# Was the decline of Steller sea lions in the Aleutian Islands from 2000 to 2009 related to the Atka mackerel fishery?

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**Summary**

The goal of our study was to determine whether there was a relationship between the decline of Steller sea lions and the Atka mackerel fishery in Fishery Management Areas 541, 542 and 543 from 2000-2009. Data available to us included the numbers of non-pup sea lions counted in 2000, 2002, 2004, 2005, 2006, 2007, 2008 and 2009 by the US National Marine Fisheries Service, and the amounts and locations of Atka mackerel caught per haul for all trawlers targeting Atka mackerel in the Aleutian Islands from 2000-2009. We applied Generalized Estimating Equation models to these data to test whether numbers of sea lions or changes in numbers of sea lions were related to the frequency of trawling (number of hauls) and amounts of fish caught within 10, 20 or 40 nautical miles of sea lion rookeries and haulouts. We considered the total amount of fish removed within the three nautical mile zones (i.e., 10, 20 and 40 nm) as a measure of possible depletion of sea lion prey, and used the average catch per haul within each zone as a localized relative measure of stock size of Atka mackerel available to sea lions.

We found significant relationships between longitude and catch, and between longitude and number of hauls, for Atka mackerel for some of the models, suggesting that these metrics could not distinguish a fishing effect (if it existed) from some other geographically influenced variable on Steller sea lion numbers at the trend sites. For the remaining models that were free of the confounding effect of geographic location—none detected a negative relationship between fishing (number of hauls and total catch) and sea lion numbers. However, three models found small positive associations between fishing and sea lion numbers. Most notably, greater numbers of sea lions were associated with greater numbers of hauls within 10 nm of rookeries and haulouts; and there was a positive relationship between total catch within 40 nm of rookeries and numbers of sea lions counted at rookeries; as well as a positive relationship using the change-based models suggesting that the haulouts that increased the fastest were associated with greater increases in fishing activity (number of hauls) and amounts of Atka mackerel removed within 20nm. None of these findings were consistent with the *apriori* expectation that lower sea lion numbers should be associated with greater fishing effort.

We considered average catch per haul to be a relative measure of Atka mackerel abundance and found that sea lion numbers at rookeries and haulouts were not dependent on Atka mackerel biomass. Thus the models failed to find a relationship between average catch (our proxy for Atka mackerel abundance) and sea lion numbers. However, a relationship was noted for the change in average catch per haul between years and longitude, suggesting that differences in stock size changed systematically with geographic location.

## Introduction

The goal of our study was to determine whether there was a relationship between the decline of Steller sea lions and the Atka mackerel fishery in Fishery Management Areas (MA) 541, 542 and 543 from 2000-2009. We used linear models to test whether numbers of sea lions or changes in numbers of sea lions were related to the frequency of trawling (number of hauls) and amounts of fish caught within 10, 20 or 40 nautical miles of sea lion rookeries and haulouts. We considered the total amount of fish removed within the three zones as a measure of possible depletion of sea lion prey, the number of trawls as an indicator of disturbance, and used the average catch per haul within each zone as a relative measure of stock size of Atka mackerel available to sea lions.

## Data

The commercial catch of Atka mackerel was obtained for the Aleutian Islands for all vessels actively participating in the Atka mackerel fishery) from 2000 to 2009 (Karl Haflinger, Sea State Inc., pers. comm.). Individual catch records are the same data used by NMFS to manage the fishery via electronic reporting by NMFS-trained observers to NMFS. Independent contractors with data sharing agreements between fishing companies and NMFS are allowed to receive these same catch reports pursuant to their duties to provide catch information reports to industry for in-season bycatch avoidance and other quota tracking duties. The number of vessels fishing for mackerel in the Aleutian Islands over the period of record ranged from 4 to 10 trawlers and up to three smaller catcher vessels delivering catch to the trawlers in the latter part of the time period of interest. The data consisted of amount landed, date and location of haul. Catch was attributed to fishing location and assigned into respective distance from sea lion sites groupings by haulback location attached to each individual catch records. Within each of three buffer zones (10, 20 and 40 nautical miles of each rookery and haulout), we calculated the total number of hauls per year, the total catch of Atka mackerel, and the average catch per haul. We also calculated the differences in total catches, average catches and numbers of hauls between the years that sea lions were surveyed (i.e., between 2000 and 2002, 2002 and 2004, 2004 and 2005, 2005 and 2006, 2006 and 2007, 2007 and 2008, and 2008 and 2009). We treated average catch as an index of relative abundance or a relative measure of catch per unit effort (CPUE).

Trawling for Atka mackerel typically consists of short duration hauls that reflect the schooling nature of Atka mackerel and the rough ocean floor that prevents extended trawls. While a measure of CPUE such as catch per hour would be preferred as an index of relative abundance, fishing practices in the Atka mackerel fishery make CPUE problematic as an index of catch rate. This is because the mackerel fishery uses a practice called "short wiring" of nets when mackerel catch rates are high to ensure the rate that fish enter the processing facility is steady and achieves labor efficiencies for processing. Short-wiring involves towing a full net at or just under the surface until the fish from the previous net has been processed—at which point the catch from the short-wired net can be brought on board. This prevents gaps in the flow of fish through the factory. The problem for CPUE therefore is that NMFS-trained observers record only the time between setting and retrieving nets and there is no way to deduct the time nets are towed in a manner that catching fish is not occurring. When short-wiring occurs, nets are not catching fish (mackerel are caught at the seafloor) and therefore the inclusion of time at the surface prior to net retrieval would downwardly bias CPUE for tows when short-wiring occurred although short-wiring occurs when catch rates are relatively high and therefore processing capacity is exceeded.

Steller sea lions were counted by the National Marine Fisheries Service from aerial photographs at 73 trend sites in 5 Rookery Cluster Areas (RCA) within MA 541-543 (13 rookeries and 60 haulouts) in the Aleutian Islands in July of 2000, 2002, 2004, 2005, 2006, 2007, 2008 and 2009 (Figure 1). Counts consisted of non-pups (i.e., juveniles and adults) and were not adjusted for missing animals that were at sea. For our analyses, we used the adjusted counts (which corrected for differences in census techniques between years — Fritz and Stinchcomb 2005; Fritz *et al.* 2008) as well as the difference in number of animals counted between surveys (2002-2000, 2004-2002, 2005-2004, 2005-2006, 2007-2006, 2008-2007 and 2009-2008).

**Modelling**

Ultimately there is some set of parameters that can explain the changes observed in numbers of sea lions using the rookeries and haulouts in the Aleutian Islands. We explored the possibilities that sea lion numbers were 1) negatively affected by the presence of fishing vessels, 2) declined due to the depletion of Atka mackerel by commercial fisheries, and 3) were affected by the abundance of Atka mackerel near their rookeries and haulouts. We thus used 1) the number of hauls as an indicator of disturbance, 2) the total amount of fish caught as a measure of possible depletion of sea lion prey, and 3) the average catch per haul as a relative measure of stock size of Atka mackerel available to sea lions. However, testing the hypotheses with the appropriate statistical model is not trivial given that the available data (sea lion counts, numbers of hauls, total catch and average catch per haul) are not independent, but effectively consist of multiple collections of the same measures under different conditions. Serial correlations may also occur and confound simple interpretations of findings when measurements are repeated at the same sites over time — and adjacent positioning of sites will also result in spatial correlations between numbers and trends. The shortcomings in time dependence can be addressed to a large degree using some of the well-developed methods for modeling of repeated measures data (Liang and Zeger 1986; Davidian and Giltinan 1995).

We used Generalized Estimating Equations (GEE) in R (GNE S-http://cran.stat.sfu.ca) to assess whether fishing affected our subjects (the numbers of sea lions at rookeries and haulouts—our repeated measure) over time. GEEs allow for repeated measures within models and account for the correlation between these measures. They also allowed us to include an exchangeable correlation structure (Li *et al.* 1998) to deal with uneven time intervals that commonly occur during surveys such as the sea lion aerial counts (flown in 2000, 2002, 2004, 2005, 2006, 2007, 2008, and 2009) and incomplete coverage (some sites were surveyed every time, while others were surveyed less frequently). Generalized Estimating Equations provide an efficient means to estimate parameters and test hypotheses using data collected on the same units across successive points in time, where these repeated observations are correlated over time. In general, GEEs are viewed as an extension of ordinary linear regression models.

Fishing for Atka mackerel has occurred throughout the central and western Aleutian Islands over the period 2000-2009 (Fig. 1), while amounts of Atka mackerel caught has varied by region. Some of the variability can be explained by the availability of fish and differences in fisheries management actions that regulated where and how much fish could be caught. For example, rookeries and haulouts west of 178°W had smaller no trawl zones (between 3 and 15 nm in Area 543 and most of Area 542) than sea lion rookeries and haulouts east of 178°W (which had 20 nm no-trawl zones in Area 541 and a small portion of Area 542). Fishing could not occur within the no-trawl zones, but could occur outside of 20 nm. Limited amounts of fish were also caught between the boundary of some of the 3-15 nm no-trawl zones and the 20 nm boundary delimiting sea lion critical habitat (see http://www.fakr.noaa.gov/rr/tables/tabl6.pdf).

We tested whether the number of hauls and total catch within the three regions of fishing (i.e., 10, 20 or 40 nautical miles of rookeries and haulouts) could be predicted as a simple function of longitude at site *i* in year *j*:

$$trawl_{ij} = \exp(\beta_0 + \beta_{lon} lon_{ij}) \quad \text{[Eq. 1]}$$

Fishing activity variables (number of hauls or total catch, compiled at the 10, 20 or 40 nautical mile buffer zones) that were significantly correlated with longitude were not pursued further and were not used in our equations to predict sea lion numbers because any possible effects of fishing could not be distinguished from the spatial influences of geographically-based fisheries regulations. We therefore only ran models that had a statistical independence between longitude and the fishing activity variables.

We constructed separate models to determine whether the distance at which fisheries occurred from the nearest rookeries and haulouts (within 10 nm, 20nm or 40nm of shore) affected the numbers of sea lions (*SSLcnt*). Each of the base Poisson GEE models attempted to predict the numbers of sea lions at a site *i* in year *j* as a function of *year*, longitude (*lon*), and trawling activity (either numbers of hauls, average catch per haul, or total landings within a given distance of a haulout or rookery). Year was treated as a discrete variable and longitude and trawling activity as continuous variables. Sea lion counts were treated as log-transformed variables (satisfying the conditions of the Poisson GEE for variance to equal the mean, and for mean counts to be >0) to construct log-linear models with interaction terms between *year* and trawling activity:

$$SSLcnt_{ij} = \exp(\beta_0 + \beta_{trawl} trawl_{ij} + \beta_{yearj} year_j + \beta_{trawl:year} year{:}trawl_{ij} + \beta_{lon} lon) \quad \text{[Eq. 2]}$$

where *trawl* was either total catch, average catch per haul, or numbers of hauls. Longitude was included in the model because Steller sea lion counts are known to differ from east to west through the Aleutian chain. Including longitude allowed the models to explain some of the variability in sea lion counts that might be related to geography. Each of the three models was applied to all sites combined, and then to rookeries and haulouts separately for three zones of trawling activities (within 10, 20 or 40 nm).

We also used GEE models to determine whether changes in sea lion numbers between years could be predicted from changes in trawling activity that occurred near sea lion rookeries and haulouts (i.e., changes in the amount of Atka mackerel caught, or changes in the average amount of fish caught per trawl, or changes in the numbers of hauls):

$$\Delta SSLcnt_{ij} = \beta_0 + \beta_{trawl}\Delta trawl_{ij} + \beta_{yearj}\Delta year_j + \beta_{trawl:year}\Delta year{:}\,\Delta trawl_{ij} + \beta_{lon}lon \text{ [Eq. 3]}$$

This Gaussian GEE assumed normality (negative change was possible) and attempted to model a linear response in sea lion numbers to a change in fishing activity. As with the previous model, we also included longitude and tested for an interaction between year and change in trawling activity. Rookeries and haulouts were initially combined, and later modeled separately.

In terms of average catch per haul within the three distances of rookeries and haulouts (our proxy for fish abundance), we only included sites where fishing occurred. In other words, we did not include any zero values for average catch associated with any of the rookeries or haulouts, as there was for total catch and number of trawls. Treating average catch as a localized relative measure of fish abundance meant that it should not be a function of fishing regulation. We ran two average catch models (20 and 40nm) recognizing that this proxy of fish abundance was only available for some rookeries and haulouts compared with the total catch models that could be applied to all rookeries and haulouts throughout Management Areas 541-543.

## Results

***Sea lion number and fishing activity.*** Fishing locations for Atka mackerel from 2000-2009 relative to the locations of Steller sea lion rookeries and haulouts showed some obvious clusters of fishing activity. Some haulouts and rookeries had little if any fishing activity close to them (e.g., RCA4 and the western portion of RCA 1 also known as MA543) while others were exposed to more fishing (e.g., some rookeries and haulouts in RCA 2; Fig. 1).

Numbers of sea lions counted from aerial photographs at 13 rookeries and 60 haulouts from 2000-2009 have ranged from 0-889 animals across the Aleutian Island chain (Fig. 2). The most comprehensive surveys were flown from 2000-2004 and 2008 and reveal a fairly even distribution of sea lions throughout their central and western Aleutian range (Fig. 2). In general, smaller numbers of sea lions used the many resting sites in RCA 2 compared to the other four RCAs. Changes in numbers of sea lions using the individual rookeries and haulouts in the central and western Aleutians were calculated (Fig. 3). The changes in numbers of sea lions show considerable variability in counts between years, with most sites experiencing both increases and decreases.

Total numbers of hauls of Atka mackerel were determined within 10, 20 and 40 nm of rookeries and haulouts in the Aleutians and are shown for 40 nm (Fig. 4). Some rookeries and haulouts had no fishing occur within 40nm (e.g., rookeries and haulouts in RCA 4 in 2007). For others that had fishing occurring within 40 nm, the number of hauls in sea lion survey years between 2000 and 2009 averaged 91.12 hauls (range 1-415 hauls, SD = 99.59, n = 452, Table 1), and total catch averaged 4617.12 mt (range 0.28-26088.95, SD = 5788.51, n = 454, Table 1). In general the amounts of fish caught near rookeries and haulouts (i.e., within 40 nm) was fairly well distributed across the Aleutians though not necessarily evenly, with some sites having no fish removed from their adjacent waters while others had large amounts of fish removed, providing considerable contrast for the models(Fig. 5).

Average catch per haul was also calculated within three distances of rookeries and haulouts and is shown for the 40 nm radius (Fig. 6). The amounts of Atka mackerel caught per haul within 40nm averaged 39.90 mtons (range 0.28-99.00 mtons, SD = 22.30, n = 454; Table 1). Assuming that average catch can be used as a measure of relative abundance of fish present, the data suggest higher and increasing concentrations of Atka mackerel occurred in RCA 2 and RCA 5, with recent increases occurring in RCA 3 (in 2008 and 2009; Fig. 6). Note, however, that areas shown in Fig. 6 with no data (dots) do not imply that no fish were present, but merely show that no sampling (i.e., no fishing) occurred here and no data are available. A complex set of regulations stemming from the 2001 BiOp moved the mackerel fishery as far from sea lion haulouts and rookeries as possible. Thus fisheries occurred outside of sea lion Critical Habitat in areas that had broad shelves, but was allowed to occur at reduced levels in portions of the range where the narrow shelf made fishing at greater distances from haulouts and rookeries impractical. The end result was that up to 60% of the Total Allowable Catch (TAC) was allowed to be taken inside Critical Habitat in MA542 and MA543, and the industry agreed to fish entirely outside of Critical Habitat in MA541 where the wider shelf allowed a greater portion of the TAC to be taken beyond 20 nm of Steller sea lion sites.

Amounts of Atka mackerel caught per haul shows relative consistency in numbers of hauls (width of boxes) within an RCA and median catch over time (2000-2009; Fig. 7). The most notable change began in 2007 (and continued through 2009) when number of hauls decreased in RCA 4 and increased in RCA 5 (Fig. 7).

Fishing effort (as measured by the number of hauls that occurred within 40 nm of rookeries and haulouts) was relatively constant between years in RCAs 3 and 4 (Fig. 8). The greatest inter-annual changes in numbers of hauls occurred in RCAs 1 and 2, and more recently in RCA 5 (2006-2008; Fig. 8).

***Standard GEE Model Results.*** Coefficients for the longitude parameters were significant for three of the six models predicting numbers of hauls and total Atka mackerel catch as a function of longitude (Table 2) suggesting that these measures of fishing reflect geographically-based fisheries management decisions. This meant that any correlation between fishing activity and Steller sea lion counts that might be found could be confounded with differences in fisheries management and reflect a longitudinal cline in fishing activity rather than an effect of fishing on sea lions. We therefore excluded all three of these models from further consideration because they could not differentiate between an effect on sea lion numbers of fishing within 10 and 20 nm (number of trawls and total landings) of rookeries and haulouts and effects that could be attributable to changes in fisheries management (Table 2). Thus we ran the three GEE models that were not confounded by longitude and found no significant effect of number of hauls or total catch on sea lion numbers within 40 nm of haulouts and rookeries (Table 3). There was however a significant interaction between years (2002 and 2006) and total number of hauls that occurred within 10 nm—but no effect of number of hauls on sea lion numbers (Table 3).

Re-running the three GEE models (Eq. 2) for rookeries alone or for haulouts alone revealed a significant positive relationship between number of hauls within 10 nm of rookeries and haulouts (i.e., more fishing activity was associated with greater numbers of sea lions; Table 4). However the possible effect is extremely small based on the size of the coefficient (Table 4). There was also a very small positive relationship between total catch within 40 nm of rookeries and numbers of sea lions counted at rookeries (Table 4), as well as some significant interactions between numbers of trawls and year of fishing at the 10nm scale (Table 4). Coefficients of the significant interactions were all negative (except for one – Table 6) suggesting that the positive relationship between fishing activity and sea lion numbers dampened over time.

We treated average catches as an incomplete survey and a measure of relative abundance where fish were sampled. We found no significant correlations between longitude and average catch within 10, 20 or 40 nm of haulouts and rookeries (Table 2). This is consistent with the fact that average catch should not be a function of fisheries policy (although the locations sampled were).

The final standard GEE models (Eq. 2) attempted to estimate sea lion numbers as a function of average catch per haul within 10, 20 or 40 nm of the rookeries and included an interaction term between average catch and years for the 40 nm model (Table 5). However, the small coefficients associated with average catch were not statistically significant suggesting that sea lion numbers were not dependent on Atka mackerel biomass for the sites and years where Atka were caught. The only significant relationship was associated with year (Table 5) and was consistent with sea lions having declined over time. Re-running the three significant GEE models (Eq. 2) for rookeries alone or for haulouts alone revealed no significant relationship between average catch per haul and the numbers of sea lions at rookeries and haulouts (Table 6). The only coefficients that contributed to explaining sea lion numbers were associated with the year of fishing. Thus the models failed to find a relationship between average catch (our proxy for Atka mackerel abundance) and sea lion numbers.

***Change-Based GEE Model Results.*** Two of the change-based models (where the change or difference in Steller sea lion counts between years was compared to changes in number of hauls and total catch within 10nm, 20nm and 40nm) were excluded from further consideration because longitude was a significant predictor of changes in fishing activity (Table 7). This correlation suggests that differences in fishing activity likely reflect geographically based fishery policy decisions. All of the remaining models (Eq. 1) predicted that the change in average catch was related to longitude (Table 7). Assuming that average catch is a proxy for stock size, this correlation suggests that differences in stock size changed systematically with geographic location.

The generalized estimating change model equations (Eq. 3) for rookeries and haulouts combined showed a significant positive relationship between changes in sea lion numbers between years, and changes in the number of hauls within 40nm and with changes in total catch within 20nm (Table 8). The positive coefficients imply that rookeries and halulouts that declined faster were associated with faster reductions in total amount of Atka mackerel caught from one year to the next —or conversely— that the rookeries and haulouts that increased the fastest were associated with greater increases in amounts of fish removed within 20nm. In terms of fishing activity (numbers of hauls), the models suggest that sea lions declined faster where number of hauls decreased, and that sea lion numbers increased the fastest when fishing activity (number of hauls) also increased. There were also some significant effects of year on changes in numbers of sea lions between years (Table 8).

Re-running our change models by type of site (rookeries or haulouts) showed the positive relationship between rates of change in sea lion numbers and numbers of hauls within 40 nm was significant at haulouts, but not at rookeries (Table 9). A similar result was found for changes in total catch — the positive relationship with changes in total amounts of fish landed was significant within 20 nm of haulouts, but not for rookeries (Table 10).

**Discussion**

We focused our analysis on the effects of the Atka mackerel fishery on Steller sea lions because of the importance of Atka mackerel in the diet of sea lions in the central and western Aleutian Islands. Atka mackerel was the most dominant prey species found in the fecal samples of sea lions collected from 1990-1998 (1,222 scats collected in summer and 148 in winter—Sinclair and Zeppelin 2002). Atka mackerel remains occurred in 92.6% of all samples collected in summer, and in 64.9% of samples collected in winter. The next most important species were salmon (found in 15.5% of all scats in summer, and 23.6% in winter), squid and octopus (18.2% summer, 11.5% winter), followed by Pacific cod (6.5% summer, and 16.9% winter), sculpins (4.5% summer, 12.8% winter), and rock greenling (<1% summer, 21.6% winter). In terms of sea lion diet, everything else pales compared to the importance of Atka mackerel in the central and western Aleutian Islands (Sinclair and Zeppelin 2002; Trites *et al.* 2007).

The Atka mackerel fishery (2000-2009) was not randomly distributed across the central and western Aleutian Islands, but showed concentrations of effort and activity that likely reflects a combination of relative fish abundance, distance from ports, and fisheries policies regulating when and where fishing occurs. Some sea lion populations were exposed to fishing within 40 nm of their rookeries and haulouts, while others had little or no exposure to fishing—and numbers of sea lions varied considerably between sites and within individual rookeries and haulouts from year to year. This wide range of treatment levels (fishing) and the large number of haulouts and rookery populations of varying sizes and trends are conducive to testing whether there was a relationship between the Atka mackerel fishery and the decline of Steller sea lions, and should provide some insights into the mechanisms that have determined sea lion numbers in the Aleutian Islands.

It has been assumed that fishing for Atka mackerel caused or contributed to the continued decline of Steller sea lions in the western Aleutians (BiOp 2010). However, we failed to find any negative relationships between fishing effort and sea lion numbers using statistical tests (Generalized Estimating Equation models that allowed for repeated measures). What few significant relationships we did find were not consistent with this *apriori* expectation. We found, for example, that greater numbers of sea lions were associated with greater numbers of hauls within 10 nm of rookeries or 10 nm of haulouts. Similarly, we found a positive relationship between total catch within 40 nm of rookeries and numbers of sea lions counted at rookeries; as well as a positive relationship using the change-based models suggesting that the haulouts that increased the fastest were associated with greater increases in fishing activity (number of hauls) and amounts of Atka mackerel removed within 20nm. All of the significant models suggested positive relations, and none pointed to any negative relationships between sea lion numbers and fishing for Atka mackerel in the central and western Aleutians.

The models we tested considered the simple premise that the number of sea lions and changes in their numbers could be explained by the relative abundance of Atka mackerel present, the amount caught by fisheries and the amount of fishing effort occurring within 10, 20 or 40 nm of rookeries and haulouts. Thus we considered whether the continued decline of sea lions in the western Aleutian Islands could be explained by a single factor — Atka mackerel — the primary prey for Steller sea lions in the Aleutian Islands (Sinclair and Zeppelin 2002; Trites *et al.* 2007). None of the model coefficients suggested even a slight negative relationship between fishing for Atka mackerel and the decline of sea lions, which raises the question of whether fishing in this region can truly be considered a contributing factor—or if the population decline might better be explained by predation and reduced birth rates associated with the quality of prey consumed (e.g., Barrett-Lennard *et al.* 1995; Rosen and Trites 2000; Heise *et al.* 2003; Rosen and Trites 2004; Williams *et al.* 2004; Guénette *et al.* 2006; Matkin *et al.* 2007; Trites *et al.* 2007; Horning and Mellish 2009; Rosen 2009).

Constructing simple predictive models to explain the population dynamics of Steller sea lions can easily be confounded by the interdependence of sea lion counts between subsequent years and the potential geographic relatedness of adjacent rookeries and haulouts and their associated marine habitats. Using longitude as a model parameter to assess the spatial independence of the catch data allowed us to rule out models that would have confounded regional differences in policy with regional effects of fishery removals. Removing models that had this significant relationship between catch and longitude allowed us to better interpret whether a relationship existed between sea lion dynamics and fishing for Atka mackerel.

The significant (but slight) positive slopes associating increases in fisheries with increases in Steller sea lion counts were counter intuitive and not expected. One possible interpretation of the positive relationships is that the amount of fishing (hauls) reflected relative abundance of Atka mackerel and Steller sea lions having access to abundant Atka mackerel. It could also be argued that Steller sea lions had no difficulty finding other prey species and were not affected by the removal of Atka mackerel.

Our equations (models) included *year* as a discrete variable, and *trawl* as a continuous variable because of the potential for fishing activity to change with time, and for the two to confound drawing unambiguous explanations for changes in sea lion numbers. All of the *year* coefficients for our models were negative, and became more negative in later years compared to earlier years—describing an overall decrease in Steller sea lion numbers from 2000 to 2009—whereas the relationship to catch was positive (more sea lions = more Atka mackerel catch). Treating *year* as a discrete variable was the most flexible way to remove variability from the residuals when we were not particularly interested in the effect of time or presumed it was not a linear relationship. All of the significant interaction coefficients of our models were negative suggesting that the positive relationship between fishing and sea lion numbers dampened with time.

Our relatively simple predictive equations tested whether a negative relationship existed between fisheries and sea lions in the central and western Aleutian Islands. We used the best data and statistical techniques available to us, but failed to find a negative relationship between sea lion counts and Atka mackerel fisheries from 2000 to 2009. Further insights into this apparent lack of negative relationships would be gained by knowing the biomass of Atka mackerel that remains following fishing in areas used by foraging Steller sea lions. However, attempts to do so have been thwarted by having no reasonable way to subdivide the mackerel stock assessment biomass into subareas used by sea lions to forage (Fritz and Logerwell 2010). More frequent counts of sea lions, and additional diet data (to clarify the relative importance of other prey species to Steller sea lions) might also contribute to a more comprehensive understanding. Until such time however, we are left to draw scientifically based conclusions from the data at hand about the hypothesized effect of fishing on sea lions. To that end, our analyses failed to find any negative relationships between sea lion numbers and fishing for Atka mackerel in the central and western Aleutian Islands.

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Table 1. Mean numbers of hauls, total catch (mt) and average catch (mt) of Atka mackerel within 10, 20 or 40 nm of rookeries and haulouts in the western and central Aleutian Islands (Fig. 1) during years that Steller sea lions were counted (2000, 2002, 2004-2009). Also shown is the range, standard deviation (SD) and sample size (n). Catch and hauls were summed within 10nm, 20nm or 40nm of rookeries and haulouts, while catch per haul was averaged. Sample size thus reflects the numbers of rookeries and haulouts and years that fishing occurred between 170.9 to -170.1 longitude.

| | *10nm* | *20nm* | *40nm* |
|---|---|---|---|
| No. of hauls | | | |
| mean | 11.91 | 35.01 | 91.12 |
| SD | 29.33 | 45.89 | 99.59 |
| range | 1-173 | 1-177 | 1-415 |
| Total catch | | | |
| mean | 692.93 | 1737.30 | 4617.12 |
| SD | 2070.61 | 2724.84 | 5788.51 |
| range | 0.35-12994.24 | 0.07-13435.50 | 0.28-26088.95 |
| Avg catch | | | |
| mean | 40.90 | 40.07 | 39.90 |
| SD | 31.33 | 25.21 | 22.30 |
| range | 0.35-117.43 | 0.07-107.41 | 0.28-99.0 |
| n | 106 | 315 | 454 |

Table 2. Model results (Eq. 1) predicting numbers of hauls, or total catch or average catch of Atka mackerel (2000-2009) as a function of longitude showing the coefficient of longitude (*βlongitude*), the statistical significance of the coefficient (*p-value*), and sample size (*n*). Catch and hauls were summed within 10nm, 20nm or 40nm of rookeries and haulouts, while catch per haul was averaged. Sample size thus reflects the numbers of rookeries and haulouts and years that fishing occurred between 170.9 to -170.1 longitude. The models describing average catch exclude zero values. Significant coefficients are highlighted in bold.

| *Model* | *βlongitude* | *p-value* | *n* |
|---|---|---|---|
| No. of hauls | | | |
| 10nm | -0.075 | 0.07 | 584 |
| 20nm | **-0.087** | **<0.01*** | 584 |
| 40nm | 0.006 | 0.80 | 584 |
| Total catch | | | |
| 10nm | **-0.107** | **<0.01*** | 584 |
| 20nm | **-0.110** | **<0.01*** | 584 |
| 40nm | 0.016 | 0.55 | 584 |
| Avg catch | | | |
| 10nm | -0.014 | 0.60 | 106 |
| 20nm | -0.010 | 0.53 | 315 |
| 40nm | -0.011 | 0.42 | 454 |

Table 3. Generalized estimating equation (Eq. 2) results predicting log annual counts of Steller sea lions at rookeries ***and*** haulouts combined (from 2000 to 2009) from the number of hauls within 10nm or 40nm, or as a function of total catch of Atka mackerel within 40nm. Years included 2000, 2002 (Year 1), 2004 (Year 2) and 2005-2009 (Years 3-7). P-values are shown within the brackets and are highlighted in bold for those that are significant. Interaction terms were not included for number of hauls and total catch within 40nm because they were not significant (based on an ANOVA). Sample size reflects the numbers of rookeries and haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude.

| *Variable* | *No. of hauls within 10nm* | *No. of hauls within 40nm* | *Tot. catch within 40nm* |
|---|---|---|---|
| Intercept | -1.958 (0.73) | -3.000 (0.61) | -3.700 (0.53) |
| βhaul | 0.019 (0.08) | 2.96e-4 (0.36) | 8.43e-6 (0.168) |
| βyear1 | -0.072 (0.27) | -0.082 (0.23) | 0.081 (0.23) |
| βyear2 | 0.034 (0.68) | 0.016 (0.84) | 0.020 (0.80) |
| βyear3 | -0.021 (0.82) | -0.038 (0.66) | -0.039 (0.66) |
| βyear4 | -0.049 (0.59) | -0.083 (0.34) | -0.085 (0.33) |
| βyear5 | -0.138 (0.16) | -0.168 (0.09) | -0.172 (0.08) |
| βyear6 | -0.125 (0.14) | -0.150 (0.07) | -0.162 (0.06) |
| βyear7 | -0.055 (0.78) | -0.093 (0.63) | -0.108 (0.57) |
| βlongitude | 0.037 (0.24) | 0.042 (0.19) | 0.046 (0.152) |
| βhaul:year1 | **-0.004 (0.01)*** | | |
| βhaul:year2 | -0.010 (0.05) | | |
| βhaul:year3 | -0.009 (0.08) | | |
| βhaul:year4 | **-0.025 (0.02)*** | | |
| βhaul:year5 | -0.006 (0.62) | | |
| βhaul:year6 | -0.003 (0.06) | | |
| βhaul:year7 | -0.010 (0.06) | | |
| n | 584 | 584 | 584 |

Table 4. GEE model (Eq. 2) results predicting annual counts of Steller sea lions at rookeries ***or*** haulouts (from 2000 to 2009) from the number of hauls within 10nm or 40nm, or as a function of total catch of Atka mackerel within 40nm. Years included 2000, 2002 (Year 1), 2004 (Year 2) and 2005-2009 (Years 3-7). P-values are shown within the brackets and are highlighted in bold for those that are significant. Interaction terms were not included for number of hauls and total catch within 40nm because they were not significant (based on an ANOVA). Sample size reflects the numbers of rookeries and haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude.

| *Variable* | *Rookeries* *No. of hauls within 10nm* | *No. of hauls within 40nm* | *Tot. catch within 40nm* | *Haulouts* *No. of hauls within 10nm* | *No. of hauls within 40nm* | *Tot. catch within 40nm* |
|---|---|---|---|---|---|---|
| Intercept | -0.883 (0.89) | -0.103 (0.99) | -0.144 (0.98) | -7.800 (0.58) | -11.7 (0.49) | -11.700 (0.48) |
| Bhaul | **0.033 (0.02)*** | 2.44e-4 (0.32) | **9.02e-6 (0.046)*** | **0.014 (<0.01)*** | 3.52e-4 (0.53) | 4.26e-6 (0.71) |
| βyear1 | -0.024 (0.79) | -0.085 (0.34) | -0.079 (0.39) | -0.049 (0.67) | -0.033 (0.57) | -0.067 (0.56) |
| βyear2 | 0.151 (0.16) | 0.062 (0.58) | 0.070 (0.55) | -0.039 (0.76) | -0.047 (0.70) | -0.050 (0.69) |
| βyear3 | 0.031 (0.69) | -0.029 (0.72) | -0.032 (0.72) | 0.016 (0.95) | 0.005 (0.99) | 0.010 (0.97) |
| βyear4 | 0.037 (0.81) | -0.048 (0.69) | -0.043 (0.71) | -0.101 (0.53) | -0.128 (0.40) | -0.130 (0.40) |
| βyear5 | -0.017 (0.89) | -0.093 (0.46) | -0.099 (0.43) | -0.233 (0.13) | -0.255 (0.09) | -0.247 (0.10) |
| βyear6 | -0.051 (0.72) | -0.112 (0.39) | -0.128 (0.32) | -0.185 (0.11) | -0.201 (0.07) | -0.207 (0.08) |
| βyear7 | -0.051 (0.77) | -0.127 (0.41) | -0.147 (0.33) | 0.171 (0.52) | 0.121 (0.64) | 0.123 (0.64) |
| βlongitude | 0.037 (0.28) | 0.033 (0.32) | 0.033 (0.32) | 0.065 (0.40) | 0.086 (0.35) | 0.086 (0.34) |
| βhaul:yr1 | **-0.040 (0.01)*** | | | **-0.005 (0.02)*** | | |
| βhaul:yr2 | **-0.154 (<0.01)*** | | | **-0.007 (<0.01)*** | | |
| βhaul:yr3 | **-0.035 (<0.01)*** | | | **-0.007 (0.02)*** | | |
| Bhaul:yr4 | **-0.039 (0.01)*** | | | **-0.032 (0.03)*** | | |
| βhaul:yr5 | **-0.098 (0.03)*** | | | 0.006 (0.56) | | |
| βhaul:yr6 | -0.048 (0.10) | | | **-0.004 (0.03)*** | | |
| βhaul:yr6 | -0.067 (0.10) | | | **-0.011 (<.01)*** | | |
| n | 104 | 104 | 104 | 480 | 480 | 480 |

Table 5. Generalized estimating equation (Eq. 2) results predicting annual counts of Steller sea lions at rookeries ***and*** haulouts combined (from 2000 to 2009) from the average catch per haul (MT) of Atka mackerel within 10, 20 or 40nm. Years included 2000, 2002 (Year 1), 2004 (Year 2) and 2005-2009 (Years 3-7). P-values are shown within the brackets and are highlighted in bold for those that are significant. Interaction terms were not included for average catch within 10 and 20nm based on an Analysis of Variance that showed they were not significant. Sample size reflects the numbers of rookeries and haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude.

| *Variable* | *Avg catch within 10nm* | *Avg. catch within 20nm* | *Avg. catch within 40nm* |
|---|---|---|---|
| Intercept | 6.583 (0.61) | 6.242 (0.29) | 0.442 (0.94) |
| Bhaul | -0.001 (0.83) | 0.002 (0.21) | 0.009 (0.10) |
| βyear1 | **-0.267 (0.04)*** | -0.103 (0.29) | 0.066 (0.79) |
| βyear2 | **-0.283 (0.02)*** | -0.001 (0.99) | 0.151 (0.59) |
| βyear3 | **-0.178 (0.01)*** | -0.162 (0.08) | 0.038 (0.92) |
| βyear4 | -0.151 (0.47) | -0.050 (0.70) | 0.143 (0.58) |
| βyear5 | **-0.480 (0.01)*** | **-0.274 (0.03)*** | 0.029 (0.95) |
| βyear6 | **-0.301 (0.01)*** | **-0.246 (0.01)*** | -0.501 (0.11) |
| βyear7 | **-0.416 (<0.01)*** | **-0.442 (<0.01)*** | -0.055 (0.97) |
| βlongitude | -0.008 (0.91) | -0.008 (0.80) | 0.022 (0.53) |
| βhaul:year1 | | | -0.004 (0.46) |
| βhaul:year2 | | | -0.005 (0.44) |
| βhaul:year3 | | | -0.004 (0.51) |
| βhaul:year4 | | | -0.007 (0.16) |
| βhaul:year5 | | | -0.006 (0.52) |
| βhaul:year6 | | | 0.002 (0.72) |
| βhaul:year7 | | | -0.004 (0.88) |
| n | 106 | 315 | 454 |

Table 6. Generalized estimating equation (Eq. 2) results predicting annual counts of Steller sea lions at rookeries ***or*** haulouts (from 2000 to 2009) from the average catch per haul (MT) of Atka mackerel within 10, 20 or 40nm. Years include 2000, 2002 (Year 1), 2004 (Year 2) and 2005-2009 (Years 3-7). P-values are shown within the brackets and are highlighted in bold for those that are significant. Interaction terms were not included for average catch within 10 and 20nm based on an Analysis of Variance that showed they were not significant. Sample size reflects the numbers of rookeries and haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude. Catches occurred too seldom within 10 nm of rookeries (n=25) to model average catch at that scale.

| | *Rookeries* | | *Haulouts* | | |
|---|---|---|---|---|---|
| *Variable* | *Avg. catch within 20nm* | *Avg. catch within 40nm* | *Avg catch within 10nm* | *Avg. catch within 20nm* | *Avg. catch within 40nm* |
| Intercept | -4.405 (0.45) | -5.162 (0.30) | 16.430 (0.08) | **13.664 (0.04)*** | 7.409 (0.23) |
| βhaul | 3.19e-4 (0.84) | -0.003 (0.76) | -0.010 (0.06) | -0.001 (0.68) | 0.007 (0.38) |
| βyear1 | **-0.274 (<0.01)*** | -0.400 (0.31) | -0.077 (0.80) | 0.204 (0.22) | 0.087 (0.84) |
| βyear2 | -0.126 (0.18) | -0.364 (0.37) | **-0.572 (0.05)*** | 0.130 (0.58) | 0.161 (0.74) |
| βyear3 | **-0.226 (<0.01)*** | -0.427 (0.24) | 0.013 (0.94) | -0.029 (0.90) | 0.404 (0.63) |
| βyear4 | -0.466 (0.09) | -0.167 (0.63) | **-1.182 (<0.01)*** | 0.091 (0.70) | 0.234 (0.57) |
| βyear5 | **-0.300 (<0.01)*** | **-1.400 (<0.01)*** | -0.780 (0.09) | -0.250 (0.42) | 0.559 (0.47) |
| βyear6 | **-0.268 (0.01)*** | **-1.078 (0.05)*** | -0.325 (0.17) | -0.216 (0.20) | -0.554 (0.27) |
| βyear7 | **-0.360 (<0.01)*** | **-1.072 (<0.01)*** | -0.169 (0.52) | **-0.573 (0.05)*** | **2.197 (0.03)*** |
| βlongitude | 0.058 (0.08) | **0.064 (0.03)*** | -0.065 (0.22) | -0.053 (0.15) | -0.019 (0.57) |
| βhaul:year1 | | 0.005 (0.61) | | | -0.002 (0.83) |
| βhaul:year2 | | 0.008 (0.46) | | | -0.006 (0.56) |
| βhaul:year3 | | 0.006 (0.50) | | | -0.010 (0.50) |
| βhaul:year4 | | -0.057 (0.36) | | | -0.011 (0.15) |
| βhaul:year5 | | **0.023 (0.02)*** | | | -0.016 (0.22) |
| βhaul:year6 | | 0.016 (0.19) | | | 0.002 (0.84) |
| βhaul:year7 | | 0.018 (0.06) | | | **-0.050 (<0.01)*** |
| n | 72 | 83 | 81 | 243 | 371 |

Table 7. Model results (Eq. 1) predicting interannual changes in numbers of hauls, or total catch or average catch of Atka mackerel (2000-2009) as a function of longitude showing the coefficient of longitude (*ßlongitude*), the statistical significance of the coefficient (*p-value*), and sample size (*n*). Catch and hauls were summed within 10nm, 20nm or 40nm of rookeries and haulouts, while catch per haul was averaged. Sample sizes reflect the numbers of rookeries and haulouts and years that fishing occurred between 170.9 to -170.1 longitude. All the models excluded areas that were not fished to remove zero values that would incorrectly infer a constant rate of fishing where none had occurred. Significant coefficients are highlighted in bold.

| *Model* | *ßlongitude* | *p-value* | *n* |
|---|---|---|---|
| Change in no. of hauls | | | |
| 10nm | -0.596 | 0.93 | 46 |
| 20nm | **26.71** | **<0.01*** | 213 |
| 40nm | 0.610 | 0.11 | 369 |
| Change in total catch | | | |
| 10nm | -16.7 | 0.99 | 46 |
| 20nm | -36.1 | 0.42 | 213 |
| 40nm | **105.0** | **<0.01*** | 369 |
| Change in average catch | | | |
| 10nm | **-3.24** | **0.02*** | 46 |
| 20nm | **0.475** | **<0.01*** | 213 |
| 40nm | **0.337** | **<0.01*** | 369 |

Table 8. Change model generalized estimating equation (Eq. 3) coefficients predicting changes in counts of Steller sea lions between years at rookeries ***and*** haulouts combined (from 2000 to 2009) from changes in number of hauls within 10nm or 40nm, or as a function of changes in total catch of Atka mackerel within 10 or 20nm. Differences were calculated between 2002 and 2000, 2004 and 2002 (Year 1), 2005 and 2004 (Year 2) and 2006-2005 (Year 3), 2007-2006 (Year 4), 2008-2007 (Year 5), 2009-2008 (Year 6). P-values are shown within the brackets and are highlighted in bold for those that are significant. Sample size reflects the numbers of rookeries and haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude.

| *Variable* | *Change in no. hauls within 10nm* | *Change in no. hauls within 40nm* | *Change in total catch within 10nm* | *Change in total catch within 20nm* |
|---|---|---|---|---|
| Intercept | -3.358e3 (0.93) | -5.878e3 (0.13) | -5.18e3 (0.90) | -1.09e4 (0.23) |
| βhaul | 0.502 (0.99) | **13.39 (<0.01)*** | 0.059 (0.92) | **0.458 (0.01)*** |
| βyear1 | 3.489e3 (0.0502) | **5.391e3 (<0.01)*** | **3.47e3 (0.05)*** | **5.76e3 (<0.01)*** |
| βyear2 | -3.313e3 (0.09) | **-3.706e3 (<0.01)*** | -3.32e3 (0.08) | **3.29e3 (<0.01)*** |
| βyear3 | 3.442e3 (0.40) | **4.543e3 (<0.01)*** | 3.38e3 (0.40) | **4.76e3 (<0.01)*** |
| βyear4 | 5.398e3 (0.09) | **4.650e3 (<0.01)*** | 5.44e3 (0.09) | **7.55e3 (<0.01)*** |
| βyear5 | **1.008e4 (<0.01)*** | **8.460e3 (<0.01)*** | **1.01e4 (<0.01)*** | **8.02e3 (<0.01)*** |
| βyear6 | -1.301e3 (0.79) | **-4.732e3 (<0.01)*** | -1.44e3 (0.77) | **-3.15e3 (<0.01)*** |
| βlongitude | 1.799 (0.99) | 15.01 (0.48) | 11.9 (0.96) | 39.4 (0.44) |
| n | 46 | 369 | 46 | 213 |

Table 9. Change model generalized estimating equation (Eq. 3) coefficients predicting changes in counts of Steller sea lions between years at rookeries ***or*** haulouts (from 2000 to 2009) from changes in number of hauls within 10nm or 40nm. Differences were calculated between 2002 and 2000, 2004 and 2002 (Year 1), 2005 and 2004 (Year 2) and 2006-2005 (Year 3), 2007-2006 (Year 4), 2008-2007 (Year 5), 2009-2008 (Year 6). P-values are shown within the brackets and are highlighted in bold for those that are significant. Sample size reflects the numbers of rookeries or haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude. The rookery model for change in number of hauls within 10nm was not calculated due to the small sample size (n=14).

| *Variable* | *Rookeries Change in no. hauls within 40nm* | *Haulouts Change in no. hauls within 10nm* | *Haulouts Change in no. hauls within 40nm* |
|---|---|---|---|
| Intercept | **-3.686e4 (0.01)*** | 4.885e4 (0.10) | -5.261e3 (0.19) |
| βhaul | 8.00 (0.14) | -16.92 (0.74) | **13.40 (<0.01)*** |
| βyear1 | 1.265e3 (0.30) | **6.005e3 (0.01)*** | **6.238e3 (<0.01)*** |
| βyear2 | -1.253e3 (0.49) | -3.938e3 (0.07) | **-4.177e3 (<0.01)*** |
| βyear3 | -2.231e3 (0.37) | 8.036e3 (0.10) | **5.967e3 (<0.01)*** |
| βyear4 | **4.420e3 (0.01)*** | 7.445e3 (0.12) | **4.384e3 (<0.01)*** |
| βyear5 | **7.003e3 (<0.01)*** | **1.025e4 (<0.01)*** | **8.748e3 (<0.01)*** |
| βyear6 | -2.331e3 (0.21) | 925.58 (0.85) | **-5.428e3 (<0.01)*** |
| βlongitude | **197.74 (0.02)*** | -294.85 (0.07) | 9.61 (0.66) |
| n | 69 | 32 | 300 |

Table 10. Change model generalized estimating equation (Eq. 3) coefficients predicting changes in counts of Steller sea lions between years at rookeries ***or*** haulouts (from 2000 to 2009) from changes in total catch within 10nm or 20nm. Differences were calculated between 2002 and 2000, 2004 and 2002 (Year 1), 2005 and 2004 (Year 2) and 2006-2005 (Year 3), 2007-2006 (Year 4), 2008-2007 (Year 5), 2009-2008 (Year 6). P-values are shown within the brackets and are highlighted in bold for those that are significant. Sample size reflects the numbers of rookeries or haulouts between 2000 and 2009 where fishing occurred within 10 or 40 nm between 170.9 to -170.1 longitude. A rookery model for change in total catch within 10nm was not calculated due to the small sample size (n=14).

| *Variable* | *Rookeries*<br>*Change in total catch within 20nm* | *Haulouts*<br>*Change in total catch within 10nm* | *Haulouts*<br>*Change in total catch within 20nm* |
|---|---|---|---|
| Intercept | -5.38e4 (0.10) | 4.475e4 (0.13) | -9.493e3 (0.32) |
| βhaul | -0.212 (0.54) | -0.206 (0.77) | **0.458 (<0.01)*** |
| βyear1 | 1.10e3 (0.42) | **5.855e3 (0.01)*** | **7.204e3 (<0.01)*** |
| βyear2 | 596.0 (0.74) | -3.952e3e (0.07) | **-3.731e3 (<0.01)*** |
| βyear3 | -3.54e3 (0.16) | 7.990e3 (0.08) | **6.946e3 (<0.01)*** |
| βyear4 | **5.61e3 (<0.01)*** | 7.504e3 (0.12) | **8.388e3 (<0.01)*** |
| βyear5 | **7.94e3 (0.02)*** | **1.021e4 (<0.01)*** | **8.796e3 (<0.01)*** |
| βyear6 | -860.0 (0.68) | -- | **-3.987e3 (<0.01)*** |
| βlongitude | 292.0 (0.11) | -271.948 (0.09) | 27.044 (0.60) |
| n | 54 | 32 | 159 |

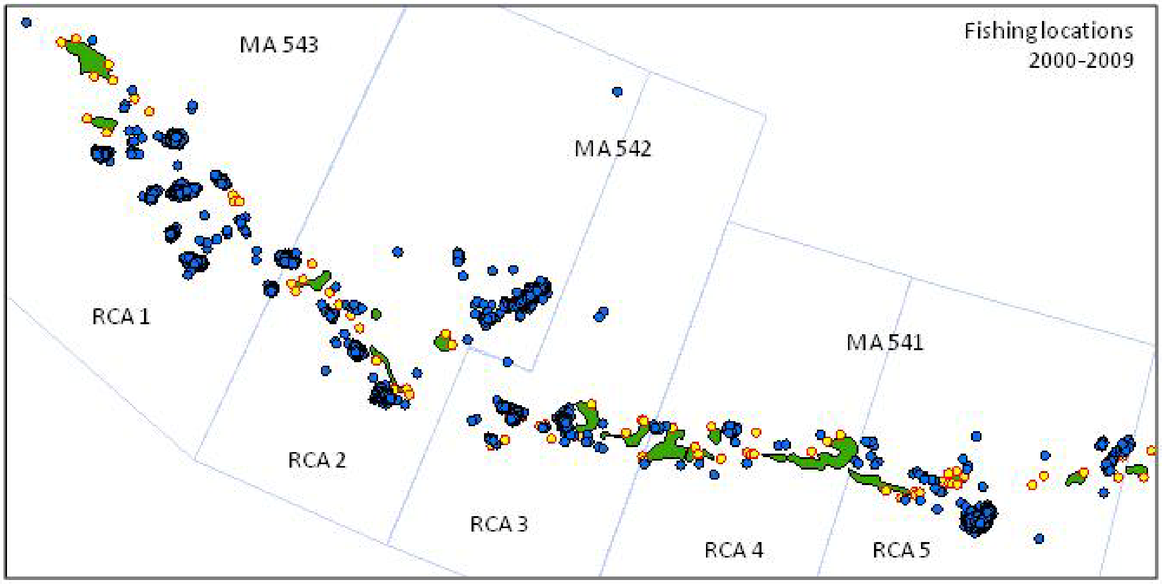


Figure 1. Locations of Steller sea lion rookeries and haulouts (yellow) and Atka mackerel catches in the central and western Aleutian Islands from 2000-2009 (blue). Each blue dot indicates a single haul of Atka mackerel. Fisheries management areas (MA) and rookery cluster areas (RCA) are also labeled with MA 543 including RCA 1, MA 542 including both RCA 2 and 3, and MA 541 including RCAs 4 and 5.

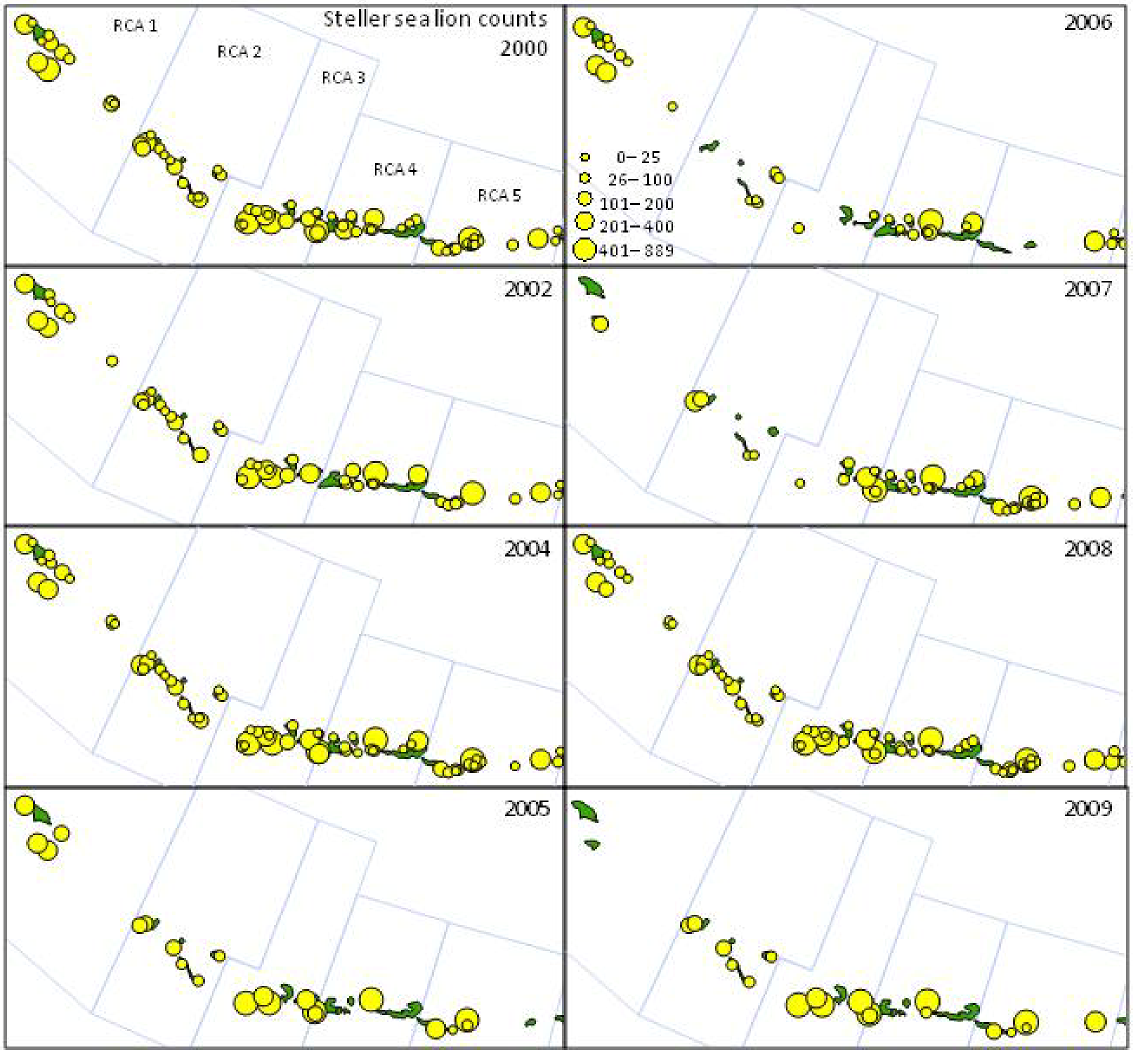


Figure 2. Aerial Steller sea lion counts by year along the central and western Aleutian Islands during July 2000, 2002, 2004, 2005-2009. Scale is equal for all years, with larger points indicating higher count. Some rookeries and haulouts are missing points in some years as complete surveys were not conducted every year. Jenks natural breaks within Arc View were used to determine the bins.

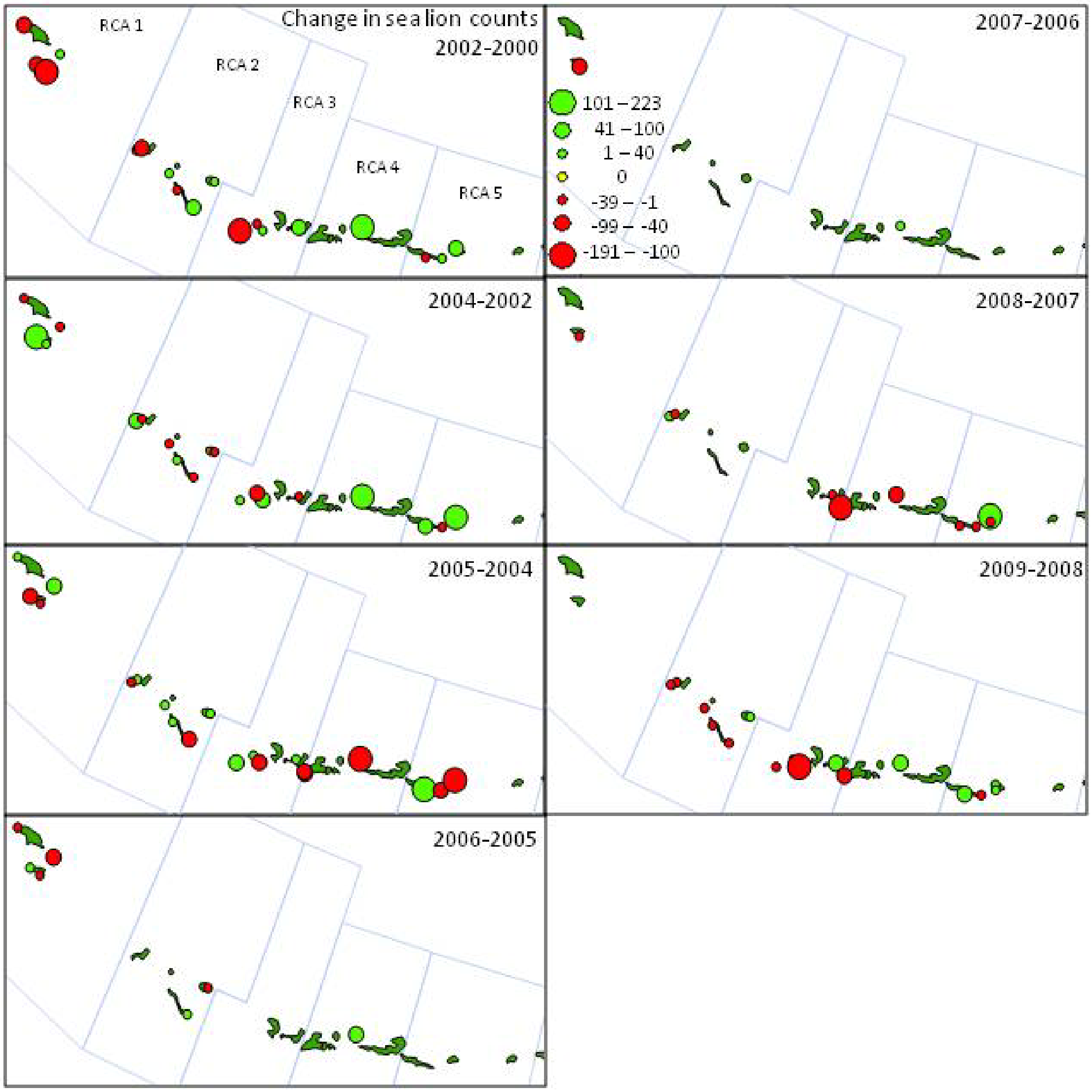


Figure 3. Change in Steller sea lion counts between years along the central and western Aleutian Islands. Scale is equal for all years with decreases in numbers shown in red and increases shown in green. No change in SSL counts was indicated by yellow points, but this did not occur between any of the years where there were counts. There are missing points at some rookeries and haulouts, as surveys were not complete each year and there was not a count in the previous year to determine a change.

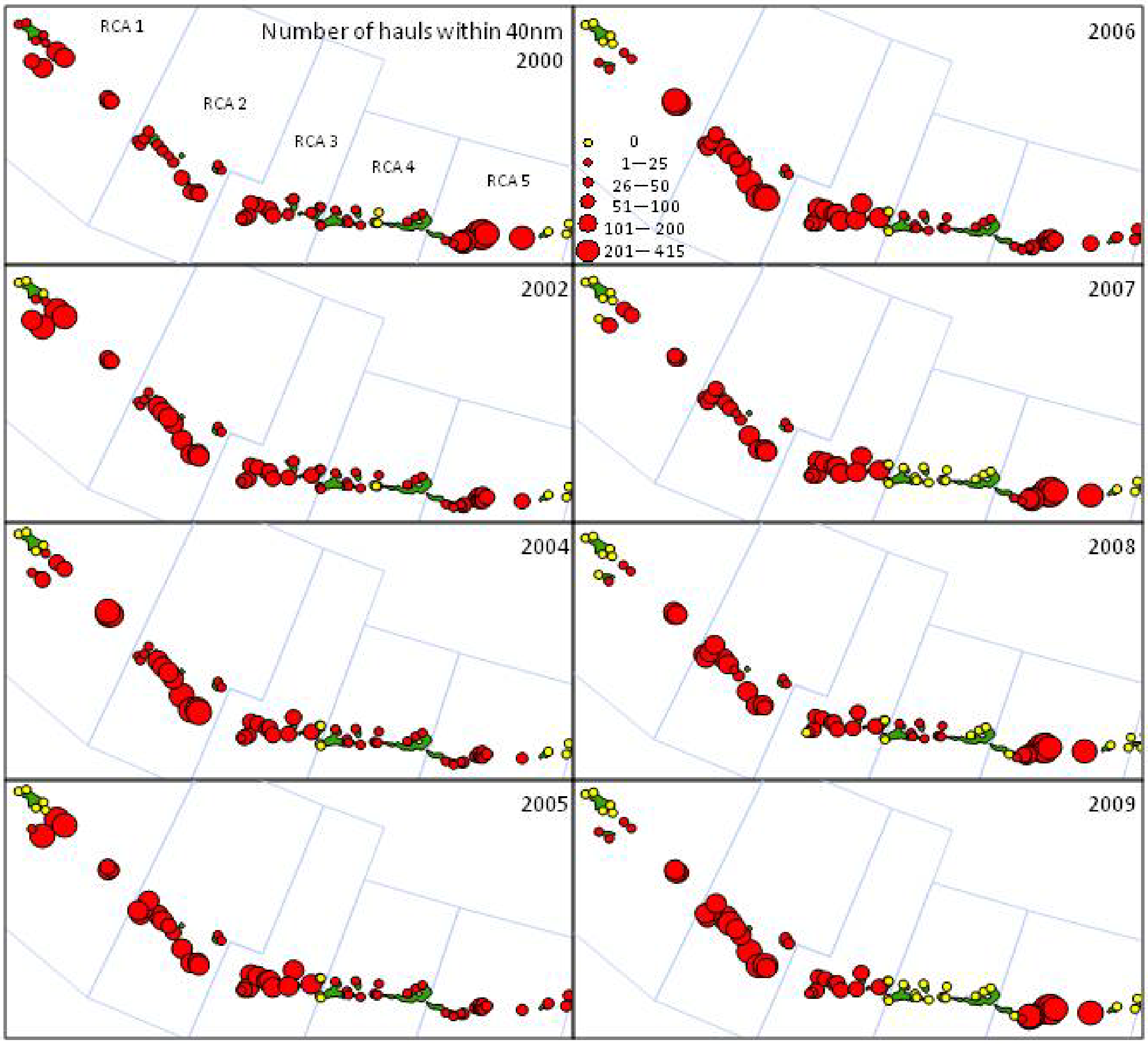


Figure 4. Number of hauls of Atka mackerel within 40nm of rookeries and haulouts by year along the central and western Aleutian Islands. Scale is equal for all years with yellow points indicating a rookery or haulout that did not have hauls within 40nm and red points indicating increasing numbers of hauls.

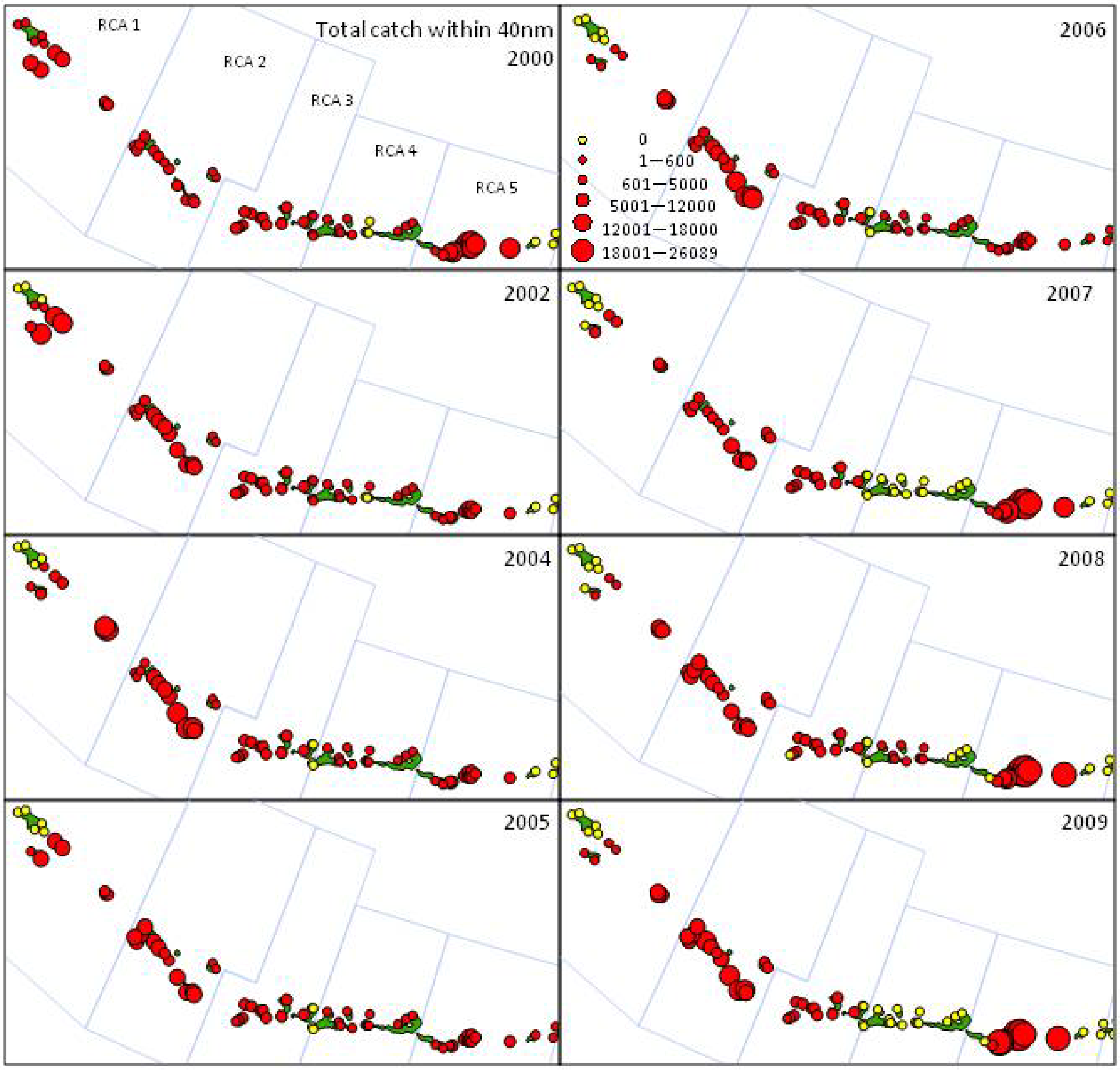


Figure 5. Total catch of Atka mackerel taken within 40nm of rookeries and haulouts by year along the central and western Aleutian Islands. Scale is equal for all years with yellow points indicating a rookery or haulout that did not have catch within 40nm and red points indicating increasing total catch (mt).

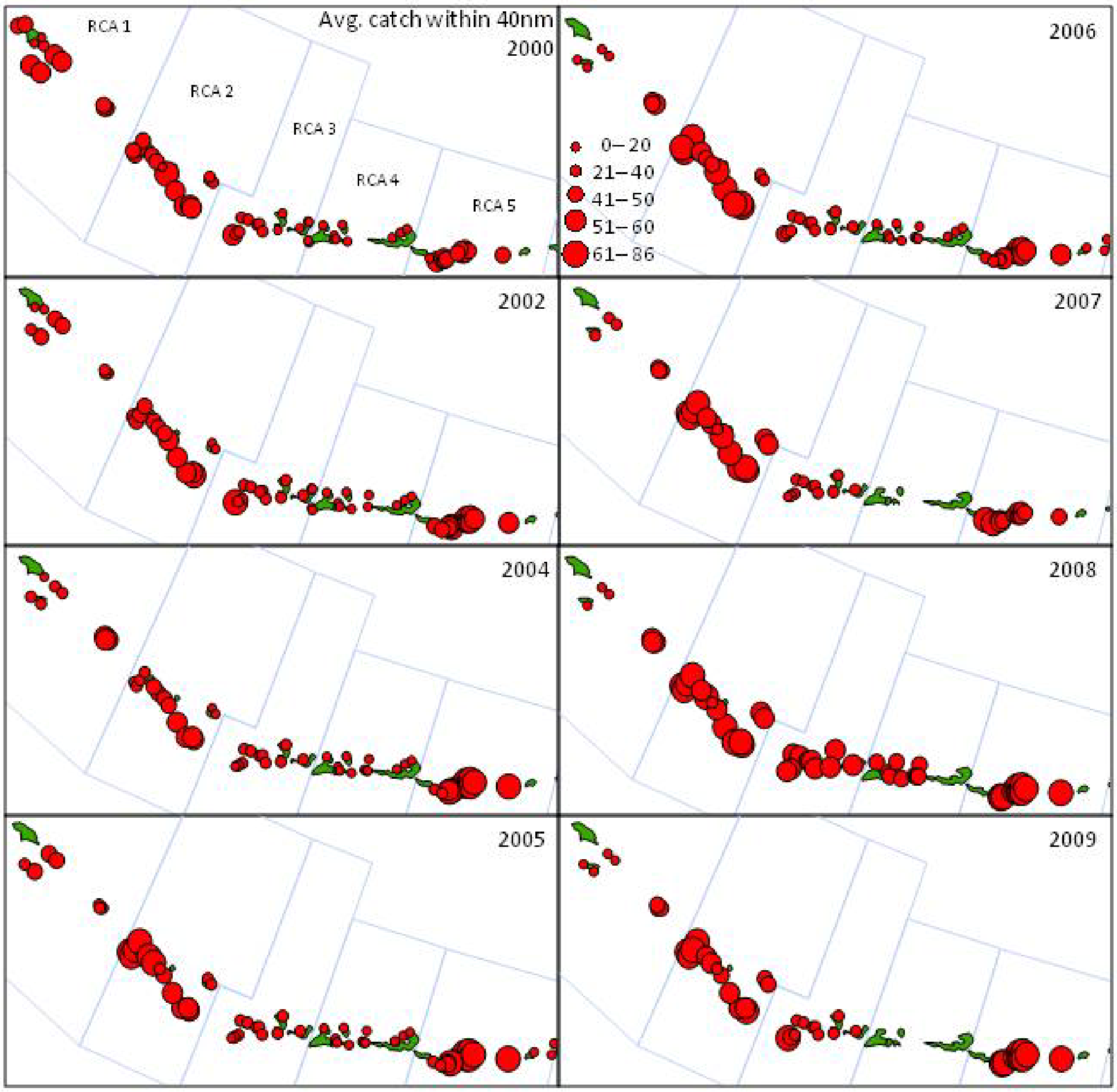


Figure 6. Average Atka mackerel catch within 40nm of rookeries and haulouts by year along the central and western Aleutian Islands. Zero data is not included and scale is equal for all years with red points indicating increasing average catch.

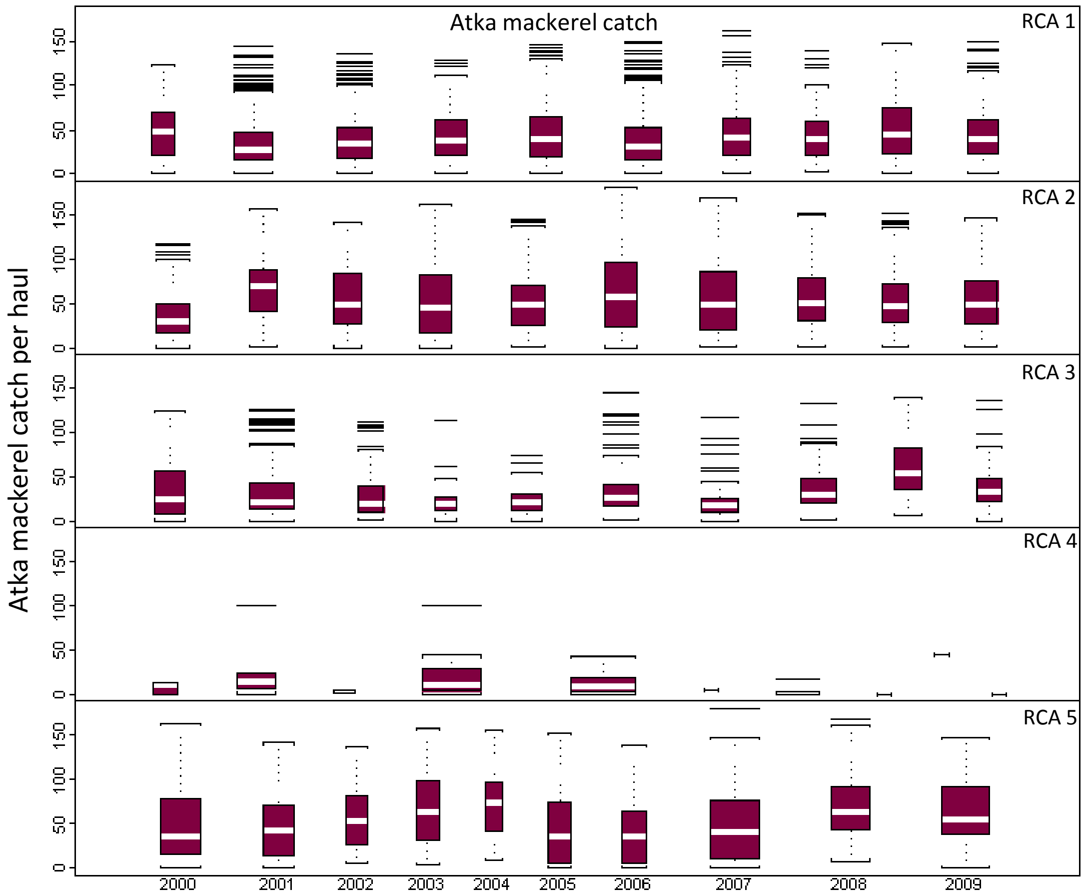


Figure 7. Range of Atka mackerel catch by year within the RCA regions along the Aleutian Island chain. The x axis indicates year and the y axis indicates Atka mackerel catch with the width of boxes representing number of hauls.

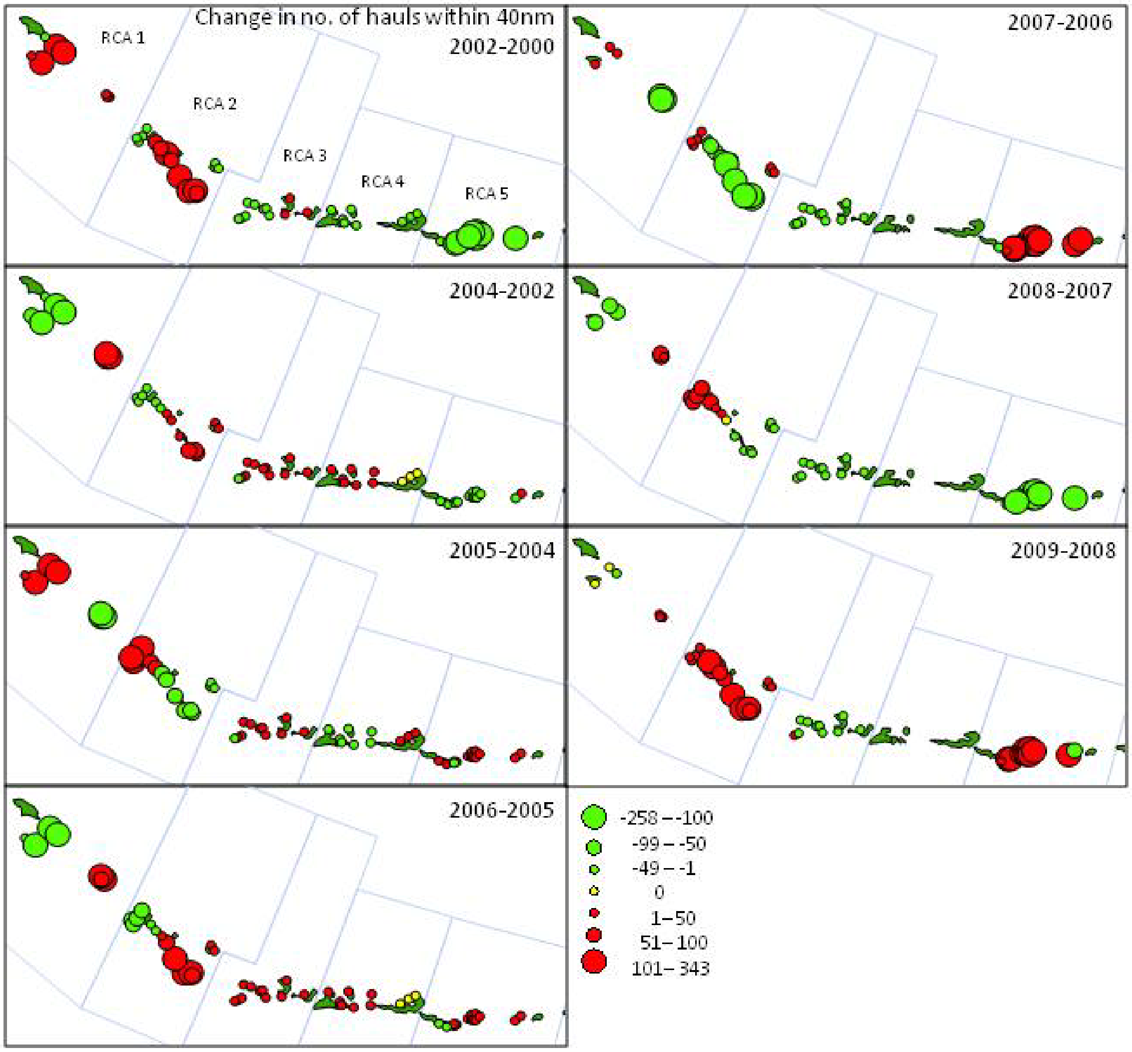


Figure 8. Change in the number of Atka mackerel hauls within 40nm of rookeries and haulouts between years along the central and western Aleutian Islands. Scale is equal for all years with decreases in number of hauls shown in red and increases shown in green. No change in number of hauls was indicated by yellow points. Fishing occurred in all years between 2000 and 2009 but differences were only calculated for those years where a survey was conducted for Steller sea lions.