# An Analysis of Groundfish Fishing Activities Near Steller Sea Lion Rookeries in Alaska

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Abstract

During the past few decades large commercial fisheries for groundfish developed in the Gulf of Alaska and Bering Sea. There has been speculation that these fishing operations may have reduced the available fish stocks and thereby contributed to the dramatic declines in the Alaskan populations of Steller sea lion *(Eumetopias jubatus)* that occurred during the same period. Previous studies that attempted to relate estimates of sea lion abundance with annual catches of walleye pollock (Theragra *chalcogramma)* produced inconclusive results. In this investigation principal component analysis was applied to data from 1979-90 on sea lion counts for 25 sea lion rookeries in the Gulf of Alaska and Aleutian Islands, and independently to fishery observer data from 1980-89 for the commercial groundfish fishing operations that occurred within a distance of about 37 kilometers of these rookeries. The component scores from the two data sets were then correlated to explore for similarities between the pattern of sea lion decline and the pattern of fishing operations.

There was an unusually large correlation between the second principal component for the adult sea lion declines and the second component for the winter pollock catches. Rookeries that suffered relatively large declines in sea lion counts early in the study period generally experienced large winter pollock catches, but rookeries that suffered declines late in the study period experienced either no winter pollock catches or ones that occurred late in the study period. There were no strong

correlations between the components for the adult sea lion declines and any other fishery components (quarterly fishing effort and total catches of groundfish, catches of Pacific cod, *Gadus macrocephalus,* and of Atka mackerel, *Pleurogrammus monopterygius).* Also, there were no strong correlations between the components for the sea lion pups and any fishery components.

## Introduction

In response to marked declines during the past several decades in the Alaskan populations of Steller sea lions *(Eumetopias jubatus),* in 1990 the US National Marine Fisheries Service (NMFS) included these animals on the list of threatened species under the provisions of the Endangered Species Act (NMFS, 1992). Although the deterioration in the populations has been widespread, it has not occurred uniformly across all breeding colonies. Loughlin et *al.* (1992) reported an 81% decline over the period 1960 to 1989 in the estimated number of adult and juvenile Steller sea lions in the Aleutian Islands, the historical center of their abundance and range, a 54% decline in the Gulf of Alaska, and a 70% increase in Southeast Alaska. The general reduction in sea lion numbers in the Aleutian Islands and Gulf of Alaska, coupled with the simultaneous growth in the fisheries for groundfish in this region, has led researchers to speculate that the fisheries may have had adverse effects on the sea lions (Braham et al., 1980; Merrick et al., 1987; Lowry et al., 1989; Loughlin and Merrick, 1989; Springer, 1992), but the nature of the linkage remains unclear.

Alternative causes for the decline that have been proposed or examined include: commercial (Merrick *et al.,* 1987) and subsistence (NMFS, 1992) harvests of sea lions; entanglement in marine debris (Loughlin *et al.,* 1986); incidental (Loughlin and Nelson, 1986; Perez and Loughlin, 1991) and deliberate killing by fishermen (Merrick *et al.*, 1987); disease (Castellini *et al.,* 1993); and changes in oceanographic conditions (Springer, 1992; Pascual and Adkison, 1994). Observations made in the mid 1970s when compared with ones from the mid 1980s indicate no apparent changes in either sea lion reproductive rates or pup survival during this period (Merrick *et al.,* 1987). A recent analysis of changes in the population's age structure suggests the decline was the result of reduced survival of juvenile rather than adult sea lions (York, 1994).

Although Steller sea lions are opportunistic predators, in the Aleutian Islands and Gulf of Alaska adults are known to feed predominantly on medium to large walleye pollock *(Theragra chalcogramma)* (Pitcher, 1981; Lowry *et al.*, 1989) and young sea lions on smaller pollock (Frost and Lowry, 1986). Other less important sea lion prey in this region include Pacific cod *(Gadus macrocephalus),* octopus, squid, salmon *(Oncorhynchus* sp.), Pacific herring *(Clupea harengus pallasi),* Pacific sand lance *(Ammodytes hexapterus),* capelin *(Mallotus villosus),* flatfish (Pleuronectidae), rockfish *(Sebastes* sp.) and Atka mackerel *(Pleurogrammus monopterygius).* Based on the apparent strong dependence of sea lions on walleye pollock for food, there have been attempts to correlate commercial harvests of pollock with trends in sea lion counts, but the results have been inconclusive.

Loughlin and Merrick (1989) compared trends in sea lion abundance at eight major rookeries in the Bering Sea and Gulf of Alaska with catch statistics for the commercial pollock fishery in the surrounding areas. They used counts made at each rookery of adult and juvenile sea lions (1976-86) and of pups (1976-88) and correlated these with annual pollock fishery data (catch, catch per hour of fishing, and average fish weight) for areas centered roughly around each rookery and measuring one degree of latitude by two degrees of longitude. They directly compared the sea lion counts with the fishery statistics for the same year and with the fishery data lagged by one to five years. Although they found several statistically significant correlations, the coefficients were both positive and negative. They concluded that their results neither supported nor rejected the hypothesis that commercial pollock harvests had influenced sea lion abundance.

Ferrero and Fritz (1994) repeated the analyses of Loughlin and Merrick (1989) but with additional fishery data and counts of adult and juvenile sea lions (1987-91). Furthermore, they conducted a new analysis, at a finer spatial scale than the original study, using data on the annual pollock harvests that occurred within 37 kilometers (20 nautical miles) of each area and using adult and juvenile sea lion counts from 13 areas rather than the original eight rookeries. In both analyses they found several statistically significant correlations, but the signs on the coefficients were inconsistent.

In the current study I search for correlations between the commercial groundfish fisheries in Alaska and the declines in the Steller sea lion populations, but with a slightly wider scope, from a different perspective, and using different analytical tools than the previous studies by Loughlin and Merrick (1989) and Ferrero and Fritz (1994). My approach is motivated by the notion that the sea lion declines may be related to human disturbance rather than to pollock harvests and that fishing activities during particular times of the year may impair the survival of juvenile sea lions. Steller sea lion rookeries are usually at remote, inaccessible sites (NMFS, 1992), perhaps reflecting this species' innate sensitivity to disturbance during the pupping season. Fishing during summer and fall may disrupt the ability of sea lion mothers to successfully nurse their pups. Fishing during fall or winter may disrupt the initial hunting activities of newly weaned pups.

## Materials and Methods

The basic data for this study consisted of counts of sea lions at selected rookeries in the Aleutian Islands and Gulf of Alaska from 1979-89 and groundfish fishery statistics from 1980-89 for the areas surrounding these rookeries. Data from other commercial fisheries, such as the crab, shrimp, herring and salmon fisheries, were not available at a sufficiently fine scale of resolution. I used sea lion data for a more extensive set of rookeries than the studies by Loughlin and Merrick (1989) and Ferrero and Fritz (1994), but for a more limited time span.

Also, rather than directly correlating the sea lion counts with the fishery data, I applied principal component analysis to the sea lion data and independently to the fishery data and extracted component scores that accounted for most of the variation in each data source; then I correlated the scores for the two data sets to explore for similarities.

Sea Lion Abundance Data

The counts of adult and juvenile sea lions and pups were made by the NMFS and Alaska Department of Fish and Game as part of their routine monitoring programs (Fiscus et al., 1981; Merrick *et al.* 1988, 1990, 1991). The counts are from either aerial photographic surveys or land surveys conducted during the peak of the breeding season, late June through early July. The counts do not include adults and juveniles that were in the sea at the time of the survey or non-breeding animals sighted at haulouts. The surveys were conducted sporadically during the period 1979-90 and never during any given year at all rookeries, although the surveys were very nearly complete during 1979, 1985, 1989, and 1990. Counts of pups, which were always from land-based surveys, are much less extensive than counts of adults and juveniles. The most complete pup surveys were conducted during 1979 and 1990.

I chose to distinguish between rookeries on the basis of their characteristics during the early versus late portion of the study period. For each rookery I used the counts from three years to calculate annual instantaneous rates of change for the numbers of animals during the early and late periods by applying the formula

$$\log_e( N_t / N_0 ) / t ,$$

where $N_0$ is the count from the base survey, $N_t$ is the count from the next survey, and $t$ is the number of years between the two surveys. If pup counts were available for a given rookery for all three surveys, I also calculated ratios of the number of pups to the number of adults and juveniles (non-pups). For these calculations I usually took counts from surveys conducted during 1979, 1985, and 1990 because there was very complete coverage of the rookeries during these years, especially for the adults and juveniles. For some rookeries (e.g., Attu and Chernabura Islands) I chose different base years to make better use of the available counts (Table 1).

The 30 rookeries included in this study cover a wide geographic range (2380 kilometers), from Attu Island in the western Aleutian Islands to Seal Rocks in the Gulf of Alaska at the entrance of Prince William Sound (Fig. 1). Four rookeries in the general study area (Semispochnoi Island, Walrus Island, Outer Island, and Wooded Island) were excluded from the analyses because they had only two or fewer survey counts during the study period.

For comparing the adult and juvenile counts with the fishery data I combined certain rookeries due to their close geographic proximity and used only the instantaneous rates of change in 25 rookeries or rookery groups (Table 1, Fig. 1). For example, I treated the adult and juvenile counts from Ulak Island, Gramp Rock, and Tag Island as if they were from a single rookery, Delarof Islands. For easier identification in figures (e.g.

Fig. l), I numbered the rookeries from 1 for the westernmost (Attu) to 25 for the easternmost (Seal Rocks).

Groundfish Fishery Data

The fishery data used in this study consisted of observed fishing effort (hours fishing) and catches (metric tons) of selected groundfish species (walleye pollock, Pacific cod, and Atka Mackerel) tabulated by year, quarter, gear type, and area. The data, which were provided by NMFS, were extracted from a database of information collected by US fishery observers aboard -foreign, joint-venture, and domestic fishing vessels. Originally the data were derived by NMFS as part of an analysis for establishing designated areas of critical habitat for Steller sea lions under the provisions of the Endangered Species Act (NMFS, 1993). The data are essentially identical to previously reported values (Fritz, 1993) except for the inclusion of fishing effort and the exclusion of catches that had no reported fishing effort values. Also, I only used data for 1980-89, The data from prior to 1979 were reported to be unreliable[1] and the data from 1979 did not distinguish between gear types. NMFS did not provide me with data for 1990 or more recent years.

The data represent observed fishing activities by longline, midwater trawl, and bottom trawl vessels that occurred within a radius of 37 kilometers (20 nautical miles) from any one of 116 rookery and major haulout sites designated as critical habitat

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for Steller sea lions (NMFS, 1993). This particular spatial scale was chosen on the basis of tagging studies by Merrick *et al.* (1994), who found that female sea lions that have young pups at a rookery do not forage more than about 37 kilometers from their pups. To avoid double counting, observations from regions of overlap between two or more sites were assigned to the westernmost site during the data extraction process. As a consequence, the fishing areas associated with each rookery have irregular surface areas (Table 2, Fig. 1).

The proportion of the fishing activities that were documented by observers was not uniform during the study period. In 1980 there was observer coverage for about 8% of the fishing days by foreign vessels operating in the eastern Bering Sea and Aleutian Islands (Bakkala, 1984); in 1989 there was 94% observer coverage of the fishing days by joint venture operations in the region (Guttormsen *et al.,* 1990). In Loughlin and Merrick (1989) and Ferrero and Fritz (1994) the observer data were expanded to account for unobserved catches. In the current study I chose instead to treat the observer data for each rookery zone on a relative basis. For each year I tabulated the observed effort and catch statistics for the set of 25 rookery zones and calculated quarterly effort and catch percentages for each zone. For example, during 1985 the total observed catch of pollock from the 25 rookery zones was 23,624.3 metric tons of which 213.5 metric tons (0.90%) was taken during the second quarter from zone 10 (Attu) and 32.8 metric tons (0.14%) was taken during the third quarter from zone 23 (Marmot).

Because large spatial areas will by chance alone tend to account for a greater proportion of the fishing activities than small areas, I adjusted the effort and catch percentages for each zone using the formula

$$\text{Adjusted Percent} = \text{Percent} * \frac{\text{Average Area } [km^2]}{\text{Zone Area } [km^2]},$$

which reduced the relative size of the catches from large zones and inflated the catches from small zones. Because the fishery data were very skewed, with a few large values and large numbers of zero or small values, I transformed the adjusted percentages using Gauch's (1982) so-called octave scale (Table 3), a base two logarithmic transformation.

Rookery Ordinations Based on Counts of Adults and Juveniles

To simplify the sea lion data for the 25 five rookery groups I applied principle component analysis (PCA) (Dillon and Goldstein, 1984) to the early and late instantaneous rates of change in the adult and juvenile counts (Table 1). In general, one uses a PCA to reduce the number of variables into a smaller set that nevertheless account for most of the variation in the original data. The first principal component provides an objective measure for ordering the samples using the observed data. The second principal component, which is always uncorrelated with the first and generally accounts for less of the original variation, provides an additional measure for ranking the samples, and so on.

Rookery Ordinations Based on Counts of Pups

For monitoring trends in pinniped populations the number of pups born is considered to be the best measure (Berkson and DeMaster, 1985). However, in this study counts of sea lion pups were unavailable for numerous rookeries in the study area. To examine whether the pup counts provided different information than the adult and juvenile counts, I applied principal component analysis to the data from the 18 rookeries that had complete information for the instantaneous rates of change in pup counts and the pup to non-pup ratios (Table 1). For this analysis I kept Chernabura and Atkins separated in spite of their geographic proximity. I repeated the PCA on the same 18 rookeries but this time to the data for the instantaneous rates change in the adult and juvenile counts; then I compared the component scores from the two analyses using simple linear correlation. Finally, to permit comparison with the fishery data, I repeated the PCA of the instantaneous rates change in the adult and juvenile counts but with Chernabura and Atkins combined.

Rookery Ordinations Based on Fishing Activities

To simplify the fishery data for the 25 five rookery zones I applied principle component analysis to the following subsets of the transformed and adjusted fishery data: fishing hours, total groundfish catches, and pollock catches, Pacific cod catches, and Atka mackerel catches. I analyzed each year's data separately by quarter (winter, January - March: spring, April - June; summer, July - September: and fall, October - December) and including all four quarters. For interpreting the PCA components I produced ordered data matrices in which the data were sorted both spatially (by rookery) and temporally on the basis of the PCA scores.

Comparisons of Sea Lion Changes and Fishing Activities

To explore for similarities between patterns in the sea lion counts and patterns in the fishery data, I calculated simple linear correlation coefficients between the components from the PCA of the adult and juvenile sea lion counts (based on all 25 rookeries) and the principal components from the analyses of the transformed and adjusted fishery data; then I identified the coefficients that were "significant" at the 5% probability level. In addition, I did a similar analysis of correlations between the components from the PCA of the pup count data from the 17 rookeries (with Chernabura and Atkins combined) and the principal components from the analyses of the fishery data.

Results

Although the fishery database did not identify the species composition for about one third of the total observed catches of groundfish that occurred within the 25 rookery zones, walleye pollock made up the vast majority (75%) of the catches whose composition was identified (Table 2). Pacific cod and Atka mackerel accounted for 11% and 12% of the catches whose composition was identified, with sablefish *(Anoplopoma fimbria),* flatfish, and rockfish making up the remaining 3%. More than 50% of the pollock catch and 30% of the fishing effort was from the 8,402 square kilometer zone around Akutan and Akun (15). There was a fairly consistent seasonal pattern to the fishing activities around certain rookeries (e.g. Akutan and Akun [15]), but activities were sporadic around most (Fig. 2).

<u>Rookery Ordinations Based on Counts of Adults and Juveniles</u>

The principal component analysis of the adult and juvenile instantaneous rates of change generated two scores for each of the 25 rookeries, with the first score accounting for about 74% of the variability in the original data (Table 4). Because in this instance there were only two variables, the two principal components incorporate all the variability in the original data and can be viewed geometrically as a simple translation and rotation of the axes for the early and late instantaneous rates of change (Fig. 3).

If the instantaneous rates of change in the adult and juvenile counts at a rookery had occurred uniformly through time, the early and late values would lie along the 45 degree line shown in Figure 3. The first principal component, which is almost at right angles to this reference line, measures the deviation from a uniform rate of change, with positive values indicating a relatively small change during the early period and a large change during the late period. For example, there were slight increases in the adult and juvenile counts at Attu (1) and Marmot (23) during the early period but large decreases during the late period: these two rookeries had the largest first component scores. At the other extreme, Chirikof (22), which had the smallest score, showed almost no change during the late period but a large decrease during the early period. The second component measures the rate of change combined over both periods, without regard to the timing of the change. Clubbing Rock (18), which had the largest second component score, was the rookery that changed the least over the two periods: Buldir (3), which had the smallest score, was the rookery that changed the most.

<u>Rookery Ordinations Based on Pup Counts</u>

For the 18 rookeries that had complete pup count information (Chernabura and Atkins separate) the first two components from the PCA of the pup count data together accounted for almost 72% of the variability in the data (Table 5A, Fig. 4). The first component, which accounted for 44% of the variability, had a large positive correlation (0.772) with the early instantaneous rate of change and large negative correlations with the pup to non-pup ratios from the three surveys (Table 5A). Adak (8), which had the largest first component score (Fig. 4), had a large increase in the number of pups during the early period and relatively small pup to non-pup ratios (Table 1). At the other extreme, Chirikof (22), which had the smallest score, had a slight decrease in the number of pups during the early period and relatively large pup to non-pup ratios. The second component was highly correlated with the late instantaneous rate of change and the middle pup to non-pup ratio.

Between the five pup count variables the strongest correlations were a negative one (-0.716) between the early instantaneous rate of change and the early pup to non-pup ratio and a positive one (0.621) between the middle and late pup to non-pup ratios (Table 5A). Both correlation coefficients were significant at less than the 1% probability level, but the latter coefficient was very sensitive to the large pup to non-pup ratios for a single rookery, Chirikof (22) (Table 1).

The principal component analysis of the adult and juvenile instantaneous rates of change from these same 18 rookeries produced results (Table 5B) that were almost identical to those obtained from the PCA of the full 25 rookeries (Table 4), which suggests that there were no fundamental differences between the rookeries for which complete pup count data were available and those for which they were not.

The two sets of principal components from the 18 rookeries with complete pup count data, one based on the pup counts and the other on the adult and juvenile counts, were not highly correlated (Table 5C), which implies that the pup counts provided fundamentally different information about the rookeries than the adult and juvenile counts. There was a strong correlation (-0.583, significant at the 1.1% probability level) between the first component for the adult and juvenile count data and the fourth component for the pup count data, but this pup component accounted for less than 7% of the variability in the data (Table 5A). The next strongest correlation (0.477, with a probability level of 4.5%) was between the first adult and juvenile component and the second pup component. Both correlations were highly sensitive to the extreme first component score for Chirikof (22) adults and juveniles (Fig. 3).

The results from the PCA of the pup count data with Chernabura and Atkins combined (Table 5D) were essentially identical to the results from the PCA with Chernabura and Atkins separated (Table 5A). For comparisons with the fishery data (below) I used the components from the PCA with Chernabura and Atkins combined.

Ordinations of the Fishery Data

From the principal component analyses of the fishery data for the 25 rookery zones I saved the first four components for each of the five types of fishery data (hours fishing, total catch, and catches of pollock, Atka mackerel, and Pacific cod) and five temporal scales (quarterly and with all quarters). The analyses with information from all four quarters reduced forty variables (quarterly observations for ten years) to sets of four components that accounted for 65% to 83% of the variability in the data (Table 6), depending on the type of fishery data. The sets of four components from the analyses with data by individual quarter accounted for 74% to 100% of the variability. The variability accounted for by the individual first components ranged from 29% (winter pollock catches) to 70% (summer pollock catches).

Chances in Adult and Juvenile Sea Lions versus Fishing Activities

To explore for similarities between changes in the adult and juvenile sea lion counts and the patterns of fishing I calculated 120 different correlation coefficients of which nine (7.5%) were significant at least at the 5% probability level (Table 7). The strongest correlation (0.624, significant at the 0.09% probability level) was between the second component from the PCA of the winter pollock catches, which accounted for 19% of the variability in the pollock data (Table 6), and the first component ("timing") from the changes in the adult and juvenile sea lion counts. There was at least one data pair (Chirikof [22]) that could be viewed as an outlier (Fig. 5), but even without this pair there was a strong correlation (0.425, significant at the 3.8% probability level). Apparently rookeries that suffered relatively large early declines in their sea lion counts generally experienced large pollock catches during the winter early in the ten year catch sequence, whereas rookeries that suffered late declines in sea lion counts generally experienced either no wintertime pollock catches or ones that occurred late in the ten year catch sequence (Table 8).

There was another relatively strong correlation (-0.410, significant at the 4.2% probability level) between the first component for wintertime fishing hours, which accounted for 31% of the variability in the effort data (Table 6), and the first component for the changes in the adult and juvenile sea lion counts. In this case the fishery component ordered the rookery zones on the basis of the cumulative amount of winter fishing hours over the entire ten year sequence (Table 9). Other than it being a spurious chance occurrence, I have no plausible interpretation for the apparent relationship between this fishery component and the sea lion declines.

The remaining seven significant coefficients were for comparisons with the third or fourth principal components from the analyses of the fishery data (Table 7). These components accounted for relatively little (5%-15%) of the variation in these fishery data (Table 6); any relationships between these fishery components and the sea lion components are likely to have little practical importance even if they are statistically significant.

<u>Chancres in Sea Lion Puns versus Fishing Activities</u>

In the correlation analysis of similarities between changes in the sea lion pup counts and the patterns of fishing, five out of 120 coefficients (4.2%) were significant at least at the 5% probability level (Table 10). The three largest coefficients were for comparisons with the third principal components from the analyses of the fishing hours and the Pacific cod catches. These components accounted for only 9% of the variability in the associated fishery data (Table 6).

There was a relatively strong correlation (0.511, significant at the 3.6% probability level) between the second component for the total springtime groundfish catch and the first component for the changes in sea lion pup counts, but this coefficient was very sensitive to the data for Ayugadak (5). Without these data the correlation was significant only at the 13% probability level. There was also a relatively strong correlation (0.488, which was significant at the 4.7% probability level) between the second component for the wintertime pollock catch and the first component for the changes in sea lion pup counts, but this coefficient was very sensitive to the data for Chirikof (22). Without the Chirikof data the correlation was significant only at the 43% probability level.

## Discussion

Declines in pup counts should subsequently produce declines in the counts of adults and juveniles, but in this study I found no strong associations between the principal components for the pup counts and the principal components for the counts of adults and juveniles. This may be an indication that the sea lions redistributed themselves between rookeries rather than returning each year to their natal rookeries. Alternatively, the differing rates of decline between rookeries may not have been due to mortality of pups, my working hypothesis, but rather to mortality of adults and juveniles.

For this study the fishery catch statistics for each rookery were aggregated over rather arbitrarily chosen spatial scales (within about 37 kilometers of the rookery). It might be instructive to repeat the analyses described above using fishery data aggregated over a variety of spatial scales. However, spatial scales larger than the one used in this study probably would not produce any better correspondence between the sea lion changes and the fishery patterns. Rookeries that were close together did not necessarily suffer more similar patterns of decline in sea lion abundance than ones that were far apart.

Analysis of fishery catch data is always problematic. To a first approximation, catch from a given location will be jointly proportional to fish abundance at the location and the fishing effort being applied there (Gulland, 1983); hence, a larger than average catch could result either from unusually high fish abundance or high fishing effort. On the one hand, fish catch from around a sea lion rookery can be viewed "as a relative measure of the amount of food . . . that is no longer available to sea lions" (Loughlin and Merrick, 1988). On the other hand, fish harvest might parallel fish abundance, in which case a large catch would indicate sufficient fish to "satisfy both harvest and sea lion needs" (Ferrero and Fritz, 1994). I attempted to clarify the situation by examining ratios of trawl catch over trawl hours of fishing (catch-per-unit-effort, CPUE), which in theory should be proportional to fish abundance. I had little success, however, because for most rookery zones there were only very sparse observations of CPUE during the study period (Table 11).

When interpreting the statistical results from this study, there are some caveats that should be considered. This investigation was an exploratory exercise, not a completely rigorous test of hypotheses. Because the fishery data were not collected according to a randomized survey and because they and the sea lion data underwent various forms of nonlinear transformation, the significance levels for the correlation coefficients between the two data sets should be viewed as providing only a rough guide to the strength of the associations.

Also, there is a technical problem associated with the principal components derived from the sea lion counts. For a given rookery the early and late instantaneous rates of change are not strictly independent because both were derived from the same count for the middle period. A positive measurement error during the middle period produces an early rate of change that is larger than expected and a late rate of change that is smaller than expected. The amount of measurement error in sea lion counts is small however. For 1992, which was the first year with replicate surveys to assess variability, Sease et al, (1993) report an estimated coefficient of variation of only 2.12% for the estimated total number of adults and juveniles counted at rookeries from Kiska (4) to Sugarloaf (24).

The above problems notwithstanding, the results from the correlation analysis comparing the principal components from the adult and juvenile sea lion counts with the components from the fishery data provide some support for the notion that sea lions are sensitive to wintertime pollock fishing that occurs near rookeries. Given this result and the lack of any strong correlations between the sea lion components and the components from either the total winter groundfish catches or the fishing hours, it appears that my working hypothesis, that sea lion declines are more related to human disturbance than to pollock harvests, is incorrect. The lack of large correlations between the sea lion components and the fishery components from other seasons individually and from all four seasons combined lends additional credence to the conjecture that pollock availability during winter may be crucial to sea' lion survival. However, the fact that there were sea lion declines even at rookeries where there were no observed winter pollock catches indicates that other factors are also involved. The estimated correlation between the sea lion data and the winter pollock data explained only 39% of the variability in the relationship.

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Table 1.

Population statistics for selected Alaskan sea lion rookeries.

| | | | | | Instantaneous Change (/year) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base Years | | | Non-pups | | Pups | | Pup / Non-pup Ratios | | |
| | Rookery | Early | Mid. | Late | Early | Late | Early | Late | Early | Middle | Late |
| 1 | Attu | 79 | 85 | 88 | 0.104 | -0.400 | | | | | |
| 2 | Agattu | 79 | 85 | 90 | -0.138 | -0.192 | | | | | |
| 3 | Buldir | 79 | 88 | 90 | -0.090 | -0.370 | -0.202 | 0.434 | 0.314 | 0.115 | 0.572 |
| 4 | Kiska | 79 | 85 | 90 | -0.153 | -0.206 | | | | | |
| | Kiska - Lief Cove | 79 | 85 | 90 | -0.184 | -0.236 | 0.103 | -0.277 | 0.092 | 0.514 | 0.419 |
| 5 | Ayugadak | 79 | 85 | 90 | -0.122 | -0.112 | 0.451 | -0.140 | 0.015 | 0.469 | 0.406 |
| 6 | Amchitka | 79 | 85 | 90 | -0.066 | -0.349 | | | | | |
| 7 | Delarof Islands | 79 | 85 | 90 | -0.021 | -0.136 | | | | | |
| | Ulak | 79 | 85 | 90 | 0.038 | -0.145 | 0.300 | -0.090 | 0.094 | 0.453 | 0.597 |
| | Gramp Rock | 79 | 85 | 90 | -0.046 | -0.119 | | | | | |
| | Tag | 79 | 85 | 90 | -0.102 | -0.136 | | | | | |
| 8 | Adak | 79 | 85 | 90 | -0.018 | -0.098 | 0.555 | -0.281 | 0.019 | 0.579 | 0.231 |
| 9 | Kasatochi | 79 | 85 | 90 | -0.085 | -0.120 | 0.239 | -0.322 | 0.109 | 0.762 | 0.278 |
| 10 | Seguam & Agligadak | 79 | 85 | 90 | -0.044 | -0.228 | | | | | |
| | Seguam - Saddleridge | 79 | 85 | 90 | -0.030 | -0.252 | 0.015 | -0.270 | 0.685 | 0.896 | 0.821 |
| | Agligadak | 79 | 85 | 90 | -0.110 | -0.126 | | | | | |
| 11 | Yunaska | 79 | 85 | 90 | -0.056 | -0.202 | 0.052 | -0.299 | 0.502 | 0.958 | 0.588 |
| 12 | Adugak | 79 | 85 | 90 | -0.109 | -0.201 | 0.359 | -0.234 | 0.053 | 0.884 | 0.749 |
| 13 | Ogchul | 79 | 85 | 90 | -0.121 | -0.165 | | | | | |
| 14 | Bogoslof | 79 | 85 | 90 | -0.021 | -0.118 | 0.032 | -0.176 | 0.625 | 0.862 | 0.647 |
| 15 | Akutan & Akun | 78/79 | 85 | 90 | -0.107 | -0.131 | | | | | |
| 16 | Ugamak | 79 | 85 | 90 | -0.151 | -0.174 | 0.093 | -0.117 | 0.161 | 0.698 | 0.930 |
| 17 | Sealion Rock | 78 | 85 | 90 | -0.118 | -0.056 | | | | | |
| 18 | Clubbing Rock | 79 | 85 | 90 | 0.012 | -0.041 | | | | | |
| 19 | Pinnacle | 79 | 85 | 90 | -0.090 | -0.039 | | | | | |
| 20 | Chernabura & Atkins | 79 | 86 | 90 | -0.202 | -0.076 | | | | | |
| | Chernabura | 79 | 86 | 90 | -0.170 | -0.008 | -0.076 | -0.169 | 0.430 | 0.831 | 0.437 |
| | Atkins | 79 | 86 | 90 | -0.213 | -0.110 | -0.206 | -0.225 | 0.908 | 0.950 | 0.598 |
| 21 | Chowiet | 79 | 85 | 90 | -0.128 | -0.166 | -0.133 | -0.394 | 1.235 | 1.199 | 0.384 |
| 22 | Chirikof | 79 | 86 | 90 | -0.348 | -0.008 | -0.016 | -0.222 | 0.317 | 3.237 | 1.373 |
| 23 | Marmot | 79 | 86 | 89 | 0.046 | -0.444 | -0.062 | -0.230 | 1.056 | 0.497 | 0.943 |
| 24 | Sugarloaf | 79 | 85 | 89 | -0.063 | -0.119 | -0.083 | -0.097 | 1.171 | 1.040 | 1.133 |
| 25 | Seal Rocks | 79 | 84 | 90 | 0.003 | -0.119 | 0.097 | -0.056 | 0.166 | 0.266 | 0.388 |

Table 2.

Rookery zone areas and observed catches (metric tons) and fishing effort (hours) during 1980-89.

| Rookery Zone | Area (km^2) | Pollock | Pacific Cod | Atka Mackerel | Sablefish | Flatfish | Rockfish | Total | Effort |
|---|---|---|---|---|---|---|---|---|---|
| 1 Attu | 3745 | 2010 | 38 | 29 | 0 | 36 | 6 | 3722 | 421 |
| 2 Agattu | 5888 | 1222 | 199 | 2 | 1 | 143 | 16 | 2459 | 928 |
| 3 Buldir | 4286 | 20 | 2 | 1 | 0 | 7 | 11 | 136 | 66 |
| 4 Kiska | 5422 | 267 | 96 | 35 | 14 | 43 | 16 | 812 | 651 |
| 5 Ayugadak | 5774 | 429 | 535 | 3388 | 2 | 82 | 118 | 6269 | 1297 |
| 6 Amchitka | 5706 | 751 | 1699 | 8471 | 1 | 61 | 41 | 17295 | 2897 |
| 7 Delarof Islands | 9457 | 40 | 98 | 768 | 1 | 2 | 16 | 1648 | 160 |
| 8 Adak | 5884 | 1482 | 78 | 0 | 6 | 7 | 2 | 1937 | 324 |
| 9 Kasatochi | 5820 | 10 | 117 | 1 | 63 | 8 | 4 | 292 | 235 |
| 10 Seguam/Agligadak | 9608 | 14213 | 7502 | 23374 | 352 | 660 | 102 | 58750 | 7725 |
| 11 Yunaska | 7386 | 15147 | 146 | 117 | 34 | 1283 | 16 | 23758 | 6261 |
| 12 Adugak | 8213 | 1759 | 1143 | 179 | 285 | 524 | 65 | 6444 | 3721 |
| 13 Ogchul | 2635 | 160 | 453 | 0 | 49 | 2 | 9 | 969 | 524 |
| 14 Bogoslof | 3987 | 62480 | 1 | 0 | 1 | 67 | 0 | 107367 | 6185 |
| 15 Akutan/Akun | 8402 | 121515 | 6315 | 1459 | 447 | 2170 | 169 | 190089 | 20229 |
| 16 Ugamak | 3434 | 774 | 91 | 6 | 10 | 13 | 18 | 1372 | 180 |
| 17 Sealion Rock | 4120 | 4499 | 345 | 0 | 0 | 228 | 0 | 8369 | 668 |
| 18 Clubbing Rock | 8019 | 2177 | 1431 | 147 | 116 | 76 | 64 | 5834 | 1544 |
| 19 Pinnacle | 2910 | 849 | 3729 | 9 | 1 | 5 | 4 | 5440 | 2292 |
| 20 Chernabura/Atkins | 7880 | 2698 | 8652 | 133 | 196 | 9 | 200 | 15220 | 7453 |
| 21 Chowiet | 7546 | 1067 | 266 | 0 | 27 | 2 | 0 | 2414 | 541 |
| 22 Chirikof | 4505 | 1484 | 347 | 0 | 27 | 59 | 101 | 3916 | 1254 |
| 23 Marmot | 4084 | 799 | 303 | 0 | 17 | 296 | 7 | 1797 | 467 |
| 24 Sugarloaf | 6315 | 18 | 27 | 0 | 1 | 7 | 1 | 78 | 34 |
| 25 Seal Rocks | 5935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Totals | 235868 | 33610 | 38120 | 1650 | 5790 | 985 | 466387 | 66057 |

Table 3.

Octave scale for transforming the fishing activity percentages.

| Raw Value (%) | Transformed Value |
|---|---|
| 0 | 0 |
| $0 < X < 0.5$ | 1 |
| $0.5 \leq X < 1$ | 2 |
| $1 \leq X < 2$ | 3 |
| $2 \leq X < 4$ | 4 |
| $4 \leq X < 8$ | 5 |
| $8 \leq X < 16$ | 6 |
| $16 \leq X < 32$ | 7 |
| $32 \leq X < 64$ | 8 |
| $64 < X$ | 9 |

Table 4.

Results from principal component analysis of changes in adult and juvenile sea lion counts (including rookeries without pup counts),

Correlations of components with adult and juvenile data.

| Variable | Early Change | Late Change | Var%[a] |
|---|---|---|---|
| 1st Comp. | 0.857 | -0.857 | 73.5% |
| 2nd Comp. | 0.515 | 0.515 | 26.5% |
| Late Change | -0.470 | | |

[a] Variation accounted for.

Table 5.

Results from principal component analyses of changes in sea lion counts for rookeries with pup count data.

A. PCA of pup changes and pup/non-pup ratios (Chernabura and Atkins separate).

Correlations of components with pup count data.

| | | | Pup / Non-pup Ratio | | | |
|---|---|---|---|---|---|---|
| Variable | Early Change | Late Change | Early | Middle | Late | Var%[a] |
| 1st Comp. | 0.772 | 0.085 | -0.771 | -0.654 | -0.769 | 44.4% |
| 2nd Comp. | 0.519 | -0.804 | -0.220 | 0.610 | 0.135 | 27.1% |
| 3rd Comp. | 0.168 | 0.568 | -0.536 | 0.299 | 0.515 | 19.9% |
| 4th Comp. | 0.276 | -0.049 | 0.191 | -0.305 | 0.340 | 6.5% |
| Late Change | -0.245 | | | | | |
| Early Pup/Non | -0.716 | -0.176 | | | | |
| Mid. Pup/Non | -0.200 | -0.342 | 0.176 | | | |
| Late Pup/Non | -0.361 | 0.087 | 0.334 | 0.621 | | |

[a] Variation accounted for.

B. PCA of adult and juvenile changes (Chernabura and Atkins separate).

Correlations of components with adult and juvenile data.

| Variable | Early Change | Late Change | Var% |
|---|---|---|---|
| 1st Comp. | -0.852 | 0.852 | 72.6% |
| 2nd Comp. | 0.524 | 0.524 | 27.4% |
| Late Change' | -0.451 | | |

Table 5. (continued)

C. Correlations of pup count components with adult and juvenile components (Chernabura and Atkins separate).

| | Adult/Juvenile PC1 | Adult/Juvenile PC2 |
|---|---|---|
| Pup PC1 | -0.200 | 0.381 |
| Pup PC2 | 0.477 | 0.184 |
| Pup PC3 | 0.222 | -0.190 |
| Pup PC4 | -0.583 | 0.174 |

D. PCA of pup changes and pup/non-pup ratios (Chernabura and Atkins combined).

Correlations of components with pup count data,

| Variable | Early Change | Late Change | Pup / Non-pup Ratio Early | Pup / Non-pup Ratio Middle | Pup / Non-pup Ratio Late | Var% |
|---|---|---|---|---|---|---|
| 1st Comp. | 0.786 | 0.062 | -0.767 | -0.648 | -0.780 | 44.7% |
| 2nd Comp. | 0.504 | -0.816 | -0.204 | 0.618 | 0.131 | 27.2% |
| 3rd Comp. | 0.165 | 0.554 | -0.554 | 0.307 | 0.501 | 19.7% |
| 4th Comp. | 0.263 | -0.050 | 0.171 | -0.296 | 0.339 | 6.1% |
| Late Change | -0.258 | | | | | |
| Early Pup/Non | -0.720 | -0.170 | | | | |
| Mid. Pup/Non | -0.202 | -0.341 | 0.173 | | | |
| Late Pup/Non | -0.392 | 0.092 | 0.334 | 0.627 | | |

Table 6.

Variation in the groundfish fishery data accounted for by the first four principal components (PC1 - PC4).

| | All Qtrs | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|---|
| Observed Hours Fishing | | | | | |
| PC1 | 36.5% | 30.7% | 43.9% | 51.6% | 51.0% |
| PC2 | 12.5% | 25.2% | 23.1% | 19.3% | 14.2% |
| PC3 | 8.5% | 15.9% | 7.8% | 8.3% | 10.9% |
| PC4 | 7.1% | 9.2% | 7.2% | 7.0% | 7.9% |
| Sum | 64.6% | 81.0% | 82.0% | 86.2% | 84.0% |
| Total Observed Catches | | | | | |
| PC1 | 42.9% | 29.5% | 50.4% | 63.3% | 58.9% |
| PC2 | 9.5% | 24.0% | 19.3% | 12.3% | 12.2% |
| PC3 | 8.9% | 13.9% | 8.9% | 8.1% | 8.8% |
| PC4 | 7.1% | 9.1% | 7.9% | 5.5% | 7.4% |
| Sum | 68.4% | 76.5% | 86.5% | 89.2% | 87.3% |
| Observed Pollock Catches | | | | | |
| PC1 | 46.6% | 28.8% | 56.0% | 69.5% | 65.6% |
| PC2 | 9.9% | 19.1% | 12.5% | 10.8% | 9.4% |
| PC3 | 7.9% | 14.4% | 11.6% | 7.0% | 7.5% |
| PC4 | 5.5% | 11.3% | 6.8% | 4.9% | 6.8% |
| Sum | 69.9% | 73.6% | 86.9% | 92.2% | 89.3% |
| Observed Atka Mackerel Catches | | | | | |
| PC1 | 45.0% | 50.3% | 55.3% | 51.1% | 46.5% |
| PC2 | 20.6% | 32.3% | 21.3% | 17.9% | 30.3% |
| PC3 | 12.2% | 12.4% | 11.2% | 15.8% | 9.2% |
| PC4 | 5.4% | 5.0% | 7.8% | 7.2% | 5.6% |
| Sum | 83.2% | 100.0% | 95.6% | 92.0% | 91.6% |
| Observed Pacific Cod Catches | | | | | |
| PC1 | 34.2% | 39.7% | 40.8% | 48.1% | 47.1% |
| PC2 | 12.3% | 22.3% | 20.0% | 18.1% | 18.9% |
| PC3 | 12.0% | 15.8% | 10.9% | 14.6% | 11.8% |
| PC4 | 7.9% | 9.7% | 10.2% | 8.4% | 9.3% |
| Sum | 66.4% | 87.5% | 81.9% | 89.2% | 87.1% |

Table 7.

Correlations[a] between PCA scores for adult sea lion changes (timing [lst component] and size [2nd component]) and PCA scores for the groundfish fishery (PC1 - PC4).

| | All Quarters | | Winter Only | | Spring Only | | Sumer Only | | Autumn Only | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Timing | Size | Timing | Size | Timing | Size | Tiring | Size | Timing | Size |
| Observed Hours Fishing | | | | | | | | | | |
| PC1 | 0.183 | 0.111 | -0.410* | 0.098 | 0.057 | 0.140 | 0.139 | 0.093 | 0.146 | 0.124 |
| PC2 | -0.281 | -0.043 | 0.145 | 0.253 | 0.104 | -0.012 | -0.364 | -0.094 | 0.134 | -0.088 |
| PC3 | -0.265 | 0.266 | -0.051 | 0.084 | 0.035 | 0.154 | -0.052 | 0.382 | 0.422* | 0.187 |
| PC4 | 0.049 | -0.077 | 0.125 | -0.175 | -0.313 | -0.118 | 0.003 | 0.145 | -0.140 | 0.359 |
| Total Observed Catches | | | | | | | | | | |
| PC1 | 0.100 | 0.080 | 0.295 | -0.175 | 0.013 | 0.131 | 0.065 | 0.058 | 0.079 | 0.059 |
| PC2 | -0.292 | 0.227 | -0.326 | -0.293 | 0.111 | -0.009 | -0.343 | -0.090 | 0.163 | -0.067 |
| PC3 | 0.175 | 0.209 | -0.289 | 0.042 | -0.180 | 0.020 | -0.141 | -0.217 | 0.227 | -0.268 |
| PC4 | 0.248 | -0.098 | -0.213 | 0.281 | 0.076 | 0.066 | 0.026 | -0.057 | 0.359 | 0.033 |
| Observed Pollock Catches | | | | | | | | | | |
| PC1 | 0.084 | 0.011 | -0.092 | 0.209 | 0.054 | -0.022 | 0.074 | 0.023 | 0.069 | 0.022 |
| PC2 | 0.080 | 0.170 | 0.624* | 0.233 | -0.008 | 0.065 | -0.221 | -0.139 | -0.326 | 0.261 |
| PC3 | -0.185 | 0.089 | 0.272 | 0.098 | -0.029 | -0.025 | 0.077 | -0.179 | -0.074 | -0.142 |
| PC4 | -0.209 | -0,108 | 0.238 | -0.098 | -0.090 | 0.107 | 0.153 | -0.040 | -0.195 | -0.017 |
| Observed Atka Mackerel Catches | | | | | | | | | | |
| PC1 | -0.129 | 0.025 | 0.121 | -0.022 | 0.182 | -0.163 | 0.093 | 0.022 | -0.074 | -0.045 |
| PC2 | -0.137 | 0.091 | 0.057 | -0.123 | 0.008 | -0.062 | -0.194 | 0.095 | -0.128 | -0.007 |
| PC3 | -0.108 | 0.176 | -0.052 | -0.162 | -0.086 | -0.285 | -0.174 | 0.110 | 0.409* | -0.010 |
| PC4 | -0.045 | -0.193 | -0.009 | -0.427* | -0.133 | -0.147 | -0.056 | -0.223 | 0.242 | 0.328 |
| Observed Pacific Cod Catches | | | | | | | | | | |
| PC1 | 0.166 | 0.097 | 0.353 | -0.129 | -0.029 | -0.132 | -0.052 | -0.144 | 0.111 | 0.149 |
| PC2 | 0.010 | 0.198 | -0.124 | -0.261 | 0.038 | 0.022 | 0.212 | -0.088 | 0.043 | 0.129 |
| PC3 | -0.276 | 0.118 | -0.076 | 0.115 | -0.4371 | -0.265 | -0.4521 | -0.344 | 0.081 | 0.187 |
| PC4 | -0.100 | 0.157 | -0.137 | -0.439* | 0.048 | -0.291 | -0.059 | -0.037 | -0.417* | -0.349 |

[a] Correlation coefficients marked with asterisks (*) are significant at least at the 5% probability level.

Table 8.

Observed relative pollock catches (octave scale) - winter only: ordered data matrix based on the second principal component.

| | Rookery | Fishery Comp.2 | Year 83 -0.54 | 85 -0.53 | 81 -0.52 | 80 -0.27 | 84 -0.23 | 82 0.02 | 88 0.05 | 87 0.09 | 86 0.11 | 89 0.12 | Sea Lion Change (Comp.1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | Chirikof | -4.38 | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -3.13 |
| 11 | Yunaska | -2.23 | 0 | 3 | 1 | 1 | 3 | 0 | 3 | 0 | 0 | 0 | 0.41 |
| 20 | Chernabura & Atkins | -1.74 | 1 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | -1.54 |
| 17 | Sealion Rock | -1.61 | 1 | 5 | 0 | 0 | 0 | 0 | 4 | 3 | 4 | 1 | -0.98 |
| 18 | Clubbing Rock | -0.89 | 0 | 0 | 3 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | -0.04 |
| 15 | Akutan & Akun | -0.73 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 7 | 1 | 2 | -0.44 |
| 2 | Agattu | -0.50 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -0.30 |
| 12 | Adugak | -0.37 | 0 | 1 | 1 | 1 | 0 | 0 | 3 | 0 | 1 | 0 | -0.02 |
| 10 | Seguam & Agligadak | -0.25 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0.67 |
| 13 | Ogchul | -0.07 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -0.34 |
| 4 | Kiska | -0.04 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.33 |
| 21 | Chowiet | 0.07 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -0.39 |
| 19 | Pinnacle | 0.27 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | -0.87 |
| 24 | Sugarloaf | 0.70 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | -0.16 |
| 16 | Ugamak | 0.75 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | -0.52 |
| 1 | Attu | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.93 |
| 3 | Buldir | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.19 |
| 5 | Ayugadak | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.68 |
| 6 | Amchitka | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.24 |
| 7 | Delarof Islands | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.29 |
| 8 | Adak | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.07 |
| 25 | Seal Rocks | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 |
| 9 | Kasatochi | 1.00 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -0.33 |
| 23 | Marmot | 1.20 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 5 | 2.73 |
| 14 | Bogoslof | 2.11 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 9 | 8 | 1 | 0.17 |

Table 9.

Observed relative fishing hours (octave scale) - winter only: ordered data matrix based on the first principal component.

| Rookery | Fishery Comp.2 | Year 89 0.15 | 88 0.18 | 81 0.18 | 87 0.19 | 82 0.21 | 83 0.24 | 80 0.27 | 86 0.47 | 84 0.47 | 85 0.50 | Sea Lion Change (Comp.1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Attu | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.93 |
| 3 Buldir | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.19 |
| 5 Ayugadak | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.68 |
| 6 Amchitka | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.24 |
| 7 Delarof Islands | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.29 |
| 8 Adak | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.07 |
| 25 Seal Rocks | -1.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 |
| 4 Kiska | -1.33 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | -0.33 |
| 9 Kasatochi | -1.12 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | -0.33 |
| 24 Sugarloaf | -0.98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | -0.16 |
| 16 Ugamak | -0.86 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | -0.52 |
| 23 Marmot | -0.71 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2.73 |
| 2 Agattu | -0.41 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | -0.30 |
| 21 Chowiet | -0.29 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | -0.39 |
| 22 Chirikof | -0.03 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | -3.13 |
| 11 Yunaska | 0.30 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 0.41 |
| 10 Seguam & Agligadak | 0.33 | 0 | 0 | 2 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 0.67 |
| 18 Clubbing Rock | 0.41 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | -0.04 |
| 13 Ogchul | 0.46 | 0 | 0 | 2 | 0 | 4 | 0 | 5 | 0 | 0 | 0 | -0.34 |
| 17 Sealion Rock | 0.61 | 3 | 3 | 0 | 3 | 0 | 1 | 0 | 3 | 0 | 1 | -0.98 |
| 12 Adugak | 1.28 | 0 | 2 | 2 | 0 | 2 | 1 | 5 | 1 | 1 | 1 | -0.02 |
| 14 Bogoslof | 1.38 | 1 | 8 | 0 | 9 | 0 | 0 | 0 | 5 | 0 | 0 | 0.17 |
| 15 Akutan & Akun | 2.97 | 4 | 2 | 2 | 5 | 1 | 1 | 2 | 2 | 3 | 3 | -0.44 |
| 19 Pinnacle | 3.45 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 7 | 5 | 6 | -0.87 |
| 20 Chernabura & Atkins | 5.19 | 0 | 0 | 1 | 0 | 2 | 4 | 3 | 7 | 5 | 6 | -1.54 |

Table 10.

Correlations[a] between PCA scores for changes in the sea lion pups (Pup 1 - Pup 2) and PCA scores for the groundfish fishery (PC1 - PC4).

| | All Quarters | | Winter Only | | Spring Only | | Summer Only | | Autumn Only | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pup 1 | Pup 2 | Pup 1 | Pup 2 | Pup 1 | Pup 2 | Pup 1 | Pup 2 | Pup 1 | Pup 2 |
| Observed Hours Fishing | | | | | | | | | | |
| PC1 | 0.278 | -0.322 | -0.360 | 0.084 | 0.081 | -0.222 | 0.377 | -0.392 | 0.195 | -0.321 |
| PC2 | -0.259 | 0.190 | 0.021 | -0.189 | 0.387 | -0.304 | -0.188 | 0.060 | 0.365 | 0.008 |
| PC3 | -0.285 | -0.212 | -0.037 | -0.270 | -0.093 | 0.654* | 0.290 | -0.217 | 0.556* | -0.298 |
| PC4 | -0.338 | 0.238 | 0.449 | -0.381 | -0.116 | -0.209 | -0.087 | 0.147 | 0.089 | -0.245 |
| Total Observed Catches | | | | | | | | | | |
| PC1 | 0.301 | -0.230 | 0.376 | -0.080 | 0.100 | -0.176 | 0.343 | -0.235 | 0.257 | -0.224 |
| PC2 | -0.337 | -0.103 | -0.238 | 0.303 | 0.511* | -0.001 | -0.294 | -0.139 | 0.397 | -0.073 |
| PC3 | 0.264 | -0.168 | -0.300 | 0.024 | -0.368 | 0.100 | 0.103 | 0.152 | -0.368 | 0.226 |
| PC4 | 0.017 | -0.006 | -0.032 | 0.257 | 0.089 | -0.310 | -0.203 | -0.063 | 0.373 | 0.006 |
| Observed Pollock Catches | | | | | | | | | | |
| PC1 | 0.269 | -0.203 | -0.198 | 0.021 | 0.073 | -0.168 | 0.379 | -0.182 | 0.216 | -0.193 |
| PC2 | 0.136 | -0.155 | 0.488* | -0.454 | 0.162 | -0.188 | -0.368 | -0.227 | 0.032 | -0.175 |
| PC3 | -0.322 | 0.141 | -0.080 | -0.188 | -0.343 | 0.045 | -0.214 | -0.134 | 0.228 | -0.063 |
| PC4 | -0.325 | 0.055 | -0.230 | -0.095 | 0.033 | -0.084 | -0.246 | 0.096 | -0.086 | 0.147 |
| Observed Atka Mackerel Catches | | | | | | | | | | |
| PC1 | 0.101 | -0.065 | -0.145 | 0.045 | 0.037 | 0.054 | -0.116 | 0.076 | 0.102 | -0.104 |
| PC2 | -0.001 | -0.041 | 0.145 | -0.045 | 0.371 | 0.047 | 0.165 | -0.056 | 0.082 | -0.102 |
| PC3 | -0.438 | -0.022 | -0.145 | 0.045 | -0.187 | 0.043 | -0.345 | 0.004 | -0.056 | -0.071 |
| PC4 | -0.127 | 0.069 | 0.145 | -0.045 | 0.040 | 0.071 | -0.095 | 0.063 | -0.026 | 0.062 |
| Observed Pacific Cod Catches | | | | | | | | | | |
| PC1 | 0.287 | -0.193 | 0.266 | -0.027 | -0.027 | 0.139 | -0.351 | 0.254 | 0.304 | -0.245 |
| PC2 | 0.095 | -0.102 | -0.028 | 0.176 | 0.346 | -0.042 | -0.264 | 0.076 | 0.035 | -0.096 |
| PC3 | 0.057 | -0.153 | -0.045 | -0.216 | -0.380 | 0.211 | -0.437 | 0.347 | 0.589* | -0.298 |
| PC4 | 0.310 | -0.218 | -0.088 | -0.076 | -0.068 | -0.107 | -0.178 | -0.233 | -0.398 | 0.105 |

[a] Correlation coefficients marked with asterisks (*) are significant at least at the 5% probability level.

Table 11.

Observed trawl catch per unit effort
(metric tons / hour) in the winter pollock fishery.

| | Rookery | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Attu | | | | | | | | | | |
| 2 | Agattu | | 0.02 | | 0.13 | | | | | | |
| 3 | Buldir | | | | | | | | | | |
| 4 | Kiska | | | | 0.20 | | | | | | |
| 5 | Ayugadak | | | | | | | | | | |
| 6 | Amchitka | | | | | | | | | | |
| 7 | Delarof Islands | | | | | | | | | | |
| 8 | Adak | | | | | | | | | | |
| 9 | Kasatochi | | | | | | | | | | |
| 10 | Seguam & Agligadak | 0.01 | 0.00 | 0.18 | | 5.04 | 0.03 | | | | |
| 11 | Yunaska | 0.43 | 2.14 | | | 8.24 | 5.05 | | | 39.80 | |
| 12 | Adugak | 1.77 | | | | | 9.93 | | | 17.00 | |
| 13 | Ogchul | | | | | | | | | | |
| 14 | Bogoslof | | | | | | | 14.75 | 11.69 | 7.87 | 2.70 |
| 15 | Akutan & Akun | | | | 1.13 | 0.74 | 0.07 | 0.69 | 31.62 | 0.19 | 1.21 |
| 16 | Ugamak | | | | | 0.42 | | | | 0.00 | 2.56 |
| 17 | Sealion Rock | | | | 0.77 | | 22.50 | 7.62 | 10.21 | 11.78 | 0.43 |
| 18 | Clubbing Rock | | 2.53 | | | 3.05 | | | | 0.16 | |
| 19 | Pinnacle | | | | | | | | | 0.03 | |
| 20 | Chernabura & Atkins | 1.11 | | | | | | 3.43 | | | |
| 21 | Chowiet | | 2.67 | | | | 1.68 | | | | |
| 22 | Chirikof | | 2.08 | | | 0.00 | 4.66 | | | | |
| 23 | Marmot | | | | | 1.03 | | | | 0.16 | 10.87 |
| 24 | Sugarloaf | | | | | 1.53 | | 0.26 | | | |
| 25 | Seal Rocks | | | | | | | | | | |

Figure Legends

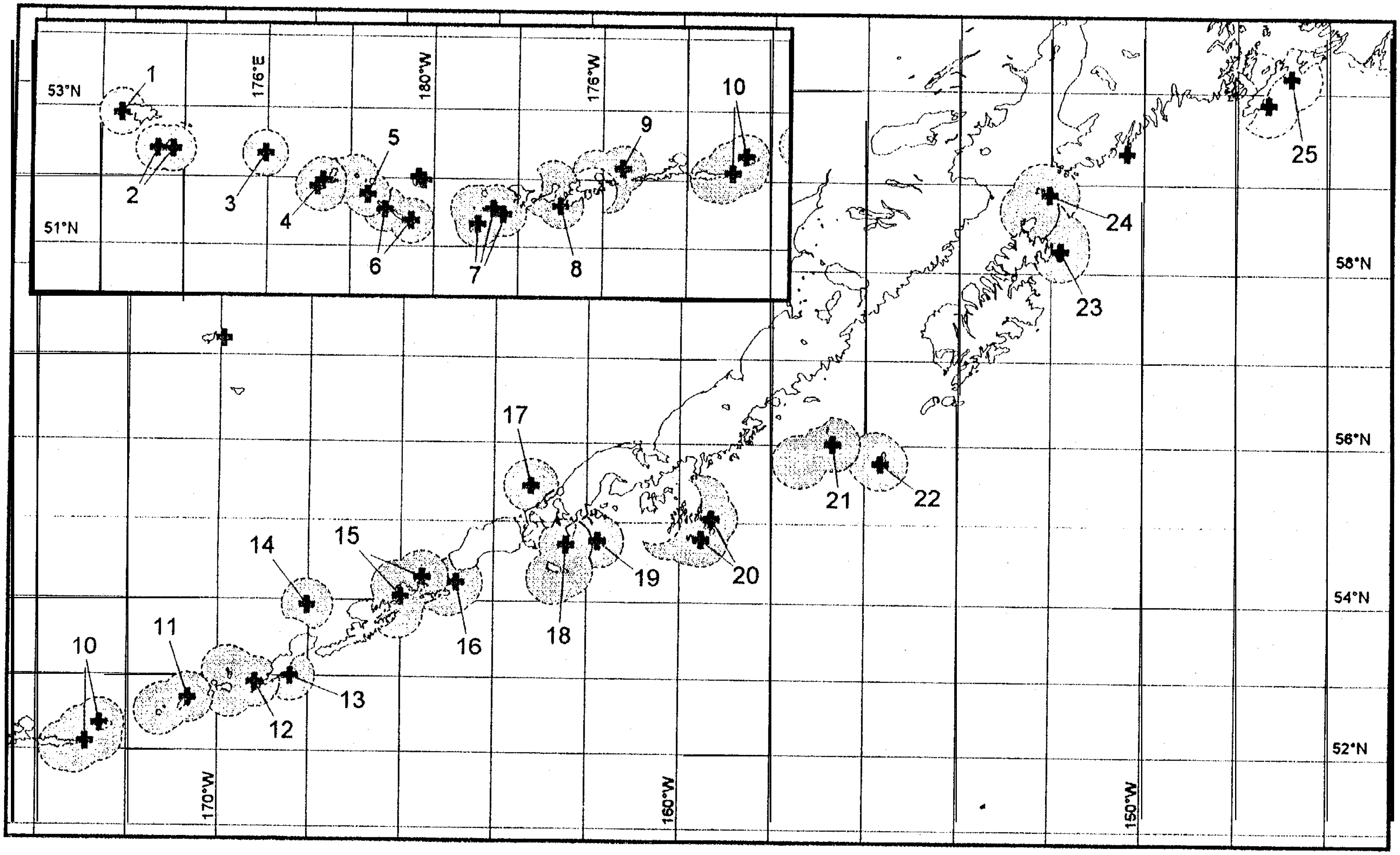
Figure 1. Map showing rookeries (crosses) and associated fishing zones (shaded areas) included in this study. There were four rookeries (indicated by crosses without any shaded areas) that had incomplete sea lion counts and were excluded from the study.

Figure 2. Relative distribution of fishing hours by rookery zone and quarter.

Figure 3. Comparison of late and early instantaneous rates of change in the counts of adult and juvenile sea lions at 25 rookeries, The first principal component axis ("Axis 1") measures the timing of the change, early versus late. The second axis ("Axis 2") measures the magnitude-of the combined changes. The two component axes are not at right angles to each other because the data have differing amounts of variability along the "early change" versus "late change" axes.

Figure 4. First and second principal components from the PCA of pup count data from 18 rookeries with complete data (Chernabura and Atkins separate). The first component axis is related with the early instantaneous rate of change and the pup to non-pup ratios from the three surveys, and the second axis with the late instantaneous rate of change and the pup to non-pup ratio from the middle survey. Rookeries with similar characteristics have similar component scores and appear close together on the plot.

Figure 5. Comparison of second component from the PCA of the winter pollock catches and the first component from the PCA of the instantaneous rates of change in the counts of adult and juvenile sea lions at 25 rookeries. The correlation coefficient was significant at the 0.1% probability level for the data shown and at the 3.8% level when the data pair for Chirikof (22) was excluded.


53°N
51°N
176°E
180°W
176°W
58°N
56°N
54°N
52°N
170°W
160°W
150°W
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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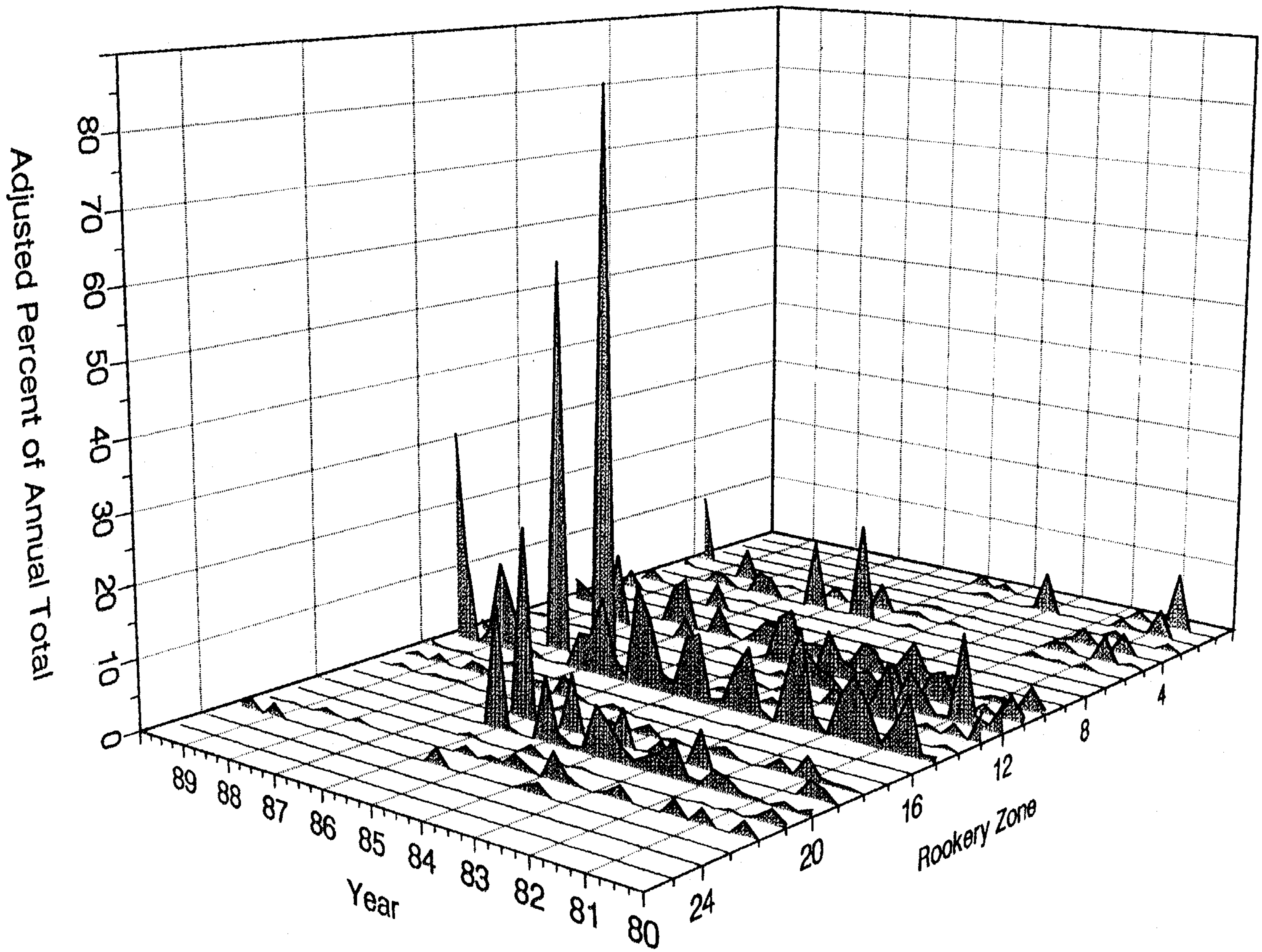
24
25

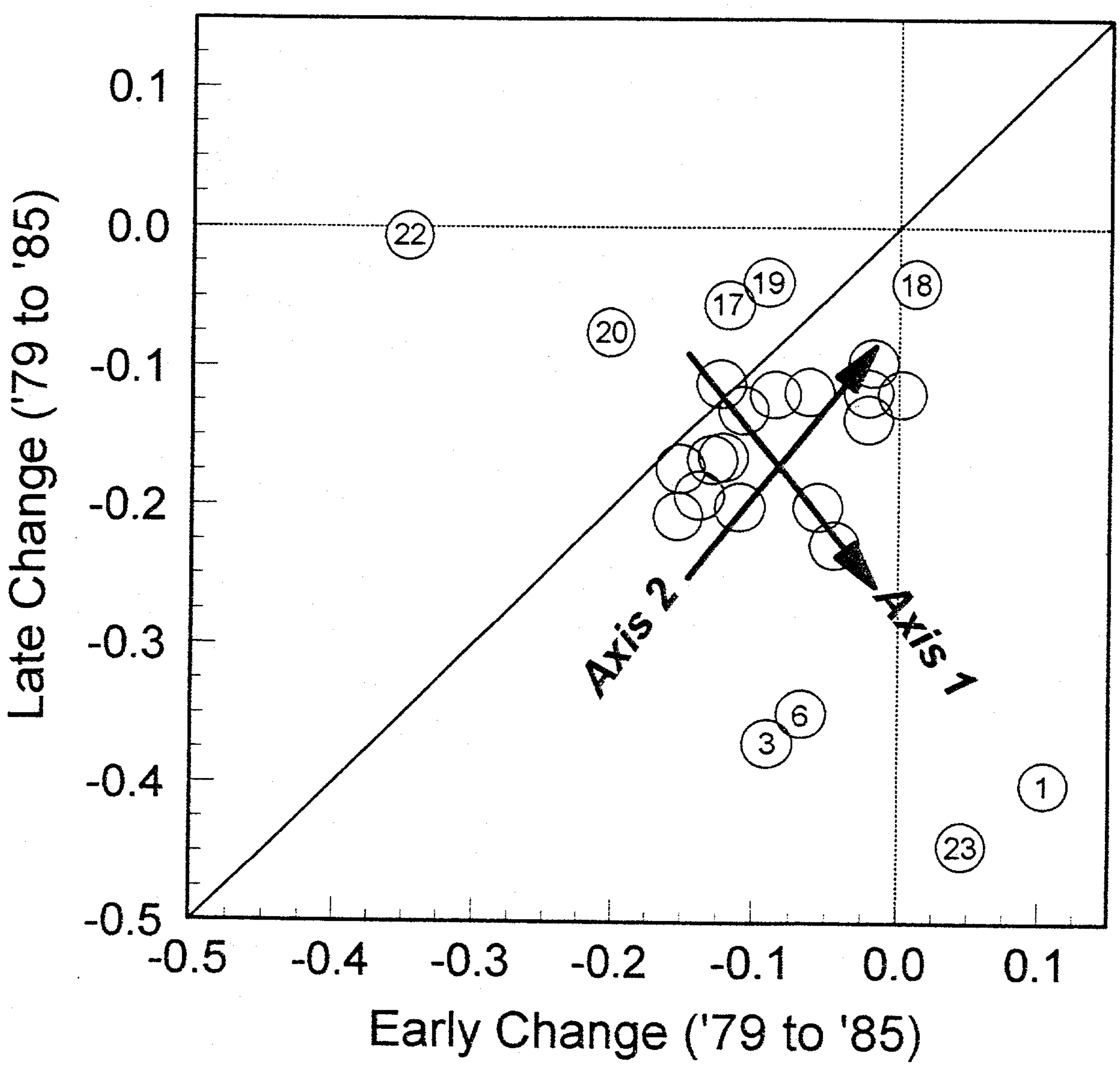
Figure 1



Adjusted Percent of Annual Total
0
10
20
30
40
50
60
70
80
Year
89
88
87
86
85
84
83
82
81
80
Rookery Zone
4
8
12
16
20
24

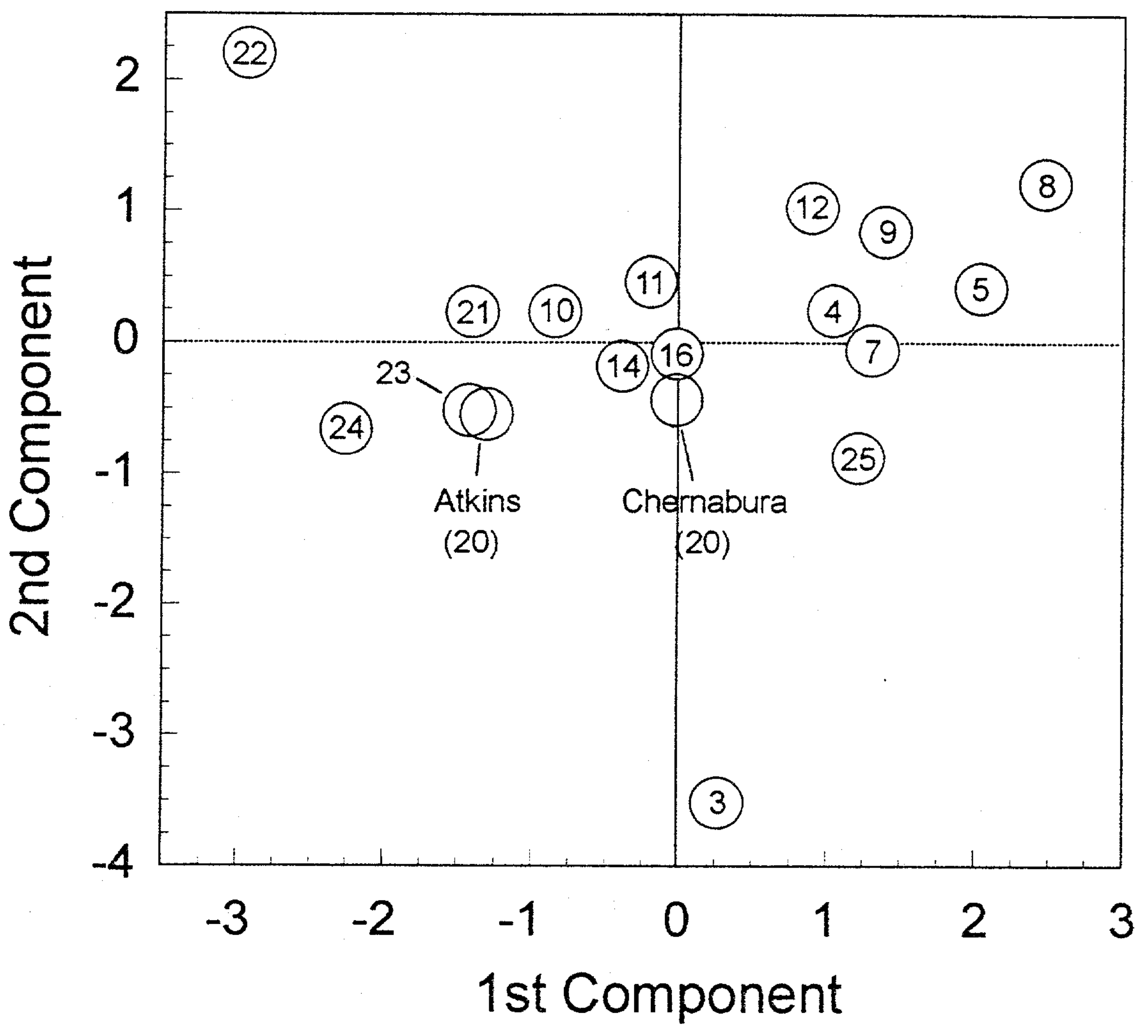

Figure 2

Figure 3



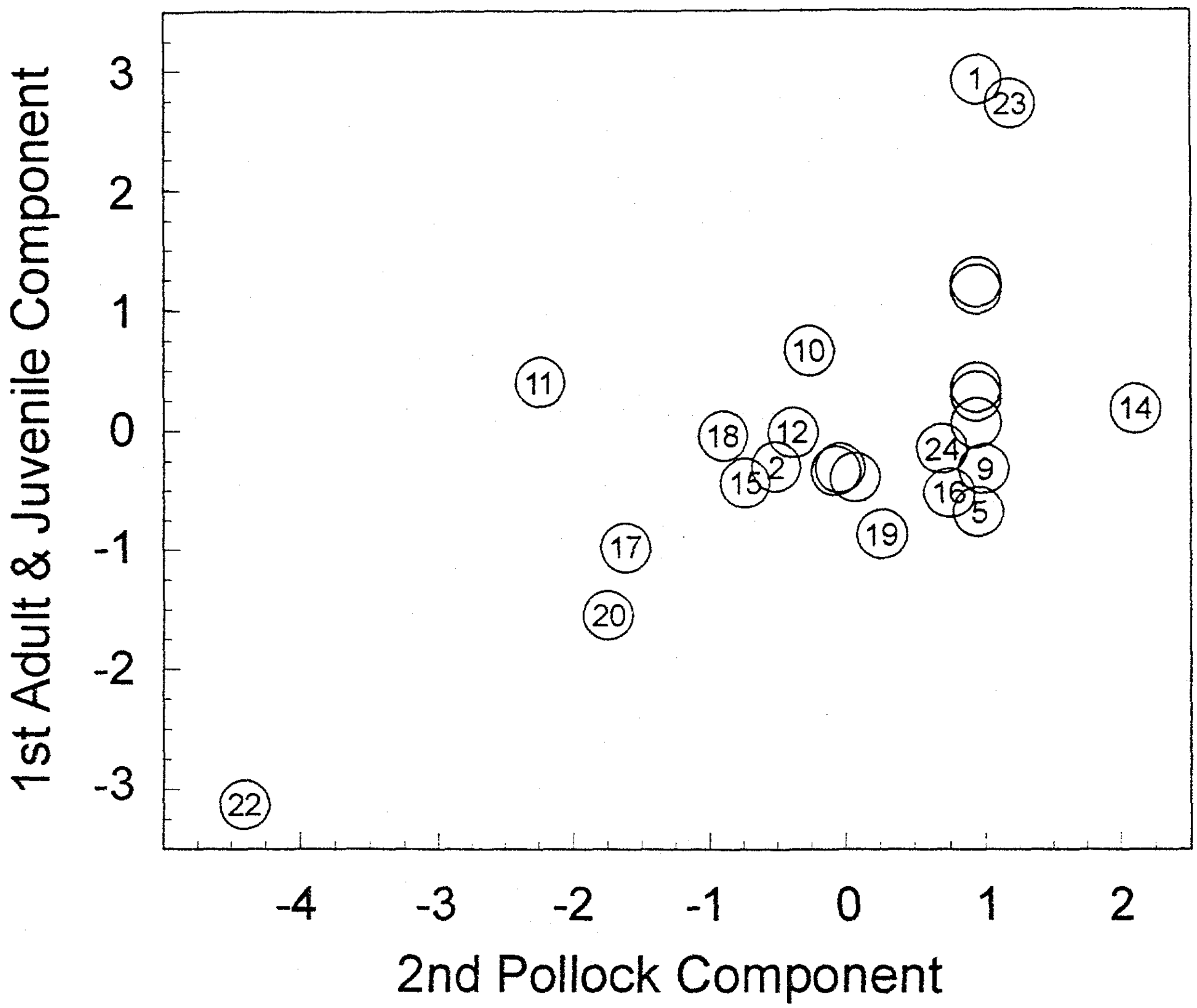
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
Late Change ('79 to '85)
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
Early Change ('79 to '85)
22
20
17
19
18
Axis 2
Axis 1
6
3
1
23

Figure 4



2nd Component
1st Component
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
3
22
8
12
9
11
5
21
10
4
16
7
14
23
24
25
3
Atkins
(20)
Chernabura
(20)

Figure 5



1st Adult & Juvenile Component
3
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
2nd Pollock Component
1
23
10
11
14
18
12
24
2
9
15
16
5
19
17
20
22