Development of an Acoustic Index of Midwater Walleye Pollock From the Eastern Bering Sea Bottom Trawl Survey to Complement Biennial Acoustic-Trawl Survey Estimates

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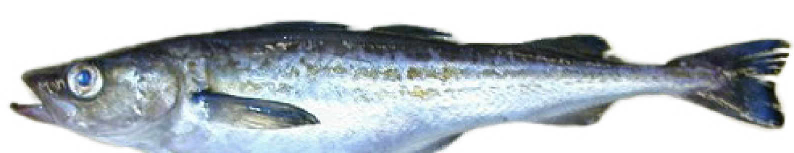
Eastern Bering Sea walleye pollock (*Theragra chalcogramma*) support one of the world's largest fisheries. Due to this species' high recruitment variability and relatively short life span (approximately 15–17 years), timely and accurate abundance indices are needed for the proper management of this valuable stock. Information that is critical for the estimation of walleye pollock population dynamics and stock size traditionally comes from the National Marine Fisheries Service (NMFS) biennial acoustic-trawl (AT) survey and annual bottom trawl (BT) survey conducted by scientists from the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division. The annual BT survey tracks the older, demersal portion of the population and uses chartered commercial fishing vessels, whereas the biennial AT survey tracks the younger, midwater portion and uses NOAA research vessels.

In order to provide more frequent assessment information on the walleye pollock midwater component at a relatively modest cost, scientists with the RACE Division's Midwater Assessment and Conservation Engineering (MACE) program initiated a project in 2005 to investigate the feasibility of collecting annual acoustic backscatter data from the BT survey charter vessels. The objective of the project was to determine whether an abundance index for the midwater component could be developed to augment the biennial AT survey estimate. Many challenges were faced as the BT survey is not designed or executed as a formal AT survey. For example, it was not possible to directly sample the midwater acoustic backscatter for species classification or run a dedicated AT survey trackline pattern. Nevertheless, since walleye pollock comprise a large proportion of midwater backscatter in the eastern Bering Sea (EBS), and the AT and BT surveys largely overlap temporally and spatially, the project was considered to have a reasonable likelihood of success. The resulting acoustics-based BT survey index, based on several years of data, demonstrates that it is possible for the BT survey to provide critical information on the midwater component of the pollock population, which would be otherwise unavailable during the AT survey off-years.



Methods

Surveys: The NMFS AT and BT walleye pollock stock assessment surveys take place in June and July, proceeding from east to west across the EBS shelf and slope during daylight hours (Fig. 1*a*). The BT survey also monitors commercially important crab and other groundfish species. The biennial AT survey is carried out aboard NOAA research vessels (63–66 m in length) equipped with calibrated scientific acoustic systems. The split-beam transducers are located 9 m below the water surface at the bottom of the vessel's centerboard. The principal frequency used to survey walleye pollock is 38 kHz. Acoustic backscatter is measured along parallel north-south transects spaced 20 nmi apart at vessel speeds of 11–12 knots from about 14–16 m from the surface to within 0.5 m of the bottom, to maximum depths of 500 m. Midwater trawls are conducted to verify the species composition of the observed backscatter and to obtain other biological information. Acoustic backscatter is manually classified into taxonomic groups by trained analysts based on visual examination of backscatter characteristics and on midwater trawl catch composition. Length, weight, and age information from the trawls are used to convert echo integral information attributed to walleye pollock into numbers and weight of pollock per unit area. The latter is then expanded to represent the midwater component of the walleye pollock stock for the surveyed area.

The demersal component of the walleye pollock stock is assessed by the BT survey aboard two chartered commercial fishing vessels (40–50 m in length), which deploy bottom trawls in a grid of 396 stations spaced 20 nmi apart, forming rows of 20 × 20 nmi cells (Fig. 1*a*). About 280 cells overlap the AT survey trackline. Vessel speeds range from about 3 knots when trawling to about 9–10 knots when free-running. The bottom trawl catch-per-unit effort for walleye pollock is used to estimate demersal biomass. BT survey vessels are typically equipped with commercial echosounders and hull-mounted transducers located 4–5 m below the water surface.

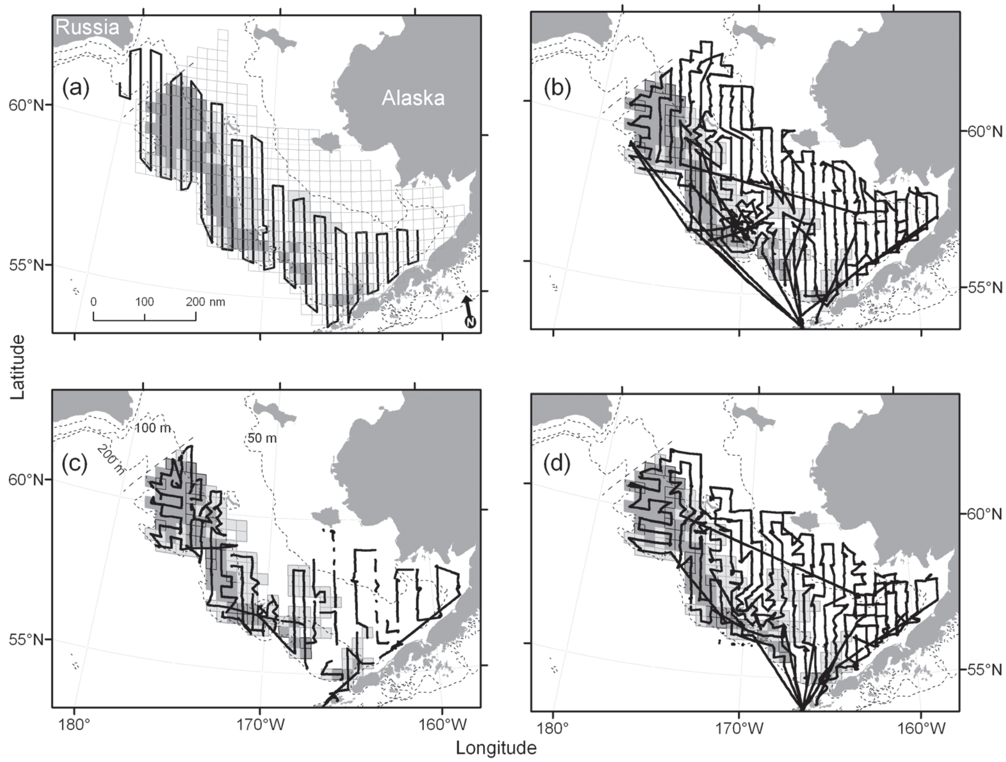


Figure 1. Study area showing a) typical spatial coverage of the BT survey (squares) and AT survey (solid lines), b) 2006 BT vessel tracks, c) 2007 BT vessel track (only trackline of vessel that collected 38 kHz acoustic data is shown), and d) 2008 BT vessel tracks. The 2009 vessel tracks (not shown) were very similar to 2006 and 2008. Shaded squares indicate index area cells where data were auto-processed (dark gray) or hand-processed (medium gray). Also shown are depth contours (short dashes), and the boundary between the U.S. and the Russian Exclusive Economic Zone (long dashes).

Routine AT and BT surveys were carried out from 2006 to 2009. On AT surveys, acoustic backscatter was measured, examined, and post-processed in near real-time by acoustics experts, whereas on the chartered BT survey vessels, backscatter was measured without immediate review by an acoustics expert and post-processed semi-automatically following the survey. Detailed BT survey acoustic data collection protocols were developed (http://www.afsc.noaa.gov/RACE/midwater/avo/FVA_protocols.pdf) for the calibration and collection of high-quality acoustic data from the commercial vessels. Concerns affecting acoustic data quality included system installation issues, noise from various acoustic (other sounders, air bubbles sweeping across the transducer face causing transmission loss, known as bubble sweepdown), electrical, or mechanical sources, intermittent navigation information, and inconsistent bottom tracking.

BT survey acoustic systems used commercial Simrad ES60 echosounders with transducers operating at 38 kHz, which were generally calibrated at the start and end of the surveys. Upper and lower water column depth bounds for backscatter measurements were the same as for the AT survey, with final data analysis restricted to a maximum depth of 200 m. Custom, semi-automated, data analysis software for post-processing were developed in Matlab, which included filters to remove pings potentially compromised by bubble sweepdown, as well as other data processing features. Echoview software (Myriax Pty., Ltd., Hobart, Australia) was used where the presence of contaminant taxa required manual processing. Overall, the 2006–09 field methods specific to AT and BT surveys were similar across years, which resulted in similar spatial coverage (Fig. 1*b*, *c*, *d*). Although two vessels were contracted to conduct the BT survey in 2007, only one was equipped with a 38-kHz echosounder and used in this study.

Index area: A retrospective analysis of AT survey backscatter information was completed to explore ways to save time by only post-processing a subset of the BT survey data (Fig. 1*a*). Based on data from four past AT surveys (1999, 2000, 2002, 2004), an index sub-region was defined where a) most of the acoustic backscatter at 38 kHz was attributed to walleye pollock, and b) the pollock backscatter from the index area tracked the interannual trend in midwater pollock biomass in the entire EBS. For about half of the index-region grid cells, all backscatter from 30 m below the surface to 3 m off the seafloor could be automatically classified as walleye pollock, while backscatter from the remainder of the index region was more heterogeneous and needed to be scrutinized by a trained analyst to exclude backscatter from non-pollock organisms. To compute an abundance index value (I_{AT}) for a particular year, the mean backscatter attributed to walleye pollock in each BT survey grid cell was summed over all grid cells.

The BT survey index (2006–09; I_{BT}) was computed in the same way as I_{AT} except using BT-survey backscatter. Data were collected when the vessels were not trawling (defined as vessel speeds > 4 knots). For reasons unrelated to this study, annual rather than biennial summer AT surveys were conducted between 2006 and 2009. This provided 4 years of the AT survey biomass to compare with the I_{BT} to validate the new index. For the comparison, the AT survey biomass was normalized to mean 1999–2004 values, and the I_{BT} time series was normalized to the mean I_{AT} values from 1999 to 2004. The trend in each time series was compared to assess whether I_{BT} tracked the AT survey biomass and could thus be used to provide annual rather than biennial information to assess the EBS midwater walleye pollock abundance at very little additional cost.

Statistics: Spatial statistics (center of gravity (CG) and corresponding inertia (I), as well as global and local indices of spatial collocation (I_g and I_l)) were computed to compare the distribution patterns and degree of overlap and coherence between walleye pollock backscatter from the AT survey and I_{BT}. The global index of collocation is computed from CG and I, and measures the large-scale overlap of two distributions with values ranging from 0 (no overlap) to 1 (complete overlap). The local index of collocation measures the fine-scale spatial coherence, with values ranging from 0 (no coherence) to 1 (complete coherence). Relative estimation errors to characterize uncertainty associated with backscatter sampling variability and spatial structure were derived for the index and survey totals in each year using a one-dimensional geostatistical method.

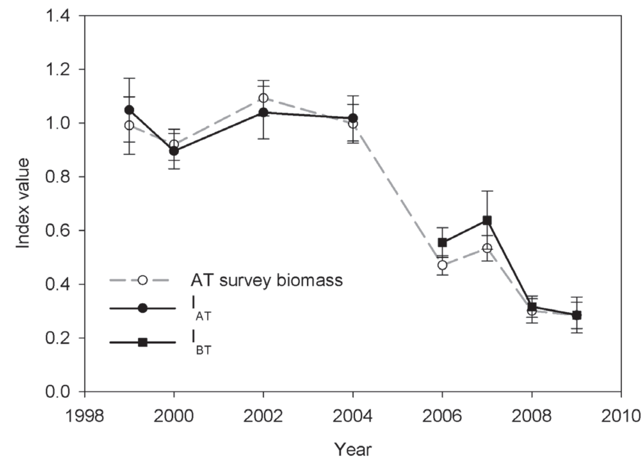


Figure 2. Time series of AT survey biomass, and I_{AT} and I_{BT} indices. See text for index definitions. Each time series was divided by its average during the period 1999 – 2004. Error bars indicate 1-D geostatistical 95% confidence intervals.

Results

Calibration and data quality: All acoustic system calibrations on the chartered commercial and NOAA vessels determined that instrument performances were acceptable. The centerboard-mounted transducers on the NOAA AT survey vessels were not susceptible to transmission loss due to bubble sweepdown, but the hull-mounted transducers on the commercial BT survey vessels were susceptible, particularly in rough sea conditions or at high vessel speeds. Ping data affected by bubble sweepdown were removed using post-processing data filters as their presence negatively biased the water column backscatter data.

Retrospective analysis (1999–2004): The retrospective backscatter index from the AT survey (I_{AT}) closely tracked the AT survey walleye pollock biomass across all four survey years (1999–2004; Fig. 2). The 1D geostatistical error bars about the values in each time series indicate that I_{AT} has a similar relative estimation error (0.04–0.06) to that of the full AT survey (0.03–0.06). These findings supported use of BT survey data from only the subsampled or index area, which dramatically reduced the processing time needed to compute the new BT survey index.

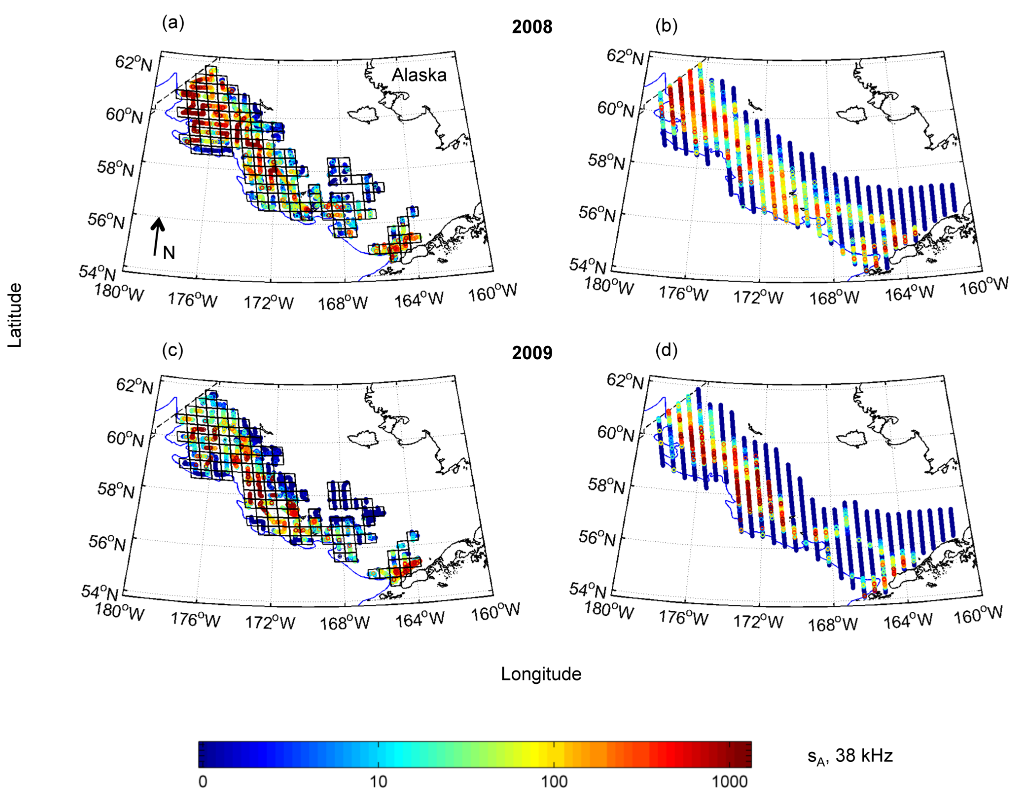


Figure 3. Backscatter (nautical area scattering coefficient (NASC, m²/nmi²) classified as walleye pollock from the BT survey Index Area (panels a, c) and the AT survey (panels b, d) in summers 2008–09. Summers 2006 and 2007 are not shown.

BT survey index (I_{BT}, 2006–09): Estimates of I_{BT} were compared within- and between-years with results of the full AT survey for 2006–09. The results show that I_{BT} (2006–09) closely tracked the midwater walleye pollock biomass measured by the full AT survey (Fig. 2).

Large-scale walleye pollock spatial patterns based on the full AT-survey or the BT-survey acoustic index (I_{BT}) also agreed well with one another, showing similar pollock distributions across the shelf during summer (Figs. 3*a-h*). Although the index area covers only part of the full AT survey area, both data sets indicated that most midwater pollock were located west of 170°W in 2006–09. Over 80% of the total AT survey midwater walleye pollock biomass occurred in the index area. These observations corroborate the retrospective analysis findings that the index area is a reasonable indicator of both the distribution and the abundance of the entire EBS midwater pollock stock. The I_{AT} CG was slightly west of the AT survey CG in each year (mean 46 km; Fig. 4). The I_{BT} CG (2002–09) was generally close to (mean 38.6 km) and either west of the AT survey CG in 2006, 2008 and 2009, or east in 2007. The global index of collocation for I_{AT} and the full AT survey indicated nearly complete overlap (I_g =1.0), while the local index of collocation showed somewhat less fine-scale coherence (I_l = 0.9; Fig. 5). For I_{BT} and the full AT survey there was strong shelf-wide overlap (mean I_g >0.99), but on a fine scale there was less spatial coherence (mean I_l = 0.5; Fig. 5).

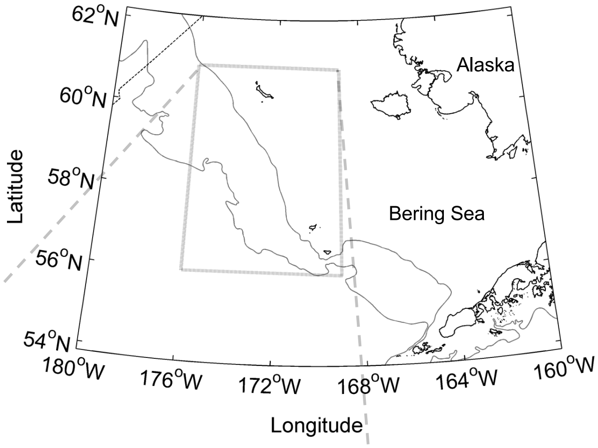
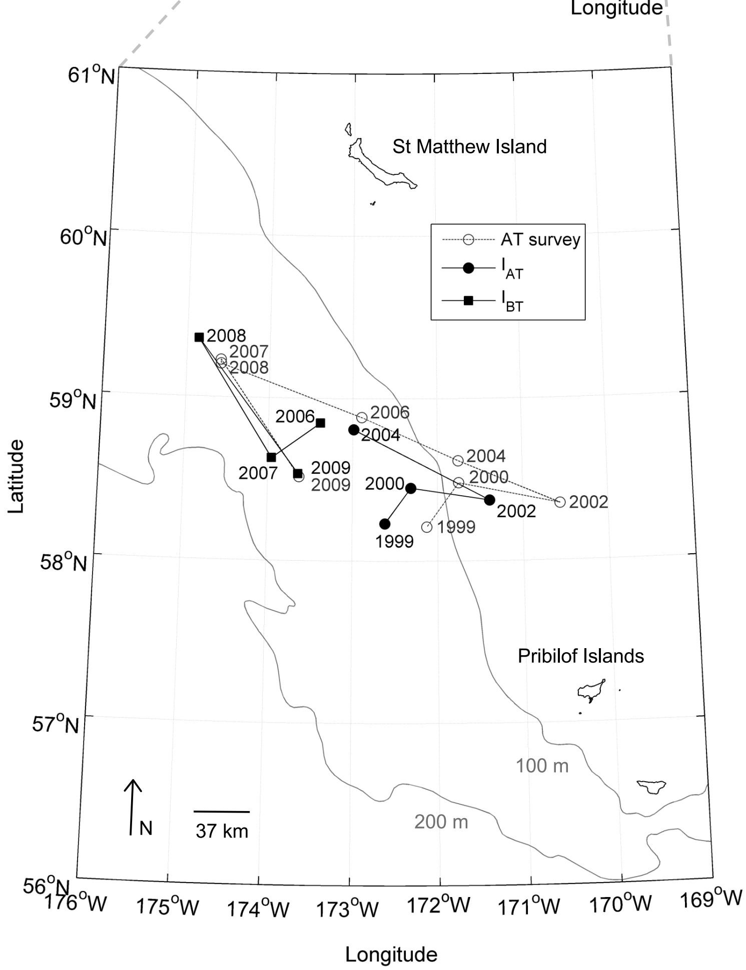


Figure 4. Center of gravity estimates for walleye pollock backscatter from the indicies I_{AT} (1999–2004) and I_{BT} (2006–09; solid black lines), and the AT survey (dashed gray line) for 1999–2009. The 200 m and 100 m isobaths are shown by solid gray lines.



Discussion

The new annual BT index (I_{BT}; 2006–09) closely tracked the results of the full AT survey and thus can provide information on midwater walleye pollock abundance at relatively little cost when the AT survey is not conducted. The retrospective index (I_{AT}; 1999–2004) demonstrated that analyzing a region smaller than the entire AT survey area to track walleye pollock abundance was feasible and an automated data post-processing procedure could be used to process much of these data, saving significant time and effort.

Spatial analyses of I_{AT} and the full AT survey backscatter provided context for subsequent comparison of the I_{BT} and AT survey backscatter. Both sets of comparisons showed broad overlap at a large scale. The large-scale spatial agreement between the walleye pollock distributions estimated by the full AT survey and the new I_{BT} suggests that the index provides a way of monitoring not only annual abundance but also shelf-wide spatial distribution of midwater pollock. Spatial information together with observations of physical oceanographic conditions, distribution of prey resources, and age-structure of the stock can potentially be used to better understand the mechanisms that determine walleye pollock distribution patterns. These distribution patterns can be used in economic models to forecast economic impacts on the fishery. For example, fishing vessels traveled significantly greater distances from port during 2007 and 2008 and incurred greater transportation costs to find sufficient concentrations of pollock.

The use of commercial vessels as platforms to measure acoustic backscatter to assess commercial fish species is becoming more common, especially in lieu of using scientific vessels when competition for ship time is intense among programs and operational costs are high. Despite design differences between the BT and AT surveys, the interannual variability, shelf-wide spatial pattern, and sampling variance of the 2006–09 I_{BT} weas similar to that of the AT survey. The calibration variability among fishing vessel acoustics systems was not dramatically different than those of the research vessels. Acoustic interference was largely eliminated in the present study by turning off or synchronizing other acoustic equipment on board the fishing vessels. Weather-generated data collection problems such as bubble sweepdown were infrequent enough to be successfully detected and addressed during post-processing, although these types of problems may be more common during other seasons for vessels with hull-mounted transducers.

This study did not investigate or control for differences in fish density estimates due to potential differences in fish reaction between vessels. In other work, comprehensive NOAA vessel-comparison experiments have been conducted by MACE staff between the noise-reduced *Oscar Dyson* and conventional *Miller*

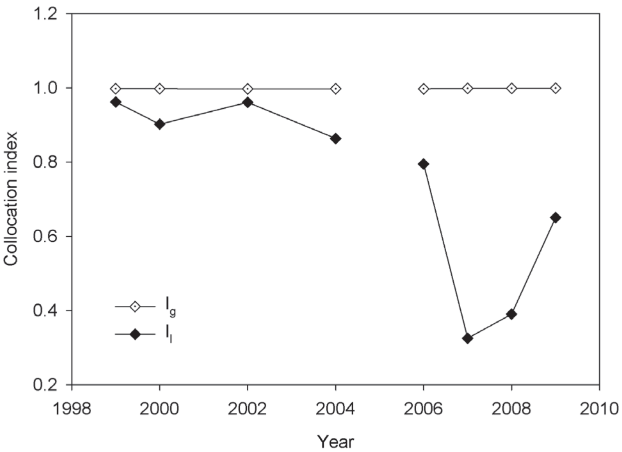


Figure 5. Global (I_g, white diamond with dot) and local (I_l, solid black diamond) index of collocation estimates between AT survey walleye pollock s_A and I_{AT} index s_A (1999–2004), and AT survey pollock s_A and I_{BT} index s_A (2006–09).

Freeman research vessels during EBS summer AT surveys to address potential vessel avoidance by walleye pollock. Results from that work found virtually no detectable differences during the daytime in walleye pollock backscatter measured by the two vessels. The good spatial agreement between I_{BT} and the AT survey estimates from the present study also implies that vessel avoidance to the commercial fishing vessels was not severe, and backscatter data while free-running may be used to construct a summer index of walleye pollock abundance and distribution.

For a new index survey where only a portion of the stock of interest is detected, the trend in abundance for the index must accurately represent changes in the entire stock. The index for walleye pollock presented here, based on 4 years of BT survey data, was consistent with the trend in the abundance and spatial distribution of the midwater pollock stock based on the dedicated AT survey. Another feature that makes this index valuable is that it not only provides an annual abundance index, but its performance can be evaluated every other year when it and the biennial AT survey estimate are both produced. These alternate year comparisons will be useful, for example, in assessing whether the index area boundaries are appropriate.

Acoustic-trawl survey estimates of abundance are critically important in fisheries management as illustrated by their direct influence on quota recommendations. The costs of collecting, processing, and using results based on acoustic backscatter measurements from fishing vessels are minor compared to the costs of conducting a dedicated AT survey. Although the annual I_{BT} index will likely have lower precision than the AT surveys, it will augment the biennial AT survey time series, thereby improving the fishery-independent information available for advice on making critical near-term fisheries management actions.

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