 years. Sled tows were conducted 1-2 days after the experimental trawling.

In 2006, the same sets of sweep modifications were used as in the herding experiments. Sea whips were classified as normal (undamaged in a vertical position), flat (horizontal on the substrate) or damaged (with visible disruption to tissue or breaking of support rod). During summer 2007, scientists returned to the area to examine the potential for recovery or delayed mortality. While the 2006 study only assessed damage after 1–2 days, the 2007 work also compared effects after approximately 1 week, 1 month, and 1 year. As in 2006, a seafloor sled was towed across trawl tracks that included areas affected by conventional and modified sweeps; however, trawling and sled transects were scheduled and placed so that the time since trawling varied from a repetition of the 1-2 day period to examination of the 2006 tracks 1 year after trawling. Also, since the 2006 catch rate and effects studies indicated that the 20-cm disks, creating 7.5-cm clearance, best balanced flatfish catch and seafloor effect considerations, only that configuration was tested in 2007.

After 1-2 days, areas swept by conventional sweeps had a lower proportion of normal (i.e., upright and undamaged) sea whips than the control area, and the proportions of normal sea whips in areas covered by the modified sweeps were intermediate between the conventional and control (Fig. 6). The same pattern held after 1 week, indicating reduced damage due to the modification. All differences were statistically significant.

Damage counts after immediate- and short-term periods were able to ignore bare rods left from sea whips that had died previously (Fig. 7). After a day or a week, recently damaged sea whips were easily distinguished from rods remaining from prior mortalities. However, after a month or a year these could not be separated. Therefore, our comparison across all time periods included these bare rods in the total counts of sea whips used to calculate proportions of undamaged sea whips. While the average number of bare rods was not expected to vary between test areas and times, adding their count to the non-normal animals did increase the variability of the estimates.

The proportions of upright and undamaged sea whips in the control, conventional sweep, and modified sweep areas for each of the time periods were also compared (Fig. 8). The relationships between these proportions were similar for the day, week, and month periods, with more normal sea whips in the control area than in either affected area, and more in the modified sweep area than that for conventional sweep. After a year, the proportion of normal sea whips in the conventional sweep area dropped considerably, while that for the modified sweep moved closer to the proportion in the control area. This may indicate delayed mortality to sea whips affected by conventional sweeps and recovery of those affected by the modified sweeps.

## Tests of alternative spacing of lifting devices

Through this development process, commercial trawlers were asked to experiment with the sweep modifications to assess practical issues in their handling and implementation. In discussions with our industry partners, it was recognized that wider spacing between elevating devices would be easier to work with, and would further reduce direct contact area, providing that

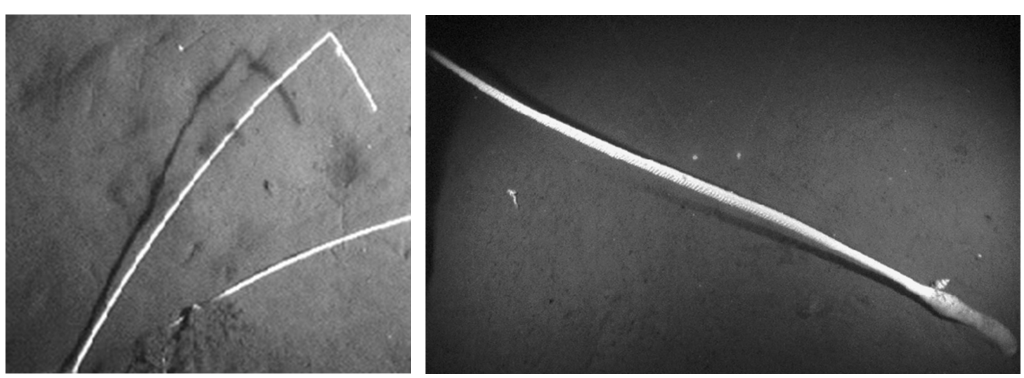

Figure 7. Two bare rods remaining after decomposition of a sea whip (left) and a sea whip recently flattened by recent passage under a trawl (right).

a similar actual clearance could be maintained. Therefore, field tests were conducted in 2007-08 to see if the clearances achieved during the herding and seafloor effect tests could be achieved using longer spacings between elevating devices (intervals of 30 ft, 60 ft, and 90 ft). Clearance indicators were developed to measure actual clearances between the sweep material and the seafloor during operation. They consisted of recording inclinometers mounted on triangular frames that could rotate freely around the sweeps. With the end of the triangle riding over the seafloor and its base against the sweep, the recorded tilts could be used to calculate clearances between the sweep and the seafloor. These indicators were installed at several points across the span between elevating devices. Indicators installed next to the elevating devices evaluated the degree of sinking (elevating devices may sink up to 0.5 in into the mud), while those near the center of the span measured sag. Figure 9 illustrates various clearance ranges for the tested disk sizes and spacings. Our general conclusion was that actual clearance similar to the 2006 tests could be achieved using elevating devices producing a 3-in nominal clearance at 60-ft spacing (tested using 8-in disks on 2-in sweeps), and 4-in nominal clearance at 90-ft spacing (10-in discs on 2-in sweeps). The 60-ft spacing achieved similar clearance to the 30-ft spacing, especially on firmer sediments (as illustrated by the boxes in dashed lines). At 90-ft spacing, the 10-in bobbins provided much higher clearance than the 8-in bobbins.

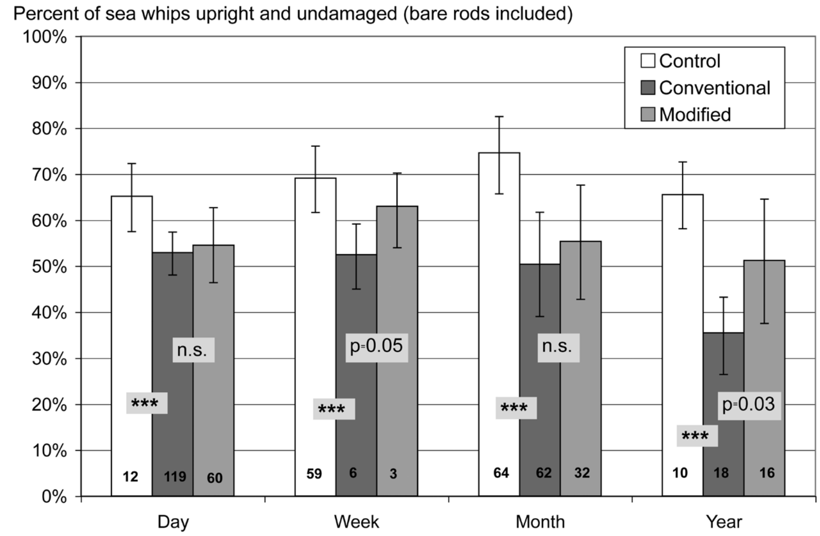


Figure 8. Percentage of normal seawhips after passage under modified and unmodified trawl sweeps (compared to control area) with sample sizes in each bar and significance test results between bars (n.s.—$p > 0.05$, ***—$p < 0.001$). Bare rods included in non-normal counts.

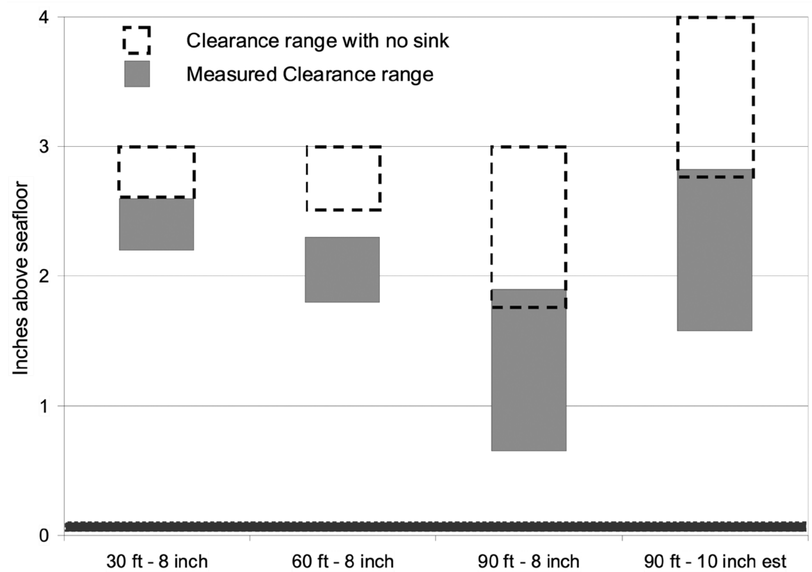


Figure 9. Clearance range of sweep at various elevation heights and spacings; also shows what clearance would be without accounting for the degree to which the elevation device (disk) sank into the seafloor.

## Effects on crab mortality rates

In 2007, RACE scientists initiated a project, funded by the North Pacific Research Board, to estimate unobserved mortality rates for crabs from flatfish trawl fisheries. These are mortalities of crabs that pass underneath the trawl itself, or over the sweeps, and therefore remain on the seafloor. Because the sweep modification research was well under way, and unobserved mortality had been a pressing issue between crab and trawl industries as well as for crab managers, the modified sweeps were added to the gear components tested during this project to see if they changed how sweep encounters affected crabs.

To estimate mortality rates due to contact with trawls, crabs were captured with small auxiliary nets fished behind different parts of a commercial bottom trawl. They were carefully brought aboard and assessed using a six-part reflex test. A subsample of those crabs was held for 5–12 days to establish the relationship between reflex state and delayed mortalities. The proportions of crabs in different reflex states and the reflex-mortality relationship were used to estimate raw mortality rates for crabs encountering each part of the trawl. Results for crabs captured with a control net, fished in front of the trawl were used to assess and adjust for mortalities due to capture and handling.

A pilot study in 2007 established the relationship between crab reflexes and mortality after holding. This allowed reflex assessments to be used as an effective predictor of delayed mortality. Eliminating the need to hold all crabs greatly increased the number of crabs available for our mortality estimates. These results were reported in Stoner et al. (2008). The pilot study also established methods for rigging and handling the recapture and control nets.

Field work to estimate mortalities of Tanner and snow crabs (*Chionoecetes bairdi* and *opilio*) was conducted in 2008 and for red king crab (*Paralithodes camtschaticus*) in 2009. Approximately 20 tows were

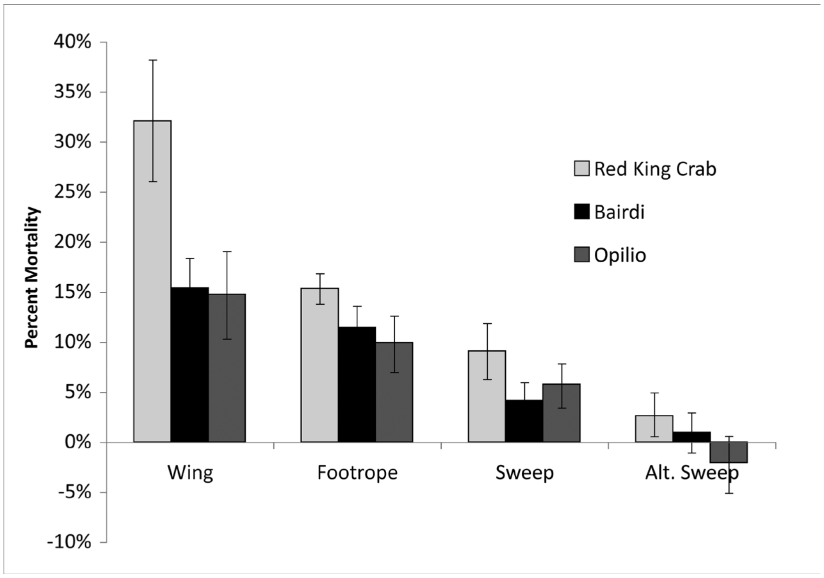


Figure 10. Mortality rates for crabs passing under trawls or past sweeps. Alternative sweeps were equipped with disk clusters to raise sweeps 5 – 7.5 cm above seafloor.

made with recapture nets behind each trawl component and in the control position. Mortality rates were higher for crabs encountering the trawl footrope, particularly in the wing section, than those encountering the sweeps (Fig. 10). Red king crabs had higher mortality rates than either of the *Chionoecetes* species. The modified sweeps reduced crab mortalities substantially for all species. Considering the much larger area covered by the sweeps, these modifications mitigate much of the unobserved crab mortality from bottom trawling.

## Management actions and conclusions

The cooperative research project to reduce the effects of Bering Sea flatfish trawling on seafloor habitat and crabs resulted in the development and demonstration of a relatively simple modification to trawl sweeps that reduces effects on seafloor animals while maintaining their ability to herd flatfish for capture. While from the outset, most in the flatfish industry were supportive of the modifications to reduce impacts on seafloor habitat and crabs, especially since the research showed no negative effects on target catch rates, implementation of this gear modification involved some cost to fishermen. In addition to the gear-up costs of the modified sweeps, these modifications make gear handling more difficult and may require some changes to deck machinery. So to level the playing field, avoid "free rider" (those not using modifications getting the same benefit as those that do) issues, and ensure that benefits were as large as possible, the flatfish industry group that had been involved in the research and development from the outset (through the Best Use Cooperative, a Bering Sea fishing cooperative targeting mostly flatfish) supported moving forward with the sweep modification as a requirement for any Bering Sea vessel targeting flatfish. With this support from industry, the task of creating regulations and specifying the exact requirements in regulations was greatly facilitated.

Results of each phase of the project were presented to fisheries managers through periodic updates to the NPFMC. Several public workshops were convened to discuss potential implementing definitions. The Best Use Cooperative even made one of its coop member vessels available for an at-sea workshop to help regulators understand how to measure clearance tolerances and spacing requirements so that everyone would know from the outset how the regulations would be enforced at sea and dockside. At their October 2009 meeting, the NPFMC developed regulations that will require the sweep modifications for all Bering Sea flatfish trawling starting at the beginning of the 2011 fishing season. This project demonstrated an effective collaboration between industry and AFSC researchers to reduce the unintended effects of fishing through conservation engineering.

## Additional reading

National Marine Fisheries Service. 2005. Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska. http://www.fakr.noaa.gov/habitat/seis/efheis.htm

Rose, C.S., Gauvin, J.R. and Hammond C.F. 2010. Effective herding of flatfish by cables with minimal seafloor contact Fishery Bulletin 108(2):136-144.

Stoner, A.W., Rose, C.S., Munk, J.E., Hammond, C.F. and Davis, M.W. 2008. An assessment of discard mortality for two Alaskan crab species, Tanner crab (*Chionoecetes bairdi*) and snow crab (*C. opilio*), based on reflex impairment. Fishery Bulletin 106(4):337-347.