Evaluation of sub-area management boundaries within the Aleutian Islands area with respect to estimated catch and biomass of blackspotted/rougheye rockfish.

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Introduction

At the December, 2016, meeting of the Scientific and Statistical Committee (SSC) of the North Pacific Fishery Management Council, the SSC recommended "*further analyses on two topics in preparation for the 2017 PT and SSC process: 1) the biological basis for dividing the species catch, and for using the specific current management line between the WAI and CAI; and 2) the relative merits of MSSCs versus alternative management tools.*"

Concerns about the biological basis for the boundary between the western Aleutian Islands (WAI) and central Aleutian Islands (CAI), and the degree to which this boundary bisects important fishing grounds, originated in summer 2016 during a workshop intended to identify spatial management options for BSAI blackspotted/rougheye rockfish. Subsequent analyses presented at the September, 2016 BSAI Plan Team meeting indicated that the proportion of WAI blackspotted/rougheye catch and hauls (for the Atka mackerel and rockfish fisheries) within 0.25° longitude of the WAI/CAI was relatively small (i.e. not exceeding 16.2% in any year from 2008-2015) (Spencer, 2016).

The purpose of this document is to examine spatial patterns of estimated survey biomass and catch within the Aleutian Islands to explore whether alternative boundaries would be more appropriate for BSAI blackspotted/rougheye rockfish than the existing boundaries separating areas 541, 542, and 543. A "management unit estimator" (MUE; Cope and Punt 2009) designed to identify geographic areas with similar trends in population indices such as survey biomass estimates was applied to the Aleutian Islands trawl survey data. Additionally, the spatial analysis of fishing effort and blackspotted/rougheye rockfish catch is extended to the entire Aleutian Islands subarea (i.e., areas 541-543). The merits of various management tools will be addressed by NOAA-Fisheries Alaska Regional Office staff in a separate document.

Methods

Estimates of Aleutian Islands trawl survey biomass by subareas for the 1991- 2016 surveys were produced from tow-specific catch-per-unit effort data (CPUE; kg/km^2) and estimates of strata areas, using standard stratified design calculations (Wakabayashi et al. 1985). Currently, the Aleutian Islands management area has three subareas: the western Aleutian Islands (WAI, 170° E - 177° E longitude), the central Aleutian Islands (CAI, 177° E - 177° W longitude), and the eastern Aleutian Islands (EAI, 177° W - 170° W longitude). Additionally, the area on the north side of the Aleutian Islands from 170° W - 165° W longitude, referred to as the “southern Bering Sea” (SBS) area, is within the Bering Sea management area but sampled in the Aleutian Islands trawl survey. In order to consider alternative boundaries, the WAI, CAI, and EAI were each divided into east and west areas, resulting in 7 subareas (including the SBS area) for which survey biomass estimates were produced (Figure 1). In the WAI, separate trawl survey strata exist on either side of 175° E longitude, thus obviating the need to restratify existing strata. The two CAI areas were divided at 180° W longitude, which necessitated restratifying several existing strata that were bisected by 180° W longitude. In the EAI, most existing survey strata occur on either side of 174° W longitude, although one strata (594) spanned the width of the EAI and needed to be stratified. The boundaries of the current subareas boundaries, and the boundaries considered for this analysis, are shown in Table 1.

The MUE clustering algorithm introduced by Cope and Punt (2009) was applied to the WAI and CAI Aleutian Islands survey data, and identifies management units as sets of spatial areas with similar trends in abundance indices, while incorporating the uncertainty of the abundance index. Differences in trends in estimated abundance between spatial areas has been considered as evidence of stock structure by the Stock Structure Working Group (Spencer et al. 2010). The MUE analysis requires a time series of abundance and associated coefficient of variation (CV) for each spatial area. For each survey year, a simulated abundance value is obtained from a normal distribution with a mean and CV set to the input data. A *k*-medoid clustering algorithm is then applied the standardized simulated index to obtain assignments of each spatial area to management unit clusters, and this process is repeated for 1000 simulations. To account for the variability between simulated data sets in the assignments of areas to clusters, a second level of clustering is applied to the assignments of the management units.

Silhouettes (Rousseeuw 1987) were used as a clustering diagnostic to identify the optimal number of clusters (i.e., management units). Silhouettes use the dissimilarity matrix, which in this example is the Euclidean distance between each pair of areas with respect to the standardized survey biomass estimates. The silhouette width is defined as

$$s(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}} \qquad \text{Eq. 1}$$

where cluster *a* is the cluster which contains area *i*, *a(i)* is the average dissimilarity between area *i* and all other areas within cluster *a*, and *b(i)* is the lowest average dissimilarity between area *i* to the other clusters not containing area *i*. Silhouette widths can take on values between -1 and 1, with a value of 0 resulting from *a(i)* equaling *b(i)* and implying that area *i* is equally similar to clusters *a* and *b*. An *s(i)* value of 1 results from the *a(i)* = 0, implying that area *i* is identical to all other areas within its assigned cluster *a*. Conversely, *s(i)* values < 0 indicate that area *i* has been misclassified to the wrong cluster because it is more similar to cluster *b* than its assigned cluster *a*. As the silhouette width increases from 0 to 1, the ratio *a(i)*/*b(i)* decreases. The optimal number of clusters chosen is one that maximizes the average of *s(i)* across the areas. Silhouette plots (Kauffman and Rousseeuw 1990) showing the *s(i)* for each area are used to display the results. Average silhouette values of > 0.5 within a cluster indicate strong management unit distinction, whereas average silhouette values between 0.25 and 0.50 indicate weak but potentially meaningful management units, and values < 0.25 indicate no support for management units (Kauffman and Rousseeuw 1990, Cope and Punt 2007).

To examine the spatial distribution of fishing effort and catch of blackspotted/rougheye rockfish, hauls sampled by groundfish observers in the Aleutian Islands since 2008 were binned into sections of 0.5° longitude, and number of hauls and catch per section and target fishery were recorded. Assignment of a target fishery to hauls was based on the dominant species or species group in the catch, and the Atka mackerel and rockfish fisheries were separated from the other target fisheries. The level of sampling coverage during these years was very high, such that the catch estimates from the observed hauls alone are very close to the Catch Accounting System catch estimates.

Results

Time series of survey biomass estimates show differences in trends between areas (Figure 2). Biomass estimates in the WAI-W and WAI-E from 1991-1997 averaged 743 t and 2,362 t, respectively, and declined to averages of 259 t and 591 t, respectively, from 2000-2016. In the CAI-W, biomass estimates from 1991-1997 averaged 2,049 t, and increased to an average of 6,105 t from 2000-2016. Biomass estimates in other areas have generally fluctuated without apparent trends (SBS and EAI-W), or have shown decreasing trends (EAI-E).

Differences in the trends of survey biomass between spatial areas are more evident after standardizing the survey biomass estimates, as in done in the MUE analysis. Focusing on the 4 areas in the WAI and CAI (where management concerns exist), the standardized time series show that the WAI-E and WAI-W have similar trajectories with the highest biomass levels in the early part of the time series (1991-1994 for WAI-W, and 1991-1997 for WAI-E) and lower biomass levels for the remainder of the time series (Figure 3a). In contrast, area CAI-W shows the lowest biomass levels in the early portion of the time series (1991 and 1994), with increased biomass in the post-1994 surveys (Figure 3b). Relative to area CAI-W, area CAI-E shows higher relative biomass in 1991-1994, and lower relative biomass in 2016, but these two portions of the CAI generally show a similar trends to each other between 1997 and 2012.

The differences in biomass between areas can also be seen in plots of biomass across spatial areas within survey years (Figure 4). In the 1991-1997 surveys, relatively high biomass levels were observed in the EAI-E area, and the ratio of CAI-W to WAI-E biomass ranged from 0.25 to 1.3. In the 2000-2006 surveys, the estimated biomass in the EAI-E was still larger than neighboring areas, but the ratio of CAI-W to WAI-E biomass increased to a range of 4 to 39. The range of the ratio of CAI-W to WAI-E generally decreased in the 2010-2016 surveys relative to the 2000-2006 surveys (with the exception of the 2012 survey), but the year with the lowest ratio during this period (2010) still had a higher ratio (1.68) than in any of the three observed surveys from 1991-1997.

The MUE analysis applied to the 4 areas in the WAI and CAI indicated two clusters separated at 177° E longitude, with the WAI-W and WAI-E grouping into a single cluster and the CAI-W and CAI-E grouping into another cluster (Figure 5). The silhouette widths were above 0.5 for each of the 4 areas considered, indicating strong distinction of the clusters (Kauffman and Rousseeuw 1990, Cope and Punt 2007). The MUE analysis considers the uncertainty in the point estimates of biomass, as high levels of uncertainty could result in an inability to recognize meaningful clusters. The WAI and CAI showed relatively high coefficients of variation, which ranged from an average (across 1991-2016) of 0.37 for CAI-E to 0.52 for WAI-E. The high silhouette widths from the MUE analysis despite the high CVs is an indication of the degree to which the trends in survey abundance are relatively similar within the WAI and CAI areas, but different between these areas.

Aleutian Islands blackspotted/rougheye catch occurs throughout the Aleutian Islands subarea, and is not located primarily in habitats near the WAI/CAI boundary. The total numbers of hauls and the blackspotted/rougheye rockfish catch from the observed hauls used in this analysis is shown in Table 2, and comprised 79% to 98% of the Catch Accounting System catch estimates for the AI subarea. The relative cumulative hauls across area within the Aleutian Islands are shown in Figure 6a-c, from the western edge of the WAI to the eastern edge the EAI. Areas with positive hauls are shown as increases in the cumulative plots, whereas flat portions of the plots indicate areas with no hauls. The proportion of Atka mackerel hauls within 0.5° of the WAI/CAI boundary ranged from 0 to 12%, whereas the proportion of rockfish tows within 0.5° of the WAI/CAI boundary ranged from 0.8% to 6.2%. For the rockfish fisheries, higher percentages of observed hauls occurred in areas to the west of the WAI/CAI boundary, particularly between 174.5° E and 176° E. Similarly, for the Atka mackerel and rockfish fisheries more blackspotted/rougheye catch occurred between 174.5° E and 176° E than within 0.5° of the WAI/CAI boundary.

Discussion

Application of the MUE estimator indicates a relatively strong boundary at 177° E between the WAI and CAI subareas, and examination of the underlying time series of survey abundance by area reveals higher biomass in the CAI-W area than in either the WAI-W or WAI-E areas. The decline in WAI survey biomass estimates from relatively high levels in the 1990s is likely related to high fishing rates in the 1990s, and the continued low WAI survey biomass estimates despite higher survey biomass estimates in the nearby CAI area is evidence of mechanisms establishing spatial structure near the WAI/CAI boundary. Areas depleted of rockfish are expected to take many years to rebuild abundance due to relatively long generation times (Spies et al. 2015).

The existence of spatial structure near the current WAI/CAI boundary is also consistent with the Aleutian Islands Ecosystems Assessment (Zador and Ortiz 2016). This report utilizes Aleutian Islands ecoregions that were defined based on spatial variation in bathymetry, physical oceanography, and species abundance. Three ecoregions are recognized, with the boundary between the western ecoregion and eastern ecoregion also occurring at 177° E longitude. Zador and Ortiz (2016) note that the western ecoregion is considered distinct from the neighboring central ecoregion due to relatively fewer islands, and the flow of the Alaska Stream through deeper and wider passes. The authors of stock structure reports for both BSAI and GOA rougheye rockfish have also noted that deep passes may pose a barrier to rockfish movement (Spencer and Gharrett 2010, Shotwell and Hanselman 2010).

Although fishing effort and blackspotted/rougheye rockfish catch does occur near the WAI/CAI boundary, this border does not appear to account for a large portion of Aleutian Islands fishing effort or blackspotted/rougheye rockfish catch, and higher levels of catch generally occur to the west of the WAI/CAI boundary (i.e., between 174.5° E and 176° E). The catch of blackspotted/rougheye rockfish occurs throughout the Aleutian Islands, which limits the locations where AI subarea boundaries could be relocated without affecting any fishing ground.

References

Cope, J.G., and A.E. Punt. 2009. Drawing the lines: resolving fishery management units with simple fisheries data. Can J. Fish. Aquat. Sci. 66:1256-1273.

Kauffman, L., and P.J. Rousseeuw, 1990. Finding groups in data: an introduction to cluster analysis. John Wiley & Sons, Inc., New York.

Rousseeuw, P.J. 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. **20**(1): 53–65.

Shotwell, S.K. and D. Hanselman. 2010. Assessment of the rougheye and blackspotted and rougheye rockfish stock in the Gulf of Alaska, Appendix A: Stock structure evaluation for the Gulf of Alaska rougheye and blackspotted rochfish complex. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, pp. 568-588. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501.

Spies, I., P.D. Spencer, and A.E. Punt. 2015. Where do we draw the line? A simulation approach for evaluating management of marine fish stocks with isolation by distance stock structure. Can. J. Fish. Aquat. Sci. 72:968-982.

Spencer, P.D. 2016. Evaluation of the potential implications of subarea ABCs for Bering Sea/Aleutian Islands blackspotted/rougheye rockfish. Paper prepared for the September 2010 NPFMC Plan Team meeting.

Spencer, P., M. Canino, J. DiCosimo, M. Dorn, A.J. Gharrett, D. Hanselman, K. Palof, and M. Sigler. 2010. Guidelines for determination of spatial management units for exploited populations in Alaskan fishery groundfish management plans. Paper prepared for the September 2010 NPFMC Plan Team meeting.

Spencer, P.D. and A.J. Gharett. 2010. Assessment of blackspotted and rougheye rockfish stock complex in the Bering Sea/Aleutian Islands, Appendix A: Evaluation of stock structure for the Bering Sea/Aleutian Islands Blackspotted/Rougheye rockfish complex. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, pp. 1172-1194. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501.

Wakabayashi, K., R.G. Bakkala, and M.S. Alton. 1985. Methods of the U.S.-Japan demersal trawl surveys. In R.G Bakkala and K. Wakabayashi, eds. Results of the cooperative U.S.Japan groundfish investigations in the Bering Sea during May-August 1979, p. 7-29. Int. North Pac. Fish. Comm., Bull. 44.

Zador, S. and I. Ortiz. 2016. Aleutian Islands Ecosystem Assessment. *In* Ecosystem considerations 2016: Status of the Aleutian Islands marine ecosystem, pp. 26-39. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501.

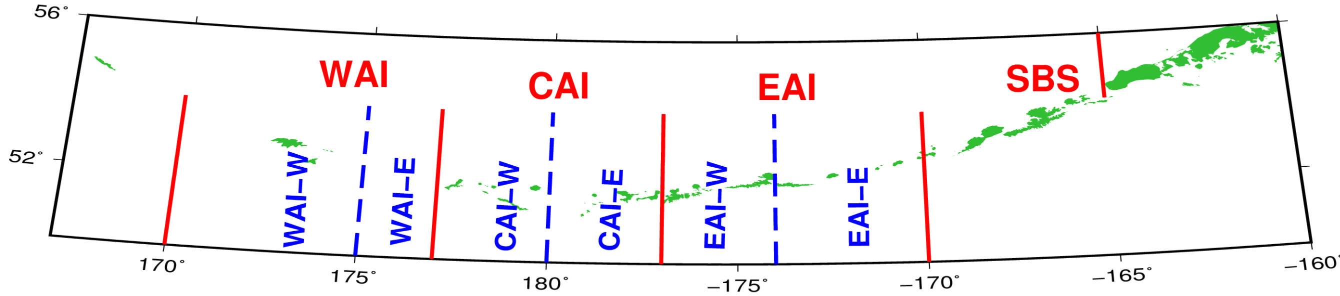

Figure 1. Current boundaries separating the WAI, CAI, EAI, and SBS areas (red), and boundaries separating additional subareas considered in this analysis (blue).

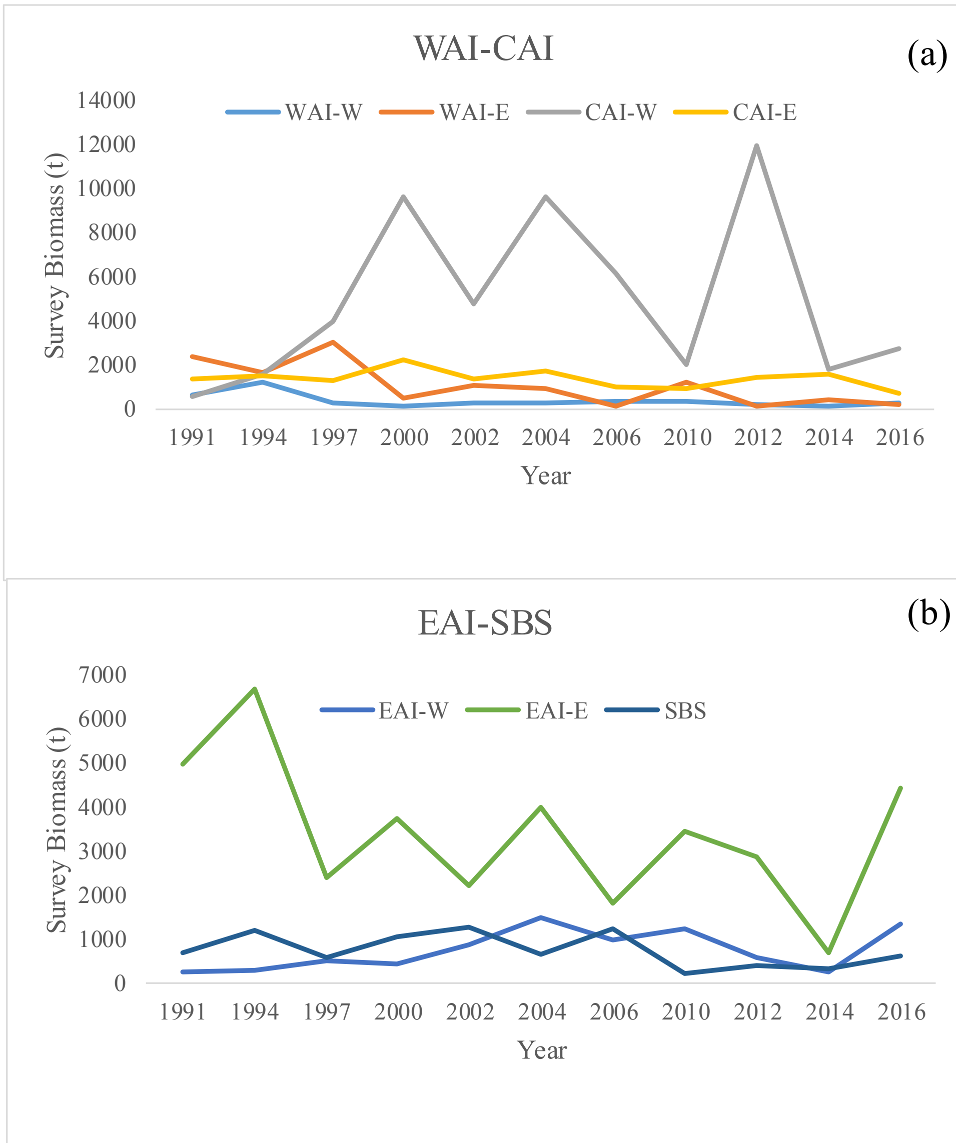

Figure 2. Aleutian Islands trawl survey biomass estimates by subarea.

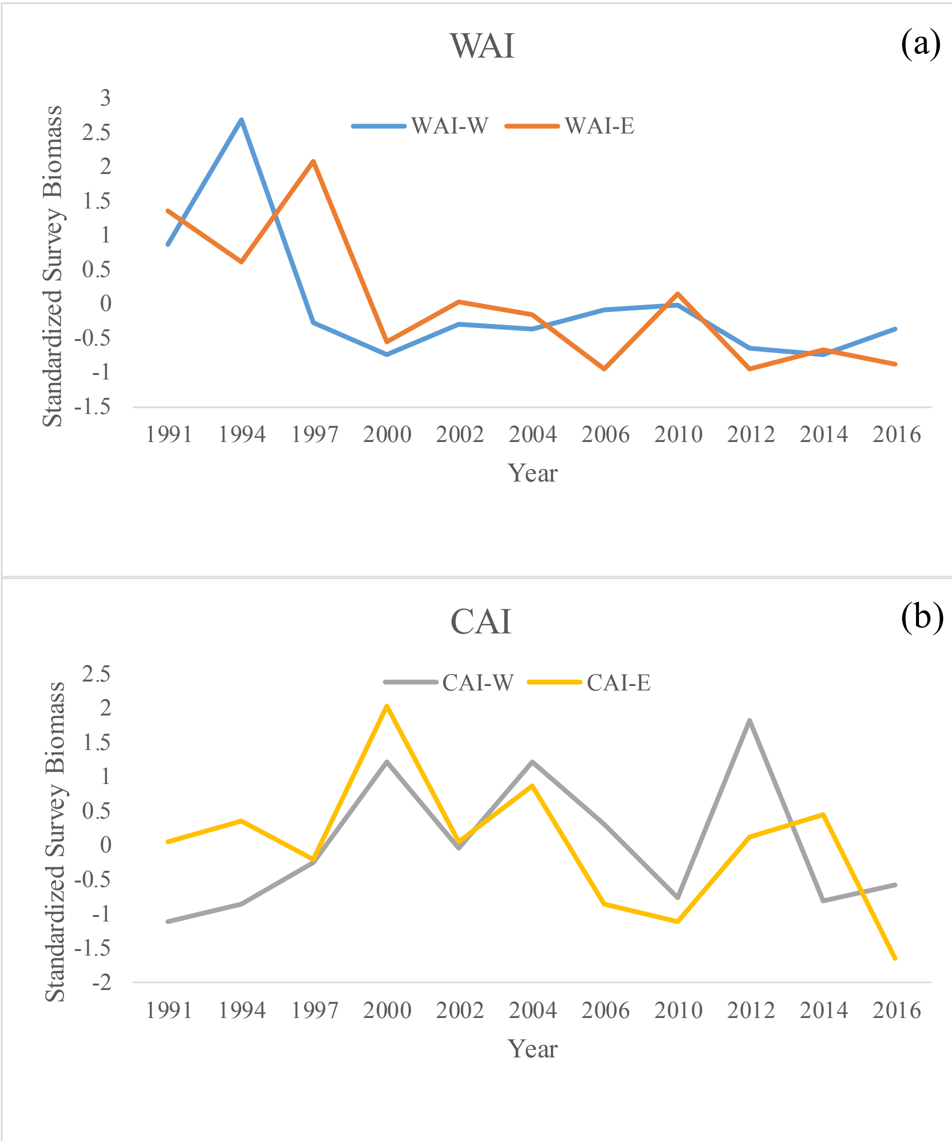

Figure 3. Standardized Aleutian Islands trawl survey biomass estimates for the WAI and CAI areas.

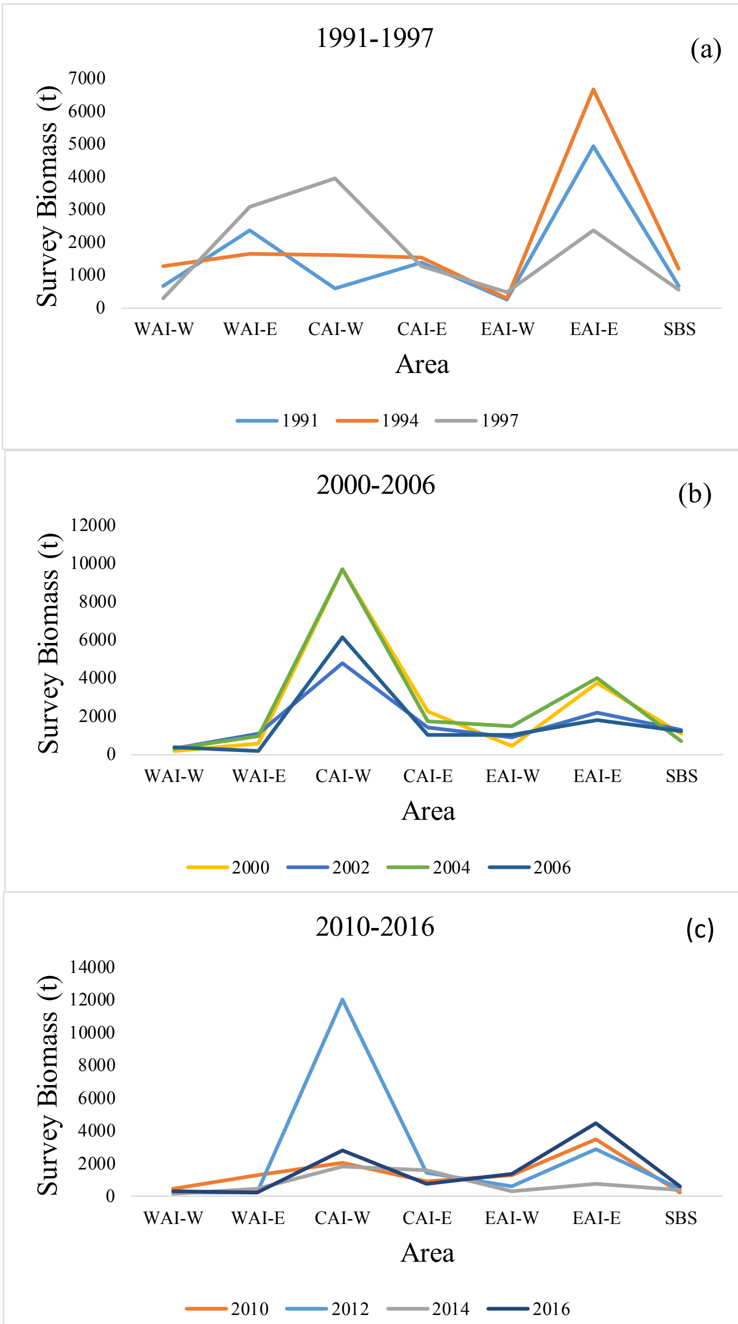

Figure 4. Spatial patterns of Aleutian Islands trawl survey biomass estimates by year.

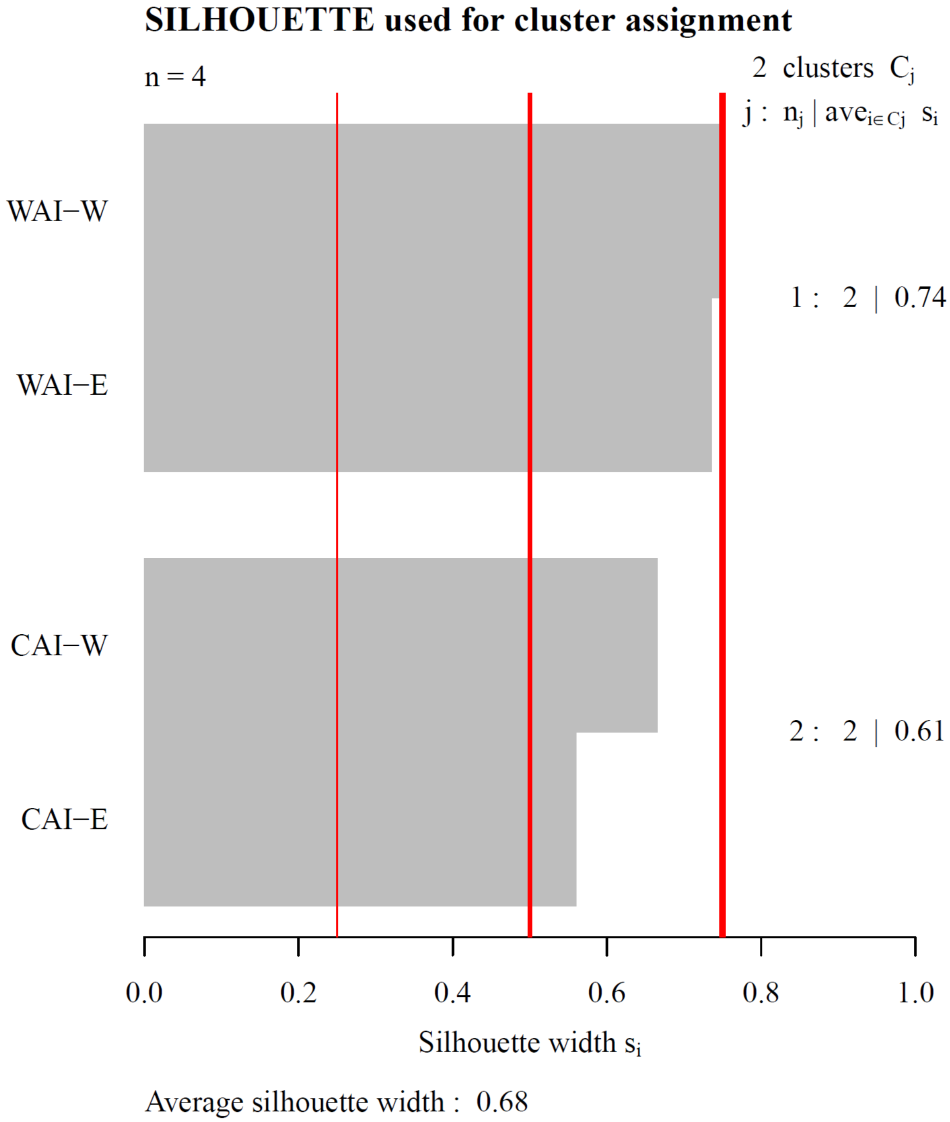

Figure 5. Silhouette widths (*s(i)*. Eq. 1) of 4 WAI and CAI spatial areas, with areas within each cluster plotted together. The average of the silhouette widths within each of the 2 identified clusters are shown on the right, whereas the average silhouette width for all 4 areas is shown on the bottom of the plot.

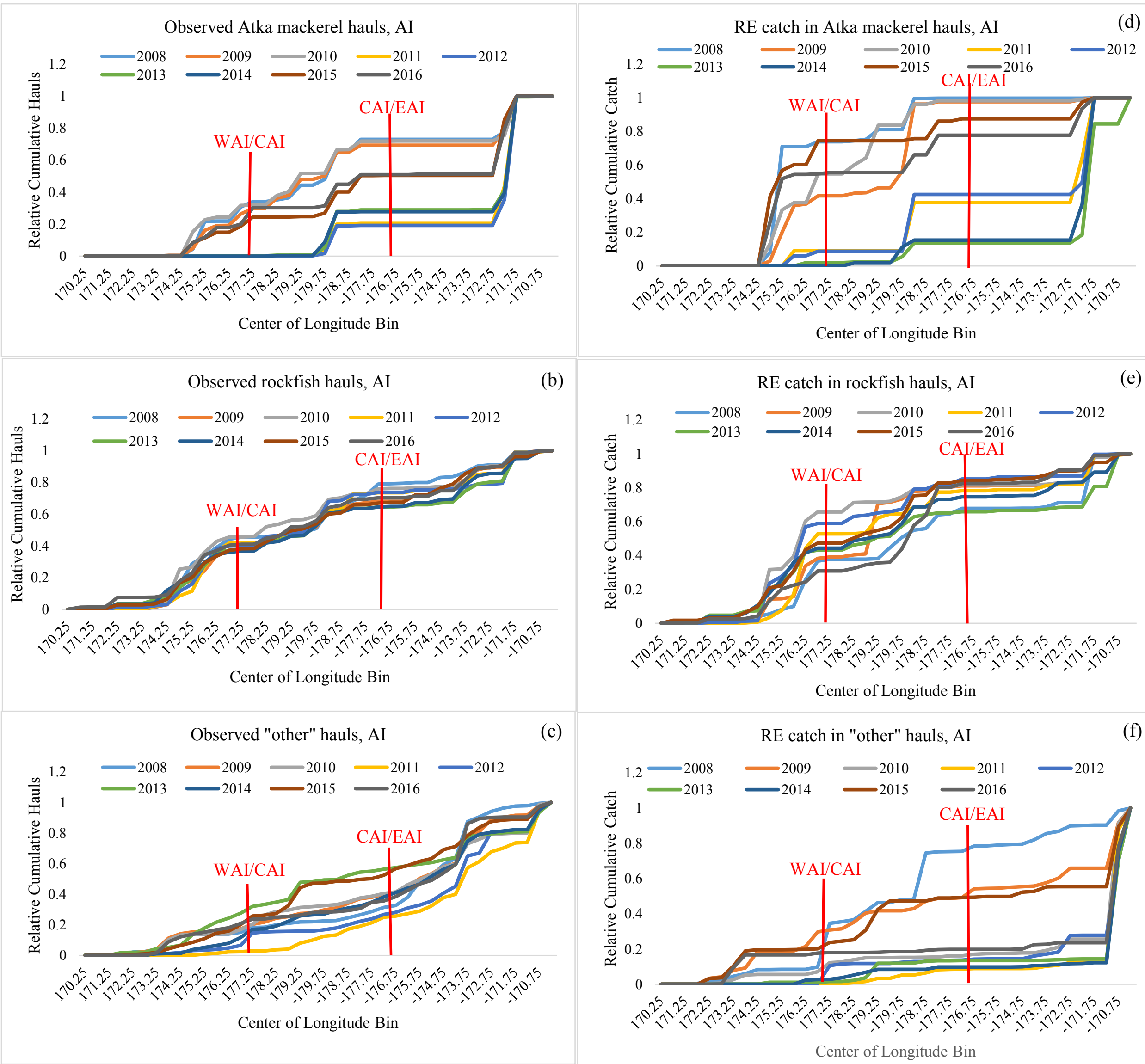

Figure 6. Relative cumulative distributions across Aleutian Island longitudinal cells for number of hauls and blackspotted/rougheye catch observed by north Pacific groundfish observers from 2008-2016, with the rockfish and Atka mackerel target fisheries shown separately. Boundaries between the WAI and CAI, and between the CAI and EAI, are shown with red vertical lines.

Table 1. Boundaries and average number of Aleutian Islands trawl survey tows (from 1991-2016) for current Aleutian Islands subareas and the "research" areas analyzed in this study.

Longitude Boundaries		Current	"Research"	Average Number of
West	East	Subarea	Subarea	Survey Tows
170°	175°	WAI	WAI-W	65
175°	177°	WAI	WAI-E	42
177°	180°	CAI	CAI-W	66
180°	-177°	CAI	CAI-E	48
-177°	-174°	EAI	EAI-W	37
-174°	-170°	EAI	EAI-E	88
-170°	-165°	SBS	SBS	53

Table 2. Number of hauls and blackspotted/rougheye rockfish catch from observed fishery hauls from 2008-2016 by target fishery.

	Observed Number of Hauls by Fishery				Observed RE/BS Catch of Hauls by Fishery (t)				
Year	Atka Mackerel	Rockfish	Other	Total	Atka Mackerel	Rockfish	Other	Total	Percent of CAS catch
2008	976	403	1942	3321	4.95	113.44	17.22	135.61	79%
2009	1284	341	2406	4031	18.28	117.74	21.44	157.46	85%
2010	1293	320	3661	5274	12.51	102.08	62.51	177.10	88%
2011	1006	446	1714	3166	4.23	86.34	33.29	123.86	97%
2012	1336	496	1657	3489	5.86	110.23	34.86	150.95	87%
2013	603	803	1672	3078	3.30	191.68	92.67	287.66	98%
2014	720	703	1270	2693	2.89	124.43	41.65	168.98	97%
2015	1276	781	1152	3209	8.09	110.67	24.88	143.65	96%
2016	1470	693	901	3064	12.18	87.95	14.00	114.14	97%