FINAL REPORT

FIXED GEAR - MARINE MAMMAL INTERACTIONS STUDY

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NOAA Fisheries Operations, Management, and Information Division

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From

Texas A&M University Research Foundation

College Station, Texas

By

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EXECUTIVE SUMMARY

This report provides the results of a study to investigate the indirect interactions of the Pacific cod (*Gadus macrocephalus*) freezer longline fishery with the western stock of Steller sea lions (*Eumetopias jubatus*) in the Bering Sea and Aleutian Islands (BSAI) regions during the period 1996-2004. NOAA Fisheries provided a grant to the Texas A&M University Research Foundation (TAMU) who then contracted North Pacific Wildlife Consulting, LLC, in July 2007 to conduct the study. The objective of the study was to analyze information on interactions of marine mammals (i.e., specifically the western stock of Steller sea lion) with fixed gear (i.e., Pacific cod longline) fishers. This was accomplished by analysis of NMFS observer reports of the Pacific cod longline fishery for the years 1996-2004. The hypothesis to assess the impact of the fishery on Steller sea lions was that the Pacific cod freezer longline fishery did not adversely impact the western population of Steller sea lions through indirect interaction by removing prey (Pacific cod) at the depth and location and of the size and age consumed by sea lions sufficient to cause deleterious effects on Steller sea lion population status and trend.

The basic approach examined available data for both Pacific cod longline fishing and sea lion population trend to look for relationships. Steller sea lion population counts by year were fit using a spline-type regression model with three parameters. A slope (population trajectory) from the beginning of the study period (1996) to a hinge point was estimated, as well as a slope from the hinge point to the last year of the study (2004). The hinge point was fixed at 2000 because a power analysis indicated that three census counts were required to estimate trend. Because the study period covered only six sea lion surveys, the data were split evenly to estimate two distinct population trajectories. There

were 44 rookeries with sufficient population surveys to estimate two separate population trends.

Results from the study showed that rookeries where longline fishers were successful (high catch per unit effort - CPU), but did not have high effort (low values in the other fishing metrics such as number of hauls, sum of the weight of fish removed, and the duration of time of fishing), seemed to drive the patterns found. These rookeries tended to have slower (or negative) population growth, relative to other rookeries during 1996 – 2000, and faster population growth during 2000 – 2004. In both cases the adjusted R^2 values describing the strength of the relationship were low. There are no ecological reasons why low effort or efficient fishing should have any effect on sea lion population growth trends, let alone a negative and then positive effect within eight years. It is more likely that there is some other factor not considered in this study that is driving sea lion population trends in the western stock. Given the lack of a consistent, clear result, we conclude that the results are consistent with the hypothesis that longline fishing and Steller sea lion population trends are largely independent of each other.

INTRODUCTION

This report provides the results of a study to investigate the indirect interactions of the Pacific cod (*Gadus macrocephalus*) freezer longline fishery with the western stock of Steller sea lions (*Eumetopias jubatus*) in the Bering Sea and Aleutian Islands (BSAI) regions during the period 1996-2004. The Pacific cod freezer longline fleet comprised about 39 vessels fishing in the Bering Sea and Aleutian Islands region through 2006 (SCS 2006). Members of the fleet became interested in conducting this study as a result of the Endangered Species Act (ESA) Section 7 Biological Opinion by NOAA Fisheries (NMFS) to protect Steller sea lions (*Eumetopias jubatus*). Little information was available on the nature and magnitude of interactions between the cod longline fleet and ESA listed marine mammal species/populations during development of the Opinion. Consequently, these fisheries were grouped along with other groundfish fisheries that may adversely affect marine mammals and that may have deleterious impacts on them (NMFS 2003). This grouping of longline and other fixed-gear fisheries with other groundfish fisheries resulted in restrictive measures on the longline fleet, along with

fisheries for pollock and Atka mackerel (NMFS 2003; SCS 2006). It is, therefore, important to both the economic stability of the Pacific cod longline fleet and the management of that fishery by the federal government that the relationship between the fishery and marine mammals be better understood.

Segments of the Pacific cod longline fleet asked Washington State's congressional delegation to include funds in the fiscal year 2006 federal budget to study the possible impact of their fishery on marine mammals, specifically Steller sea lions. The 2006 federal budget directed NOAA Fisheries to conduct the study. NOAA Fisheries subsequently provided a grant to the Texas A&M University Research Foundation (TAMU) who then contracted North Pacific Wildlife Consulting, LLC, (NPWC) in July 2007 to conduct the study.

This study as originally proposed intended to obtain information on indirect interaction between fishers and sea lions by examination of entries by fishers in daily logbooks, including time, location (lat./long.), and other relevant information, and by analysis of data collected by NMFS observers on the vessels. Secondarily there was to be a comparison of interactions based on data from logbooks with data collected by observers. However as the study progressed it became apparent that use of data extracted from logbooks was not optimal and was discontinued. Reasons for not using logbook data included problems with access to the logbooks, minimal temporal and geographic coverage of the available logbooks, the applicability of the data obtained in the logbooks to testing the study's hypothesis, and the similarity of data collected by observers compared to the information in the vessel logbooks. In essence, observers collect much of the same information as is contained in the vessel logbooks. Given the redundancy between the observers and logbooks entries, the objectives of the present study were best served by exclusive use of the NMFS observer data. NPWC requested the NMFS observer data from NOAA Fisheries' Alaska Fisheries Science Center in early August 2007; it was received by NPWC on 22 August 2007. It should be noted that the observer data requested only covers the time period and geographic area of the proposed study.

There has been discourse for over 30 years regarding the possible deleterious impact of commercial fishing on Steller sea lions (see reviews in NMFS 2008; Small and

DeMaster 2006). Fisheries activities could plausibly affect Steller sea lion populations by changing fish species composition, distribution, or abundance in a way that could decrease Steller sea lion foraging efficiency or otherwise contribute to nutritional stress. Fishing can remove or disperse large aggregations of fish from an area (Baraff and Loughlin 2000), and can also result in reduced overall levels of fish biomass (NMFS 2001). Pinnipeds may abandon a traditional foraging region, or change their foraging patterns, as a result of such fisheries-related disruptions (NMFS 2001). Furthermore, direct kill of Steller sea lion by fishers in defense of gear or catch, as well as Steller sea lions being caught in fishing gear incidentally, may have contributed to Steller sea lion population trajectories in the 1970s (Loughlin and Nelson 1986; Merrick et al. 1987; Perez and Loughlin 1991). Some cases of food shortages resulting in local depletions of otariid pinniped stocks have been documented. For example, the northern fur seal (*Callorhinus ursinus*) population on San Miguel Island dropped considerably during the El Niño Southern Oscillation (ENSO) events of the early 1980s (DeLong and Antonelis 1991). Aureioles and Le Boeuf (1991) noted lowered California sea lion (*Zalophus californianus*) pup production in parts of Mexico, also resulting from ENSO events in 1982 and 1983.

Several studies have attempted to find connections between Steller sea lion population trends and fishing activities (Loughlin and Merrick 1989; Ferrero and Fritz 1994; Sampson 1995; Dillingham et al. 2006; Hennen 2004, 2006). Loughlin and Merrick (1989) and Ferrero and Fritz (1994) examined walleye pollock (*Theragra chalcogramma*), while Sampson examined pollock, Pacific cod, and Atka mackerel (*Pleurogrammus monopterygius*). Hennen (2006) examined entire hauls, including bycatch, in addition to particular species of fish. All but Hennen (2006) used only photographic Steller sea lion count data from the late 1970s up to some point previous to the publication of their results while Dillingham et al. (2006) and Hennen (2006) extended the Steller sea lion time series in both directions, using photographic data and visual estimates. The present study uses methods similar to those used by Dillingham et al. (2006) and Hennen (2006), where the fisheries data were restricted to the longline fishery for cod. Hennen (2006) also examined fishing data found at a range of distances from Steller sea lion rookeries, where the other studies tended to focus on fixed

geographic areas or a single distance from Steller sea lion rookeries. Sampson (1995) compared fishing in different seasons to Steller sea lion trends where Hennen (2006) examined seasons, as well as different types of fishing gear. None of these previous studies found conclusive evidence of a relationship between fisheries activities and the Steller sea lion decline. However Hennen (2006) did show that a positive correlation existed between several metrics of historical fishing activity and the Steller sea lion population decline. The relationship was less consistent after 1991, supporting a hypothesis that management measures around some of the rookeries may have been effective in moderating the localized effects of fishing activity on Steller sea lions.

During the formative aspect of this study there was interest in assessing the direct effects (mortality or injury through incidental take) of the Pacific cod longline fishery on Steller sea lions. However, the level of incidental take by the Pacific cod longline fishery is virtually non-existent. Anglis and Outlaw (2007) documented only one Steller sea lion caught incidental to the Pacific cod longline fishery between 2000 and 2005 in the Bering Sea and Aleutian Islands regions. The estimated annual mortality for sea lions during this period was 0.74 sea lions. Consequently this report does not include analysis of direct mortality by this fishery but focuses on possible impact of indirect injury or mortality caused by removal of sea lion prey, principally Pacific cod.

METHODS

Hypothesis

As discussed in the proposal that accompanies the contract for this project, the objective of the study was to analyze information on interactions of marine mammals (i.e., specifically the western stock of Steller sea lion) with fixed gear (i.e., Pacific cod longline) fishers. This was accomplished by analysis of NMFS observer reports of the Pacific cod longline fishery for the years 1996-2004. The hypothesis proposed by NPWC to assess the impact of the fishery on Steller sea lions was that the Pacific cod freezer longline fishery did not adversely impact the western population of Steller sea lions through indirect interaction by removing prey (Pacific cod) at the depth and location and of the size and age consumed by sea lions sufficient to cause deleterious effects on sea lion health and condition.

Operationally, Steller sea lion health and condition were not assessed during this study but were implied by using population status and trend information (as determined by a time-series of non-pup counts) obtained by NMFS Steller sea lion surveys. Population status and trend data were analyzed and compared to fisheries data using the methods described below.

Analysis of NMFS-Provided Observer Data

The basic approach examined available data for both Pacific cod longline fishing and sea lion population trend to look for relationships. Steller sea lion population counts by year were fit using a spline-type regression model with three parameters. A slope (population trajectory) from the beginning of the study period (1996) to the hinge point, which was the second parameter, was estimated, as well as a slope from the hinge point to the last year of the study (2004). The two slope parameters were free to take any value and were fit using a numerical least squares minimization. The hinge point was fixed at 2000 because a power analysis (below) indicated that three census counts were required to estimate trend. Because the study period covered only six sea lion surveys, the data were split evenly to estimate two distinct population trajectories. Furthermore, it is commonly accepted that the population of the western stock of Steller sea lions in Alaska in general stopped decreasing in 2000 (Fritz and Stinchcomb 2005). It is possible that there is no natural break in the population trajectory at some rookeries, in which case the hinge point in the spline would be meaningless and a single slope would describe the trajectory over the entire time period. Steller sea lion population trend was estimated independently for each rookery. There were 44 rookeries with sufficient population surveys to estimate two separate population trends (Appendices 1 and 2).

Fisheries variables were initially fit with a similar model for comparative purposes. The fishing variables used were the estimated total number of fishing events (hauls), the sum of the weights of all hauls, the duration of time that the gear was at fishing depth, and the catch per unit effort (CPU) that occurred within varying distances from each Steller sea lion rookery. CPU represents the summed weight of all hauls divided by the summed duration of time that the gear was at fishing depth. These values were corrected for observer coverage using a simple multiplier based on the observer

coverage for each type of vessel. For example, vessels between 60 and 120 feet in length have observers on board a certain percentage of the time and observers on these boats observe a certain percentage of the hauls (when they are "on effort" or working). These values also depend on whether the boat is fishing in the Bering Sea or Gulf of Alaska, but in each case observed fishing values were multiplied by the inverse of the expected percentage of hauls observed.

As discussed in Hennen (2006), the timing of fisheries removals may have been important, so the fishing data were stratified by season. December, January, and February collectively were referred to as winter; March, April, and May were spring; June, July, and August were summer and September, October, and November were fall. Because there are many possibilities for stratification in this data set, many analyses of the same sets of variables were necessary.

Fishing variables were used to predict Steller sea lion population trend in each time period using simple linear regression. Raw and ranked fishing variables were used because the fishing data were not normally distributed. Principal components analysis (PCA) of ranked near-shore fishing variables indicated that several of the fishing variables were highly correlated. (For the reader unfamiliar with PCA, a summary of the technique as given in Hennen (2004) is provided in Appendix 3). The principle components that accounted for more the 2% of the total variation in the data were included in a multiple linear regression (MLR) predicting Steller sea lion population trend. All possible models were compared and the models with the highest adjusted R^2 were discussed. All statistical analyses were carried out using FORTRAN source code written by Dr. Hennen.

Analysis of this type includes several assumptions. Tracking population trend at individual rookeries using non-pup census counts implies that the population of each rookery be adequately represented by the animals present at the time the census takes place. At any given point, some animals that breed at a particular rookery will not be on shore and available to be counted. Absent animals are not particularly problematic for this type of analysis unless there is a systematic or geographic pattern associated with animal attendance. Using small scale population trends as a response to fishing pressure also assumes that animals do not move from rookery to rookery in response to fishing

pressure or some other variable. The available literature (e.g. Raum-Suryan et al. 2002) indicates that they do not. There has also been some question about the timing of the mechanisms in question, that is, can fishing in the winter really predict sea lion abundance in the summer. Sea lion abundance is only measured in the summer because that is time when the most breeding animals are likely to be on shore and available for counting. Other questions regarding the likelihood of seasonally mismatched fishing affecting sea lion population trends are addressed by the analysis here

During study development, it was suggested that we consider inclusion of an additional power analysis of results to help understand whether non-significant results should be interpreted as the lack of a significant impact. Such an analysis could determine whether a result of non-significance is a representation of the truth, or simply the result of an inadequate sample size (missing the truth due to not enough observations). Although considered a reasonable suggestion, we did not include this power analysis because the limitations of the data gave us very few options for increasing power. The three variables of concern in a power analysis are the effect size (how closely are fishing and Steller sea lion population levels related), variance in the predictor and response variables, and sample size. Power is typically increased by increasing sample size, which in this case is the number of sea lion rookeries. In this study we compared Steller sea lion population trend at each rookery to the fishing effort around that rookery - sample size is fixed by the number of rookeries at which we could estimate population trend. The only means of increasing power in this analysis was decreasing the variance around the predictor and response variables, which could be accomplished by adding or subtracting years, or possibly fitting a different model to Steller sea lion population trends. These methods were not seriously considered because it would have set *a-priori* limits on the number of years included in the study, and because the initial models did not indicate any problems with fit. Furthermore, *post-hoc* manipulation of the data to reduce variance is indistinguishable from data mining to achieve a particular result, and was therefore avoided.

Possible Outcomes

Because there was not a controlled experiment to test for effects of fishing, cause and effect relationships could not be stated definitively. However, informed statements can be made about the *likely* causative relationship (or lack thereof) between the longline sector and Steller sea lion population trends.

1. **No** relationship between fixed gear sector variables (i.e., from the cod fishery) and the western stock of Steller sea lion population trends. This was the most likely outcome and would allow one to conclude that either: a) there was no relationship and that the Pacific cod longline fishery as it was prosecuted was probably not impeding the recovery of the western stock of Steller sea lion (at its current levels), b) that some critical information that explains the relationship between fishing and sea lion population trend was not captured by the data sources we chose to analyze , or c) the statistical power in this analysis was insufficient to reject the null hypothesis.

2. **Negative** association between fixed gear sector variables and western Steller sea lion population trends. This finding would be consistent with an interpretation that Pacific cod longline fishing had impeded or was potentially impeding the recovery of the western stock of Steller sea lions.

3. **Positive** association between fixed gear sector variables and western Steller sea lion population trends. This finding would be consistent with an interpretation that the Pacific cod longline fishing probably was not impeding the recovery of the western population of Steller sea lions. In this case both fishers and sea lions were probably both doing well in highly productive regions, or both were doing poorly in depleted regions.

Power Analysis:

The requirement of three counts to estimate trend was derived using the method of Gerrodette (1987). Gerrodette (1987) points out that generally in distance sampling, the coefficient of variation (cv) of abundance does not depend on abundance. Therefore,

reduction of statistical errors in the regression analysis used to estimate trends to the specified α and β levels, the following inequality must be true.

$$[\ln(1+r)]^2 n(n-1)(n+1) \geq 12(z_{\alpha/2} + z_{\beta})^2 [\ln(cv^2+1)] \qquad (1)$$

r = fractional rate of change per unit time

n = number of samples

$z_{\alpha/2}$ = value of the standard normal probability function

z_{β} = value of the standard normal probability function

cv = coefficient of variation for abundance estimates

Since α and β are known (0.05), and cv can be estimated from existing Steller sea lion data, this inequality can be solved in iterative fashion for various *n*. The cv estimate used here is an average of the cv's for all the replicate counts in the data set (counts made during June and July of the same year, at the same rookery, a measure of the observation error). Using (1) and a cv estimate of 0.0271, the minimum number of counts required to detect a trend of minimum size r = – 0.02 is three (a reasonable estimate of the Steller sea lion decline and, in absolute value, the ensuing increase).

RESULTS

Simple Linear Regression (SLR)

In general the pattern seen in the SLR analysis indicated a negative association between longline fishing and Steller sea lion population trend during the first time period (1996-2000) and a positive association between longline fishing and Steller sea lion population trend in the second time period (2000-2004). In general these associations were not statistically significant. There were some notable exceptions, particularly concerning the fishing variable CPU. Between 1996 and 2000 CPU was negatively associated with sea lion population trajectory over the same time period at most of the distances we tested (Fig. 1). This implies that areas where longline fishermen were relatively efficient (high CPUE) were the same areas where sea lions had the least population growth. One must bear in mind that affects of fisheries on sea lion population trajectories lag by one or

more years after fishing occurs. It may be that the lag is four or more years, considering the time to sexual maturity by female sea lions (Pitcher and Calkins 1981). Thus, our analysis indicated that CPU over the entire period (1996 – 2004) was positively associated with sea lion population trajectory between 2000 and 2004 at most distances we tested, but not earlier (Fig. 2). These results are difficult to interpret. The results may indicate that management actions taken in the late 1990s or early 2000s were effective at mitigating an adverse interaction. On the other hand, the correlation of CPU of the cod fleet and trends in abundance of western Steller sea lions in the early time period may be spurious (e.g., caused by some other factor), but in the later time period is consistent with an interpretation that areas where fishermen were efficient over the entire time period were associated with areas of relatively high sea lion population growth. There were a few other statistically significant regression coefficients found in our analysis, but most had very low (< 1%) R^2 values or were far off shore (>30 km) (Fig. 3).

Principal Components Analysis (PCA) and Multiple Linear Regression (MLR)

When using all seasons and all fish species caught at distances less than 30 km from shore (divided into three sections: 0-10 km, 10-20 km, and 20-30 km), and during the period 1996 – 2000, PCA indicated that the majority (71%) of the total variation in the fishing data was explained by the first principal component (Table 1). The first principal component (PC 1) in this case and in every other PCA we ran, was described by the positive correlation between all of the fishing variables used (Fig. 4). When all principal components that accounted for more than 2% of the total variation in the data were used to build MLR models predicting Steller sea lion population trend at all rookeries, the models with the highest adjusted R^2 values (aR^2, adjusted to account for the number of predictor variables used) came from the first time period (Table 2). PC 2 was significant in all of the statistically significant models we found ($p < 0.05$, based on the model F statistic). PC 2 accounts for 12.9% of the total variation in the fishing data. Sites that scored highly on PC 2 had relatively high CPU values at each distance and relatively low values in the other fishing metrics (Fig. 4). The MLR coefficient for PC 2 was negative indicating that sites that experienced this type of fishing (high CPU with low effort) had relatively low Steller sea lion population growth over the early period of our analysis.

PCA using the same data, but from 2000 - 2004, indicated that most (73%) of the variation in the data was again captured by the first principal component, which described the extent to which each of the fishing variables were related (Fig. 5). MLR using the principal components from this PCA showed that fishing from 2000 - 2004 best predicted sea lion population trend from 1996 - 2000. This is a chronological impossibility, but since it describes a correlation it is reasonable if one reverses the arbitrary assignments of "predictor" and "response." PC 2 was once again prominent, as was PC 5. In this case PC 2 explained 11.7% of the total variation in the data and once again was capturing the extent to which CPU was negatively correlated with the other fishing variables (Fig. 5). Sites that scored highly on PC 2 in this case would have high CPU and relatively low effort around them. PC 5 explained only 2.3 % of the total variation in the fishing data and was not worth discussing further. The sea lion population trajectory from 1996 - 2000 was negatively associated with PC 2 and MLR models indicated that sites with low sea lion growth over this period saw efficient (high CPU with low effort) fishing later.

An interesting pattern emerges when the same fishing variables over the entire time period were subjected to PCA. The eigenvalues looked very similar to those from the PCA on the separate time periods (Table 3). MLR models using 1996 - 2000 sea lion trend data had about equal aR^2 values as those models that use 2000 - 2004 sea lion trend as the response variable. Once again, PC 2 was important (Table 4). PC 2 explained 14% of the variation in the fishing data and was once again a measure of fishing efficiency. It tracked the extent to which CPU at each distance was negatively correlated with most of the other fishing variables, so that sites that scored highly on PC 2 would show high CPU and low effort. In the MLRs that use sea lion population trend from 1996 - 2000 as the response, the coefficient for PC 2 was negative, indicating that fishing efficiency predicted low sea lion population growth rates, or that low sea lion growth rates predicted efficient fishing. In the MLR that used sea lion population trend from 2000 - 2004 as the response, the coefficient for PC 2 was positive, indicating that fishing efficiency predicted high sea lion population growth rates.

When season was considered separately, PCA using fishing data from 1996 to 2000 again indicated that most of the variation came from the extent to which all of the fishing variables were positively correlated, PC1 (Table 5). The MLR models using

these principal components to predict Steller sea lion population trend showed that the highest aR^2 values were generated using data from the first time period (Table 6). The only statistically significant principal component (p value <0.05, based on t value for each predictor variable) in any of the statistically significant MLR was PC 4. PC 4 accounted for only 5.7% of the total variation in the data. PC 4 was apparently picking up a contrast between CPU in spring and summer and effort variables (number of hauls, weight of fish removed and duration of fishing) in winter (Fig. 6). The MLR coefficient for this principal component was positive indicating that sites that had relatively efficient fishing in spring and summer and relatively low effort in winter had higher growth rates, at least for the time period from 1996 to 2000. This contrast, however, is probably not important given the small amount of the total variation explained by this PC.

Multiple linear regression based on the principal components from the PCA of fishing data, stratified by season during 2000 - 2004 and separately from 1996 - 2004, were only significant when sea lion population trend from 1996 to 2000 was used as the response variable. From the perspective of using fishing metrics to explain sea lion population trajectory, these results are not particularly informative because the only significant models were based on a response variable that occurred before the predictor variable. Furthermore, the most important principal component from these MLR analyses explained little of the total variation in the fishing data. Consequently these models will not be discussed in detail.

When fish species was considered separately, PCA showed that most of the variation in the data (58% - 65%) was again explained by the extent to which the fishing variables were positively correlated (Tables 7 - 9). The MLR with the highest aR^2 used fisheries data from 1996 to 2000 and predicted sea lion population trend from 2000 to 2004. These MLR analyses feature PC 1 and PC 5 prominently because they were the only significant predictors in each model (Table 10). PC 5 accounted for only 3.6% of the total variation and will not be discussed in detail. The MLR coefficient for PC 1 was positive in each of these MLR, indicating that sites that had relatively high fishing values from 1996 to 2000, regardless of the species caught, tended to have higher sea lion growth rates from 2000 to 2004.

DISCUSSION

As discussed in MRAG (2000a), fish species abundance in an area will vary annually with and without fishing and can include shifts in dominance of species at different trophic levels. The degree to which fishing affects the system depends on the dynamics of species (recruitment, survivorship, growth, reproduction, migration), the dynamic interaction amongst species (competition, predation, habitat etc.) and the manner in which the fishery causes change in these processes, including changes in the relationship between biota and the physical environment such as might arise from modification of the habitat by bottom trawling (MRAG 2000a). Detecting the effects of specific fisheries is a difficult task. As described in MRAG (2000b), given a set of data concerning the decline of marine mammals, one view of the role of analysis is that its purpose is to confront each explanation for the decline with the data and allow the data to arbitrate between the different models. Hilborn and Mangel (1997) call this process ecological detection. Ecological detection recognizes that our understanding of the world will always be incomplete and that the goal should be to achieve the best understanding possible by working with multiple hypotheses.

Knowing that there is a high level of uncertainty in our assessment of the indirect effects of fisheries on marine mammals, the impacts of fisheries on Steller sea lions will depend on spatial, temporal, and target species overlap for which little data is currently available (Baraff and Loughlin 2000). As summarized in the Steller sea lion recovery plan (NMFS 2008), the potential for fisheries to reduce local abundances of fish was shown for Atka mackerel (Lowe and Fritz 1997) and Pacific cod fisheries (Fritz and Brown 2005), where local, short-term harvest rates were much greater than the annual target harvest rates on the stocks as a whole. Many of the areas fished by the Atka mackerel fishery in the Aleutian Islands and all of the Pacific cod fishery data analyzed by Fritz and Brown (2005) were collected within designated sea lion critical habitat. However, longline fishing removes a relatively small amount of biomass from Steller sea lion critical habitat. Over the entire time period of this study (1996 - 2004), longline fishermen removed about 3.3 billion kg of biomass, while all other gear types removed about 60 billion kg. The relative impact of the longline fleet was highest in the 10 - 20

km range, where longline fishers took about 13.7% of the total catch over the period of our study.

The results of the SLR using the NMFS-provided fishery observer data and Steller sea lion count data from 1996 to 2000 indicated that CPU, a rough measure of fisher efficiency, was the fisheries variable most strongly associated with sea lion population trend. That CPU and sea lion population growth were negatively associated with sea lion population trend while other metrics of fishing effort were not is puzzling. If longline fishing were detrimental to sea lions then one would expect the measures of fishing effort, such as duration of hauls or sum of the weight of hauls to be negatively associated with sea lion population growth. The variable CPU was not scaled to effort, even though areas with high CPU can have very low or very high effort. CPU was instead a rough indicator of the relative abundance of fish, or fish biomass, and the efficiency of fishers to catch those fish in an area. In that light a negative association between CPU and sea lion trend was surprising since high fish abundance (biomass) should benefit sea lions as well as fishers. It is possible that areas of high fish abundance attract fishers from other gear sectors that are more apt to affect sea lions than longline fishers. As discussed by numerous authors, commercial fishing activity may affect Steller sea lion population trajectories by disruptions of foraging behavior (Fritz and Ferrero 1998), bycatch (Loughlin and Nelson 1986), shooting (Alverson 1992), disruption of forage fish aggregations (Sinclair and Zeppelin 2002), or by depletion of local fish stocks (Loughlin and Merrick 1989; Fritz and Ferrero 1998; DeMaster et al. 2001). Of these, depletion of local fish stocks is most likely to cause a major impact (DeMaster et al. 2001). As mentioned above, the question as to the affect of fisheries on Steller sea lion population trajectories has been examined by several others and no such association has been found with any sector of the fishers in Alaska since 1991 when sea lion-based fisheries restriction began (e.g., Hennen 2006, Dillingham et al. 2006). Another possibility is that four years is too short of a period for any response to favorable conditions in sea lion demographics to appear. This possibility is supported by the result of this study that high CPU from 1996 to 2000 predicted high Steller sea lion growth trends from 2000 to 2004.

In an analysis similar to this study (but including Southeast Alaska), Dillingham et al. (2006) found negative relationships between longline effort and the instantaneous

rate of Steller sea lion population change, but the relationships generally were not statistically significant. When Southeast Alaska was excluded from their model, a significant relationship was seen in the regionally adjusted models which they interpreted as the set of factors that might lead to 100 extra days of longline effort and would decrease the annual rate of Steller sea lion change by 0.34% from its current level.

The results of the PCA and MLR analyses in the present study highlight some interesting patterns in the data. The general PCA that examined fishing over all seasons and species (but used all the fishing variables at three near-shore distances simultaneously) showed that rookeries where there was relatively little fishing, but high CPU tended to be less productive between 1996 and 2000. This result indicates that areas that were rich in biomass that were not well exploited by longline fishers were not particularly good habitat for Steller sea lions. Exactly the opposite pattern was true after 2000. High longline CPU coupled with low effort predicted high sea lion population growth during the period 2000 - 2004. Further investigation is needed to validate that the absence of longline fishers is not simply a predictor of the presence of other types of fishers or some other factor that might explain both low sea lion population trends and low exploitation rates by longline fishers.

It is not clear what drives this contradictory pattern, but it is clear that something in the marine environment occupied by both sea lions and longline fishers changed in the late 1990s and early 2000s. Dillingham et al. (2006) cite Klyashtorin (1998) who notes that current climate changes suggest conditions seen in the 1950s - 1970s. It was during this period that Steller sea lion populations were high (Loughlin et al. 1992). This is coupled with evidence of smaller regime shifts in the north Pacific in 1989 and 1998 (Beamish et al. 2004) and the gradual stabilization of Steller sea lion populations. Differing effects of regime shifts on fisheries at a local scale (Beamish et al. 2004) could explain differences in the timing and scale of the Steller sea lion decline.

Changes in fisheries management in the late 1990s and early 2000s could have altered sea lion population trajectories. As summarized in NMFS (2008), NMFS reviewed federally managed groundfish fisheries in a series of consultations under Section 7 of the ESA in the late 1990s and early 2000s. Two of those consultations resulted in a determination that commercial fisheries were likely to jeopardize the

continued existence of the western stock of Steller sea lion and adversely modify its critical habitat. The consultations resulted in additional conservation measures being implemented to avoid jeopardy and adverse modification (NMFS 2001). The expectation was that those measures would promote the recovery of Steller sea lions in areas where potential competition from commercial fisheries may have contributed to the population decline.

The implementation of these conservation measures in the 1990s and early 2000s occurred at about the same time as a reduction in the rate of decline of the western stock of sea lions. The suite of fishery conservation measures implemented in 2002 (NMFS 2003) was intended to reduce fishing in near-shore critical habitat, reduce seasonal competition for prey during critical winter months, and disperse fisheries spatially and temporally to avoid local depletions of prey. The 2002 measures increased protection for near-shore critical habitat areas, specifically identifying those areas within 0-10 nm of listed haulouts and rookeries as more important for foraging sea lions than waters from 10-20 nm offshore. Whether or not the these measures were related to amelioration of the sea lion decline is equivocal since the information necessary to determine if the conservation measures actually contributed to the reduced rate of decline is not currently available.

Finally, noise in the data can disrupt or obscure underlying patterns. There is no reason to think that the data discussed in this paper were free of noise. The Steller sea lion data used were slope estimates based on count data with varying reliability. The fisheries data represent a subset of the total fishing in the area (vessels with observers on board) and have been expanded in a coarse fashion to approximate that total. It is not possible to assess how noise may have affected this analysis, but the possibility remains that any true underlying relationship, either positive or negative, could be masked by an inability to accurately capture the situation with the data available.

CONCLUSIONS

The low aR^2 derived from the models used in the present study (Table 2, 4, 6 and 10) and the lack of consistent and clear patterns makes it difficult to interpret the results of the analysis presented herein. SLR analysis indicated that management actions taken in the

late 1990s or early 2000s were effective at mitigating an adverse interaction. On the other hand, the correlation of CPU of the cod fleet and trends in abundance of western Steller sea lions in the early time period were equivocal; in the later time period they were consistent with an interpretation that areas where fishermen were efficient over the entire time period were associated with areas of relatively high sea lion population growth. When season was considered separately, PCA using fishing data from 1996 to 2000 indicated that most of the variation came from the extent to which all of the fishing variables were positively correlated, PC 1. MLR based on the principal components from the PCA of fishing data, stratified by season during 2000 - 2004 and separately from 1996 - 2004, were only significant when sea lion population trend from 1996 to 2000 was used as the response variable. When fish species was considered separately, PCA showed that most of the variation in the data (58% - 65%) was explained by the extent to which the fishing variables were positively correlated (Tables 7 - 9). The MLR with the highest aR^2 used fisheries data from 1996 to 2000 and predicted sea lion population trend from 2000 to 2004.

Put more simply, the rookeries where longline fishers were successful (high CPU), but did not have high effort (low values in the other fishing metrics such as number of hauls, sum of the weight of fish removed, and the duration of time of fishing), seemed to drive the patterns found. These rookeries tended to have slower (or negative) population growth, relative to other rookeries during 1996 – 2000, and faster population growth during 2000 – 2004. In both cases the aR^2 values describing the strength of the relationship were low. There are no ecological reasons why low effort or efficient fishing should have any effect on sea lion population growth trends, let alone a negative and then positive effect within eight years. Given the lack of a consistent, clear result, we conclude that the results are consistent with the hypothesis that longline fishing and Steller sea lion population trends are largely independent of each other.

ACKNOWLEDGEMENTS

This study would not have occurred without the encouragement and involvement of the Pacific cod freezer longline fleet based principally in Seattle, WA. Of particular note was the involvement of D. Little (Clipper Seafoods, Ltd.), and D. Wells, and C. Hosmer

(Romanzof Fishing Company LLC) who provided logbooks and other material assistance when needed. Dr. Daniel Hennen (Seward, AK) was responsible for data analysis and interpretation. TRL Wildlife Consulting (Redmond, WA) was responsible for oversight of the review of log books and observer data, and preparation of reports. D. DeMaster and M. Loefflad of NOAA Fisheries' Alaska Fisheries Science Center provided the observer data used in this study. R. Davis and S. Spurlin of Texas A&M University Research Foundation provided contract assistance. The final report was improved through comments on an earlier draft by D. DeMaster.

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FIGURES

The results of many different simple linear regressions (SLR) are plotted in Figures 1, 2, and 3 below. Each SLR corresponds to a different fishing variable. The x axis indicates the different distances from Steller sea lion rookeries tested. If a SLR resulted in a negative slope coefficient, meaning that higher fishing variable values predict a lower Steller sea lion population growth trend, then the point corresponding to that particular SLR is plotted below the y = 0 line (in negative y space). If a positive slope coefficient was found, the point corresponding to that particular SLR is plotted above the y = 0 line (positive y space). The absolute value of displacement from the origin on the y axis is equal to the R^2 value found in each SLR.

Figure 1. Significant and near significant results from linear regressions using fishing variables from 1996 to 2000 to predict 1996 - 2000 Steller sea lion population trend.

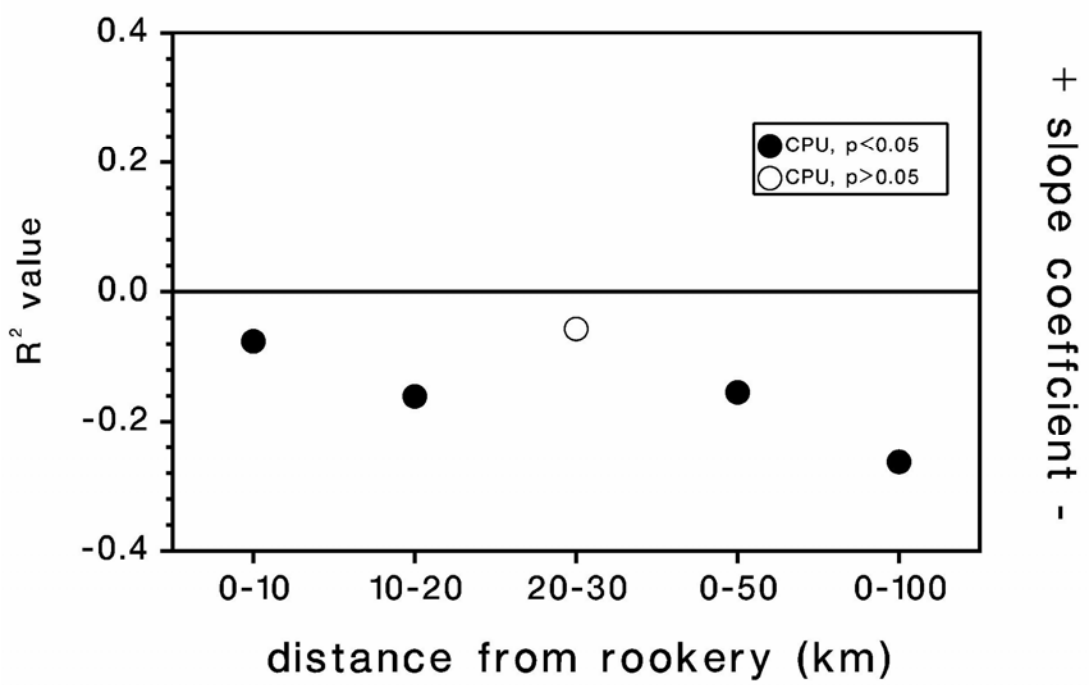


Figure 2. Results from linear regressions using fishing variables from 1996 to 2004 to predict 2000 - 2004 Steller sea lion population trend. An explanation to interpret this and the following figure can be found above.

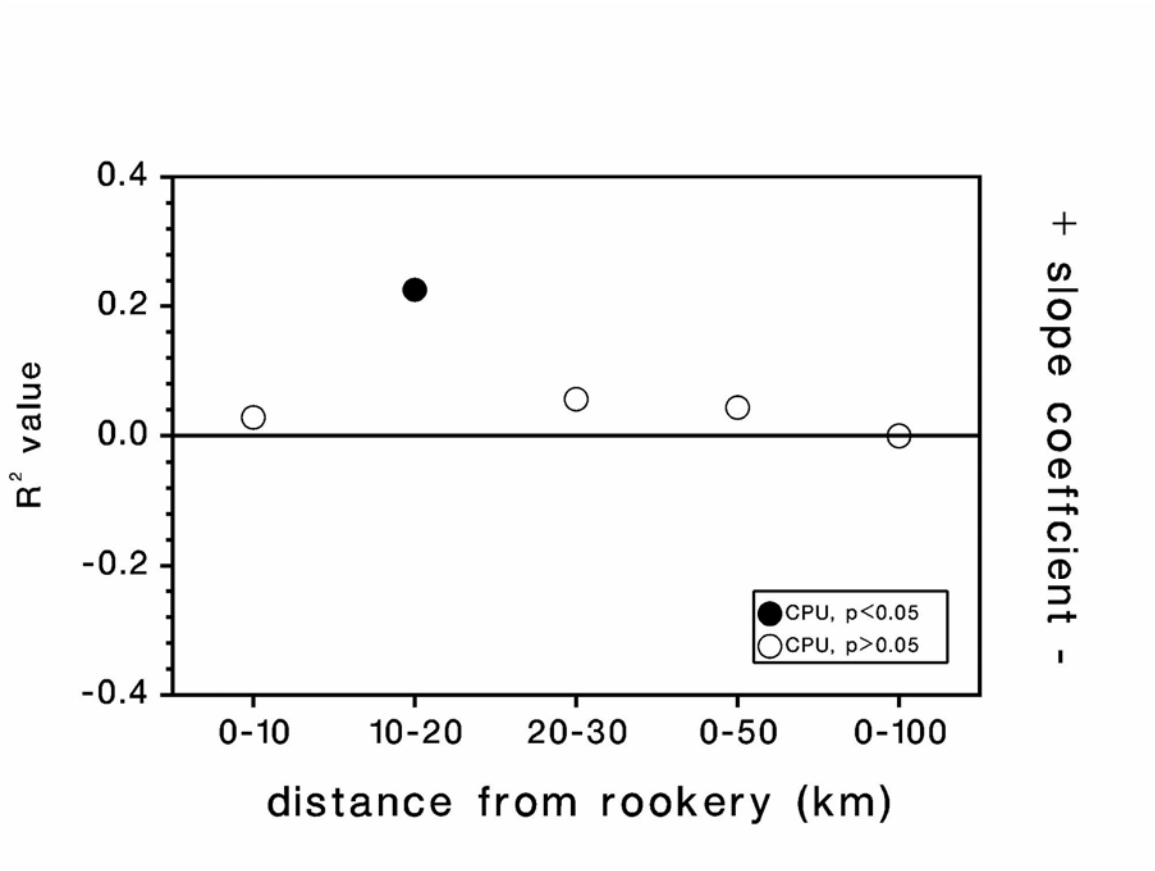


Figure 3. Results from linear regressions using fishing variables from 2000 to 2004 to predict 2000 - 2004 Steller sea lion population trend. An explanation to interpret this figure can be found above.

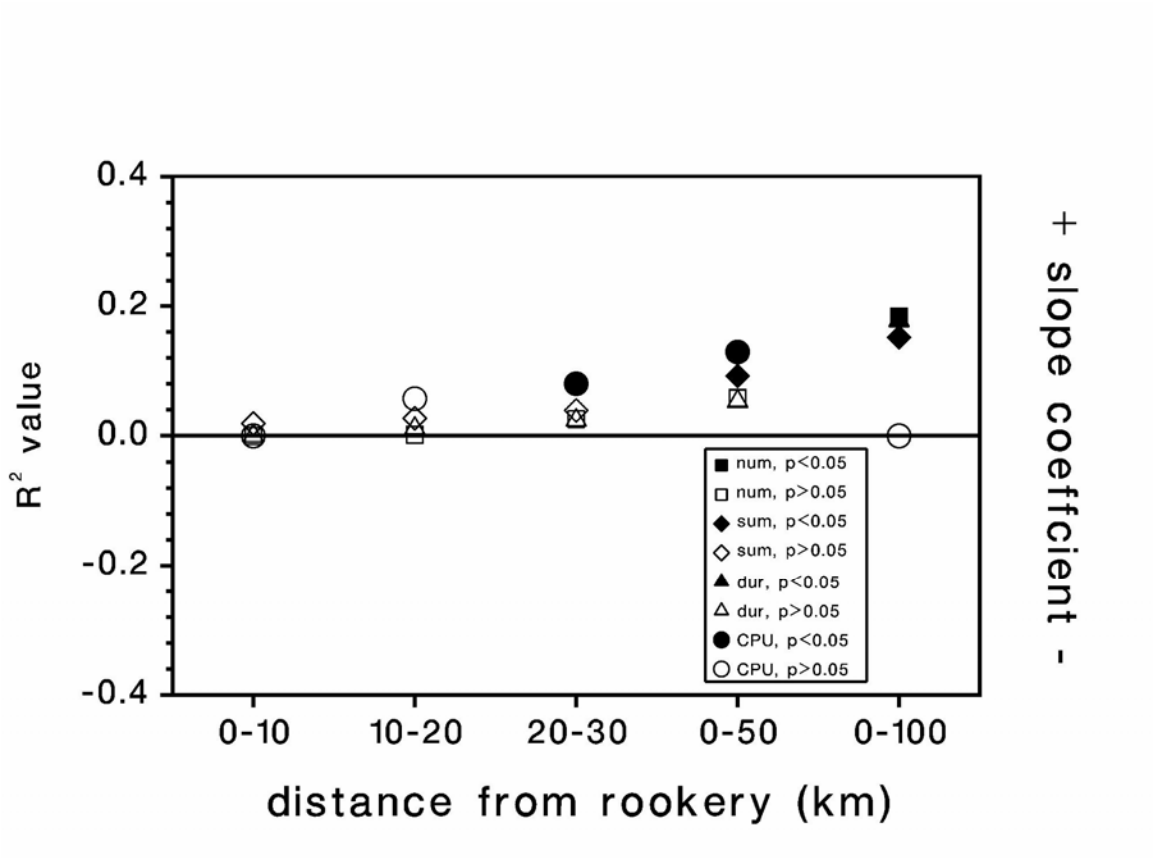


Figure 4. Eigenvector values corresponding to principal components one and two, from a principle components analysis of 1996 – 2000 fishing variables.

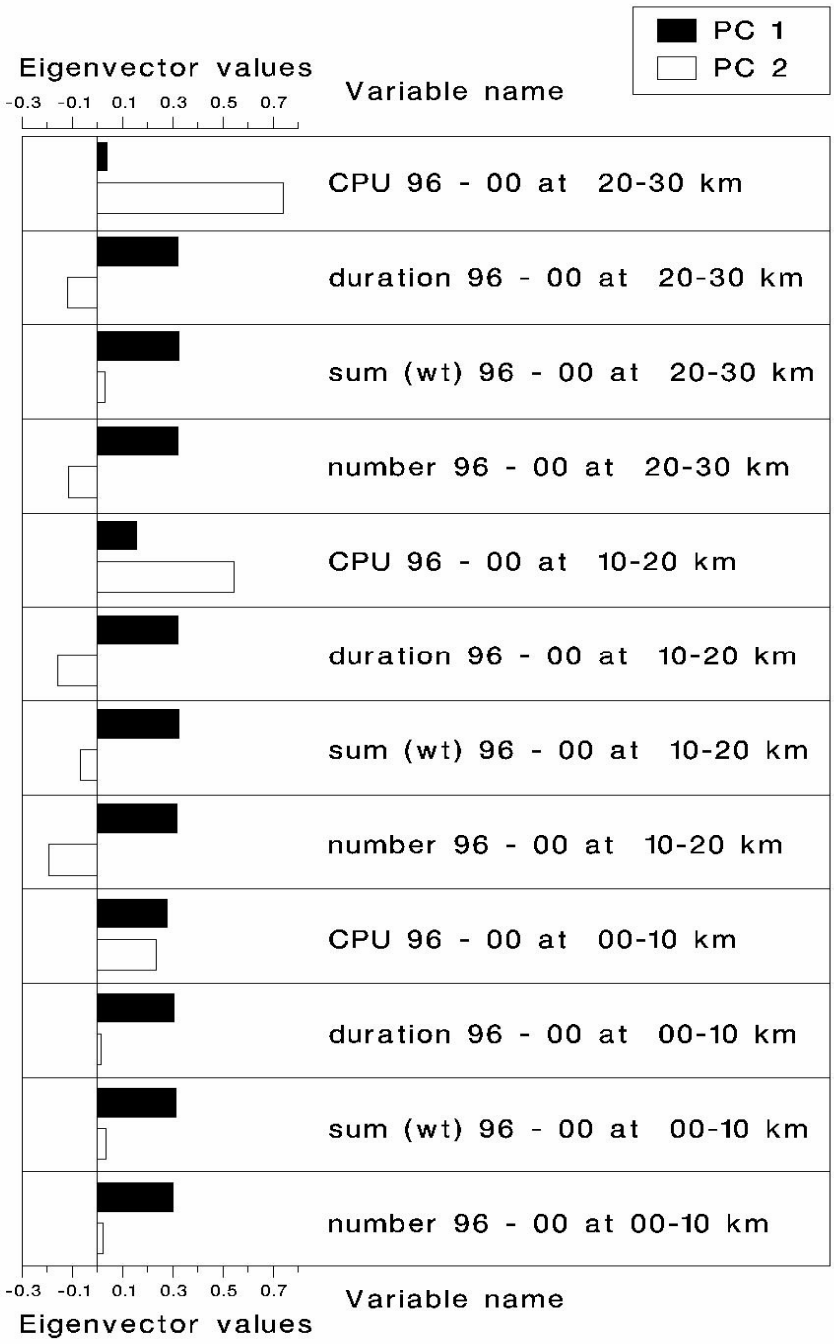


Figure 5. Eigenvector values corresponding to principal components one, two and five, from a principal components analysis of 2000 - 2004 fishing variables.

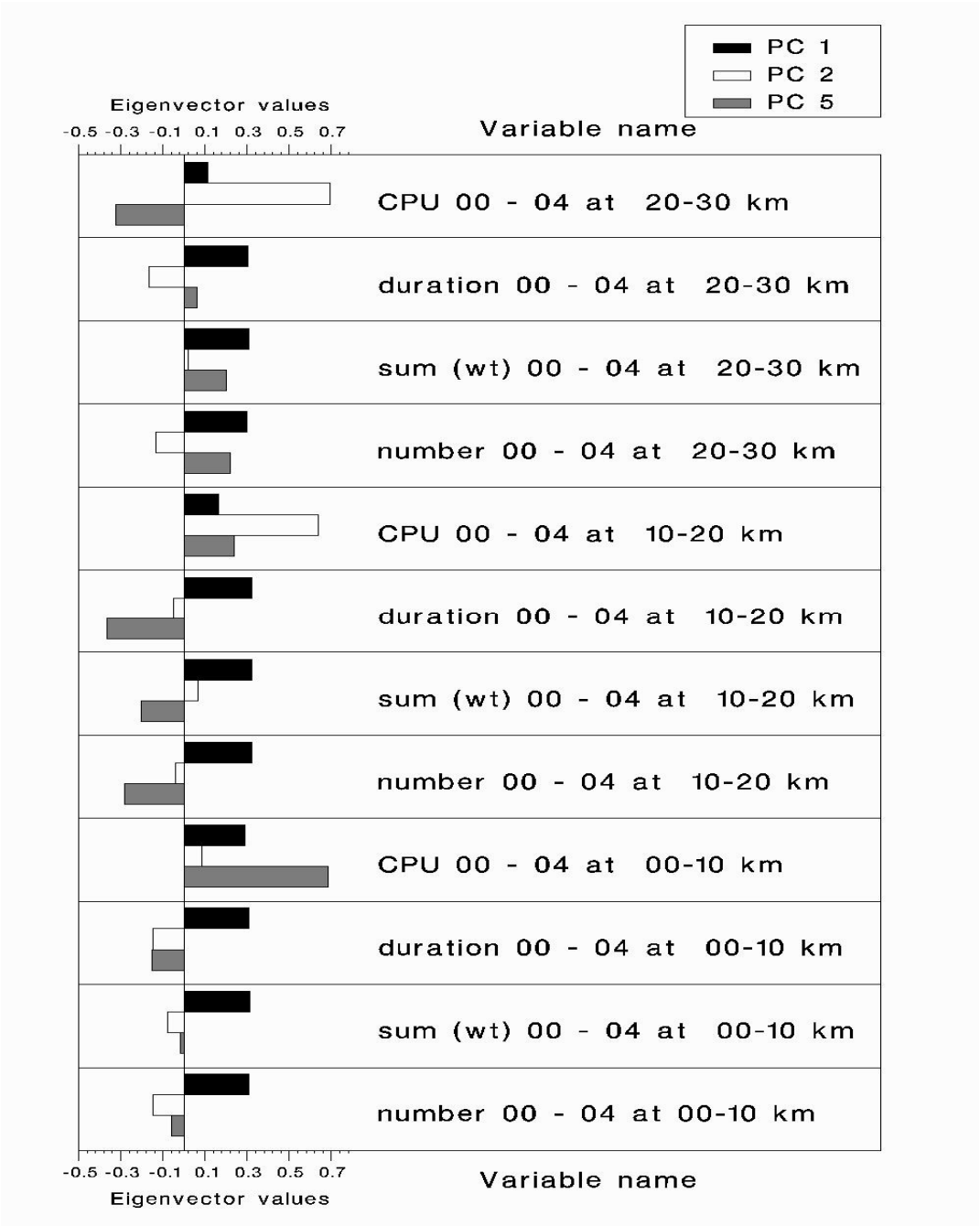
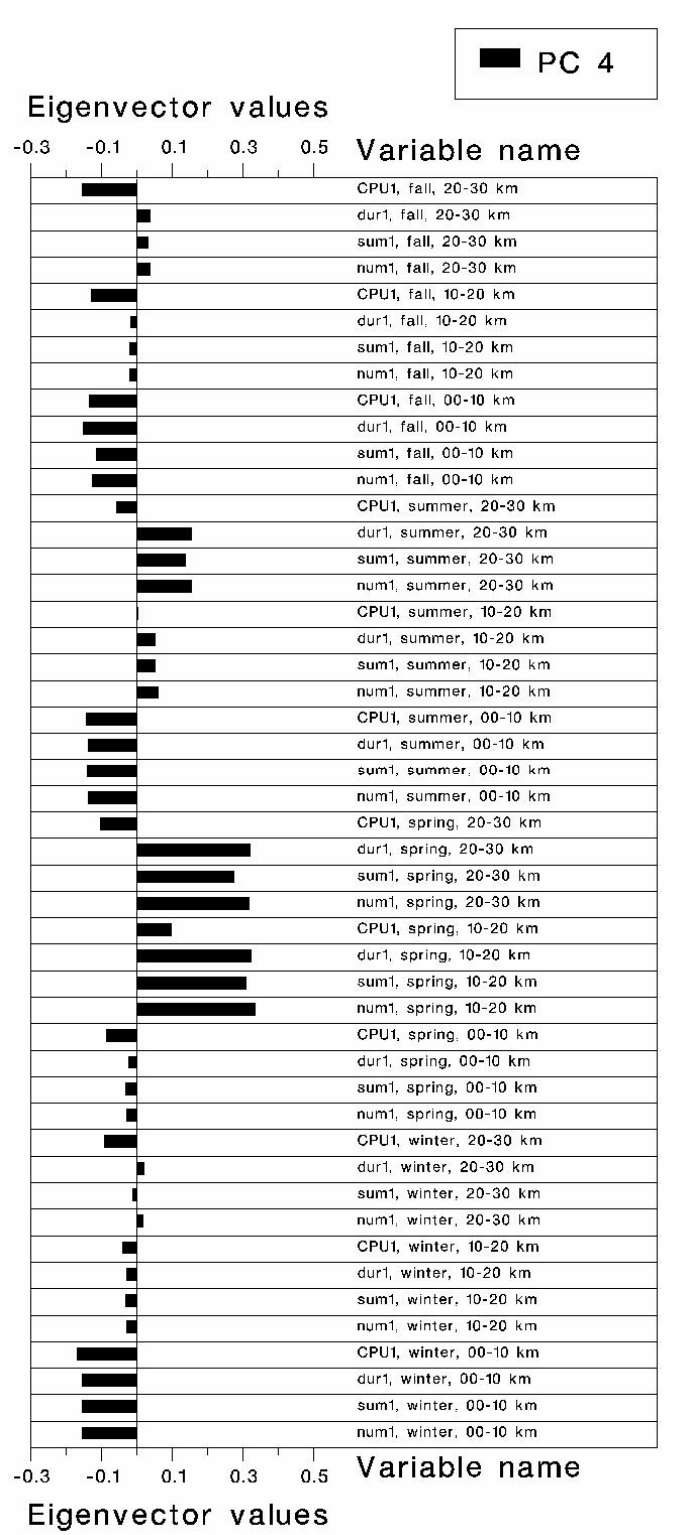


Figure 6. Eigenvector values corresponding to principal component four, from a principal components analysis (PCA) of 1996 - 2000 fishing variables, stratified by season.



TABLES

Table 1. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing in all seasons, for all species at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 1996 to 2000.

PC	Eigenvalue	% of Total Variation
1	8.276	70.6%
2	1.517	12.9%
3	1.169	10.0%
4	0.398	3.4%
5	0.199	1.7%

Table 2. Results of multiple linear regression (MLR) models using principal component scores from principal components analysis scores on fishing data from 1996 to 2000, to predict Steller sea lion (SSL) population trend. All possible combinations of principal component scores were tested and the model with the highest adjusted R^2 (aR^2) is shown.

Response Variable: 1996 - 2000 SSL Population Trend			
Predictor	Slope Coefficient (β)	p - value	aR^2
PC2	-0.423	0.003	21.944
PC4	-0.278	0.046	

Table 3. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing in all seasons, for all species at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 1996 to 2004.

PC	Eigenvalue	% of Total Variation
1	8.458	72.1%
2	1.678	14.3%
3	0.757	6.5%
4	0.334	2.8%
5	0.294	2.5%
6	0.147	1.3%

Table 4. Results of multiple linear regression (MLR) models using principal component scores from principal components analysis on fishing data from 1996 to 2000, to predict Steller sea lion (SSL) population trend. All possible combinations of principal component scores were tested and the models with the highest adjusted R^2 (aR^2) for each response variable, are shown.

Response Variable: 1996 - 2000 SSL Population Trend

Predictor	Slope Coefficient (β)	p - value	aR^2
PC1	-0.173	0.216	18.725
PC2	**-0.344**	**0.017**	
PC4	0.219	0.120	
PC5	-0.259	0.067	

Response Variable: 2000 - 2004 SSL Population Trend

Predictor	Slope Coefficient (β)	p - value	aR^2
PC1	0.274	0.054	18.317
PC2	**0.320**	**0.025**	
PC3	-0.175	0.213	
PC5	-0.226	0.110	

Table 5. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing in separate seasons, for all species at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 1996 to 2004.

PC	Eigenvalue	% of Total Variation
1	28.967	61.8%
2	3.829	8.2%
3	3.307	7.1%
4	2.693	5.7%
5	1.737	3.7%
6	1.304	2.8%
7	1.165	2.5%
8	0.812	1.7%

Table 6. Results of multiple linear regression (MLR) models using principal component scores from principle components analysis on fishing data from 1996 to 2004, stratified by season, to predict Steller sea lion (SSL) population trend. All possible combinations of principal component scores were tested and the model with the highest aR^2 is shown here.

Response Variable: 1996 - 2000 SSL Population Trend			
Predictor	Slope Coefficient (β)	p - value	aR^2
PC1	-0.162	0.250	16.730
PC2	0.156	0.270	
PC4	**0.359**	**0.014**	
PC5	-0.152	0.281	
PC7	-0.248	0.083	

Table 7. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing stratified by species, for all seasons at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 1996 to 2000.

PC	Eigenvalue	% of Total Variation
1	41.081	58.4%
2	9.546	13.6%
3	5.588	7.9%
4	2.817	4.0%
5	2.517	3.6%
6	2.077	3.0%
7	1.729	2.5%
8	1.153	1.6%

Table 8. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing stratified by species, for all seasons at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 2000 to 2004.

PC	Eigenvalue	% of Total Variation
1	45.481	64.6%
2	8.726	12.4%
3	4.003	5.7%
4	2.817	4.0%
5	2.389	3.4%
6	1.800	2.6%
7	1.338	1.9%
8	0.834	1.2%

Table 9. Eigenvalues from the principal components analysis (PCA) of ranked longline fishing stratified by species, for all seasons at distances of 0 - 10 km, 10 - 20 km, and 20 - 30 km from Steller sea lion rookeries, from 1996 to 2004.

PC	Eigenvalue	% of Total Variation
1	42.420	60.3%
2	10.345	14.7%
3	3.709	5.3%
4	3.099	4.4%
5	2.066	2.9%
6	1.901	2.7%
7	1.741	2.5%
8	0.961	1.4%

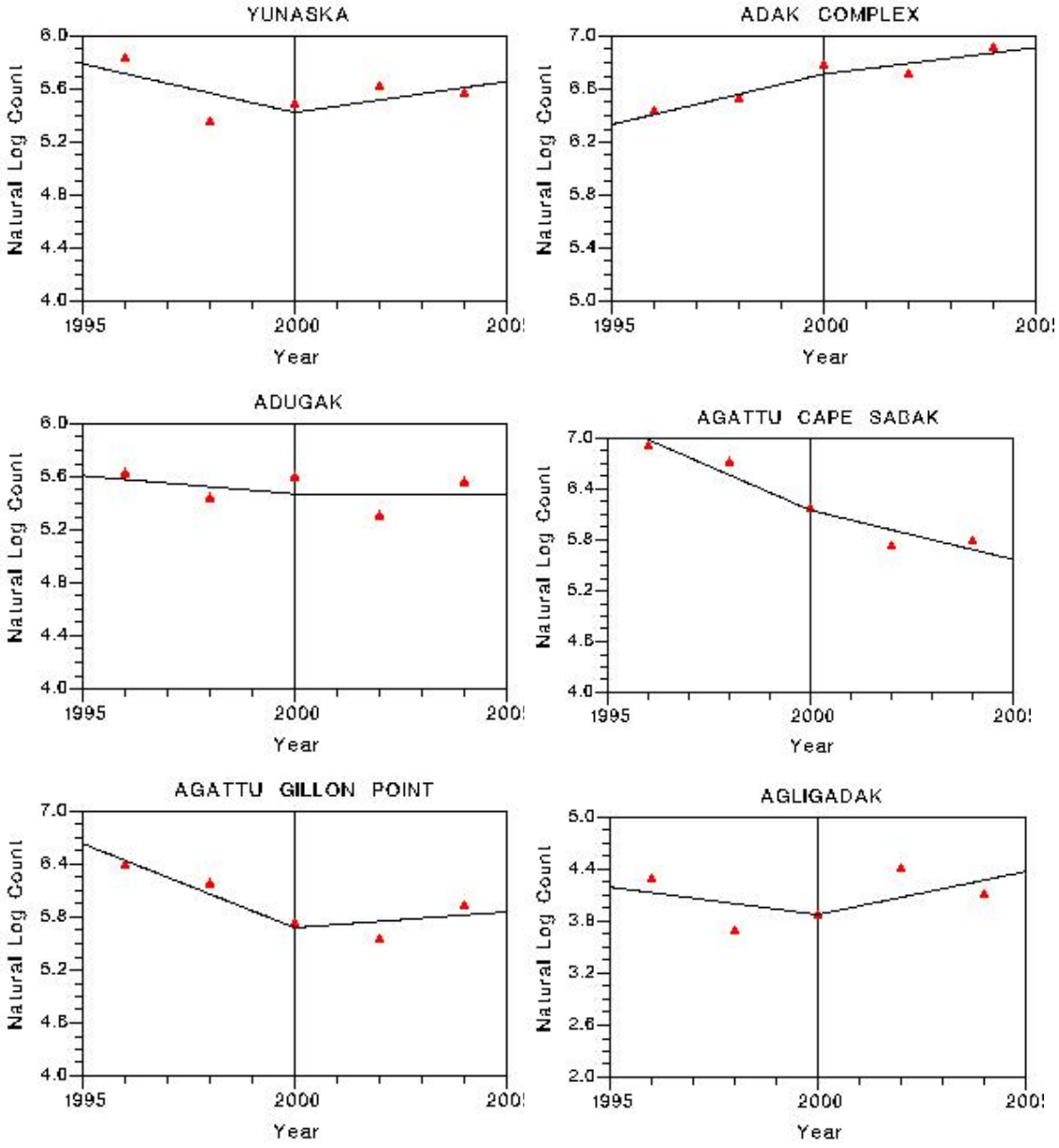
Table 10. Results of multiple linear regression (MLR) models using principal component scores from principal components analysis (PCA) on fishing data from 1996 to 2004, stratified by species, to predict Steller sea lion population trend. All possible combinations of PC scores were tested and the model with the highest aR^2 is shown.

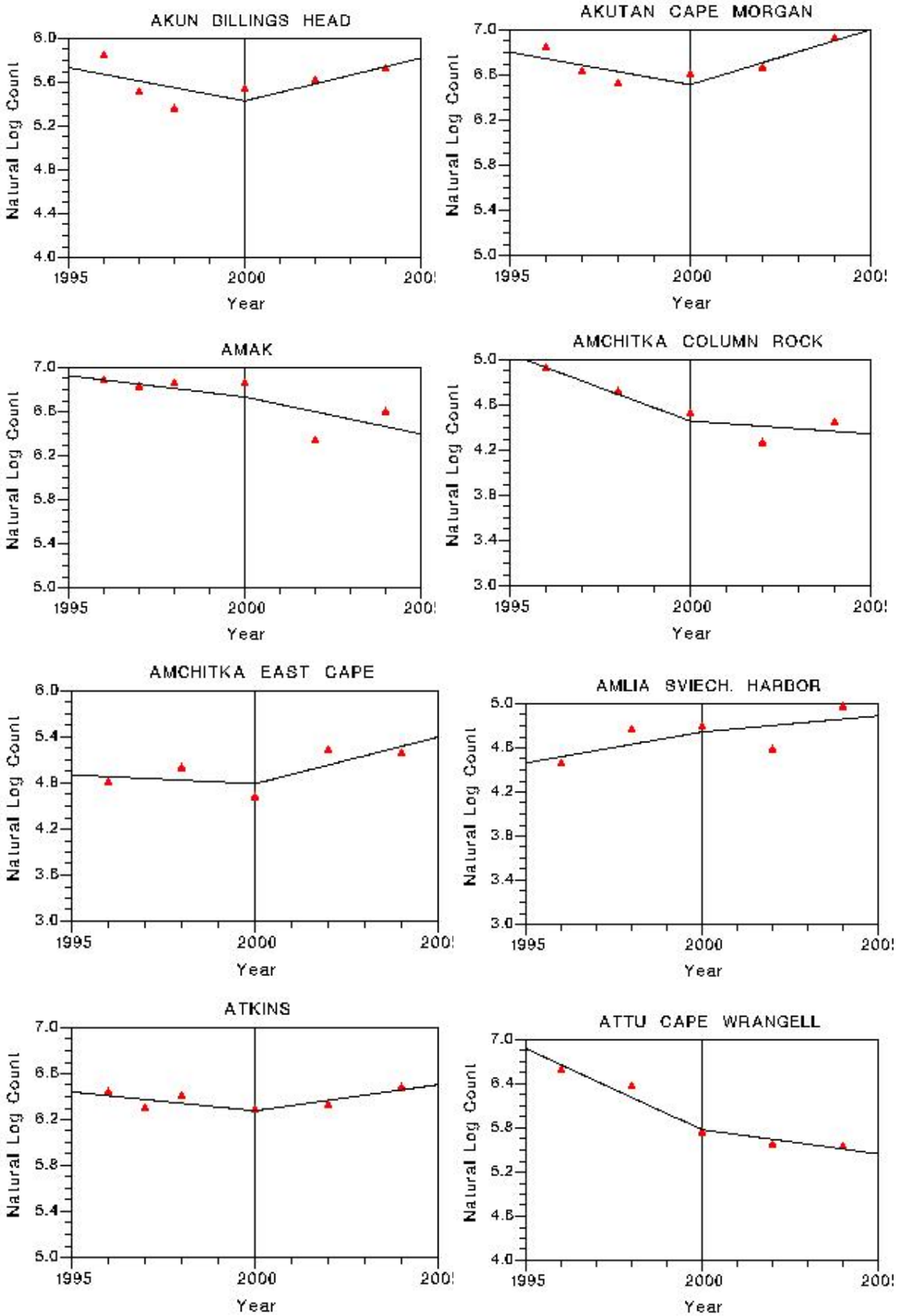
Response Variable: 2000 - 2004 SSL Population Trend			
Predictor	Slope Coefficient (β)	p - value	aR^2
PC1	**0.295**	**0.034**	22.630
PC3	-0.22	0.109	
PC4	0.152	0.264	
PC5	**0.309**	**0.027**	
PC7	-0.249	0.071	

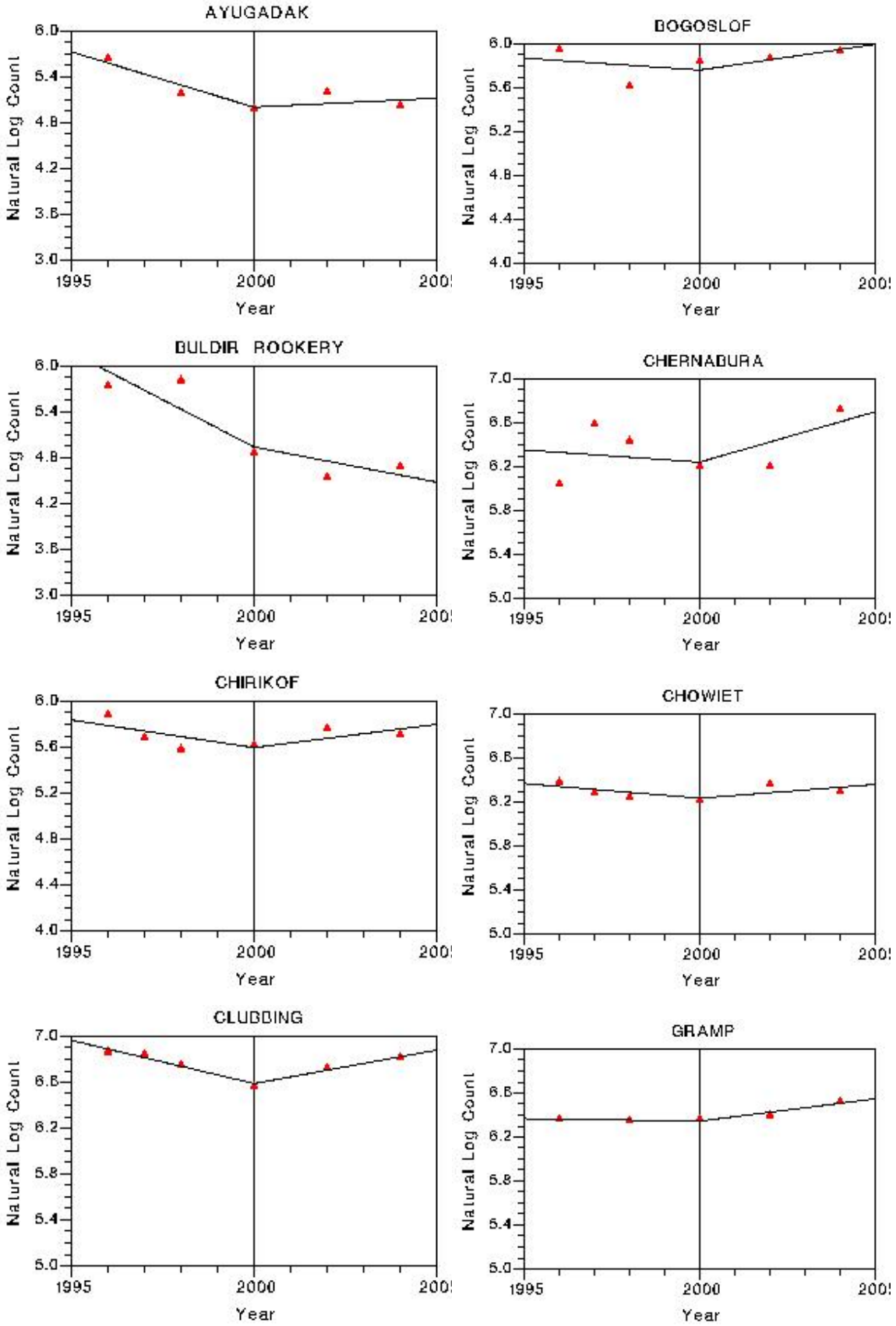
Appendix 1. Estimated population trend at each rookery during each time period. Trends are derived from natural logs of the non-pup count in each available year.

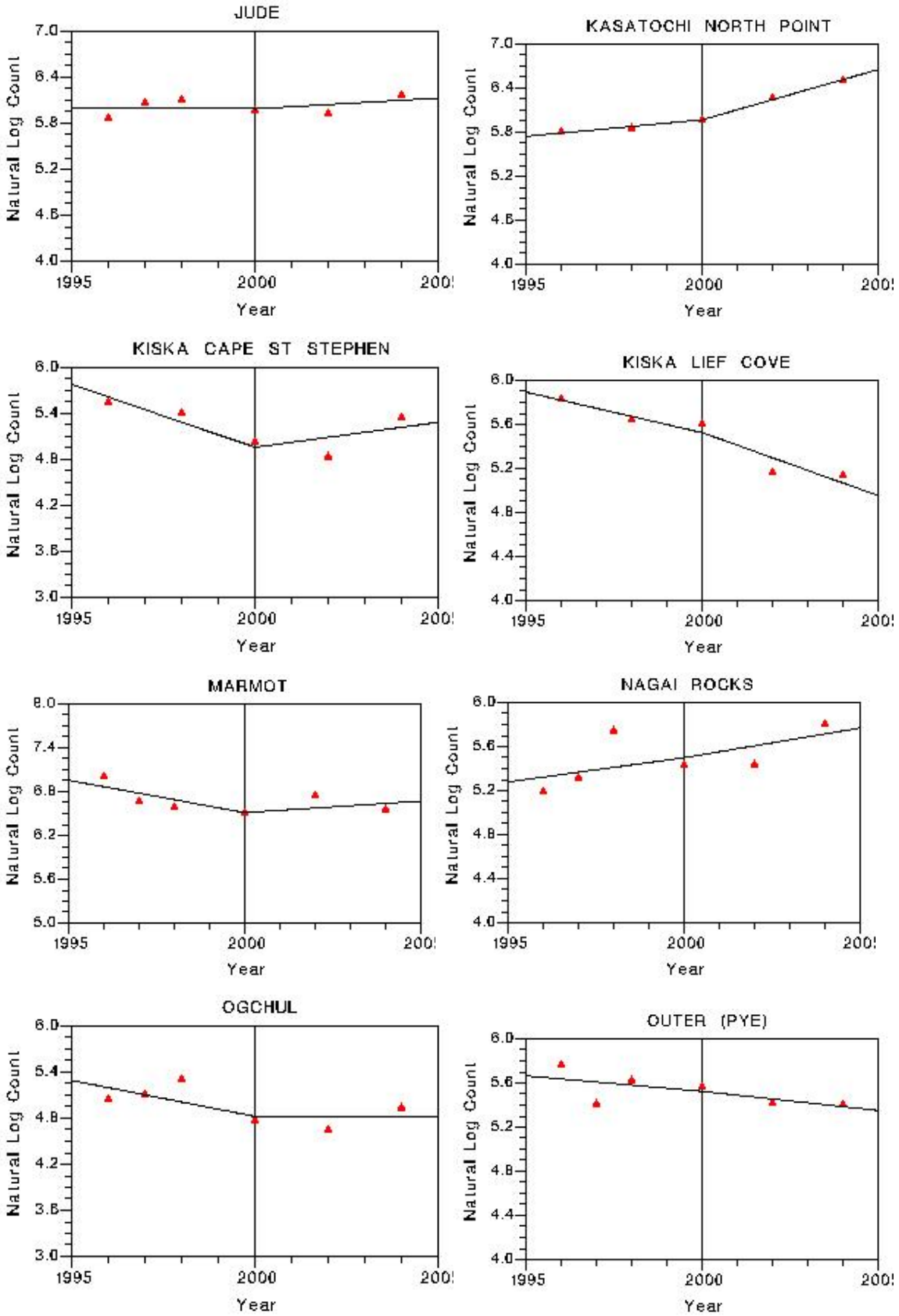
Population Trend During Each Period		
1996 - 2000	2000 - 2004	Rookery Name
0.0655	0.0316	Seal rocks
-0.0800	0.1129	Wooded (fish)
-0.0281	-0.0346	Outer (pye)
-0.0884	0.0317	Marmot
0.0083	-0.0131	Sugarloaf
0.1267	-0.1362	Ushagat
0.0079	-0.0338	Two Headed
-0.0480	0.0406	Chirikof
0.0441	0.0539	Nagai Rocks
-0.0266	0.0249	Chowiet
-0.0330	0.0456	Atkins
-0.0223	0.0918	Chernabura
-0.1581	-0.1497	Whaleback
-0.0011	0.0282	Jude
-0.0364	0.0464	Pinnacle
-0.0751	0.0582	Clubbing
-0.2222	0.2459	South rocks
-0.1652	0.1386	Sea lion rock (Amak)
-0.0387	-0.0673	Amak
-0.0314	0.1461	Ugamak+Round
-0.0606	0.0781	Akun - Billings Head
-0.0576	0.0975	Akutan - Cape Morgan
-0.0217	0.0468	Bogoslof
-0.0938	0.0054	Ogchul
-0.0274	0.0005	Adugak
-0.0732	0.0469	Yunaska
-0.0004	0.1156	Seguam - Saddleridge
-0.0636	0.0995	Agligadak
0.0561	0.0293	Amlia - Sviech. Harbor
0.0452	0.1368	Kasatochi - North Point
0.0762	0.0400	Adak complex
-0.0044	0.0404	Gramp
-0.0150	-0.0691	Tag
-0.0774	-0.0526	Ulak - Hasgox Point
-0.0310	-0.1660	Semisopochnoi
-0.1183	-0.0227	Amchitka - Column Rock
-0.0233	0.1217	Amchitka - East Cape
-0.1448	0.0235	Ayugadak
-0.0737	-0.1145	Kiska - Lief Cove
-0.1640	0.0653	Kiska - Cape St Stephen
-0.2477	-0.0919	Buldir
-0.2078	-0.1161	Agattu - Cape Sabak
-0.1908	0.0360	Agattu - Gillon Point
-0.2198	-0.0659	Attu - Cape Wrangell

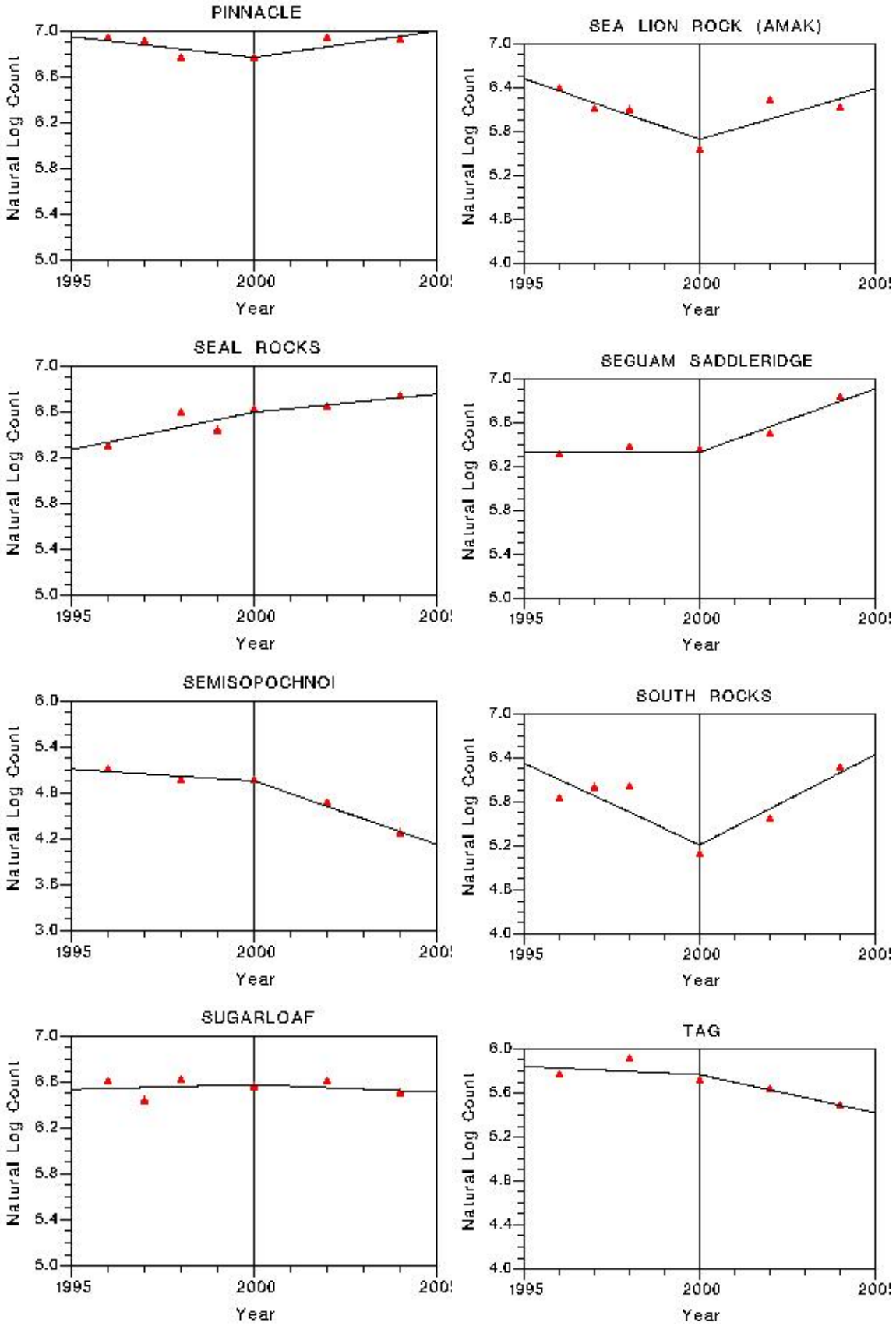
Appendix 2. Model fits for trend estimation at each rookery. Natural log of count is on the y axis and year of count is on the x axis.

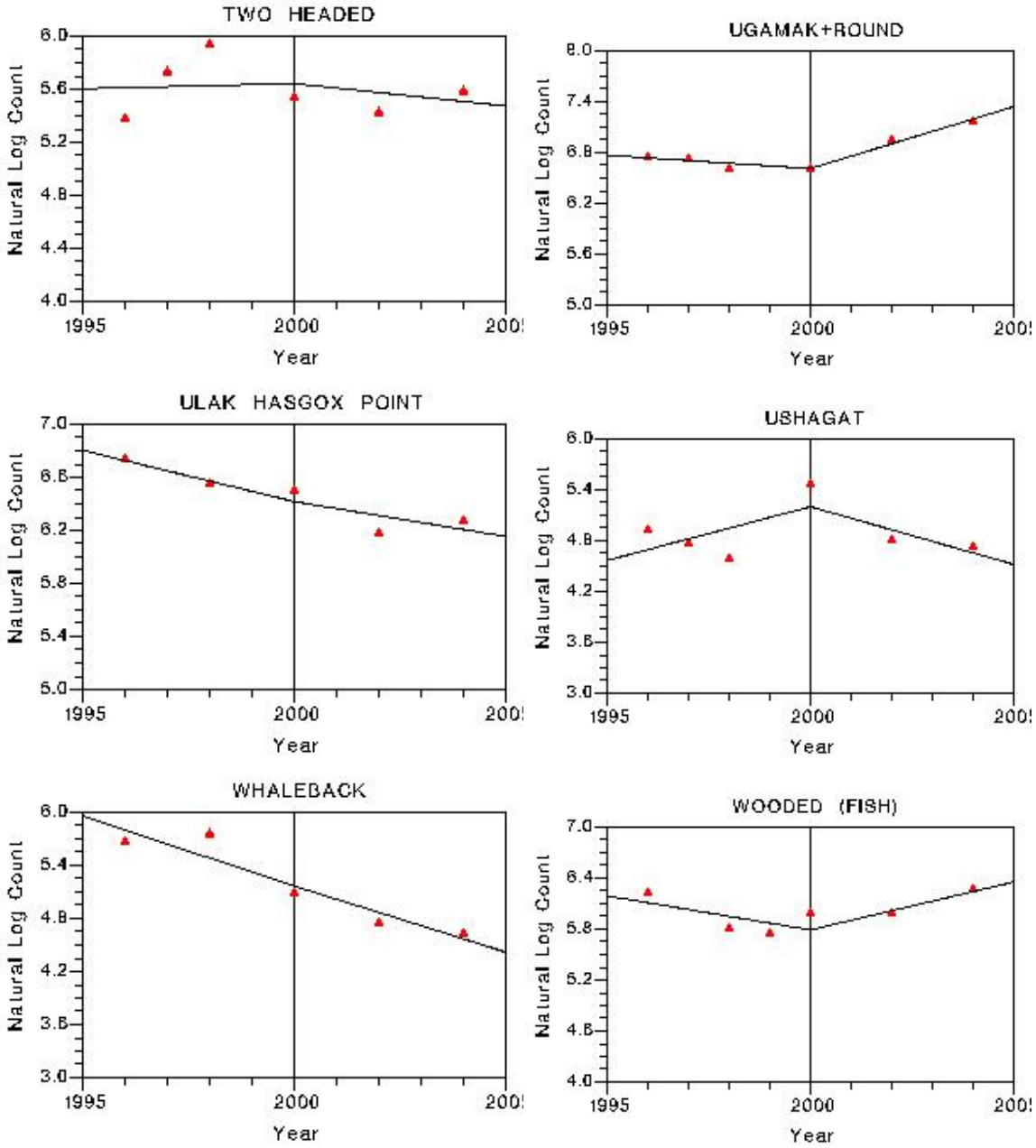



AKUN BILLINGS HEAD
AKUTAN CAPE MORGAN
AMAK
AMCHITKA COLUMN ROCK
AMCHITKA EAST CAPE
AMLIA SVIECH. HARBOR
ATKINS
ATTU CAPE WRANGELL
Natural Log Count
Year
1995
2000


AYUGADAK
BOGOSLOF
BULDIR ROOKERY
CHERNABURA
CHIRIKOF
CHOWIET
CLUBBING
GRAMP
Natural Log Count
Year
1995
2000


JUDE
KASATOCHI NORTH POINT
KISKA CAPE ST STEPHEN
KISKA LIEF COVE
MARMOT
NAGAI ROCKS
OGCHUL
OUTER (PYE)
Natural Log Count
Year
1995
2000


PINNACLE
SEA LION ROCK (AMAK)
SEAL ROCKS
SEGUAM SADDLERIDGE
SEMISOPOCHNOI
SOUTH ROCKS
SUGARLOAF
TAG
Natural Log Count
Year
1995
2000


TWO HEADED
UGAMAK+ROUND
ULAK HASGOX POINT
USHAGAT
WHALEBACK
WOODED (FISH)
Natural Log Count
Year
1995
2000

Appendix 3. Explanation of Principal Components Analysis (PCA)

The following explanation of PCA is from Hennen (2004)

Mechanics

Given n observations on m variables, create an n x m data matrix X. The matrix should be standardized so that each column has a mean of zero and a variance of one. This is easily accomplished by subtracting the column mean from each value in that column and then dividing by the standard deviation of that column. Let the covariance matrix of X be denoted as $\sum_x$. Do an eigenvector/eigenvalue decomposition on $\sum_x$. Because $\sum_x$ is symmetric, the eigenvalues and eigenvectors should be real. The eigenvalues should be arranged in a vector $\underline{\lambda}$, in order of decreasing magnitude and the corresponding eigenvectors arranged in that same order in a matrix U. Subtract the appropriate column mean from each value of the original (un-standardized) data matrix, and call the result X_1. Multiplying the matrix X_1 by U yields Y, the n x m matrix of principal component scores.

Interpretation

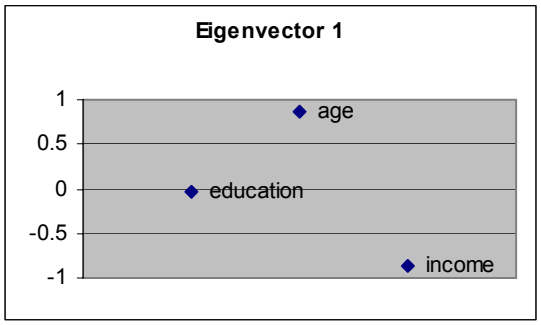
PCA is a tool for understanding what a multivariate dataset looks like. The first eigenvector, also called the first principal component, describes the axis of maximum variation in the dataset. Imagine a football shaped cloud of data points in three dimensional space. If you could only look at two dimensional plots (an analogy for our inability to examine 4+ dimensional space) it might be difficult to see the football shape. You would be limited by the orientation of both the football and the axes we typically use (y = 0, x = 0 and so on), to project these marginal distributions. In this situation the first principal component would orient directly down the long axis of the football, the direction of maximum spread of the data. Remember, the first eigenvector will consist of three (or m in the mechanics section) coefficients, each corresponding to one of the variables. Drawing a line through the three coefficient values would be equivalent to piercing both tips of the football. The second principal component describes the axis of the greatest variation that is orthogonal to the first axis. Given that the first axis goes through the pointed ends of the football the second is free to roam the length of the

football (as long as it stays perpendicular to the long axis) and to rotate around the long axis to any angle. Obviously, in a football, the point of second greatest spread is going to be the exact center. The coefficients from the second principal component will describe a line located at the center of the long axis and perpendicular to it, however that line could be rotated about that point of intersection to any angle (imagine a cross section of a football, cut perpendicular to the long axis, it would be spherical so one orientation includes no more variation in the data than any other). The third principal component follows the same rules. It will be oriented in the direction that describes the most variation, given that it is orthogonal to the other two. PCA does not work well when the data cloud is spherical. Given these constraints, the coefficients from the principal components describe the correlation structure of the variables along that component. For example, if variable one has a large positive coefficient, variable two is near zero and variable three has a large negative coefficient, variables one and three are negatively correlated and variable two plays very little roll in determining the variation along principal component one. The eigenvector coefficients are indeterminate to a scale factor and sign, so nothing can be made of the sign or magnitude of a coefficient, unless it is considered relative to the other coefficients.

Dividing each eigenvalue by the sum of all the eigenvalues gives a measure of the percent of the total variation in the data described by each of the principal components. If you were looking at a data cloud that resembled a very long and narrow football, a large percentage of the total would be concentrated in eigenvalue one. If your data cloud were more spherical, the first eigenvalue would probably account for not much more of the total than the other eigenvalues.

Each data point gets a principal component score for each eigenvector. Examination of these allows you to determine how extreme a data point is in the direction of each principal component. For example, a data point on the tip of the football would score highly on principal component one. Component scores can be very useful in elucidating spatial or temporal patterns. For example, if the data points which score highly on principal component one are located preferentially in the northern part of your study area, or occur early in the time series, you may have found an interesting pattern. Such patterns might not be transparent without PCA, because a high component score

does not necessarily indicate an extreme value on any one variable axis. Further more, the component scores allow you to combine the information given in several variables into one or a few. For example, let's say that you have collected 100 observations of three variables; age, education and income. A PCA of this data might indicate that the first eigenvalue accounted for 87% of the total variation and that a graph of the coefficients from the first principal component looked like this:



The coefficients for age and income are much closer to 1.0 than the coefficient for education. This means that they account for much more of the variation in principal component one. Incidentally they are also on opposite sides of zero, which indicates that they are negatively correlated with each other (this is obviously not a real dataset). Using the component score generated from this principal component as you would a normal variable in other statistical analyses allows you to capture information about both age and income (and a tiny bit about education) in one variable.

In essence, PCA does two things; it moves the traditional x, y, z coordinate system into a more useful orientation, tailored specifically for your dataset, and it allows you to combine the information in multiple variables into a smaller set of variables.