THE STELLER SEA LION (EUMETOPIAS JUBATUS) DECLINE AND THE

GULF OF ALASKA / BERING SEA COMMERCIAL FISHERY

by

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ACNKOWLEDGMENTS

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Abstract

The Steller sea lion (SSL) population in Alaska was listed as threatened under the Endangered Species Act in 1991. Several procedural restrictions were placed on the commercial fisheries of the region at that time in an effort to reduce the potential for human induced mortality on sea lions. Several years have elapsed since these restrictions were put into place and questions about their efficacy abound. In an effort to determine whether or not fisheries interventions have helped the SSL population to recover, estimates of the fishing activity of the Bering Sea/ Gulf of Alaska commercial fisheries in the vicinity of individual Steller sea lion rookeries and SSL population trends at those rookeries were made using data from the National Marine Fisheries Service (NMFS) Fisheries Observer Program and Steller Sea Lion Adult Count Database. Fisheries data from 1976 – 2000 were analyzed in relation to SSL population counts from 1956 – 2001, at 32 rookeries from the endangered Western Stock. Linear regression on the principal components of the fisheries data show that a positive correlation exists between several metrics of historical fishing activity and SSL population decline. The relationship is less consistent after 1991, supporting a hypothesis that fishing closures around some of the rookeries have been effective in moderating the localized effects of fishing activity on SSL.

CHAPTER 1

INTRODUCTION

The Steller sea lion (*Eumetopias jubatus*) population has declined

dramatically in the last 30 years. Trites and Larkin (1996) estimated that the

population was about 282,000 animals in the mid 1970's, compared to 76,000 in

1992. Index counts of Steller sea lions (SSL) made by the National Marine

Fisheries Service (NMFS) in the late 1970's and 1996 show a decline from

109,880 to 22,223 animals breeding west of 144° W longitude (known as the

western stock, Bickham et al. 1996, Loughlin 1997). Due to this severe decline,

the western stock of SSL was listed as "threatened" under the Endangered Species

Act (ESA) in 1990, and "uplisted" to "endangered" in 1997. Legal protections of

SSL and their habitat began in mid 1990, under the auspices of the ESA. These

protections included many alterations in the way commercial fisheries were

prosecuted in the Bering Sea and Gulf of Alaska.

The detected SSL decline began at about the same time the Bering Sea/

Gulf of Alaska (BS/GOA) groundfish fisheries began to expand (Megrey and

Wespestad 1990, Alverson 1991, Hanna 2000). There have been a number of

changes in the BS/GOA fisheries over the last 30 years. These include

technological advances, shifts in species emphasis, and many management

alterations designed to preserve both the valuable commercial resources of the

area, and SSL. Although the BS/GOA ecosystems support vast populations of

marine life, some commercially important species have been fished below economically profitable levels (Megrey and Westpestad 1990).

Until now, there have been no studies that found consistent significant correlations between fishing activities and the SSL population decline. Fishing has been posited as a contributing factor, partly because of the approximate temporal coincidence of the expansion of the fishery and the decline, and partly because foraging SSL and human fisheries are known to target some of the same species and size of fish (Alverson 1991, Lowry 1982, Lowry 1986). Furthermore, although it is currently considered to be having negligible effect (NMFS 2000a), direct kill by humans in defense of fishing gear or catch (which was legal at the time), as well as SSL injury due to being caught in fishing gear incidentally, may have contributed heavily to SSL mortality in the 1970's (Loughlin and Nelson 1986, Merrick et al. 1987, Perez and Loughlin 1991).

Fisheries activities may affect pinniped populations in less direct ways as well. Changes in fish species composition and distribution may decrease foraging efficiency. Fishing can remove or disperse large aggregations of fish from an area (Baraff and Loughlin 2000). Pinnipeds may abandon a traditional foraging area or change their foraging patterns as a result of these fisheries related disruptions (NMFS 2000a).

There have been documented cases of food shortages resulting in local depletions of otariid pinniped stocks. For example, the northern fur seal (Callorhinus ursinus) population on the San Miguel Islands dropped considerably

during the El Nino Southern Oscillation (ENSO) events of the early 1980's
(DeLong and Antonellis 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.

Documented cases of fisheries activities negatively affecting pinniped
populations are rare. However, the Barents Sea harp seal (*Pagophilus
groenlandicus*) population suffered increased juvenile mortality due to food
shortages resulting from the fisheries induced collapse of the capelin (*Millotus
villosus*) stock in the 1980's (Baraff and Loughlin 2000).

In this study, the data contained in the NMFS Fisheries Observer Database
are summed over two time periods, before and after the expanded protection of
SSL began around 1991. The summed measures of fisheries activity, at a range of
distances from SSL breeding areas, are then compared with SSL population trends
at those areas from 1956 to 2001.

Although it is impossible to show cause and effect without a controlled
experiment, it appears that the SSL management measures implemented in 1991
have helped to slow the SSL population decline.

CHAPTER 2

THE STELLER SEA LION

Physical Description

Eumetopias jubatus, the Steller sea lion (SSL) is the largest otariid (eared seals). Adult males commonly measure as much as 325 cm in length and 1120 kg in mass (Loughlin and Nelson 1986). They appear light bluff to reddish brown, and slightly darker on the chest and abdomen. Adult females commonly measure up to 291 cm in length and 350 kg in mass. They are somewhat lighter in color than males. The skin of both sexes is black. Adult males have massive, muscular necks and shoulders, while females have a more uniform, sleek shape. Both sexes have a bear-like, short muzzle, but the nose of the male is slightly more up-turned. SSL appear darker in color when they are wet; and underwater they appear white.

Newborn pups are typically about 100 cm long and weigh 16 to 23 kg (Loughlin and Perez 1987). SSL grow very quickly in the first two years of life. They can double in mass from birth to 7 weeks of age (Fiscus and Baines 1966, Scheffer 1945). By age one year, they are typically 179 cm in length. SSL are born a dark chocolate brown that is molted to a lighter brown pelt after about 6 months. They molt each year beginning in July and ending in early December (Calkins and Pitcher 1982).

Male SSL reach sexual maturity in 3 to 7 years and physical maturity after 10 years (Calkins and Pitcher 1982). Females reach sexual maturity between the

ages of 3 and 8 (Calkins and Pitcher 1982) and skeletal growth is usually complete by age 6 years (Thorsteinson and Lensink 1962).

Reproduction

Pups are born starting in late May through early July, peaking in June (Calkins and Pitcher 1982). Twin births are rare (Gentry 1970). Pups are born with their eyes open, and are able to swim within a few hours of birth (*ibid*).

The gestation period for SSL is approximately 50 weeks. Copulation typically occurs within 16 days of parturition (Gentry 1970, Sandegren 1970). Soon after fertilization, further development of the blastocyst ceases for about three months. Implantation occurs in late September to October (Calkins and Pitcher 1982). The delay of implantation may lessen the resource demands on pregnant females, while they are recovering from birth and nursing new pups (NMFS 2000a).

Fetal mortality rates for SSL are probably high. Pitcher et al. (1998) found that pregnancy rates in sexually mature females dropped from 97 % early in the mating season, to 55 - 67 % later in the season. Other birth rate estimates vary from 60 to 75 % (Belkin 1966, Gentry 1970, Sandegren 1970, Withrow 1982).

Habitat

SSL range throughout the northern Pacific Ocean rim: from central California, up the western coast of the United States and Canada, throughout

South East Alaska, the Aleutian Islands, the East coast of Kamchatka, Russia and the Okhotsk Sea, down to Hokaido, Japan. SSL use land for the purposes of resting, breeding and rearing newborn pups (Hoover 1988). On-land sites used by SSL are usually isolated rocks or beaches. Calkins and Pitcher (1982) define rookeries as a terrestrial site where all adult males defend territories and where birth and copulation generally take place. They define haulouts as sites where sea lions predictably haul out, but where few or no pups are born, and males do not defend territories. There are currently 48 rookeries and 342 haulouts in Canadian and United States territory (NMFS unpublished data).

SSL forage at sea. They are usually sighted in the relatively shallow waters over the continental shelf region, but have been seen as far as 137 km from shore and in waters that are over 2000 m deep (Hoover 1988). SSL generally occur at the surface or mid-water depths (0 to approximately 1000 m) (Fiscus and Baines 1966), but even immature sea lions have the ability to dive to depths of over 300 m (Loughlin et al. 2003). Merrick and Loughlin (1997) estimated minimum home range areas of 2415 - 130,000 km^2 for adult females in winter.

SSL in the Aleutian Islands (AI), western GOA and Russia have declined in the past several decades while SSL in the eastern GOA, British Columbia and Oregon have increased (NMFS 2000a).

<u>Behavior</u>

Dominant male SSL defend territories starting in May and hold them continuously for about 40 days (Thorsteinson and Lensink 1962, Gentry 1970, Gisiner 1985). During this time the males do not eat unless they hold territories adjacent to water, in which case they may feed opportunistically (Gisiner, 1985). Territories are defended through fighting and territorial displays (*ibid*). Males less than 9 or older than 13 years of age generally are not able to hold territories (Thorsteinson and Lensink 1962, Gentry 1970, Gisiner 1985).

SSL are polygamous. Dominant males usually breed with several females. Females typically copulate only once, although, about 5 - 15 % will copulate a second time (Gentry 1970, Sandegren 1970, Gisiner 1985). Gisiner (1985) found that on Marmot Island, the number of copulations per male increases with the number of seasons in which they successfully hold a territory, from 2.1 in the first year to 20.0 in the sixth. Holding a territory is critical to the breeding success of males (Gisiner 1985). However, Gisiner (1985) noted that 54% of the females he observed in copulation did not breed with the male in whose territory they typically rest, or where their pups are located. Females are not generally territorial, although they may defend an area for a few days following parturition (Gentry 1970, Sandegren 1970).

Female SSL stay on shore and, without eating, nurse their newborn pups for 4 - 13 days (Higgins et al 1998, Sandegren 1970). Over the next month, females will alternate between spending time foraging at sea, apart from their pup,

and time on shore nursing. Sandegren (1970) observed each of these activities occurring in periods of about 9 to 40 hours. Separated females and pups recognize each other through smell and vocalization (Gentry 1970, Sandegren 1970, Ono 1972). Females are generally unwilling to nurse a pup other than their own, but pups will attempt to nurse unfamiliar, adult females (Gentry 1970, Sandegren 1970).

Pups develop quickly. At age 36 - 41 days, pups are generally proficient swimmers and are able to follow their mothers out to sea (Gentry 1970, Sandegren 1970). Play between pups is possibly an important component in developing adult behavior patterns (Gentry 1974). Pup play often mimics adult fighting and territory defense (Farentinos 1971, Gentry 1974).

Pups are generally weaned slightly before age 1 year (Calkins and Pitcher 1982). In some cases a juvenile sea lion will continue to nurse after one year of age (Gentry 1970, Sandegren 1970). However, it is unusual for a female to nurse both a pup and juvenile offspring simultaneously (Calkins and Pitcher 1982).

Calkins and Pitcher (1982) noted that while many young, branded SSL were sighted far (up to 1500 km) from their natal rookeries during the winter months, most female SSL return, and give birth, at the rookeries where they were born. Genetic evidence also suggests a high degree of site fidelity. Bickham et al. (1996) made gene flow estimates indicating that about 9.5 females per generation would have to disperse to a nearby rookery in order to maintain the level of genetic diversity found in a 238 base pair control region of the

mitochondrial DNA in 224 SSL pups. Raum-Suryan et al., (2002) did observe

several, branded SSL with newborn pups at rookeries other than the ones at which

they were born. However, the sample size of uniquely identified animals was

small. Of the 1114 uniquely identifiable, branded females, 43 were resighted with

newborn pups. 33 of those 43 were seen at their natal rookeries and the other 10

were observed at rookeries within 400 km of their natal rookery. As of 2002,

there had been only 1 documented case of an animal switching rookeries once

breeding has been established (Raum-Suryan et al. 2002). Exceptions to the rule

of natal site fidelity may occur, but it does appear that SSL preferentially return to

breed at the rookery where they first gave birth.

Foraging

SSL are opportunistic predators. They have been known to eat many

different families of fish, including: Gadidiae, Clupeidae, Asmeridae,

Slamonidae, Cottidae, Scorpaenidae, Pleuronectidae, Rajidae, Trichontidae,

Agonidae, Ammodytidae, Hexagrammidae, Osmeridae, Cyclopteridae, and

Zoarcidae (Hoover 1988, Sinclair and Zeppelin 2002). They also eat

cephalopods, decapods, and gastropods (ibid), as well as marine mammals, such

as fur seal, harbor seal, spotted seal, ringed seal, and bearded seal (Pitcher 1982,

Hoover 1988) and even glaucus-winged gulls (O'Daniel and Schneeweis 1992).

In a scat analysis conducted from 1990 to 1998, the most used prey items were

respectively: walleye pollock (*Theragra chalcogramma*), Atka mackerel

(*Pleurogrammas monopterygius*), Pacific salmon (*Oncorhynchus*), and Pacific cod (*Gadus macrocephalus*) (Sinclair and Zeppelin 2002). Prey type taken varies by season and region (*ibid*), and has possibly shifted over decadal time scales as well (Hoover 1988).

SSL may prefer to forage at night (Loughlin and Nelson 1986, Withrow 1982). Adult males generally forage alone (Loughlin and Nelson 1986), while females and sub-adult males are often seen feeding in groups of 2 – 4 (Hoover 1988). Much larger groups do occur, i.e. when SSL are feeding on schooling prey. Workers on pollock processing boats have seen groups as large as 100 animals (Hoover 1988, West 1983).

The movements of SSL while foraging at sea have been shown to have seasonal and age dependence (Merrick and Loughlin 1997, Loughlin et al. 2003). Juvenile SSL (animals between approximately 1 year of age and sexual maturity) travel further and dive deeper than young-of-the-year (Loughlin et al. 2003), and adult female SSL travel further in winter than in summer (Merrick and Loughlin 1997).

<u>Predator Interactions</u>

Animal predators of SSL include killer whales (*Orcinus orca*) (Frost et al. 1992, Baird and Stacey 1989, Heise et al. 2003) and probably white sharks (*Carcharodon carcharius*) (Ainley et al. 1981). The effect that killer whales have on SSL population numbers is unknown. In 1992, one killer whale was found to

have ingested 15 SSL flipper tags, from 14 different sea lions (Heise et al. 2003).

However, Heise et al. (2003), reporting on the results of a survey of experienced

mariners and the contents of 12 stomachs from dead "transient" whales (the

whales that specialize in hunting marine mammals, as opposed to the fish-eating

"resident" whales), states that sea lions, both California (*Zalophus californianus*)

and Steller, probably represent a small percentage of killer whale diets. This does

not necessarily mean that killer whale predation is a negligible component of SSL

mortality. In fact, the proportion of SSL mortality that is due to predation by

killer whales and sharks is unknown.

Humans are also a predator of SSL (NMFS. 2000a). The Marine Mammal

Protection Act allows for a harvest of protected species by Alaska natives for

subsistence purposes, or for the making and selling of native handicrafts. The

subsistence harvest of SSL was approximately 448 animals per year in the early

1990's and was about 178 animals in 1998 (NMFS 2000a).

The subsistence harvest may have been minor compared to other human-

related mortality. Merrick et al. (1987), reports that a total of 45,178 pups were

killed in the Aleutian Islands (AI) and GOA, between 1963 and 1972. Perez and

Loughlin (1991) note that a high, incidental take of SSL in fishing gear may

partially account for the observed SSL decline during the 1970's. There is also a

further, unknown level of human-caused mortality due to shooting (Trites and

Larkin 1992, Strombom 1981), both for bait in the crab fishing industry (NMFS

2000a) and because SSL have been considered a nuisance animal by fisherman (Strombom 1981).

Lethal interaction with humans has been posited as an important contributing factor to the SSL decline (NMFS 2000a). Shooting of SSL was prohibited in 1990 by NMFS emergency interim rule (55 FR 12645) (*ibid*). The cessation of intentional killing of SSL has helped to slow the decline (Loughlin, T.R., personal communication 2004).

Common Diseases

Several diseases are commonly found in SSL and may contribute to SSL mortality. These include infections by parasites such as: cestodes of the genera *Diplogonoporus*, *Diphyllobothrium*, *Anophryocephalus*, *Adenocephalus*, and *Pyramicocephalus*, acanthocephalans of the genera *Bulbosoma* and *Corynosoma*, as well as nematodes of the genera *Anisakis*, *Contacaecum*, *Parafilaroides*, *Uncinaria* and *Phocanema* (NMFS 2000a). Body lice (*Antarctophthirus michrochir*) commonly infect pups and nose mites (*Orthohalarachne diminuta*) are "invariably found on adults" (Thorsteinson and Lensink 1962). Additionally, ascarid worms (*Porocaecum decipiens*) are "nearly always" found in the stomachs of adults (Scheffer 1946).

Viruses also occur in sea lions. They include: leptospirosis (NMFS 2000a), chlamydiosis (*ibid*), and eight types of calici virus, including several types of San Miguel sea lion virus (Barlough et al. 1987). NMFS (2000a) also

reports evidence for exposure to brucellosis. These diseases may have contributed to fetal mortality rates in SSL, but there is insufficient data to support that hypothesis (NMFS 2000a).

Burek et al., (2003) have reviewed the evidence linking the SSL decline to disease. Their findings are that while disease cannot be ruled out as a possible contributing factor, it cannot be conclusively implicated either.

<u>Stock Separation</u>

Bickham et al. (1996) and Loughlin (1997) made the case for the separation of the Alaskan SSL into two stocks for management purposes. The impetus for this separation was based mainly on population dynamics, and genotype (Loughlin 1997). The strongest evidence for stock separation comes from studies of mitochondrail DNA (mtDNA) (*ibid*). The separate stocks are divided at the 144° W meridian, approximately at Cape Suckling, Alaska.

The population size of SSL found in the Aleutian Islands region and the western part of the GOA, has been declining rapidly since the early 1970's, while the segment of the population found in the eastern GOA has been stable or slightly increasing (NMFS 2000a).

Finally, Bickham et al. (1996) found two genetically differentiated populations, where Oregon and southeastern Alaska make up the eastern segment, and Prince William Sound and all sites west, compose the western segment. This differentiation was based on a 238 base pair segment of the mtDNA control

region from 224 SSL pups. There was nucleotide variability at 29 sites, defining 52 haplotypes and 8 maternal lineages. The east/west division was found using cluster analysis (Bickham et al. 1996).

The Decline and Stock Comparison

Hypotheses for the cause of the SSL decline include disease, exposure to pollutants (see Barron et al. 2003), predation, nutritional stress, and fisheries related mortality. Each of these factors may have contributed to the decline, but to date none have been proven the main culprit.

Because the eastern stock is stable or slightly increasing and the western stock is declining, comparisons between the two are potentially useful in determining the causes of the decline. Several studies have compared different attributes of animals from each population.

Merrick et al. (1995) compared the mass of individual pups born in areas showing population decline and areas with stable population size. They hypothesized that pups from declining rookeries would be lighter than pups from stable rookeries, indicating poor physical condition and reduced survival probability. They found, contrary to their expectation, that pups at declining rookeries were heavier than pups at stable rookeries. However, most of the data in this study come from 1990, or later and may not accurately reflect the conditions in the peak of the decline, which probably occurred sometime in the 1980's (NMFS 2000a).

Milette and Trites (2003) and Andrews et al. (2002) compared foraging times of lactating females at rookeries in areas where SSL were declining, with rookeries in areas of stable or increasing populations. They hypothesized that foraging efficiency might be lower in the declining population. They found, contrary to their expectations, that foraging times were shorter at the two rookeries in the western stock range than at Forrester Island in the eastern stock range. However, these studies took place in the late 1990's and may not accurately portray the conditions present at the peak of the decline.

Data collected by Calkins and Pitcher (1982) and Calkins and Goodwin (1988) may give the clearest snapshot of SSL conditions during the decline. Female SSL were collected in the GOA during 1975 - 1978 and again in 1985 - 1986. Comparisons of body condition between these two samples reveals that animals taken in the 1980's were physically smaller, had higher haptoglobin levels and lower pregnancy rates. All of which indicate nutritional stress (Trites and Donelly 2003).

The quality of SSL prey may have deteriorated during the decline. This is generally referred to as the "junk food" hypothesis (Alverson 1991) and is based on studies (Rosen and Trites 2000a, Rosen and Trites 2000b) that have shown that captive SSL feeding exclusively on pollock or other "bony" fishes tend to lose weight, while those that feed on herring or other "fatty" fishes tend to gain weight. This fact coupled with the environmental shift in the BS/GOA ecosystem (see chapter 3), which may have resulted in a favorable climate for gadids and other

bony fishes (Benson and Trites 2002), has led some to believe that a lack of ideal

prey may have contributed to the decline. Analyses of the relationship between

diet diversity (the assumption being that a mono-specific diet would consist

mostly of bony fishes) and the SSL decline have generally supported this

hypothesis. Merrick et al (1997) found that SSL rookeries that showed lower diet

diversity, tended to demonstrate steeper declines, and Sinclair and Zeppelin

(2002) found that areas of high diet diversity were among the more stable, in

terms of extinction probabilities, in the western stock range. In addition, SSL in

the eastern stock range have shown an increase in diet diversity (Trites and

Donnelly 2003).

Finally, a comparison of commercial fishing effort, based on the NMFS

Fisheries Observer Database (see chapter 4), shows that a negligible amount of

fishing occurred in the eastern stock range, relative to the massive effort

undertaken in the western stock range.

Similar Species

The species that most resembles SSL is probably the South American sea

lion (*Otaria flavescens* or, less commonly *Otaria byronia* – there is debate about

the species name, see Rodriguez and Bastida 1993).   South American sea lions

(SASL) are similar in appearance to SSL, though they are considerably smaller

and males have a conspicuous "mane" of hair around their necks. Mature male

SASL can reach lengths of 3 m and weigh from 300 – 350 kg, mature females can

be m long and weigh from 140 – 150 kg (Cappozzo 2002). Newborn pups weigh

between 12 and 15 kg and range in length from 0.75 and 0.86 m (*ibid*). SASL are

born with black fur that molts to light reddish brown after 2 months. Adult male

pelts are dark brown, while females are nearly yellow (*ibid*).

 Male SASL become sexually mature at around 6 years of age, females at

about 5 years. SASL have a mating system very similar to that of SSL, with

defended territories and harems. The breeding season begins in December, and

males reach maximum rookery occupancy at about mid-January. Females reach

maximum occupancy at the end of January (Campagna 1985). Peak pup

production occurs from mid to late January (*ibid*). Copulations occur on land,

around 6 days after parturition (Cappozzo 2002). Lactation lasts for 8 - 10

months (*ibid*).

SASL occur along the Atlantic and Pacific coasts of South America. They

range from southern Brazil, around Cape Horn and up to northern Peru (Cappozzo

2002). The Atlantic population has been estimated at 110,000 and the Pacific

population is generally considered to be smaller, though there are no reliable

estimates currently available (*ibid*).

The most common prey items taken by SASL are fish, crustaceans, and

mollusks (Vaz-Ferreira 1981). SASL are known to follow fishing boats for days,

and to steal fish from the nets (ibid). SASL themselves are preyed on by various

shark species, killer whales and even pumas (*Felis concolor*) (ibid).

Interestingly, SASL have also suffered from population declines in recent years. Habitat depletion in Argentina and environmental change associated with El Nino have caused reductions in population size, due to higher death rates and migration (Cappozzo 2002). Interactions with fisheries have also caused an unspecified level of population decline, due to entanglement, incidental take, and shootings in defense of fish or fishing gear (Vaz-Ferreira 1981, Crespo 2002).

CHAPTER 3

ENVIRONMENTAL FEATURES OF THE BERING SEA AND GULF OF

ALASKA

<u>The Bering Sea</u>

The Bering Sea (BS) is a semi-enclosed body of water defined by the

coast of Alaska on the east, Russia on the north and west, and the Aleutian Islands

on the south. On the eastern edge of the BS there is a broad (>500 km)

continental shelf (depth less than 200 m). The center of the BS is a deep (>3500

m) basin and its western edge is a narrow (<100 km) continental shelf (Stabeno et

al. 1999). 3 to 5 severe storms per month cross the Aleutian Island chain in the

winter (*ibid*). Winter also brings about the expansion of sea ice over the northern

portion of the BS, covering as much as 75% of its total shelf area in late March

and early April (Niebauer et al. 1999). The bathymetry, climate, currents, and

other environmental components of the BS combine to make it one of the most

productive oceans in the world.

The BS constitutes a linkage between the Pacific Ocean and the Arctic

Ocean. Communication between the Pacific Ocean and BS is accomplished

through a number of passes in the Aleutian Island chain. Of these, only three,

Amchitka Pass, Near Strait, and Kamchatka Strait, are deeper than 700 m.

Nonetheless, there is significant exchange with the Pacific through these passes

(Stabeno et al. 1999). The main source for this exchange is the Alaska Stream,

which is the northern boundary of the North Pacific subarctic gyre. The Alaska stream provides fresh surface water and relatively warm subsurface water, and strongly influences circulation in the BS (*ibid*). Inflow through the smaller, eastern passes to the BS is balanced by outflow to the Pacific through Kamchatka Strait. Thus, circulation in the BS basin consists of the northward flowing Bering Slope current on the east and the southward flowing Kamchatka Current on the west and has been described as a cyclonic gyre (*ibid*). Circulation on the eastern BS shelf is generally northwestward, eventually passing through the Bering Strait and into the Arctic Ocean (*ibid*).

A large portion of the northern shelf of the BS is covered by sea ice in winter (Niebauer et al. 1999). Ice forms on south facing coasts first. It is then generally blown southwards by the prevailing northerly winds to form polynyas, areas of open water surrounded by ice. The ice is blown south until it melts in warmer water, thus expanding the ice edge as meltwater cools the sea surface temperature allowing the warmer water to eventually freeze. The rate of ice expansion varies from year to year but generally falls in the range of 17 – 32 km per day (*ibid*).

Sea ice cover controls many important physical features of the BS. The regional CO_2 budget depends on the location of sea ice (Pipko et al. 2002) and the dense brine that is excreted by ice formation in the BS is important ecologically, especially in maintaining the halocline of the Arctic Ocean (*ibid*). The sea ice melt also initiates the seasonal algal bloom, responsible for much of the primary

production in the BS (Schumacher and Alexander 1999). The advance and retreat of sea ice in the BS is controlled by atmospheric circulation, in particular the interaction of the Aleutian Low and the Siberian High pressure systems (Minobe 2002).

The pressure system in the BS is seasonally variable. In summer, the combination of low pressure over Asia and a high pressure system over the North Pacific result in relatively weak pressure gradients and winds over the BS. In winter, Asia is dominated by high pressure and the Aleutian Low pressure system dominates the North Pacific. This results in 3 to 5 storms per month (Niebauer et al. 1999), which cross the Aleutian Island chain, from west to east and curl into the Gulf of Alaska (GOA) or Bristol Bay. The northern part of the BS sees only 1 to 2 storms per month (*ibid*).

High sea level pressure, which can develop in winter in the BS, causes air ridges to form, which then deflect the storm tracks north or south. The pattern followed by winter storms in the BS are critical to the mixing that occurs between the nutrient rich deep water of the BS basins and the shallow waters of the continental shelves (NRC 1996). The vertical movement of nutrients is reliant on the turbulent kinetic energy provided by storm winds, because horizontal circulation over the shelf is relatively weak (Overland et al. 1999). Tidal movement is important for deeper mixing (ibid). Other factors such as solar heating and eddies near the shelf break probably contribute to the delivery of nutrients to the waters over the shelf (NRC 1996).

Profiles of the dissolved oxygen content in the waters of the BS show several vertical layers: the upper layer, a layer of maximal gradients, a layer of minimal oxygen, and a deep layer of oxygen content increasing with depth (Whitledge and Luchin 1999). Near the shelf slope, oxygen content reaches maximal levels. This is probably due to an increase in oxygen solubility caused by decreasing temperature and salinity. Intense currents and eddies near the shelf lead to mixing and penetration of oxygen rich water into the deeper layers. Wind mixing can reach the deeper layers over the shelf and oxygen there is transferred from the upper layers to those below (*ibid*). Oxygen content in the BS also varies seasonally. These variations are basically dependent on the annual variability of salinity, temperature and primary production. The upper layer stays at or near saturation level throughout the year. However, in various locations, factors such as ice cover and intense mixing in the passes in the Aleutian chain can cause some under-saturation, and intense photosynthesis of phytoplankton in spring can cause super-saturation (*ibid*).

Primary production in the BS varies considerably by location. Annual production ranges from >200 grams of carbon fixed per square meter of water (C/m^2) over the southeastern shelf to >800 C/m^2 over the northeastern shelf (Schumacher and Alexander, 1999). In areas not covered by sea ice, the spring phytoplankton bloom is triggered by an increase in solar radiation. In areas covered by sea ice, the annual ice melt triggers the start of the spring bloom, which takes place near the ice edge (*ibid*).

The phytoplankton community over the deep basin of the BS differs from the shelf phytoplankton community in several important ways. There is less species diversity, less phytoplankton biomass and lower primary production values in the oceanic community (Sukhanova et al. 1999). Picophytoplankton species dominate (in numbers, but not necessarily biomass) during all periods of seasonal succession in the oceanic community, as opposed to diatoms (nanophytoplankton species) over the shelf (*ibid*). During fall and spring the biomass of the oceanic phytoplankton community is less than that of the shelf community by 1 or 2 orders of magnitude (*ibid*).

The most productive area in the BS is the edge of the continental shelf. High primary production levels have been measured there (Hansell et al. 1993), as well as large concentrations of zooplankton (phytoplankton predators) (Springer et al. 1996). This in turn leads to abundant stocks of fish, sea birds and marine mammals in the area.

The Gulf of Alaska

The Gulf of Alaska (GOA) is a semi-enclosed basin in the North Pacific Ocean; it is bounded on the north by the Alaskan coast and Aleutian Islands and on the east by the coast of British Columbia, and extends to about 52° N latitude to the south and 62° W longitude to the west (Hood 1986). The bathymetry of the GOA is rather dramatic. A narrow (approximately 100 km wide) shelf follows the curve of the Alaskan coast and Aleutian Islands, and then rapidly drops away

into a deep (about 5000 m) trench. The basin of the eastern and central GOA is

an abyssal plain of approximately 3000 m depth, containing scattered seamounts.

The dominant oceanographic feature of the GOA shelf is the Alaska

Coastal Current (ACC). It is driven by along-shore winds and considerable fresh

water run off (Stabeno et al. 2004). The ACC is an atypical coastal current in that

it can flow at very high velocities in some places and shows high seasonal

variability in salinity (Wilson and Overland 1987). The largest scale feature of

the GOA basin is the offshore boundary current or Alaskan Stream (AS). The AS

is cyclonic and its flow varies from about 300 km wide in the central GOA to less

than 100 km wide near Kodiak Island.

Upwelling, produced by water movement along the Aleutian shelf, results

in a productive region. Annual shelf production rates are around 300 g C/m^2

(Sambrotto and Lorenzen 1987). The coastal areas are environmentally diverse

and annual production estimates in the various bays of the GOA range from 140

to over 200 g C/m^2 (*ibid*). Production over the GOA basin is somewhat less and

annual estimates range from about 50 g C/m^2 to about 100 g C/m^2 (*ibid*).

The primary production values for the different sectors of the GOA reflect

the biomass of zooplankton in those areas. The dominant taxa found in the GOA

zooplankton community are copepods. Cooney (1987), reported that about 70%

of the biomass by weight collected in net samples consisted of 3 copepod species,

Neocalanus cristatus, *N. plumchrus* and *Eucalanus bungii*. Oceanic standing

stocks of zooplankton vary seasonally by as much as a factor of 20. They are lowest in winter and highest in mid summer (Cooney 1987).

The GOA shelf is considerably narrower than that of the BS, which may help to explain some of the differences in production between the two. Both are extremely productive, but the BS generally shows greater zooplankton species diversity, higher primary production values, and higher overall zooplankton biomass per m^2 (Schumacher and Alexander 1999, Cooney 1987). Differences in plankton biomass between the BS and GOA are reflected in the differences in biomass of fish between the 2 regions. Commercial fisheries removals in the BS are generally larger by an order of magnitude or more, than those in the GOA (unpublished NMFS Fisheries Observer data).

The species assemblages of the BS and GOA, including Steller sea lions, are affected by environmental factors, many of which change over decadal time scales.

The Regime Shift Hypothesis And Steller Sea Lions

The decadal variation in the BS and GOA is interesting in terms of SSL population because of a climatic "regime shift" that occurred in 1976 – 1977. This shift has been implicated as a contributing factor in the SSL population decline (Trites et al. 1999). A regime shift is the point of separation between periods of stable, but differing climatic character (Rudnick and Davis 2003).

Identifying regime shifts is difficult, and there is currently no consensus on the 'best' method for doing so within the marine sciences community (Mantua 2004). In general, scientists look for a particular physical or biotic time series, or a combination of several different time series, and attempt to isolate instances of abrupt change in the measured variable or variables.

Regime shifts in the North Pacific Ocean are measured by different environmental indices. The most commonly cited of these are: the Southern Oscillation Index (SOI), the Pacific Decadal Oscillation (PDO), the Aleutian Low Pressure Index (ALPI), and the North Pacific Index (NPI) (Benson and Trites 2002). The SOI is defined by sea level air pressure measurements taken at 2 sites in the Pacific Ocean. It is a linear combination of normalized departures from the monthly mean values at Darwin in northern Australia and Tahiti in the South Pacific Ocean (Trenberth and Hoar 1996). The PDO is the first empirical orthogonal function of sea surface temperature in the North Pacific (Benson and Trites 2002, Mantua et al. 1997). In this case, the empirical orthogonal functions are basically geographically weighted eigenvectors from principal components analysis (see appendix D for a discussion of PCA). The ALPI is a measure of the relative intensity of the Aleutian Low pressure system. It is calculated as the mean area (in km^2) with a pressure less than or equal to 100.5 kPa, and then expressed (circa 1997) as a divergence from the 1950 - 1997 average (Beamish et al. 1997). The NPI is an area weighted mean sea level pressure measure, over the area of 30^oN - 65^oN, and 160^oE - 140^oW (Trenberth and Hurrell 1994). There are

various other, but less well known statistical indicators of environmental patterns. These include the Pacific Circulation Index (PCI), which tracks anomalies in atmospheric circulation off the west coast of Canada (King et al. 1998), Northern Hemisphere Surface Temperatures, which measures land and sea-surface temperatures, and Length-Of-Day, which tracks changes in the earth's rotational speed (Stephenson and Morrison 1995). There are still other climatic indices that are derived from combinations of these, such as the Atmospheric Forcing Index, which is a PCA of the ALPI, PDO and PCI (McFarlane et al 2000).

Biotic time series have also been employed to detect regime shifts. For example, Hare and Mantua (2000) identify a regime shift in 1989 using predominantly biological evidence, such as zooplankton mass, groundfish recruitment, and jellyfish and shrimp population size, as well as salmon catches by commercial fisheries.

Regime shifts are generally detected by changes in the predominant direction of these indexes. For example, in 1977, the PDO shifted from predominantly negative to predominantly positive, indicating a shift from a cool phase to a warm phase. Other generally acknowledged regime shifts detected using the PDO occurred in 1925, and 1947. The winter PCI and the ALPI showed regime shifts in 1925, 1947, 1977, and 1989 (King et al. 1998, Benson and Trites 2002). The SOI appears to have shifted from positive values to negative values at around 1976 (Trenberth and Hoar 1996). The NPI appears to have reversed in 1925, 1947 and 1977 as well (Trenberth and Hurrell, 1994). The

1977 shift is of particular interest because it is manifest in each of the different indicators discussed above. It is also a hypothesized contributor to the SSL decline (Trites et al. 1999).

The physical manifestations of the 1977 shift differ by region. For example, the onset of a strong Aleutian Low increased precipitation in the GOA. The input of fresh water and shifting wind patterns resulted in decreased upwelling and increased water column stability, which in turn allowed the primary producers to remain in the euphotic zone for longer periods and increased primary production overall in the GOA (Benson and Trites 2002). In the BS, the increased Aleutian Low resulted in warm air being pushed north and a reduction of the sea ice cover (*ibid*). In general, the regime shift in 1977 brought about an increase in sea surface temperatures and production in the BS and GOA.

The responses to these changes in the biota of the region varied as well. Hare and Mantua (2000) noted that zooplankton biomass increased in the BS and GOA, as did pollock, and arrowtooth flounder. GOA halibut and Pacific Ocean perch, and BS herring increased as well, while GOA shrimp, BS Pacific Ocean perch, yellowfin sole, and Greenland turbot, all decreased.

The regime shift seen in 1989 was not as obvious as the 1977 regime shift in the climatic indices listed above. It is clearly apparent only in the winter PCI, and somewhat apparent in the ALPI (though opinions vary on this, see Benson and Trites 2002). The biological changes associated with the 1989 regime shift are more evident (Hare and Mantua 2000). The biota of the GOA reflect the 1989

regime shift more clearly than the organisms found in the BS. The BS species
that did show a change roughly corresponding to 1989 were Pacific Ocean perch,
flathead sole, rock sole, yellowfin sole, and Alaska Plaice (*ibid*). GOA species
showing change included zooplankton, pollock, Pacific cod, and sablefish (*ibid*).

The regime shift of 1989 was not as widespread, or apparent as the shift of
1977. Moreover, it was not a simple reversal of the 1977 trends (Benson and
Trites 2002, Hare and Mantua 2000). Trites et al. (1999) suggested that the
regime shift of 1977 was at least a contributing factor in the decline of SSL. The
shift to a warmer regime in 1977 could have created a favorable environment for
pollock and large flatfish, such as arrowtooth flounder. The larger individuals of
these species directly compete with SSL for prey. Therefore, the regime shift
could be considered as the cause of competitive exclusion, which may have
affected the SSL decline. Under those auspices, the potential affects of the 1989
regime shift are unclear. While pollock recruitment in the BS and GOA has
dropped off considerably from post 1977 levels, that reduction started well before
1989 (Hare and Mantua 2000). Arrowtooth flounder levels in the BS and GOA
do not appear to have been affected by the 1989 shift (*ibid*).

Due to the lack of apparent response in the pollock and large flatfish
populations, it seems unlikely that the regime shift of 1989 has contributed to
reductions in the competition born by SSL.

There is however, another posited mechanism through which the regime
shift of 1977 could have affected the SSL population. Alverson (1991) and others

have suggested that SSL might suffer from a diet high in bony gadids and low in the more caloric "forage fishes". This is known as the "junk food hypothesis". The regime shift of 1977 could certainly have altered the composition of the SSL prey base and it has been suggested (see Trites and Donelly 2003, for example) that the warmer regime that started in 1977 has favored gadid species over forage fishes. Because the regime shift of 1989 was not a simple reversal of the 1977 regime shift it seems unlikely that it alone could have switched the species composition of the BS and GOA back into a more favorable configuration for SSL. In fact the only forage fish species that Hare and Mantua (2000) give population trajectories for are herring and Atka mackerel. Herring and Atka mackerel appear to have declined in the BS after 1989 and herring have declined since 1989 in the Prince William Sound area (in the GOA) as well (Atka mackerel are far less prevalent in the GOA).

Therefore, the regime shift of 1989 is unlikely to have been solely responsible for the reductions in the SSL decline of the early 1990's, though it may be a contributing factor. Since the regime shift of 1989 is not well reflected in climatic indices, disentangling its biological affects from the potential affects of changes to commercial fisheries behavior could be difficult. The question of what affect, if any, the 1989 regime shift has had on SSL requires further analysis.

CHAPTER 4

THE BERING SEA AND GULF OF ALASKA COMMERCIAL FISHERY

<u>Pre World War II</u>

The Bering Sea (BS) and Gulf of Alaska (GOA) ecosystems currently support one of the largest commercial fisheries in the world (Food and Agriculture Organization at http://www.fao.org). The North Pacific Ocean is defined as the ocean area from approximately 30° N to 65° N latitude and 120° W to 160° E longitude (Forrester et al. 1978), an area that encompasses the BS and GOA. Its commercial fishery began as a modest operation with relatively few boats and a limited number of target species. Early commercial fishing efforts were hampered by problems with fish preservation. Refrigeration at sea was not possible and salting or otherwise preserving the fish chemically, reduced its market value. Before World War I (WWI), the only significant food fish operation in the North Pacific was for Pacific Herring (*Clupea pallasi*) (Forrester et al. 1978). There was a market for salted, pickled, and dried herring, which circumvented problems associated with preservation. There were locally based operations for Pacific halibut (*Hippoglossus stenolepis*), lingcod (*Ophiodon elongatus*) and black cod (*Anoplopoma fimbria*, now called sablefish), but since transportation of fresh fish was difficult, the market for them was geographically limited.

The lack of adequate refrigeration and low consumer demand did not deter the US and Canadian fishing fleets from locally overexploiting halibut stocks. In 1915, the US and Canadian take of halibut was about 31,000 metric tons (mt) (Forrester et al. 1978). Catches then began to decline and remained low until the 1930's (Naab 1968). The desire to protect halibut stocks gave rise to the International Pacific Halibut Convention (IPHC) in 1924. The regulations formulated by the IPHC included restrictions on the seasons and areas in which fish could be taken, catch quotas, legal fishing gear and size requirements for harvested fish (*ibid*). These restrictions helped the pacific halibut stocks recover and provided a framework for later international cooperative management (*ibid*), which became vital as the North Pacific Fishery developed.

WWI produced a temporary increase in the demand for fish protein, since a large percentage of the traditional meats available in Canada and the United States were being shipped overseas to soldiers. The dogfish (family *squalidae*) fishery off the west coast of Canada flourished during this period. Dogfish oil was burned in lamps and stoves and the carcasses were used to make fish meal and fertilizer. Later, dogfish were used as food fish and their livers utilized for their high vitamin A content (Forrester et al. 1978). There was also a large annual take of salmon (family *salmonidae*) starting around 1930 (Alverson 1991). The wartime demand for fish was short-lived and the fishing industry in the North Pacific persisted at a relatively low level until World War II (WWII).

Japanese fisheries in the North Pacific, prior to WWI, utilized many different varieties of saltwater fish (Forrester et al. 1978). A large fleet of trawlers (see appendix A for a description of trawl gear), targeting mainly Pacific cod and salmon, operated off the Kamchatka coast in 1912. During WWI, most of these trawlers were converted to cargo ships and the fleet dropped from 139 vessels in 1913 to 6 vessels in 1918 (*ibid*). However, construction on new trawlers began in 1918 and by 1923, 70 large boats with extended ranges were operating in the East China Sea (*ibid*). The Japanese began fishing the Bering Sea in 1930, with 2, 250-ton freezer-trawlers. By 1933, a mothership-type fishing operation was in operation in the Bering Sea. Smaller catcher vessels would bring catches to an 8,000-ton mothership, equipped with factory or freezer capabilities, or both (*ibid*). The finished product would then be transported back to Japan on transport vessels. The main species targeted by the mothership fishery, was pollock, used to make fishmeal (*ibid*). After WWII began, the demand for food fish increased and various flounder species were also targeted. The Allied Occupational Forces restricted Japanese fishing after WWII and groundfish (a general term for fish that live on or near the sea floor, such as pollock, cod, flatfish, and rockfish) fishing did not resume for some time.

The Soviet Union (USSR) had a strong flounder fishery prior to WWII. They operated near shore and mainly in Soviet waters (Forrester et al. 1978).

World War II to 1976

From WWII to 1976, the North Pacific fishing industry was characterized by a pattern of nations overfishing a single target species and then switching to, and overfishing, another species. Overfishing is generally defined as fishing an area to the extent where ecological damage, or depletion of a fish resource occurs. Specifically, it is defined as a particular level of fishing that exceeds a management goal for each species (for example, as in NMFS 2000b). Where previously overfishing was uncommon, except in near-shore areas, Pacific Rim nations began to fish the open ocean extensively, with deleterious effects. The expansion of fisheries during WWII was driven both by an increased demand for protein and by advances in the technology concerned with seafaring and fish handling. These included freezing and packaging, as well as wireless communication and naval engineering. The construction of massive factory ships, able to process fish at sea and weather the harsh, open ocean conditions of the BS in winter became possible (Forrester et al. 1978). Fish could now safely be transported from distant fishing grounds to markets in large cities. These technological advances changed the character of world fisheries. The BS and GOA, once exclusively fished by small coastal boats, were now the province of enormous factory ships and heavy trawlers. High seas and deepwater fisheries were established and fish landings increased rapidly (Alverson 1991).

The decline in demand for fishery products that followed WWI did not occur after WWII. In fact, the demand for most species rose in the US and

Canada. Much of the increase was driven by demand for fish livers, especially those of soupfin sharks (*Galeorhinus galeus*), which have a very high vitamin A content (*ibid*). The high demand for groundfish, sharks, and herring resulted in an increase in the size of both the Canadian and US trawl fishing fleet, and many boats not originally designed for trawl fishing entered the fleet on a part-time basis (*ibid*).

The only species that suffered a reduction in market demand was dogfish. The Canadian herring fishery peaked in 1962 and continued at a high level until 1966, while the Canadian groundfish fishery remained consistent from 1956 – 1961 before increasing in 1962 (Forrester et al. 1978). The Canadian fleet in the post WWII period (1946 - 1970) consisted of about 50 - 60 small trawler vessels (*ibid*).

During the late 1950's and the 1960's, the most important US fisheries targeted Pacific halibut and Pacific salmon. From 1952 - 1970, the US salmon landings in the North Pacific averaged about 137,000 mt (INPFC 1979). US salmon landings peaked in 1970 at about 186,000 mt, but declined sharply in the ensuing years (*ibid*) (figure 1). US halibut landings peaked in 1962, at about 45,000 mt, but declined quickly over the next 22 years (International Pacific Halibut Commission at, http://www.iphc.washington.edu/halcom)(figure 2).

Figure 1. Salmon (All Species) Landings in the North Pacific, by Country and Year.
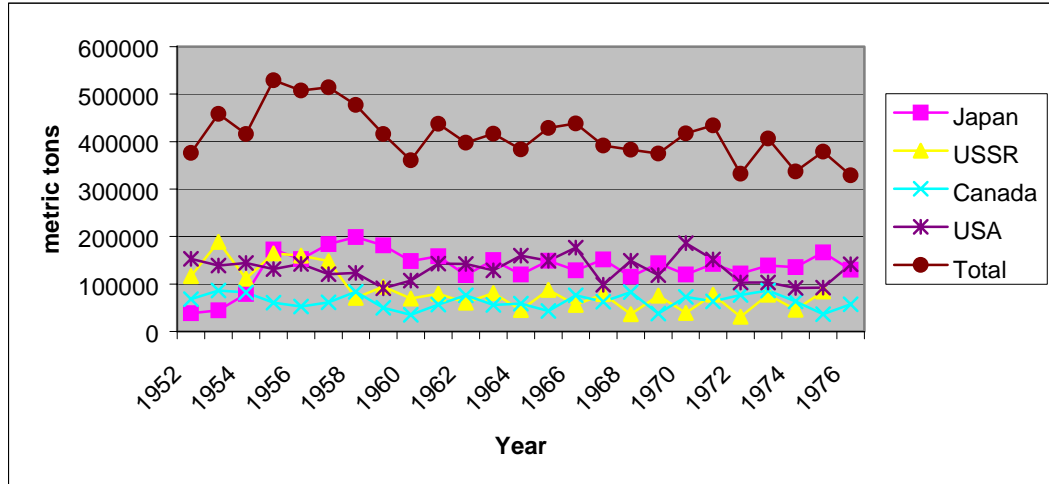
Figure 2. US BS/GOA Pacific Halibut Landings by Year.
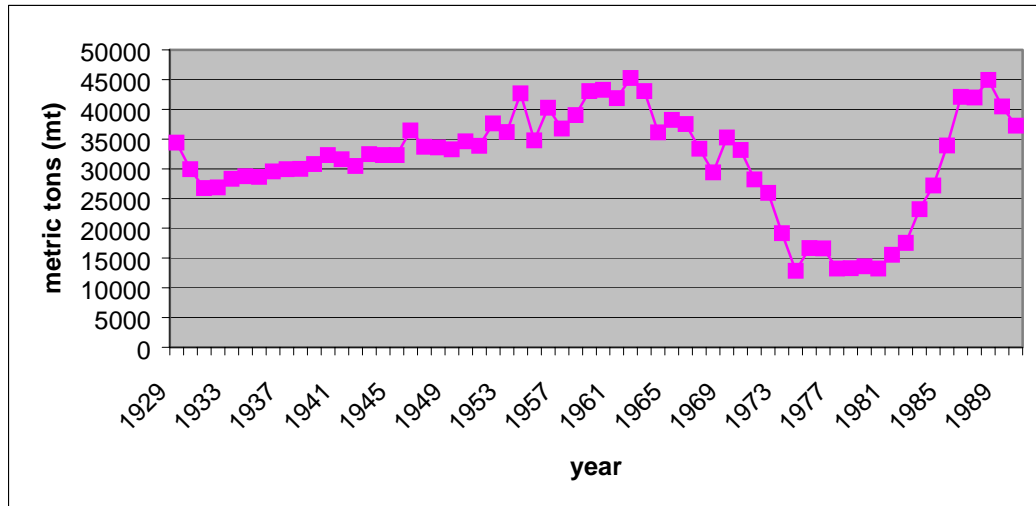
The US groundfish fishery was consistent from 1946 - 1955 and then expanded, with new fishing grounds for Dover sole (*Microstomus pacificus*) and increasing catches of rockfish (family *scorpaenidae*). A shrimp (*Pandulus* species) fishery also developed in the US and by 1970 was landing 42,000 mt per

year. Most of the groundfish taken by the US fishery between 1946 and 1970 came from waters off the northwestern US and Canadian coasts, removed by small purse-sein-type vessels (see appendix A). These boats fished both trawl and line gear. Most of the halibut and shrimp landings came from the GOA and BS, and were caught on similar vessels.   Although the US fishery removed a large tonnage of fish from the North Pacific, landings by foreign fleets, particularly the Japanese, were much greater.

Post WWII restrictions on Japanese fishing were lifted in 1952. Thereafter, the Japanese accounted for the majority of groundfish removals from the BS/GOA. The Japanese fleet was diverse in its vessel types and target species. At first the far-seas mothership fishery focused on yellowfin sole (*Limanda aspera*) in the BS, with landings peaking at around 400,000 mt in 1961 (Forrester et al. 1978) (figure 3). Thereafter, yellowfin stocks declined and the focus of the fishery shifted to walleye pollock, which was used to make minced fish, called *surimi* or imitation crab. Japanese catches of pollock reached 1,200,000 mt in 1970 (*ibid*). From 1970 to 1976 the pollock *surimi* fishery accounted for 80% of the total Japanese groundfish catch (Bakkala et al. 1979). Evidence of overfishing in the GOA can be seen in the landings of Pacific Ocean perch (*Sebastes alutus*), which peaked in 1965 and then rapidly declined (figure 4) (Ito 1988).

Figure 3. Yellowfin Sole Landings, by Nation.
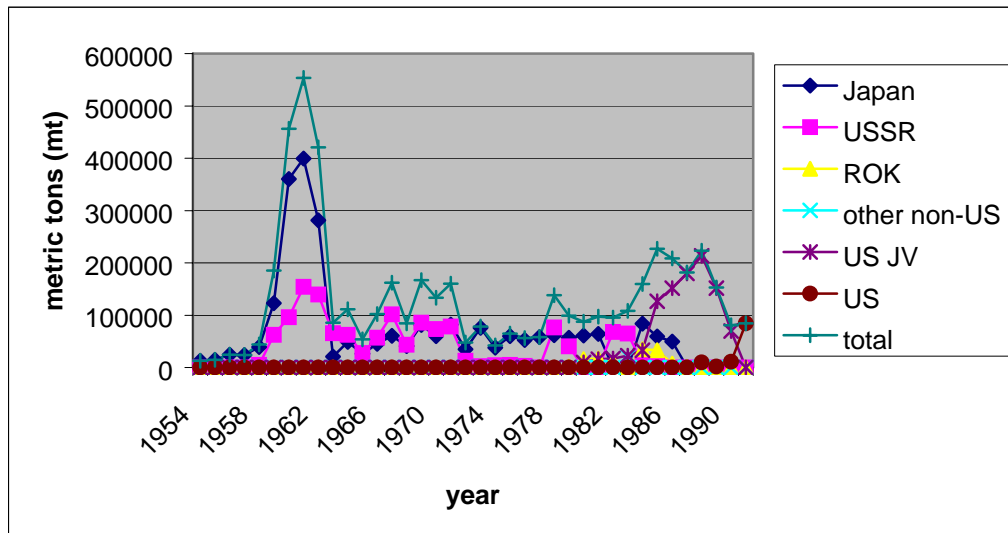
Figure 4. Landings of Pacific Ocean Perch in the Eastern Bering Sea and Aleutian Islands (All Nations), by Year.
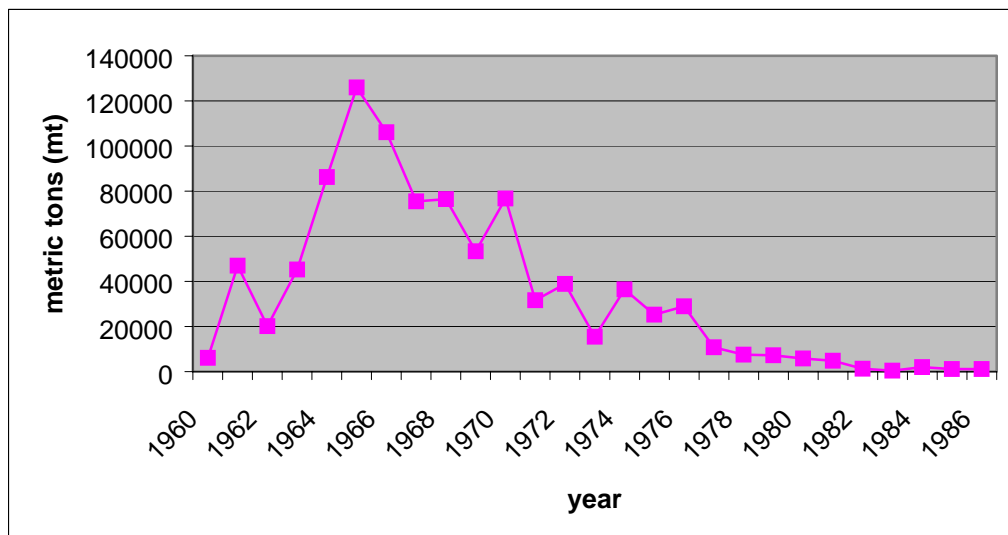
A large-scale, Japanese driftnet (see appendix A) fishery for salmon began in the early 1950's, and by 1955, it employed about 450,000 km of driftnets to land approximately 150,000 mt of salmon (Alverson 1991).

From 1953 to the early 1970's, the Japanese fished tangle nets (see appendix A) and pots (see appendix A) for Alaskan king crab (*Paralithodes camtschatica*). In 1963, over 24,000 km of tangle net was being fished off the Alaskan coast. However, the fishery began to decline in about 1965, and by 1975 no king crabs were taken by the Japanese (*ibid*).

Longliner (see appendix A) fleets took mostly halibut and sablefish in the central and northern BS, peaking at an average of about 11,000 mt and 28,000 mt, respectively, during 1961 and 1962 (Forrester et al. 1978). Shrimp trawls peaked at 28,000 mt in 1963 and herring gillnet (see appendix A) operations took between 28,000 and 44,000 mt from the northwest BS between 1963 and 1970 (*ibid*). In 1963, Japanese stern trawlers (see appendix A) began operations in the GOA, and by 1967, a longline fleet produced GOA catches of sablefish that reached 30,000 mt (*ibid*).

The Soviet Union began fishing the BS intensively in 1959. Eastern BS landings increased from around 400,000 mt in 1950, to over 2,000,000 mt in 1965 (Forrester et al. 1978). Trawl vessels near Bristol Bay targeted flounder (mostly yellowfin sole). A mothership fishery targeted herring in the central BS and Pacific Ocean perch along the continental shelf. Catches of both species peaked in the mid 1960's, but then declined thereafter. In 1964, 150,000 mt of herring were caught and in 1965, Pacific Ocean perch landings reached 384,000 mt (*ibid*). The Soviets trawled for shrimp in the central BS and GOA. Statistics for the central BS are unavailable, but shrimp landings in the GOA peaked at 11,000 mt

in 1967 and then dropped off considerably (*ibid*). A Soviet crab fishery in the eastern BS began in 1959 and crab landings peaked in 1961 at about 10,000 mt (Alverson 1991). The USSR also fished Pacific hake off the Canadian and US coasts, starting in the mid 1960's. Hake landings peaked at around 200,000 mt in 1967, 1969 and 1970 (Forrester et al. 1978).

Other nations that fished in the BS/GOA region from WWII to 1976 include the Republic of Korea, Taiwan, and Poland (Bakkala et al. 1979). The Taiwanese fishery, which began in 1974, fished only 1 or 2 stern trawlers and Poland operated a BS fishery only briefly in 1973. The Republic of Korea (ROK) had a larger presence in the BS during this period, but ROK landings were much smaller than those of the USSR or Japan. ROK pollock landings peaked in 1976 at about 77,000 mt (*ibid*).

Most of the North Pacific foreign groundfish fisheries peaked in the early 1970's (Bakkala et al. 1979). Megrey and Wespestad (1990), report that there was evidence of overfishing on yellowfin sole, Pacific Ocean perch, sablefish (figure 5), and walleye pollock. For example, between 1968 and 1973 there was a 400% increase in all nations fishing effort on pollock, along with a 50% decrease in catch per unit effort (CPUE), in addition to an increasing dependence on younger, smaller fish (Megrey and Westpestad 1990). There was also evidence that intense foreign groundfish fishing was depressing the Pacific halibut stock through incidental take (*ibid*). That is, a proportion of the available halibut stock was

taken in trawl fisheries that targeted other species. This led to reduced

profitability for US fisheries and land-based processors.

Figure 5. Bering Sea Sable Fish Landings by Year.
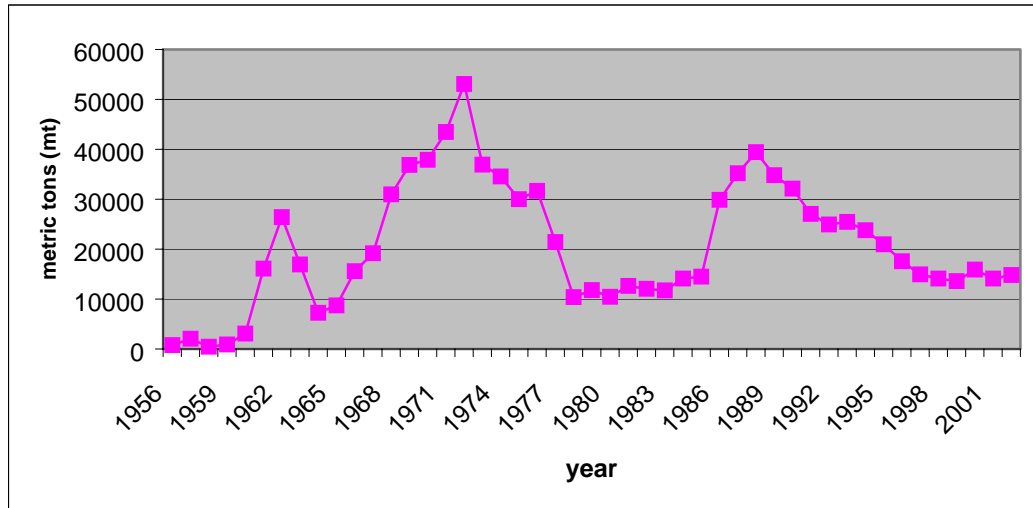
In 1953, the International North Pacific Fisheries Commission (INPFC)

established a convention between the governments of Japan, Canada, and the US.

Under the terms of this agreement, the Japanese were prohibited from fishing

salmon anywhere in the North Pacific east of 175° W, while the Canadians were

prohibited from fishing salmon in the BS, east of the same line. The Japanese

were also prohibited from fishing halibut in the GOA and herring along parts of

the Canadian coast (Naab 1968). In 1964, the US took steps to extend the area of

its jurisdiction out to about 22km from shore (*ibid*). Public Law 89-658 was

enacted in 1966. Lawmakers hoped this would reduce the competition between

foreign groundfish fleets and US crab and halibut fisherman. This change had

little affect on foreign fleets, which fished mainly in the deeper waters off shore (Megrey and Westpestad 1990).

In an attempt to protect US resources, agreements between the USSR and the US, as well as between Japan and the US, underwent several changes in the late 1960's (Naab 1969, Naab 1971). Concessions were made on all sides and the changes to established agreements largely consisted of adjustments to quotas and the areas each nation was permitted to use. The agreements between the USSR, Japan, Poland, ROK, Taiwan, and the US helped spread out the spatial and temporal distributions of groundfish take, but did not seriously reduce the biomass being removed (Megrey and Westpestad 1990). When it became apparent that foreign fishing was mainly responsible for the depletion of fish stocks, US lawmakers took action. The most important piece of legislation establishing some control over foreign fishing in the BS and GOA, was the US Fishery Conservation and Management Act (FCMA) of 1976 (*ibid*).

1976 to 2000

The FCMA of 1976 (now called the Magnuson Fishery Conservation and Management Act (MFCMA)) changed the way fisheries in the United States were managed. Fisheries in the North Pacific were affected in several ways. Instead of a constantly shifting series of compromises between nations, the MFCMA put control of the BS/GOA fisheries entirely into US hands and attempted to maximize the long-term economic value of those fisheries. The first goal of the

MFCMA was the establishment of an Exclusive Economic Zone (EEZ), at that time called a Fishery Conservation Zone, extending out into the waters off the US coast. Inside the EEZ, the US would control fishing resource utilization. The second goal was to promote conservation while achieving optimum yields from each fish stock. Both social and economic factors were to be considered when modifications to the optimum yields were made. The third goal was to shift the fishing and production work inside the EEZ towards US citizens and companies. The fourth goal was to create an infrastructure for the enforcement of the goals stated in the MFCMA. The final goal was to ensure that the best available science was used in setting out the conservation and management decisions pursuant to the act.

The EEZ was set at 200 nautical miles (about 370 km) from shore in US territory. The other stated goals of the MFCMA were more difficult to achieve. The North Pacific Fisheries Management Council (NPFMC), the body charged with making recommendations for instituting fisheries management plans for all commercially important fish species in Alaskan waters, drew up interim fishery management plans for the BS And GOA (the plans are later considered by NMFS, which is responsible for implementation and regulation). These interim plans were mainly concerned with the protection of the domestic Pacific halibut fishery, which was suffering from incidental take in other trawl fisheries. US fishing fleets were not ready to take over the lucrative BS/GOA groundfish fishery, because the boats comprising the fleet lacked the size and power necessary to tow

the huge trawl nets used by the Japanese and Soviets (Larkins 1978). Because the

domestic fleet was unable to make use of the groundfish fishery in the BS/GOA,

foreign fishing was barely affected by the early measures instituted under the

MFCMA of 1976 (Megrey and Westpestad 1990). However, a few smaller

fisheries, such as Tanner crab and Pacific herring were allocated entirely to US

fishing fleets (*ibid*).

In 1978, the NPFMC was required to recommend a more permanent

Fisheries Management Plan (FMP) for the North Pacific region. The charge of

the NPFMC followed the basic guidelines laid out in the MFCMA as described

earlier. However, additional features specific to stock assessment had to be

considered. For example, individual stocks of fish and interrelated stocks of fish

had to be managed (as much as possible) as a unit, or in close coordination

throughout their range. Further, conservation and management measures had to

take into account changes in fishing technology, efficiency and stocks (Larkins

1978). The NPFMC was immediately faced with two opposing, high priority

objectives: First, reduce the incidental catch mortality of Pacific halibut due to

trawl fishing for groundfish. Second, promote a viable US trawl fishery for

groundfish. Since both these goals centered on groundfish, the development of a

groundfish FMP was given top priority.

In order to form an FMP, estimates of several species-specific variables

need to be made for each year and for each species that makes up a management

unit. There were 9 species considered to be part of the groundfish management

unit in 1978. They were: pollock, flounders, Pacific Ocean perch, other

rockfishes, sablefish, cod, Atka mackerel, squid and others (Larkins 1978). The

variables of interest included Maximum Sustainable Yield (MSY), which is

defined as the largest amount of fisheries removals that a stock can absorb,

without year-to-year population loss. Harvesting at MSY requires a constant

environment (Larkins 1978), so a further estimate, the Acceptable Biological

Catch (ABC) was also required. Small changes in the environment can have

major affects on the size of fish stocks (Miller and Fluharty 1992). The purpose

of the ABC is to account for changes in the environment, or in fisheries

efficiency, or in the stocks themselves that might lead to departures from the year-

to-year expected production. Since the available data on stock abundance for

each species may not be entirely reliable, the general policy is to err on the side of

caution (for the fish stock), when determining MSY and ABC (Larkins 1978,

Witherell and Ianelli 1997). In 1978, 7 of the 9 species were deemed to be at

'healthy' stock levels, and only Pacific Ocean Perch and sablefish were judged

'depleted' (ibid). The final component in determining Optimum Yield (OY) is

economic. For example, if a resource is judged to be 'depleted', should the OY

level be set relatively low to promote rapid recovery of the stock, and allow the

fishery to suffer the profit loss of a low return for a year's fishing? Or, should the

OY level be set relatively higher to maintain status quo in the expected value of

the fishery for that particular stock, while holding the stock at its current low

level? Figure 6 shows some OY for various species in the Eastern BS (Bakkala

1988).

Figure 6. Optimum Yields for Various Species in the Eastern Bering Sea
1977 – 1987.
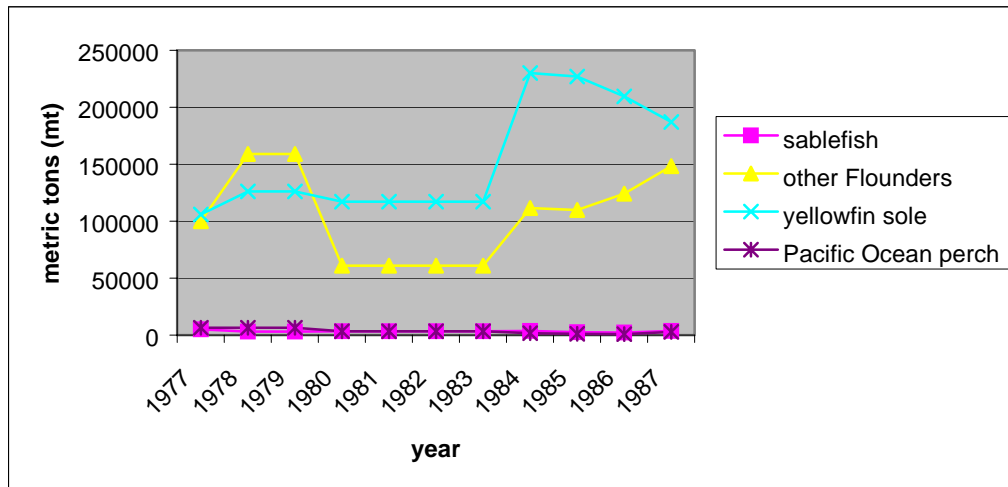
The depressed Pacific halibut stocks were addressed by setting a low OY

on the flounder complex (larkins 1978) (Figure 6). Although the flounder

complex was considered a 'healthy' stock, juvenile halibut were often taken

incidental to other flounders. The development of a strong US groundfish fishery

was handled with later legislation.

In 1980, in order to move the development of a US groundfish fishery

forward, the MFCMA was amended with the American Fisheries Promotion Act

(Public Law 96-561), commonly referred to as the "fish and chips" policy

(Megrey and Westpestad 1990). Under this amendment, foreign allocations were

determined by the extent to which nations contributed to the development of a US

groundfish fishery. Those contributions could be in the form of tariff reductions on US fishery products, or participation in a joint-venture program. In joint-venture (JV) operations, US boats served as catcher vessels for foreign factory ships.

The "fish and chips" policy was vital in moving control of the groundfish resources in the BS and GOA to domestic fleets. US boats accounted for a small fraction of the groundfish landings in the BS/GOA area in 1980. By 1983, US joint-venture boats accounted for 76% of pollock trawl catch and by 1987, 80% of the total groundfish harvest was taken by US JV vessels (Megrey and Westpestad 1990). By 1986, foreign fishing had been completely eliminated from the GOA and entirely domestic operations were quickly replacing JV procedures.

During this period of transition from foreign to domestic control of the fisheries off the coast of Alaska, several depleted stocks began to recover under the management policies recommended by the NPFMC. Landings of species such as yellowfin sole, and sablefish reached high levels in the late 1990's (Megery and Westpestad 1990) (figure 3, figure 5). However, overfishing of some resources continued. This was due, in part, to the fact that much of the monitoring effort was focused on the foreign fleets, even as the fraction of the annual fish allocation that they accounted for rapidly diminished (Megrey and Westpestad 1990). In fact, observers of the JV operations generally observed from on-board the foreign processor boats (Nelson et al. 1981b, 1982, 1983, Berger et al. 1984, 1985, 1987, 1988, Berger and Weikart 1988, 1989, Guttormsen et al. 1990, 1992). This meant

that while total catch brought to the processor could be monitored, the individual

practices of the US catcher boats could not be. Catch allocations for foreign fleets

and catch brought to processor boats by JV fleets in the GOA are shown in figure

7 (Berger et al 1986). Additionally, domestic fishing operations were often

exempt from time-area closures and incidental catch restrictions (Megrey and

Westpestad 1990).

Figure 7. Catch Allocations For Foreign Fleets and Catch by Joint
Venture Vessels in the Gulf of Alaska, by Year.
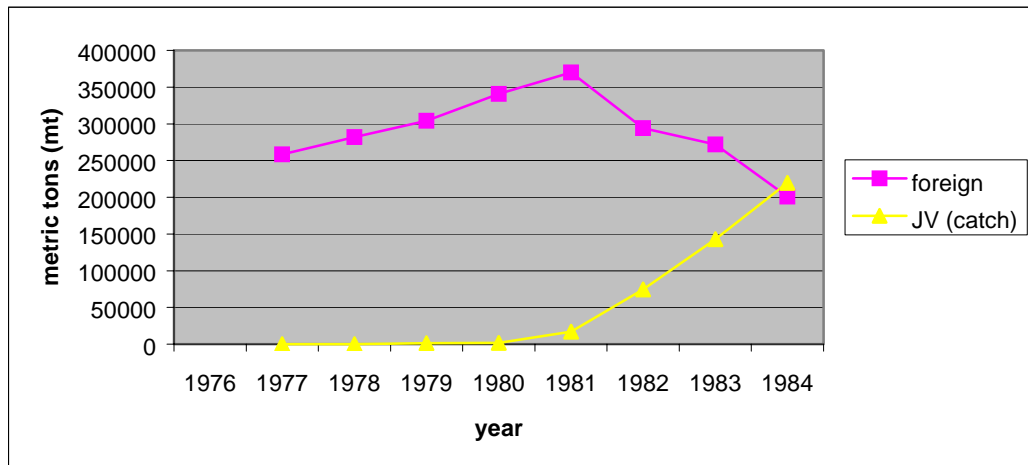
The relatively weak restrictions on US fisheries may have contributed to

the collapse of important shellfish resources in the early 1980's that were fished

exclusively by US fleets, such as the red king crab (*Paralithodes camtschaticus*)

(figure 8) (Ruccio et al. 2002) and Tanner crab (*Chinoecetes* spp.) (figure 9)

(Ruccio 2002).

Figure 8. Red King Crab Landings South of the Alaska Peninsula by Year.
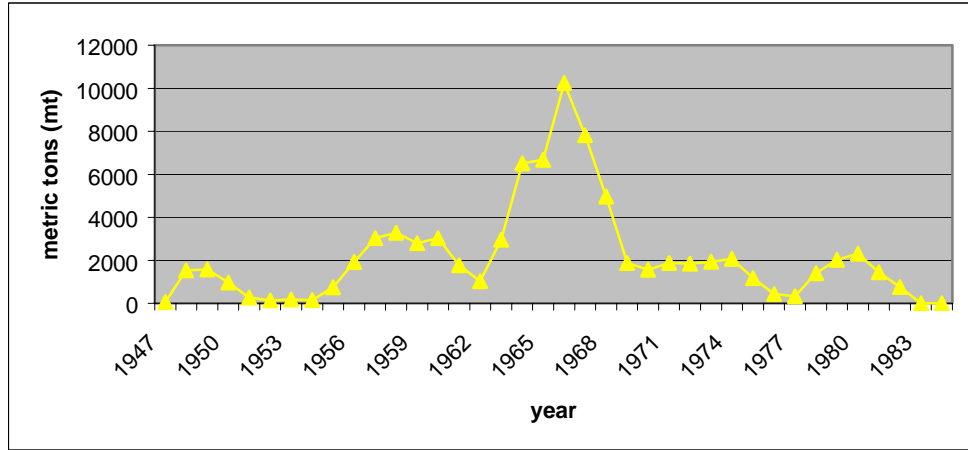
Figure 9. Tanner Crab Landings (mt) and Catch Per Unit Effort (Number of Legal Crabs Per Pot Lifted) For the Kodiak Region, by Year.
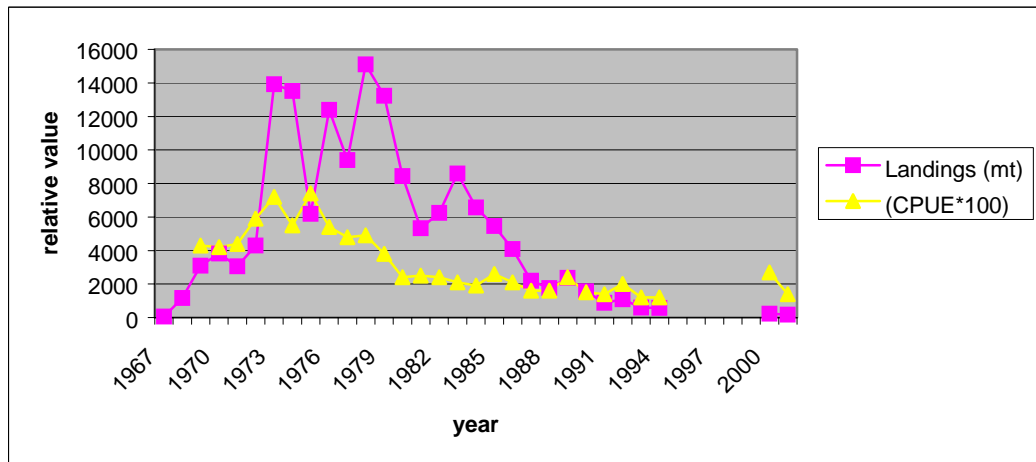
The MFCMA served an important role in increasing knowledge about the marine resources available in the BS and GOA (Megrey and Westpestad 1990). One of the provisions of the MFCMA was that each foreign vessel operating within the US EEZ was required to carry a US observer (Nelson et al. 1981a,

Wall et al. 1981a). The observer's assignment was to collect data on the composition and size of each haul and to determine the amount of incidental take of particular species. The data collected by observers could then be used to help assess the biological status of various fish stocks in the region (*ibid*). The coverage of foreign vessels by US observers was modest at first. In 1977, US observers sampled only 5.6% of hauls made on vessels in the BS (French et al. 1977). However, by 1987 96.1% of all hauls taken by foreign and JV operations in the BS were observed (Berger and Weikart 1988). Observer data included detailed information on location, effort, gear used, and depth fished by the boats they were on. This information considerably improved the stock assessment process and allowed scientists to give more accurate stock management advice (Megrey and Westpestad 1990).

Observer information also provided data on bycatch and discard rates. Bycatch is the portion of a catch that is discarded, or is commercially unusable, as well as species that might be commercially valuable, but are taken incidentally instead of, or in addition to, the targeted species. Groundfish directed fisheries often take commercially valuable, non-target species accidentally. This incidental take can have a serious economic impact on other fisheries. For example, in 1965 the estimated bycatch of Pacific halibut in the BS totaled about 9,500 mt (Williams 2004). The entire catch of Pacific halibut in 1965, by all nations, in the BS and GOA was 38,190 mt (IPHC, http://www.iphc.washington.edu/halcom/ defualt.htm).

Most of the bycatch regulations were set up to protect the stocks of designated "prohibited species", including Pacific halibut, king crab, Tanner crab, Pacific herring and Pacific salmon (Witherell and Pautzke, 1997). Before the MFCMA of 1976, these regulations were mostly designed to reduce conflicts between foreign groundfish fisheries and domestic crab and halibut fisheries. For example, a pot sanctuary, where trawling was prohibited, was set up in Bristol Bay in 1959. The establishment of a pot sanctuary removed the Japanese groundfish vessels from a major US red king crab fishery. One of the goals of the MFCMA of 1976 was to minimize the take of prohibited species. Fisheries management plans (FMP), which are required by the MFCMA, established several bycatch reduction procedures. They included pot sanctuaries and halibut savings areas, as well as time-area closures and prohibited species quotas (*ibid*). The prohibited species quotas were allocated among the nations fishing in US territory and then allocated among vessels by those nations. Any nation that exceeded its prohibited species catch limit would be excluded from fishing much of the BS for the remainder of the season. Bycatch management was not all punitive. Nations were allocated supplemental groundfish quotas based on their bycatch performance (*ibid*). The Japanese fleet implemented a voucher system, in which a vessel had to stop fishing once it reached its individual bycatch quota, unless it purchased additional bycatch shares from another vessel. This system resulted in a reduction of bycatch by the entire fleet (*ibid*).

Set in motion by the "fish and chips" policy of 1980, the transition from foreign to JV to domestic controlled fisheries resulted in several years of relatively unregulated fishing by US vessels. By 1991, the BS/GOA groundfish harvest was an entirely domestic enterprise. Imposing restrictions on US groundfish operations was politically more challenging than imposing the same restrictions on foreign fleets. The limits on prohibited species crept upwards. However, the bycatch concerns of crab and halibut fishermen were addressed to some extent. US boats operated with prohibited species limits and Bristol Bay continued to be protected from trawl fishing. Despite some seasonal closures in Bristol Bay, the red king crab industry in that area closed completely in early 1994 (Witherell and Pautzke, 1997). This collapse led to several regulatory changes in the Fisheries Management Plan for that area (*ibid*). Part of outer Bristol Bay (about 4,000 nm^2) known as the Red King Crab Savings Area, was closed to trawling in 1995, even though it was a prime area for rock sole. About 19,000 nm^2 of near-shore area in Bristol Bay was closed to trawling year round to protect juvenile red king crab (ibid). These actions, along with the reduction in allowed prohibited species catch of red king crab, indicated that bycatch was a serious concern of the NMFS.

Following the red king crab legislation, bycatch regulations for Tanner crab, Pacific herring and halibut became more stringent. The effect of bycatch on these species is variable. Witherell et al. (2002) concluded that the impact of groundfish fishery bycatch on chum salmon was negligible and that Chinook

salmon runs have been reduced by less than 2.7% as a result of bycatch. However, halibut bycatch has been as much as 47% of the total halibut catch and halibut bycatch limits have caused the most closures since 1990 (figure 10, data from Williams 2004 and IPHC at http://www.iphc.washington.edu/halcom /defualt.htm). However, closures depend on many factors, such as the levels set for their activation, the accuracy of bycatch estimates, and the investigation and enforcement of prohibited species catch violations. In addition to direct mortality, there are also less obvious ways in which non-target species are negatively affected by targeted fisheries. For example, trawl apparatus can injure or kill crabs without catching them and can also destroy or degrade habitat (Witherell and Pautzke, 1997).

Figure 10. Fraction of Pacific Halibut Catch That is Bycatch, by Year.
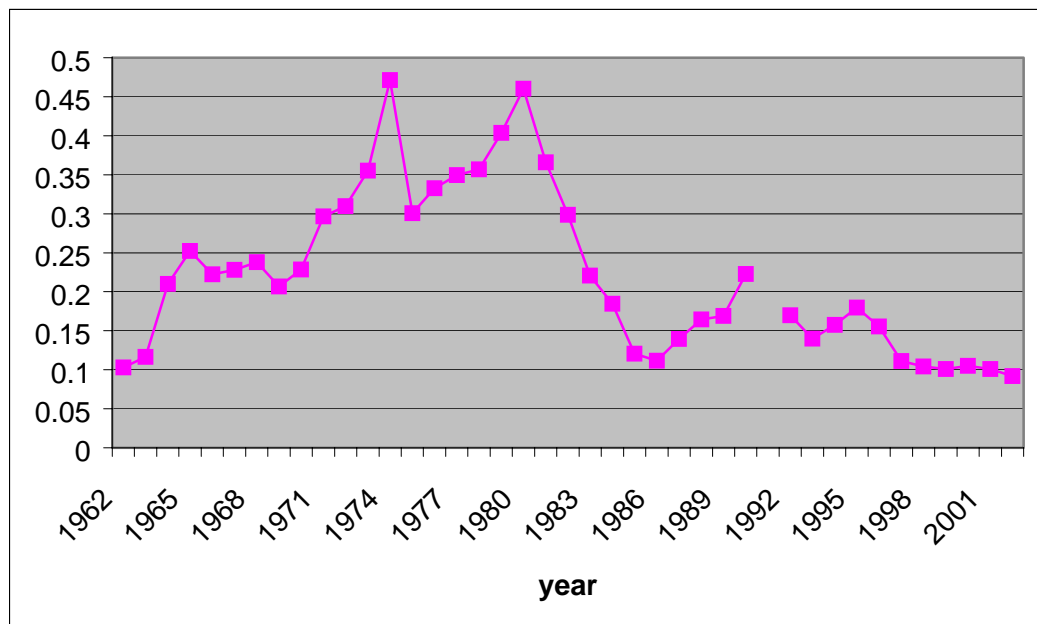
Bycatch has been mitigated in a number of ways, not all of which are obvious. For example, bycatch "hotspots" have been identified with the help of the NMFS Fisheries Observer Program, and most vessels, despite the fact that there may be good catches of target species available there as well, avoid these voluntarily (Witherell and Pautzke, 1997). Commercial fishing gear has also been modified over the years to avoid the unnecessary take of prohibited species. For example, halibut excluder grates can be installed in the intermediate section of a trawl, allowing halibut escapement and reducing halibut bycatch (Karp et al. 2001). Finally, steps have been taken to return prohibited species to the water rapidly and thus avoid bycatch mortality (*ibid*).

On-board observers could accurately measure bycatch, but the biomass of fish left in the sea after a fishing season was harder to determine. In order to make better biomass estimates of commercially important stocks, the NMFS Northwest and Alaska Fisheries Center (now called the Alaska Fisheries Science Center - AFSC) began making extensive trawl surveys in the BS and GOA in the late 1970's. Those surveys have been conducted every three years since 1979 in the BS and since 1984 in the GOA. In a trawl survey, a trawl net is towed for a fixed amount of time along the sea floor, at regular intervals. There are fixed survey stations set up in the BS and GOA that assure that the trawls are towed over a variety of habitat types. The net used has small mesh, in order to retain juvenile fish and crabs. All the fish caught in the trawl net are sorted by species and then weighed and counted. Individual fish may be sexed, measured or

dissected, to obtain information on age, growth, sexual maturity and diet, or to gather other biological samples as needed (Witherell and Ianelli 1997). Information on the quantity and condition of species taken, and the area covered by the trawl net, can then be used to extrapolate biomass estimates for that species over larger areas. There are other trawl surveys done each year in the BS, but they are far smaller in geographic scale than the triennial surveys (Megrey and Westpestad 1990).

NMFS has also done combined bottom trawl and hydro-acoustic surveys in the BS every three years since 1979. The addition of hydro-acoustic technology (also called echo-integration trawls, or EIT) allows for a more accurate assessment of the pelagic components of various stocks. Bottom trawl surveys may do a good job estimating rockfish biomass (Witherell and Ianelli 1997), but fail to catch some of the more pelagic species, such as pollock. EIT technology locates aggregations of fish that can then be caught in trawl nets set at the appropriate depth. The catch can then be sampled as with bottom trawl surveys. Recently, scientists have been able to identify individual species with the echo information alone (Lu and Lee 1995). Since 1983, combined mid water trawl and hydro-acoustic surveys have been conducted annually on spawning stocks of pollock in Shelikof Strait in the GOA. Finally, NMFS has also participated in joint survey projects with Japan and Russia in the BS and GOA. These additional resources have been vital in the development of biomass estimates and thus FMP for the various species managed under the MFCMA.

Better knowledge of stock biomass led to a contraction of the commercial fishing industry in the early 1990's, once it became clear that the level of landings seen in the 1980's could not be maintained (Hanna 2000).

The MFCMA was amended with the Sustainable Fisheries Act in 1996. Among other changes, the amended legislation was renamed as the Magnusan-Stevens Fisheries Conservation and Management Act (MSFCMA). Harvesting levels are now required to be at or below MSY and ecosystems and fish habitat must be considered as part of the management regime. Additionally, depleted stocks must now be recovered within 10 years (OSB 2002). These changes, and the status of the Steller sea lion as an endangered species, affected the management of the North Pacific Fisheries considerably in the late 1990's. Many of the issues surrounding SSL and fisheries based management will be addressed in chapter 5.

CHAPTER 5

THE HISTORY OF STELLER SEA LION MANAGEMENT RELATING TO

COMMERCIAL FISHERIES

SSL related regulatory management of commercial fisheries in the Bering

Sea and Gulf of Alaska began in 1990, with the listing SSL as a "threatened

species" under the Endangered Species Act (ESA). Section 7(a)(2) of the ESA

dictates that no federal agency fund, authorize, or take any action that will

jeopardize the continued existence of a protected species, or adversely effect its

habitat. Any "action" agency is required to consult the "consulting" agency,

before any potentially harmful activity or change in regulations takes place. The

consulting agency tasked with managing SSL is the National Marine Fisheries

Service (NMFS). The action agency for the BS/GOA commercial fishery can be

NMFS as well, although different subdivisions within NMFS would fulfill these

two roles, the protected resources and fisheries management divisions. In the case

of SSL however, most the recommendations for regulatory action are the result of

interaction between the North Pacific Fisheries Management Council (NMFPC),

which makes recommendations concerning fisheries management off the coast of

Alaska, and NMFS. These are generally implemented from within the Fisheries

Management Plans (FMP) for the Bering Sea/Aleutian Island (BSAI) and Gulf of

Alaska (GOA) regions, which are a requirement of the Magnuson-Stevens

Fisheries Conservation and Management Act (MSFCMA) (see chapter 4).

The ESA "threatened" listing of SSL occurred on April 5, 1990, and

several import conservation rules were enacted immediately. NMFS began

monitoring the incidental take of SSL in observed fisheries (those fisheries

participating in the NMFS Fisheries Observer Program), in order to produce

monthly estimates of direct fisheries related mortality. The quota for allowed

incidental take was reduced from 1350 animals to 675 animals per year. A

prohibition on shooting at or near (within 100 yards) of SSL was established (this

excluded Alaska native subsistence hunting) and aggressive enforcement of those

regulations began immediately. A Steller Sea Lion Recovery Team was

established and tasked with providing recommendations for further conservation

measures. Finally, a 3 nm "no approach" zone was established around the

principle SSL rookeries.

One of the requirements of the ESA is that the recommendations of the

consulting agency be summarized in Biological Opinion documents, which detail

how the protected species will be affected by those recommendations. In 1991,

NMFS produced 2 Biological Opinions, one for the BS/AI region and another for

the GOA region. Both of these documents speculated that commercial fisheries

could have a deleterious effect on SSL population recovery. The proposed

mechanism for this inhibitory interaction was direct competition, as both SSL and

fisheries target large schools of fish of the same species and approximate size.

The biological opinion documents also postulated that the most harmful fisheries

removals would be those that occurred near rookeries, which might affect

juvenile, and lactating SSL in particular. However, both opinions ultimately

concluded that fisheries were unlikely to jeopardize the continued existence and

potential recovery of SSL.

On January 7, 1991, NMFS issued rules limiting pollock roe stripping and

seasonally allocating the pollock "total allowable catch" (TAC) (see chapter 4).

The seasonal allocation spread the TAC out over the course of the year. On June

19, 1991, further modifications to the FMP for pollock spread the TAC out over

space as well. Other modifications included a limit on the amount of unused TAC

that could be rolled over into subsequent years and a prohibition on using trawl

gear within 10 nm of 14 major SSL rookeries. On January 23, 1992, NMFS

issued a rule prohibiting trawl fishing within 10 nm of 23 additional rookeries,

bringing the total to 37 and placing protections around all of the recognized

rookeries in the western stock (though it was not yet designated as a separate

population segment). The "no trawl" zone was expanded to 20 nm around 5 of

these rookeries (Agligadak, Akun, Akutan, Sea Lion Rock-Amak and Seguam, a

sixth, Ugamak was added on March 12, 1993) between January 1 and April 15 of

each year. NMFS also established 3 pollock management zones and limited the

amount of excess pollock seasonal harvest that could be taken during any quarter

in each district.

The final SSL Recovery Plan was issued on January 7, 1993. On July 13,

1993, NMFS issued rules spreading out the Atka mackerel harvest in the AI over

space. While this action was largely taken to protect the Atka mackerel stock, the

resulting changes were consistent with the conservation goals of the SSL

Recovery Plan. On August 27, 1993, SSL critical habitat was designated pursuant

to the requirements of the ESA. Critical habitat for SSL is currently defined as

the waters surrounding known SSL rookeries to 20 nm from shore, as well as 3

large offshore foraging areas. Two of these offshore areas surround the north side

of Ugamak Pass and one is near Seguam Island.

SSL were reclassified as two separate stocks on May 5, 1997 (see chapter

2). This led to an "uplisting" of the western stock to "endangered" under the

ESA. The eastern stock was left as "threatened". Following this decision several

additional changes to the SSL protection scheme were implemented. These

included a spatial and temporal redistribution of the Atka mackerel TAC and a

preemptive measure that created a separate category for "forage fishes" (see

chapter 4). The idea behind a separate classification for forage fish was to

prevent the development of a directed fishery for them. Furthermore, on January

22, 1999, NMFS published an emergency rule that divided the pollock fishing

season into 4 periods instead of 2 inside SSL critical habitat, and also created

trawl exclusion zones around SSL haulouts (in addition to rookeries). These

regulations effectively removed directed pollock fishing from the Aleutian

Islands.

CHAPTER 6

PREVIOUS STUDIES OF THE INTERACTION BETWEEN COMMERCIAL
FISHERIES AND STELLER SEA LIONS IN THE GULF OF ALASKA AND
BERING SEA

There are 3 previous studies that have explored the relationship between
commercial fisheries in the Bering Sea and Gulf of Alaska and SSL population
trend.

Comparison of Commercial Harvest of Walleye Pollock and Northern Sea Lion Abundance in the Bering Sea and Gulf of Alaska

This paper by Loughlin and Merrick (1988) makes a comparison between
commercial pollock catch around 8 major rookeries and SSL abundance. The
rookeries Seguam Island, Walrus Island, and Bogoslof Island in the eastern BS,
Ugamak Island (EAI), Chirikof, Chowiet and Marmot Islands, in the GOA, and
Forrester Island in Southeast Alaska had relatively complete count data and were
selected for analysis. Comparisons of fishery catch statistics and SSL counts
were made at each rookery. Areas of 1° latitude by 2° longitude around each
rookery (approximately 60 nmi from the rookery, though it is a rectangle so the
distance is not constant) were used to collate fishery catch statistics. There were
some perturbations to this design, for example the Marmot Is. zone was expanded
to include Shellikof Strait, and the zones around Chirikof and Chowiet, which
overlap, were combined. Forrester Island was included as a comparison because

there has not been a decline of SSL in that area (there has not been much pollock fishing either).

SSL counts were compared with Pollock catch statistics from the same year and from 1 to 5 years previous to the year of the count. There were two indicators of SSL abundance used: adult and juvenile censuses and number of pups born. The adult and juvenile counts are aerial surveys, made at the end of June and first week of July. The pup counts are from land surveys, made in the first week of July.

Three commercial pollock catch statistics were used: annual catch (in metric tons - mt), catch per unit effort (CPUE - mt/hour), and average fish weight. Annual catch was calculated for foreign independent fisheries, joint venture (JV) fisheries, and the combination of both. Annual CPUE was determined separately for independent and JV fisheries, and fish weight was determined only for JV fisheries. Since JV observer statistics represented only a sample of the total JV removals from the area during the early 1980's, JV catch totals were adjusted upwards. The adjustments were made based on INPFC statistical areas (circa 1988). The total estimated catch was divided by the observed catch to obtain an inflation factor that could be applied to individual observations.

SSL counts and commercial fishing statistics were compared using simple linear correlation. Each available year, that is a year for which both fishery and SSL population size data were available, represented a data point in the correlations. A separate correlation was done for each rookery.

The results of this study were inconsistent. The only sites with sample sizes and effects sufficient to merit significance when total annual catch was used as the measure of fishing, and adult SSL counts were used as the SSL population trend estimate, were Marmot, Bogoslof and Walrus Islands. The significant results occurred when lags of 3, 4 or 5 years between fishing and SSL count were tested. There were 4 significant correlations found. Two of these were negative and two were positive.

Results from the comparison of total annual fishing in Shelikof Strait and Marmot population size, show a high negative correlation with pups born, indicating that a high level of fishing was associated with fewer pups being born. There was no significant correlation between CPUE and SSL numbers, except in Shelikof Strait, where both declined. The authors noted an increase in the size of pollock taken, but did not have sufficient data to find significant correlations with SSL numbers. The pooled data for all sites together produced no significant relationships.

The authors suggest a number of explanations for the lack of clear effect in their study. One is the theory that the pollock population actually consists of several different sub-populations, which have different recruitment, response to fishery pressure, and response to oceanic events, etc, which may mask the simple relationships the authors are after. Another theory is the possibility of a decreasing percent of pollock that mature at age 3 and 4 and of smaller size pollock in general in the BS and GOA, which might coincide with smaller and

less fit SSL, sea birds, and other marine mammals. This change might indicate a general reduction in the productivity in the entire region, which would not show up in comparisons of individual rookeries. Finally, the SSL counts are made at fixed times of year, while the pollock counts are not. This discrepancy could mask an effect that is limited in its temporal scope.

Comparisons of Walleye Pollock, *Theragra chalcogramma*, Harvest to Steller Sea Lion, *Eumetopias jubatus*, Abundance in the Bering Sea and Gulf of Alaska

This study, by Ferrero and Fritz (1994) is similar in design to Loughlin and Merrick (1988). Comparisons were made between SSL counts and pollock abundance. Pollock abundance was measured by fisheries harvest data and directly compared to SSL data with lags of zero to five years. There are, however, some differences between the two studies. For example, Ferrero and Fritz (1994) use two different study areas. One study area consists of 60 or 120 nm zones around six major rookeries, and the other encompasses 20 nm around 13 rookeries. Nonparametric statistics were employed to look for significant correlations, in order to eliminate problematic normality assumptions. Ferrero and Fritz (1994) found some significant correlations, but they were both positive and negative and do not show a consistent relationship.

Ferrero and Fritz (1994) list some of the problems that may have confused the results of Loughlin and Merrick (1988). For example, there were limited SSL count data, which was problematic in that sample size was often insufficient for statistical significance, despite relatively large effects. There were also positive

and negative trends in pollock stock abundance during the study period, which would effect the direction of correlation with SSL, regardless of fishing. Furthermore, geographical differences in the recruitment and utilization of the pollock stocks could certainly affect where the majority of fishing occurred and how important pollock were to SSL in particular areas. Some sampling problems were detected, including differential (fixed vs. variable) timing of counts made of each species (SSL vs. pollock, respectively), which would tend to introduce seasonal confounds. Finally, there was application of parametric statistical tests to data that were probably not normally distributed.

Ferrero and Fritz (1994) updated Loughlin and Merrick (1988) using new data and making some alterations to the design. Pup counts were excluded because there were too few of them. Forrester Island was excluded because it hadn't been fished since the early 80's and was originally included in Loughlin and Merrick (1988) as a counter example only. Marmot Island was originally used to look at how it was affected by JV fishing in near-by Shelikof Strait, but because JV fishing did not occur in the immediate vicinity of Marmot Island, it was not used in Ferrero and Fritz (1994). Finally, the 1976 data from Chowiet Island was not used, as it was a rough estimate not an actual count.

All SSL counts used by Ferrero and Fritz (1994) are based on aerial photos taken during the same time of year as the data used in Loughlin and Merrick (1988), that is, late June and early July. The pollock catch data came from three sources. The first source was observers aboard both JV and domestic

ships, which yielded variables such as, amount of pollock caught and location of hauls sampled. The second source was the Pacific Fisheries Information Network (PacFIN), which has information on each International North Pacific Fisheries Commission (INPFC) statistical zone. Ferrero and Fritz (1994) used study areas in 3 INPFC zones. Finally, because of a lack of observers on domestic vessels, catch estimates were supplemented with data filed by shore-side processing plants.

Ferrero and Fritz (1994) updated Loughlin and Merrick (1988), but also looked at 13 study areas composed of 20 nm circles around major rookeries (Loughlin and Merrick (1988) used many of the same ones). Ferrero and Fritz (1994) intended to provide finer spatial resolution on the comparisons between pollock fishing and SSL population trend than Loughlin and Merrick (1988) who used 60 nm circles. 20 nm was chosen because new satellite tagging data (Merrick et al. 1995) showed 20 nm to be the maximum distance traveled by foraging, post-partum, female SSL in summer. 20 nm was also the size of the "no trawl" zone around those rookeries during the pollock roe fishery (circa 1994, see Chapter 5).

Correlations between fishing and SSL population trend were calculated using the same method as Loughlin and Merrick (1988). They made direct, same year comparisons between annual fishing variables and SSL censuses as well as comparisons between SSL censuses and annual fishing variables from 1 to 5 years before those censuses took place. A linear model was used to calculate r, the

coefficient of linear correlation. In order to deal with the problematic assumption of normality in the data, Kendall's rank correlation coefficients were also calculated.

Updating Loughlin and Merrick (1988), that is, using circles of radius 60 nm around rookeries for tabulating fishing statistics, increased the number of observations per correlation for lag times of 0 and 1 year, but did not help the others, as data from before 1977 were not used. Four of the parametric, updated correlations were significant, 2 positive and 2 negative. Three of the non-parametric correlations were significant, all negative. None of the significant nonparametric correlations were from the same sites as the significant parametric results.

In the 20 nm study, 10 significant parametric correlations were found, 2 negative, 8 positive (positive in this case implying that increased fishing is associated with less steep SSL decline). 3 of the non-parametric tests were significant, 2 were negative, and 1 was positive. Only 2 of these were from the same sites and had the same sign as the parametric findings.

Ferrero and Fritz (1994) point out that the lack of consistent results between the parametric and non-parametric type tests show that the results are sensitive to deviations from normality. They suggest low sample size and variables that range over several orders of magnitude as potential problems. Other potential confounds mentioned are changing oceanographic conditions and

fish community structure, which could act synergistically to confound any potential SSL/fishery effects.

Ferrero and Fritz (1994) point out that positive correlation may be explained by pollock harvest paralleling pollock abundance, where the quantity available could be sufficient to satisfy both the fishery and the SSL population. They also point out (based on the results of York 1994) that since the age class most likely to show increased mortality is juveniles, we would expect the correlations between harvest data and SSL counts should show up in lag years 3-5, the expected time to sexual maturation for female SSL. Ferreo and Fritz suggest that negative correlations in lag years could be explained by local depletions of pollock biomass caused by the fishery, which could result in a reduction of food available to the SSL population.

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

This paper by Sampson (1995) expanded on Ferrero and Fritz (1994) and Loughlin and Merrick (1988) by using more rookeries (25) and more fish species (pollock, Atka mackerel and Pacific cod). Sampson (1995) used principal components analysis (PCA) on trend estimates of SSL counts, adults and pups from 1979-1990 and independently on fishery observer data from commercial groundfish fishing operations that occurred within about 37 km of the rookeries in question, from 1980 to 1989. Sampson (1995) then correlated the component scores from each data set to look for relationships between the decline of SSL and

groundfish fishing activities. This approach was motivated by the hypothesis that

reduced juvenile survival (as discussed in York 1994) could result from

disturbance caused by fishing, rather than direct competition for food.

The SSL census data are from NMFS Adult Count Database, the same

source used by Loughlin and Merrick (1988) and Ferrero and Fritz (1994). They

are aerial adult and juvenile surveys and land based pup surveys, all completed in

late June and early July. However, the data are from more rookeries over less

time than Loughlin and Merrick (1988), or Ferrero and Fritz (1994). Sampson

(1995) examined the characteristics of each rookery in the early vs. late parts of

the study period. Census data from three years were used to estimate population

trends, with the following formula: $\log_e (N_t/N_o)/t$. Where N_o is the count from the

base-year survey, N_t is the count from the next survey and t is the number of years

between them.   He also calculated the ratio of pups to non-pups, where pup

counts were available. The years most commonly used for these analyses were

1979, 1985, and 1990 because those years had the most complete census data. As

in Loughlin and Merrick (1988) and Ferrero and Fritz (1994), some of the

rookeries that are close together were combined for comparison with fishing in

that area.

The NMFS Fishery Observer Program provided the fisheries data used in

this analysis. They consisted of effort (hours) and catches (mt) of the three

selected species, which were chosen based on the relative availability of data.

The numbers were tabulated by year, quarter, gear type, and area. The data

reported are essentially the same as Ferrero and Fritz (1994), but include effort estimations and exclude catches that do not report effort values. The data are observed fishing activities of longline, midwater trawl, and bottom trawl vessels that occurred within 20 nm (approximately 37 km) of SSL critical habitat (116 major haulouts and rookeries). The spatial scale is based on the results of tagging studies by Merrick et al. (1995). To avoid double counting, areas of overlap were assigned to the western-most site during the data extraction process. Assigning the overlap zones in this way produced irregularly shaped fishing areas associated with some rookeries. In order to account for differential observer coverage, Sampson (1995) corrected for effort and catch based on the quarterly effort and catch percentages for each zone. (Example: total observed catch of pollock from the 25 rookery zones is 23624.3 mt, of which 213.5 mt was taken during the second quarter from zone 10). Effort and catch data were adjusted to account for the assumption that larger removals would tend to occur in larger zones. That is, adjusted percent = percent * (Average area / Zone area). The fishery data were non-normal (a few large values and many zero or small values), and the author transformed the values using Gauch's octave scale (a base two logarithmic transformation).

In order to simplify the SSL data, Sampson (1995) applied PCA to the early and late instantaneous rate of change variables in the adult and juvenile counts. The motivation for this was to have some simple means of ranking the rookeries, according to rates of change in each period (early vs. late). This

process was repeated for the rates of change in pup counts (for the 18 rookeries with that information available), and pup to non-pup ratio. He then compared the principle component scores from these analyses using simple linear correlation.

PCA was also applied to the following fishery data: fishing hours, total groundfish catches, pollock catches, cod catches, and mackerel catches. Data were analyzed separately by year and quarter and sorted both temporally and spatially (by zone). Finally, the SSL principal components and pup-count-based principal components were correlated with the fishery principal components.

Sampson (1995) discusses the rankings of the rookeries according to rate of change in each period as follows. The first principle component measures the deviation from a uniform rate of change. A large positive component score represents a small change in the early period and a large change in the late period, while a negative component score shows the opposite. The second principal component measures the rate of change combined over both periods, without regard to timing of the change. This is an inverse relationship, where a large value represents a small amount of change.

The principal components of the pup-count study show a large positive correlation with early instantaneous rate of change (in pups) and a large negative correlation with pup/non-pup ratio (early, middle, and late). The principal components based on pup-counts and those based on adult/juvenile counts were not highly correlated, which implies that each set of data may provide fundamentally different information about the rookery in question.

In comparing the possible similarities between changes in adult/juvenile counts and fishing patterns, 9 of 120 correlation coefficients were significant. The highest positive correlation was between the second principal component of winter pollock catches and the first component of the changes in adult/juvenile SSL counts. According to the author, this implies that rookeries that suffered large early declines generally had large pollock catches in winter, early in the 10-year catch sequence. Furthermore, rookeries with late declines generally had either no pollock catches during the winter or ones that occurred late in the catch sequence. There was also a strong negative correlation between the first principal component for cumulative winter pollock effort and early season SSL counts. The remaining significant correlations were with third and fourth components of the fishery data, which account for less of the total variability in the original data and were not pursued.

5 out of 120 correlation coefficients were significant in comparisons between the principal components from pup-count data and the fishery principal components. The three strongest used the third principal component of the fishing hours analysis, which accounted for 9% of the variability in the original data. These were not further pursued. The next strongest correlation (0.511) occurred between the second component for spring groundfish catch and the first component for changes in the SSL pup-counts. However, this correlation depends on one rookery and when that datum was left out, the correlation became

insignificant. The final correlation was also sensitive to the influence of a single datapoint.

The author points out that declines in pup count should lead to declines in adult/juvenile count later, but he finds no such relationship. He suggests that perhaps as SSL mature they redistribute themselves across rookeries, or perhaps the important mortality occurs at some later life stage. He suggests one possible improvement: repeating the analysis at a variety of spatial scales, but also points out that close together rookeries did not really show patterns of decline more similar than those far apart. Thus increasing the scale may not improve the significance of results. Sampson (1995) also mentions some statistical problems that arise from the nonrandom collection of fishery data and the various non-linear transformations the data experienced. These indicate that the significance level of the correlation coefficients can only be used as a rough guide. Also, the early and late SSL counts are not really independent, since both are derived from the same middle count. The author failed to find any large correlations between SSL components and components from either total winter groundfish catch or fishing hours, which does not support his working hypothesis that the declines were caused by fisheries related disturbance.

Comments

None of these 3 analyses have examined cumulative fisheries removals as a potential cause of the SSL decline. Part of the reason for this is the limited

amount of data available at the time these studies were undertaken. There is

reason to believe that repeated localized removals of fish stocks could alter

species composition and dispersal over time (NMFS 2000a). This could, in turn,

alter the fitness of the SSL who forage in those areas. The possibility of

synergistic effects of fisheries removals over successive years could be addressed

by using cumulative fishing around rookeries as a variable in fisheries/SSL

correlation analyses.

The fisheries data used in all three analyses seem to have been recycled

from the base data provided by Loughlin and Merrick (1988). It involves a fairly

complex combination of Fisheries Observer Database, Pacific Fisheries

Information Network (PacFIN), and shore-side processor data. The spatial

information from these three sources is increasingly course. The Fisheries

Observer Database provides explicit latitude and longitude for gear retrieval for

any fishing event that occurred on a contracted vessel (when the observer was "on

effort"), while the PacFIN data are composed of estimates for removals only from

specific statistical areas and the shore-side processor data reflect entire $\frac{1}{2}^o$ latitude

by 1° longitude zones (Ferrero and Fritz 1994). The Fisheries Observer Database

probably provides the most complete and geographically unbiased information of

the three.

Each of these analyses uses limited SSL data to represent the status of a

rookery population over time. In Loughlin and Merrick (1988) and Ferrero and

Fritz (1994), SSL population is a single census. In Sampson (1995), two SSL

population trends are estimated using three counts. According to the method of

Gerodette (1987) at least three annual census counts would be required to detect a

trend of the magnitude seen in the western stock decline (see Appendix C).

CHAPTER 7

CORRELATIONS BETWEEN THE STELLER SEA LION DECLINE AND

THE BERING SEA / GULF OF ALASKA FISHERY

Introduction

Several previous studies have attempted to find connections between SSL

population trends and fishing activities, including: Loughlin and Merrick (1988),

Ferraro and Fritz (1994), and Sampson (1995) (See Chapter 6). These studies

differed from this one in several ways. All three previous studies concentrated

only on particular species of fish. Loughlin and Merrick (1988) and Ferraro and

Fritz (1994) looked at only walleye pollock (*Theragra chalcogramma*), while

Sampson looked at pollock, Pacific cod (*Gadus macrocephalus*), and Atka

mackerel (*Pleurogrammus monopterygius*). This analysis examines entire hauls,

including by-catch, in addition to particular species of fish. The three previous

studies used only photographic SSL count data from the late 1970's, up to some

point previous to the publication of their results. This study extends the SSL time

series in both directions, using photographic data from the 1950's as well as

ocular estimates from the 1960's and early 1970's, in addition to recent

photographic counts, which run through 2001. This study also looks at fishing

data found at a range of distances from SSL rookeries, where the previous studies

tended to focus on fixed geographic areas or a single distance from SSL rookeries.

Sampson (1995) compared fishing in different seasons to SSL trends; this analysis

examines seasons, as well as different types of fishing gear. Finally, this study looks at cumulative fishing over a number of years, while the previous studies used catch in individual years as their measure of fishing.

Methods

The Steller sea lion data used here come from the National Marine Fisheries Service Adult Count Database. Adult SSL are usually counted using photographs taken from low flying aircraft. Some of the data, especially those data recorded during the 1960's and early 1970's are from ship or land based estimates, using ocular methods (binoculars or spotting scopes). Ocular counts are generally regarded as less reliable than overhead, photographic counts (Merrick 1987). The analysis reported here incorporates all the available data recorded during the peak of the breeding season, that is, the months of June and July (Calkins and Pitcher 1982), for known SSL rookeries, west of 144° W longitude.

The natural log of the observations (number of adults present on land, at the time of observation) for each rookery, were fit using a two-stage linear regression model. The two-stage model fits three parameters. The first is a slope estimate, starting at the year corresponding to the first observation recorded at that site and ending at 1991. For example, if the first observation at Marmot island rookery was recorded in 1957, the first slope parameter will be the slope of the line that "best" (subject to a hinge constraint) fits the natural log of the

observations from 1957 to 1991. The second parameter is a 1991 intercept. The

model uses 1991 as a hinge point because active restrictions on the Bering Sea

and Gulf of Alaska fisheries, around SSL rookeries began around that year

(NMFS 2000a). The last parameter of the two-stage regression model is a slope

estimate for the years 1991-2001.

The earliest SSL data are not often used in analyses because there have

been questions about their accuracy (for example, Withrow 1982). To explore the

effects of possible accuracy problems, several different starting points for the two-

stage regression model have been employed here. The first two-stage regression

estimates were made using all the available data from 1956 on. These estimates

will be referred to as year-of-first-census (50's) - 1991 slope, or YFC (50's) -

1991 slope, 1991 intercept (50's), and 1991 - 2001 (50's) slope. The counts from

the 1950's were generally lower than counts from the 1960's and counts later than

the 1960's reflect the range-wide decline of SSL. This results in a peak shape,

with its apex somewhere in the 1960's. This pattern is not fit well with a single

straight line, but the data are too sparse to identify the date of the reversal. Since

a fraction of the SSL rookeries were sampled in the 1950's, only some of the sites

show a poor fit using YFC - 1991 as the first slope estimate. However, in order to

examine the influence of the sites that were poorly fit, a second set of SSL

population parameter estimates were made, without the data from the 1950's.

These estimates will be referred to as YFC (no 50's) - 1991 slope, 1991 intercept

(no 50's), and 1991 - 2001 (no 50's) slope. Furthermore, since it may be useful to

speculate on the nature of the relationship between fishing and SSL decline, I also examined SSL data subset confined to the years for which I have fishing data. That is, SSL population parameter estimates were also made using the data from the years 1977 - 2001. These estimates will be referred to as 1977 - 1991 slope, 1991 intercept, and 1991 - 2001 slope. The fit of each of these models to the data at each rookery is shown in appendix C.

This SSL population trajectory model was fit numerically using Marquardt's Algorithm, which in this case was used to find the parameter values that minimized the squared residuals from the regression fit. There were 32 rookeries with enough data to reasonably estimate all three parameters. Attu Cape Wrangell had enough observations that occurred after 1991 to estimate the 1991-2001 slope and was used in analyses of that period, while Agattu had enough pre-1991 observations to be used in the YFC - 1991 analyses, resulting in a sample size of 33 rookeries for each analysis. Two composite rookeries, Adak Complex and Ugamak Complex were created, in order to make use of data that was collected under different naming protocols before and after 1991. These composite rookeries are agglomerations of closely spaced rookeries. Otherwise, the unit of SSL population used in this analysis is the individual rookery. In order to avoid double counting of fisheries data around them, composite sites were assigned a single latitude and longitude, located in between the included sites.

The SSL data were compared to fisheries data from the NMFS Fisheries Observer program. The Observer program began in 1977, and consisted of

trained NMFS observers accompanying fishing vessels and monitoring various characteristics of the catches made aboard these vessels. Among the many data recorded by observers were the global position (latitude and longitude) and weight of each individual haul made while the observer was "on effort", or working. Not all fishing vessels had observers during any one season. To correct for the fact that only a fraction of the total fishing was "observed", observer coverage rates were extracted from the NMFS summaries of observer program documents and from individuals involved in the observer program (Wall et al. 1978, Nelson et al. 1978, Wall et al. 1979, Nelson et al. 1979, Wall et al. 1980, Nelson et al. 1980, Wall et al. 1981, Nelson et al. 1981, Wall et al. 1982, Nelson et al. 1982, J. Berger pers. comm. 2003, Nelson et al. 1983, Berger et al. 1984, Berger et al. 1985, Berger et al. 1987, Berger et al. 1988, Berger and Weikart 1988, Berger and Weikart 1989, Guttormsen et al. 1990, Guttormsen et al. 1992, L. Fritz pers. comm. 2001). These sources provide a percentage of the total fishing days that were "observed", during each calendar year, in both the Being Sea and Gulf of Alaska. The quantities derived from each haul during a given year were then expanded by a factor equal to the inverse of the proportion of hauls observed for that year, in that area (Bering Sea vs. Gulf of Alaska).

The fishing variables used in this analysis are 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), which is equal to the weight of a haul divided by the duration of time that the gear was at

fishing depth, that occurred within varying distances from SSL rookeries. The variables, number of hauls, sum of the weight of hauls, and duration of fishing can be thought of as measures of fishing activity. CPU can be thought of as a rough measure of fish abundance, before fishing took place. Fishing that occurred within distances of 10 km, 20 km, 30 km, 50 km, 100 km, 10-20 km, 10-30 km and 20-30 km, from each SSL rookery were analyzed.

Because the type of fishing gear used has an effect on the size of the haul taken, the fishing data were also stratified by gear type. The fishery data were divided into 10 different gear types, 5 of which were used near SSL rookeries. The gear types used near SSL rookeries were: mothership/processor vessel, small trawl/non-pelagic trawl, large trawl/pelagic trawl, pot or trap, and longline. Mothership is not strictly a gear type, but represents a type of fishery in which several smaller "catcher vessels" bring their hauls directly to the mothership for at-sea processing. During the JV fishery period (a period in which much of the fishery was prosecuted by "joint venture" operations, in which domestic catcher boats provided fish to foreign processor ships. See chapter 4), observers were not generally stationed on the domestic catcher vessels, so the only data on specific hauls for that period come from motherships, which often carried observers (Berger et al. 1987, others). However, these observers recorded information on each delivery made by a catcher boat. Therefore the number, sum of the weight of the haul and duration of fishing events using "mothership gear", are the values reported by catcher vessels. Data from the foreign fisheries do not distinguish

between pelagic and non-pelagic trawl gear, but rather divide trawl boats by their size. The combination of small boats and non-pelagic trawls and large boats with pelagic trawl is therefore probably not strictly an accurate characterization of the gear used. However, there is very little overlap between the foreign and domestic fisheries in the time periods used in this analysis. Domestic data do not contribute much information until 1990, so there is only one year of overlap between the designations "small" with "non-pelagic" and "large" with "pelagic".

The timing of fisheries removals may be important, so the fishing data were also stratified by season. December, January and February collectively are referred to as 'winter', March, April and May are 'spring', June, July and August are 'summer' and September, October and November are 'fall'. Because there are many possibilities for stratification in this dataset, many analyses of the same sets of variables were necessary. Abbreviations of the variable names are often used in this document to save time and space, when reporting particular results. Table 1 lists those abbreviations.

Table 1. List of Abbreviations Used.

num1	number of fishing events from 1977 - 1991
sum1	sum of the weight of hauls from 1977 - 1991
dur1	duration (time gear is at fishign depth) per haul from 1977 - 1991
CPU1	sum1 divided by dur1
num2	number of fishing events from 1991 - 2000
sum2	sum of the weight of hauls from 1991 - 2000
dur2	duration (time gear is at fishign depth) per haul from 1991 - 2000
CPU2	sum2 divided by dur2
Tnum	number of fishing events from 1977 - 2000
Tsum	sum of the weight of hauls from 1977 - 2000
Tdur	duration (time gear is at fishign depth) per haul from 1977 - 2000
TCPU	Tsum divided by Tdur

Table 1. Continued.

mship	mothership fishing
smtrl	non-pelagic trawl fishing
lgtrl	pelagic trawl fishing
pt_hk	pot or trap fishing
lngln	longline fishing
pl_wt	weight of walleye pollock
plnum	number of walleye pollock
cd_wt	weight of Pacific cod
cdnum	number of Pacific cod
at_wt	weight of Atka mackerel
atnum	number of Atka mackerel
winte	winter (December, January, February)
sprin	spring (March, April, May)
summ	summer (June, July, August)
fall	fall (Spetmeber, October, November)

The fishing variables are not normally distributed. There are many near zero values and a few very large values. The ranked fishing variables (ranks of values) were often substituted for the raw variable values, to allow for non-linearity in relationships.

Fishing that occurred from 1977-1991 was compared to the SSL slope estimates for the years YFC - 1991, where YFC is the year of first (accepted) census at that site.

Fishing that occurred from 1991 - 2000, 1977-1991 and 1977-2000 was compared to the slope estimates for the years 1991 - 2001 at each site. Note that these estimates will vary slightly, depending on which starting point for the earlier slope estimate was used, based on differences in the 1991 intercept estimate.

SSL decline estimates were compared with fishing variables using linear regression. Some fishing variables tend to be very large in value, while the slope

estimates based on the natural log of SSL population are near zero. Therefore, all variables were standardized to have a mean of zero and a standard deviation of one. The p-values in this stage of the analysis tested whether the regression coefficient corresponding to each predictor variable was different from zero.

The principal components (derived from a principal components analysis (PCA), see appendix D for a discussion of PCA) of available fishing variables that occurred before or during each segment of the SSL population decline were used as predictors of each respective SSL population slope estimate, in a series of multiple linear regressions (MLR).

<div align="center">Results</div>

Simple Linear Regression

1977 – 1991 Fishing as a Predictor of YFC – 1991 SSL Population Trend. Table 2 shows the results of a linear regression using 1977 - 1991 fishing events, individually, as predictors of YFC (50's) - 1991 SSL population trend. Any slope coefficients that were significantly different from 0, at the $\alpha = 0.05$ level, are in bold. The slope in this case represents the relative increase in decline rate, per unit fishing.

Table 2. Fishing From 1977 - 1991 vs. YFC (50's) - 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 10 km	num1	**-0.44**	**0.01**	**-0.713**	**-0.166**	**16.75%**
0 - 10 km	sum1	**-0.374**	**0.032**	**-0.656**	**-0.092**	**11.21%**

Table 2. Continued.

0 - 10 km	dur1	-0.323	0.067	-0.611	-0.035	7.55%
0 - 10 km	CPU1	0.191	0.287	-0.108	0.49	0.53%
0 - 20 km	num1	**-0.495**	**0.003**	**-0.76**	**-0.231**	**22.09%**
0 - 20 km	sum1	**-0.422**	**0.014**	**-0.698**	**-0.146**	**15.19%**
0 - 20 km	dur1	**-0.424**	**0.014**	**-0.7**	**-0.148**	**15.30%**
0 - 20 km	CPU1	**-0.41**	**0.018**	**-0.688**	**-0.132**	**14.13%**
0 - 30 km	num1	**-0.433**	**0.012**	**-0.708**	**-0.159**	**16.13%**
0 - 30 km	sum1	-0.308	0.081	-0.598	-0.018	6.56%
0 - 30 km	dur1	-0.31	0.079	-0.599	-0.02	6.68%
0 - 30 km	CPU1	-0.185	0.302	-0.485	0.114	0.32%
0 - 50 km	num1	-0.315	0.074	-0.604	-0.026	7.03%
0 - 50 km	sum1	-0.177	0.325	-0.477	0.123	0.00%
0 - 50 km	dur1	-0.21	0.24	-0.508	0.088	1.34%
0 - 50 km	CPU1	-0.129	0.474	-0.431	0.173	0.00%
0 - 100 km	num1	-0.199	0.266	-0.498	0.099	0.88%
0 - 100 km	sum1	-0.118	0.512	-0.421	0.184	0.00%
0 - 100 km	dur1	-0.117	0.516	-0.42	0.185	0.00%
0 - 100 km	CPU1	-0.287	0.105	-0.579	0.004	5.29%
10 - 20 km	num1	**-0.49**	**0.004**	**-0.756**	**-0.225**	**21.60%**
10 - 20 km	sum1	**-0.422**	**0.014**	**-0.698**	**-0.146**	**15.17%**
10 - 20 km	dur1	**-0.404**	**0.02**	**-0.683**	**-0.126**	**13.64%**
10 - 20 km	CPU1	0.014	0.938	-0.291	0.318	0.00%
10 - 30 km	num1	**-0.421**	**0.015**	**-0.698**	**-0.145**	**15.10%**
10 - 30 km	sum1	-0.298	0.092	-0.589	-0.008	5.96%
10 - 30 km	dur1	-0.297	0.093	-0.588	-0.006	5.87%
10 - 30 km	CPU1	-0.173	0.334	-0.473	0.126	0.00%
20 - 30 km	num1	-0.341	0.052	-0.627	-0.054	8.75%
20 - 30 km	sum1	-0.199	0.267	-0.497	0.1	0.86%
20 - 30 km	dur1	-0.233	0.193	-0.529	0.064	2.36%
20 - 30 km	CPU1	-0.112	0.534	-0.415	0.19	0.00%

There are several significant (negative) relationships in Table 2. Number

of fishing events from 1977 - 1991 (num1) is a significant predictor of SSL

decline from YFC - 1991 (50's) for distances of 0 - 10 km, 0 - 20 km, 0 - 30 km, and 10 - 20 km and 10 - 30 km. The highest R^2 value for number of fishing events is 22.1% at a distance of 0 - 20 km from SSL rookeries. Tons of total fish removed (catch + bycatch) from 1977 - 1991 (sum1) is a significant predictor of SSL decline from YFC - 1991 (50's) for distances of 0 - 10 km, 0 - 20 km, and 10 - 20 km. The highest R^2 value for tons of total fish removed is 15.2% for a distance of 0 -20 km. The total duration that gear was at fishing depth from 1977 – 1991 (dur1) is a significant predictor of SSL decline from YFC - 1991 (50's) for distances of 0 - 20 km, and 10 - 20 km. The highest R^2 value for duration is 15.3% at 0 - 20 km.   CPU1, or tons of total fish removed (catch + bycatch) from 1977 – 1991, divided by the total duration that gear was at fishing depth from 1977 – 1991, is a significant predictor of SSL decline from YFC - 1991 (50's) at a distance of 0 - 20 km. The R^2 value in that regression is 14.1%.

Table 3 shows the linear regression of 1977 - 1991 fishing events and YFC- 1991 (no 50's) SSL population trend. Only regressions resulting in slope coefficients that were significant, or near significant at the $\alpha = 0.05$ level are shown.

Table 3. Fishing From 1977 - 1991 vs. YFC - 1991 (no 50's) Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 10 km	num1	**-0.397**	**0.022**	**-0.677**	**-0.118**	**13.08%**
0 - 10 km	sum1	-0.337	0.055	-0.624	-0.05	8.50%
0 - 20 km	num1	**-0.431**	**0.012**	**-0.705**	**-0.156**	**15.91%**
0 - 20 km	sum1	**-0.359**	**0.04**	**-0.644**	**-0.075**	**10.11%**

Table 3. Continued.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 20 km	dur1	-0.331	0.06	-0.619	-0.044	8.11%
0 - 20 km	CPU1	**-0.367**	**0.035**	**-0.651**	**-0.084**	**10.71%**
0 - 30 km	num1	**-0.351**	**0.045**	**-0.636**	**-0.065**	**9.46%**
10 - 20 km	num1	**-0.424**	**0.014**	**-0.7**	**-0.148**	**15.35%**
10 - 20 km	sum1	**-0.357**	**0.041**	**-0.641**	**-0.072**	**9.92%**
10 - 20 km	dur1	-0.314	0.075	-0.603	-0.025	6.95%
10 - 30 km	num1	-0.339	0.054	-0.625	-0.052	8.60%

All the slope coefficients in Table 3 are negative. Num1 is a significant predictor of SSL population trend at distances of 0 - 10 km, 0 - 20 km, 0 - 30 km, and 10 - 20 km. Num1 can explain 15.9% of the variation in SSL population trend at 0 - 20 km. Sum1 is a significant predictor of SSL population trend at distances of 0 - 20 km, and 10 - 20 km. Sum1 can explain 10.1% of the total variation in SSL population trend. CPU1 is significant at 0 - 20 km and explains 10.7% of the variation in SSL population trend.

Table 4 shows the linear regression of 1977 - 1991 fishing events on 1977 - 1991 SSL decline. Only regressions resulting in slope coefficients that were significant, or near significant at the $\alpha = 0.05$ level are shown.

Table 4. Fishing From 1977 - 1991 vs. 1977 - 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 10 km	num1	**-0.41**	**0.02**	**-0.692**	**-0.127**	**14.00%**
0 - 10 km	sum1	-0.34	0.057	-0.631	-0.048	8.60%
0 - 20 km	num1	**-0.45**	**0.01**	**-0.727**	**-0.173**	**17.57%**
0 - 20 km	sum1	**-0.373**	**0.036**	**-0.66**	**-0.085**	**11.03%**
0 - 20 km	dur1	-0.311	0.084	-0.605	-0.016	6.63%
0 - 30 km	num1	**-0.396**	**0.025**	**-0.681**	**-0.112**	**12.90%**

Table 4. Continued.

distance	fish var	Slope coefficient	p-value (slope)	LCI	UCI	adj. R²
10 - 20 km	num1	**-0.444**	**0.011**	**-0.721**	**-0.166**	**17.02%**
10 - 20 km	sum1	**-0.371**	**0.036**	**-0.659**	**-0.084**	**10.92%**
10 - 20 km	dur1	-0.302	0.093	-0.597	-0.006	6.08%
10 - 30 km	num1	**-0.385**	**0.03**	**-0.671**	**-0.099**	**11.99%**
20 - 30 km	num1	-0.314	0.08	-0.608	-0.02	6.85%

Table 4 shows several significant, negative relationships. Num1 is a significant predictor of SSL population trend from 1977 - 1991 at distances of 0 - 10 km, 0 - 20 km, 0 - 30 km, 10 - 20 km and 10 - 30 km, from SSL rookeries. Sum1 is a significant predictor of SSL population trend from 1977 - 1991, at distances of 0 - 20 km, and 10 - 20 km. Dur1 and CPU1 are not significant predictors of SSL population trend from 1977 - 1991, at any of the distances tested. Num1 and sum1 at 0 - 20 km can explain 17.6% and 11.0% of the variation in SSL population trend from 1977 – 1991, respectively.

These regressions produce slightly different results when the ranked fishing variables are substituted for the raw fishing variables. Table 5 shows the linear regression of ranked 1977 - 1991 fishing events on YFC - 1991 (50's) SSL decline. Only regressions resulting in slope coefficients that were significant, or near significant at the $\alpha = 0.05$ level are shown.

Table 5. Ranked Fishing From 1977 – 1991 vs. YFC (50's) – 1991 Slope estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 10 km	num1	**-0.487**	**0.004**	**-0.753**	**-0.221**	**21.26%**
0 - 10 km	sum1	**-0.409**	**0.018**	**-0.687**	**-0.132**	**14.08%**

Table 5. Continued.

0 - 10 km	dur1	**-0.436**	**0.011**	**-0.71**	**-0.162**	**16.44%**
0 - 10 km	CPU1	-0.327	0.063	-0.615	-0.039	7.82%
0 - 20 km	num1	**-0.589**	**0**	**-0.835**	**-0.343**	**32.57%**
0 - 20 km	sum1	**-0.535**	**0.001**	**-0.792**	**-0.278**	**26.32%**
0 - 20 km	dur1	**-0.49**	**0.004**	**-0.755**	**-0.224**	**21.53%**
0 - 20 km	CPU1	**-0.544**	**0.001**	**-0.8**	**-0.289**	**27.35%**
0 - 30 km	num1	**-0.521**	**0.002**	**-0.781**	**-0.261**	**24.81%**
0 - 30 km	sum1	**-0.459**	**0.007**	**-0.729**	**-0.188**	**18.51%**
0 - 30 km	dur1	**-0.441**	**0.01**	**-0.714**	**-0.167**	**16.81%**
0 - 30 km	CPU1	-0.341	0.052	-0.627	-0.054	8.75%
0 - 50 km	num1	**-0.486**	**0.004**	**-0.752**	**-0.22**	**21.19%**
0 - 50 km	sum1	**-0.362**	**0.039**	**-0.646**	**-0.078**	**10.28%**
0 - 50 km	dur1	**-0.374**	**0.032**	**-0.656**	**-0.091**	**11.19%**
0 - 100 km	num1	**-0.362**	**0.038**	**-0.646**	**-0.078**	**10.29%**
0 - 100 km	sum1	-0.324	0.066	-0.612	-0.036	7.62%
0 - 100 km	CPU1	**-0.353**	**0.044**	**-0.638**	**-0.068**	**9.65%**
10 - 20 km	num1	**-0.591**	**0**	**-0.836**	**-0.345**	**32.79%**
10 - 20 km	sum1	**-0.545**	**0.001**	**-0.8**	**-0.29**	**27.46%**
10 - 20 km	dur1	**-0.492**	**0.004**	**-0.757**	**-0.227**	**21.79%**
10 - 20 km	CPU1	**-0.487**	**0.004**	**-0.753**	**-0.221**	**21.24%**
10 - 30 km	num1	**-0.508**	**0.003**	**-0.77**	**-0.246**	**23.40%**
10 - 30 km	sum1	**-0.446**	**0.009**	**-0.718**	**-0.173**	**17.29%**
10 - 30 km	dur1	**-0.426**	**0.013**	**-0.702**	**-0.151**	**15.51%**
10 - 30 km	CPU1	**-0.343**	**0.05**	**-0.629**	**-0.057**	**8.94%**
20 - 30 km	num1	**-0.449**	**0.009**	**-0.721**	**-0.177**	**17.62%**
20 - 30 km	sum1	**-0.426**	**0.014**	**-0.701**	**-0.15**	**15.48%**
20 - 30 km	dur1	**-0.393**	**0.024**	**-0.673**	**-0.113**	**12.75%**

Table 5 shows several significant, negative slope estimates. The largest

R^2 value of 32.8% comes from a regression of num1 at 10 - 20 km from SSL

rookeries.

Table 6 shows the linear regression of ranked 1977 - 1991 fishing events on YFC - 1991 (no 50's) SSL decline. Only regressions resulting in slope coefficients that were significant, or near significant at the $\alpha = 0.05$ level are shown.

Table 6. Ranked Fishing From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 10 km	num1	**-0.472**	**0.006**	**-0.741**	**-0.204**	**19.81%**
0 - 10 km	sum1	**-0.437**	**0.011**	**-0.711**	**-0.163**	**16.50%**
0 - 10 km	dur1	**-0.413**	**0.017**	**-0.691**	**-0.136**	**14.41%**
0 - 10 km	CPU1	**-0.355**	**0.043**	**-0.639**	**-0.070**	**9.77%**
0 - 20 km	num1	**-0.501**	**0.003**	**-0.764**	**-0.237**	**22.66%**
0 - 20 km	sum1	**-0.431**	**0.012**	**-0.705**	**-0.156**	**15.91%**
0 - 20 km	dur1	**-0.374**	**0.032**	**-0.656**	**-0.091**	**11.18%**
0 - 20 km	CPU1	**-0.481**	**0.005**	**-0.748**	**-0.214**	**20.63%**
0 - 30 km	num1	**-0.391**	**0.025**	**-0.671**	**-0.110**	**12.52%**
0 - 30 km	sum1	**-0.350**	**0.046**	**-0.635**	**-0.064**	**9.39%**
0 - 50 km	num1	**-0.410**	**0.018**	**-0.688**	**-0.133**	**14.16%**
10 - 20 km	num1	**-0.502**	**0.003**	**-0.766**	**-0.239**	**22.82%**
10 - 20 km	sum1	**-0.444**	**0.010**	**-0.717**	**-0.171**	**17.15%**
10 - 20 km	dur1	**-0.364**	**0.037**	**-0.648**	**-0.081**	**10.47%**
10 - 20 km	CPU1	**-0.438**	**0.011**	**-0.712**	**-0.164**	**16.56%**
10 - 30 km	num1	**-0.381**	**0.029**	**-0.663**	**-0.100**	**11.77%**
10 - 30 km	sum1	-0.329	0.062	-0.616	-0.041	7.92%
20 - 30 km	num1	-0.339	0.053	-0.626	-0.053	8.67%

Table 6 shows several significant, negative slope estimates. The largest R^2 value of 22.8% comes from a regression of num1, at 10 - 20 km from SSL rookeries.

Table 7 shows the linear regression of ranked 1977 - 1991 fishing events on 1977 - 1991 SSL decline. Only regressions resulting in slope coefficients that were significant, or near significant at the $\alpha = 0.05$ level are shown.

Table 7. Ranked Fishing From 1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 10 km	num1	-0.319	0.075	-0.613	-0.026	7.20%
0 - 10 km	sum1	-0.305	0.089	-0.600	-0.010	6.31%
0 - 20 km	num1	**-0.413**	**0.019**	**-0.695**	**-0.130**	**14.25%**
0 - 20 km	sum1	-0.316	0.078	-0.610	-0.022	6.98%
0 - 20 km	CPU1	**-0.380**	**0.032**	**-0.666**	**-0.093**	**11.57%**
0 - 30 km	num1	**-0.412**	**0.019**	**-0.695**	**-0.130**	**14.24%**
0 - 50 km	num1	**-0.402**	**0.023**	**-0.685**	**-0.118**	**13.33%**
10 - 20 km	num1	**-0.418**	**0.017**	**-0.700**	**-0.137**	**14.73%**
10 - 20 km	sum1	-0.335	0.061	-0.627	-0.043	8.24%
10 - 20 km	CPU1	-0.329	0.066	-0.622	-0.037	7.88%
10 - 30 km	num1	**-0.402**	**0.023**	**-0.686**	**-0.118**	**13.37%**
20 - 30 km	num1	**-0.431**	**0.014**	**-0.710**	**-0.151**	**15.84%**
20 - 30 km	dur1	-0.303	0.092	-0.598	-0.007	6.13%

Table 7 shows several significant, negative slope estimates. The largest R^2 value of 15.8% comes from a regression of num1, at 20 - 30 km from SSL rookeries.

Regressions using fishing measures at 10 – 20 km and 0 – 20 km from SSL rookeries, in summer and fall, with small/non-pelagic trawl gear as

predictors of YFC – 1991 SSL population trend, were consistently significant,

regardless of the YFC used.

Tables 8 - 22 show the results of regressions using small/non-pelagic trawl

fishing during the summer and fall, to predict SSL population trend from YFC –

1991. The regressions in tables 8 - 22 are further broken down by species type.

Table 8. Ranked Summer, Pollock, Small/Non-pelagic Trawl Fishing
From 1977 – 1991 vs. YFC (50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 20 km	num1	**-0.509**	**0.003**	**-0.775**	**-0.242**	**23.39%**
0 - 20 km	sum1	**-0.467**	**0.007**	**-0.741**	**-0.193**	**19.20%**
0 - 20 km	ind1	**-0.467**	**0.007**	**-0.741**	**-0.193**	**19.20%**
0 - 20 km	dur1	**-0.467**	**0.007**	**-0.741**	**-0.193**	**19.20%**
0 - 20 km	CPU1	-0.345	0.053	-0.636	-0.055	9.00%
10 - 20 km	num1	**-0.526**	**0.002**	**-0.789**	**-0.262**	**25.22%**
10 - 20 km	sum1	**-0.467**	**0.007**	**-0.741**	**-0.193**	**19.19%**
10 - 20 km	ind1	**-0.481**	**0.005**	**-0.753**	**-0.210**	**20.60%**
10 - 20 km	dur1	**-0.476**	**0.006**	**-0.748**	**-0.203**	**20.07%**
10 - 20 km	CPU1	-0.345	0.053	-0.636	-0.054	8.97%

Table 8 shows that the regressions using the 10 – 20 km distance variables

had higher R^2 values than the regressions using the 0 – 20 km distance variables.

This implies that the 0 – 10 km distance variables are not adding mush useful

information to the regression. The following tables will show only the results

from the regressions on the 10 – 20 km variables, unless the R^2 values for other

regressions are higher.

Table 9. Ranked Summer, Pollock, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.474**	**0.005**	**-0.742**	**-0.206**	**19.99%**
10 - 20 km	sum1	**-0.454**	**0.008**	**-0.726**	**-0.183**	**18.08%**
10 - 20 km	ind1	**-0.465**	**0.006**	**-0.735**	**-0.195**	**19.09%**
10 - 20 km	dur1	**-0.435**	**0.011**	**-0.709**	**-0.160**	**16.28%**
10 - 20 km	CPU1	**-0.417**	**0.016**	**-0.694**	**-0.141**	**14.76%**

Table 10. Ranked Summer, Pollock, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.513**	**0.003**	**-0.784**	**-0.243**	**23.83%**
10 - 20 km	sum1	**-0.456**	**0.010**	**-0.737**	**-0.175**	**18.07%**
10 - 20 km	ind1	**-0.470**	**0.008**	**-0.749**	**-0.192**	**19.41%**
10 - 20 km	dur1	**-0.458**	**0.010**	**-0.738**	**-0.177**	**18.21%**
10 - 20 km	CPU1	**-0.419**	**0.019**	**-0.705**	**-0.132**	**14.69%**

Table 11. Ranked Fall, Pollock, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. YFC (50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.381**	**0.032**	**-0.667**	**-0.094**	**11.64%**
10 - 20 km	sum1	**-0.440**	**0.012**	**-0.718**	**-0.161**	**16.64%**
10 - 20 km	ind1	**-0.446**	**0.010**	**-0.724**	**-0.169**	**17.26%**
10 - 20 km	dur1	**-0.398**	**0.024**	**-0.682**	**-0.114**	**13.04%**
10 - 20 km	CPU1	**-0.519**	**0.002**	**-0.784**	**-0.254**	**24.51%**

Table 12. Ranked Fall, Pollock, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.419**	**0.015**	**-0.695**	**-0.142**	**14.87%**
10 - 20 km	sum1	**-0.457**	**0.008**	**-0.728**	**-0.186**	**18.33%**
10 - 20 km	ind1	**-0.450**	**0.009**	**-0.722**	**-0.178**	**17.69%**
10 - 20 km	dur1	**-0.427**	**0.013**	**-0.702**	**-0.152**	**15.59%**
10 - 20 km	CPU1	**-0.494**	**0.004**	**-0.758**	**-0.229**	**21.93%**

Table 13. Ranked Fall, Pollock, Small/Non-pelagic Trawl Fishing From
1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.488**	**0.005**	**-0.764**	**-0.213**	**21.22%**
10 - 20 km	sum1	**-0.565**	**0.001**	**-0.825**	**-0.305**	**29.59%**
10 - 20 km	ind1	**-0.583**	**0.001**	**-0.839**	**-0.327**	**31.72%**
10 - 20 km	dur1	**-0.513**	**0.003**	**-0.784**	**-0.242**	**23.75%**
10 - 20 km	CPU1	**-0.622**	**0.000**	**-0.869**	**-0.375**	**36.54%**

Table 14. Ranked Summer, Pacific Cod, Small/Non-pelagic Trawl
Fishing From 1977 – 1991 vs. YFC (50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.579**	**0.001**	**-0.832**	**-0.327**	**31.36%**
10 - 20 km	sum1	**-0.549**	**0.001**	**-0.808**	**-0.290**	**27.85%**
10 - 20 km	ind1	**-0.525**	**0.002**	**-0.788**	**-0.261**	**25.11%**
10 - 20 km	dur1	**-0.529**	**0.002**	**-0.792**	**-0.266**	**25.55%**
10 - 20 km	CPU1	**-0.508**	**0.003**	**-0.775**	**-0.241**	**23.34%**

Table 15. Ranked Summer, Pacific Cod, Small/Non-pelagic Trawl
Fishing From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.547**	**0.001**	**-0.802**	**-0.293**	**27.71%**
10 - 20 km	sum1	**-0.553**	**0.001**	**-0.807**	**-0.300**	**28.39%**
10 - 20 km	ind1	**-0.543**	**0.001**	**-0.799**	**-0.288**	**27.24%**
10 - 20 km	dur1	**-0.513**	**0.002**	**-0.775**	**-0.252**	**23.96%**
10 - 20 km	CPU1	**-0.573**	**0.000**	**-0.823**	**-0.323**	**30.66%**

Table 16. Ranked Summer, Pacific Cod, Small/Non-pelagic Trawl
Fishing From 1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.473**	**0.007**	**-0.751**	**-0.195**	**19.72%**
10 - 20 km	sum1	**-0.491**	**0.005**	**-0.766**	**-0.216**	**21.48%**
10 - 20 km	ind1	**-0.480**	**0.006**	**-0.756**	**-0.203**	**20.34%**
10 - 20 km	dur1	**-0.429**	**0.016**	**-0.714**	**-0.144**	**15.57%**
10 - 20 km	CPU1	**-0.522**	**0.003**	**-0.791**	**-0.253**	**24.75%**

Table 17. Ranked Fall, Pacific Cod, Small/Non-pelagic Trawl Fishing
From 1977 – 1991 vs. YFC (50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	-0.337	0.060	-0.628	-0.045	8.37%
10 - 20 km	sum1	**-0.377**	**0.033**	**-0.664**	**-0.090**	**11.34%**
10 - 20 km	ind1	-0.340	0.057	-0.632	-0.049	8.64%
10 - 20 km	dur1	-0.341	0.056	-0.633	-0.050	8.71%
10 - 20 km	CPU1	**-0.427**	**0.015**	**-0.707**	**-0.146**	**15.48%**

Table 18. Ranked Fall, Pacific Cod, Small/Non-pelagic Trawl Fishing
From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.391**	**0.024**	**-0.671**	**-0.111**	**12.55%**
10 - 20 km	sum1	**-0.441**	**0.010**	**-0.714**	**-0.167**	**16.83%**
10 - 20 km	ind1	**-0.423**	**0.014**	**-0.699**	**-0.147**	**15.26%**
10 - 20 km	dur1	**-0.397**	**0.022**	**-0.676**	**-0.117**	**13.02%**
10 - 20 km	CPU1	**-0.480**	**0.005**	**-0.747**	**-0.212**	**20.52%**

Table 19. Ranked Fall, Pacific Cod, Small/Non-pelagic Trawl Fishing
From 1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	**-0.444**	**0.012**	**-0.727**	**-0.162**	**16.98%**
10 - 20 km	sum1	**-0.502**	**0.004**	**-0.775**	**-0.230**	**22.67%**
10 - 20 km	ind1	**-0.475**	**0.007**	**-0.752**	**-0.197**	**19.87%**
10 - 20 km	dur1	**-0.471**	**0.008**	**-0.749**	**-0.192**	**19.46%**
10 - 20 km	CPU1	**-0.503**	**0.004**	**-0.776**	**-0.231**	**22.76%**

Summer small/non-pelagic trawl fishing for Atka mackerel did not yield

consistent significant regressions.

Table 20. Ranked Fall, Atka Mackerel, Small/Non-pelagic Trawl Fishing
From 1977 – 1991 vs. YFC (50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	sum1	**-0.381**	**0.031**	**-0.668**	**-0.095**	**11.69%**
10 - 20 km	ind1	**-0.351**	**0.049**	**-0.641**	**-0.061**	**9.38%**
10 - 20 km	dur1	-0.313	0.082	-0.607	-0.018	6.76%
10 - 20 km	CPU1	**-0.541**	**0.001**	**-0.801**	**-0.280**	**26.86%**

Table 21. Ranked Fall, Atka Mackerel, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. YFC (no 50's) – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	num1	-0.306	0.084	-0.596	-0.016	6.43%
10 - 20 km	sum1	**-0.375**	**0.031**	**-0.657**	**-0.093**	**11.30%**
10 - 20 km	ind1	**-0.348**	**0.047**	**-0.634**	**-0.063**	**9.30%**
10 - 20 km	dur1	-0.318	0.072	-0.607	-0.029	7.20%
10 - 20 km	CPU1	**-0.496**	**0.003**	**-0.760**	**-0.231**	**22.13%**

Table 22. Ranked Fall, Atka Mackerel, Small/Non-pelagic Trawl Fishing From 1977 – 1991 vs. 1977 – 1991 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
10 - 20 km	sum1	-0.315	0.085	-0.614	-0.015	6.79%
10 - 20 km	CPU1	**-0.468**	**0.008**	**-0.747**	**-0.189**	**19.20%**

Near-shore fisheries activity and fish abundance as measured by the fishery, are consistent, significant, negative predictors of each 1977 – 1991 SSL population trend estimate. This relationship is particularly evident when small/non-pelagic trawl fishing in summer and fall are used as predictors.

1977 – 1991 Fishing as a Predictor of 1991 – 2001 SSL Population Trend. CPU of 1977 – 1991 fishing is a significant, positive predictor of SSL population trend, but only when measured at moderate distance from shore. In particular, CPU1 during spring and summer fishing, for pollock and Pacific cod, using trawl gear, at distances of 20 – 30 km, and 0 – 50 km from SSL rookeries demonstrate this relationship. 1977 – 1991 fisheries activity variables are generally not significant predictors of SSL population trend from 1991 – 2001 at any distance.

Table 23. Ranked Large/Pelagic Trawl, Pollock, (All Seasons) Fishing From 1977 – 1991 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	CPU1(50's)	**0.415**	**0.016**	**0.138**	**0.692**	**14.56%**
20 - 30 km	CPU1(no 50's)	**0.397**	**0.022**	**0.118**	**0.677**	**13.07%**
20 - 30 km	CPU1	**0.401**	**0.021**	**0.122**	**0.680**	**13.35%**
0 - 50 km	sum1(50's)	**0.368**	**0.035**	**0.085**	**0.651**	**10.77%**
0 - 50 km	CPU1(50's)	**0.381**	**0.029**	**0.099**	**0.662**	**11.74%**
0 - 50 km	sum1(no 50's)	**0.367**	**0.035**	**0.084**	**0.651**	**10.70%**
0 - 50 km	CPU1(no 50's)	**0.368**	**0.035**	**0.085**	**0.651**	**10.75%**
0 - 50 km	sum1	**0.371**	**0.034**	**0.088**	**0.654**	**10.96%**
0 - 50 km	CPU1	**0.368**	**0.035**	**0.085**	**0.652**	**10.79%**

Table 24. Ranked Spring, Pacific Cod, (All Gear Types) Fishing From 1977 – 1991 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 50 km	CPU1(50's)	**0.434**	**0.012**	**0.159**	**0.708**	**16.20%**
0 - 50 km	CPU1(no 50's)	**0.410**	**0.018**	**0.132**	**0.688**	**14.13%**
0 - 50 km	CPU1	**0.411**	**0.017**	**0.133**	**0.689**	**14.21%**

1977 – 1991 fishing activities variables are not significant predictors of SSL population trend from 1991 – 2001. Offshore fish abundance, as measured by the fishery is a significant, positive predictor of SSL population trend from 1991 – 2001. This relationship is strongest when large/pelagic trawl fishing for pollock and spring Pacific cod fishing are used as predictors.

1991 – 2000 Fishing as a Predictor of 1991 – 2001 SSL Population Trend.

Fishing from 1991 – 2000 is a significant positive predictor of SSL population trend over the same period. The most consistent (meaning that regressions using each of the different SSL population trend estimates show similar results)

relationship occurs when offshore, winter and spring trawl fishing for pollock and

Pacific cod are used as predictors.

Table 25. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.425**	**0.014**	**0.149**	**0.701**	**15.41%**
0 - 100 km	sum2	**0.437**	**0.011**	**0.163**	**0.711**	**16.45%**
0 - 100 km	dur2	**0.416**	**0.016**	**0.139**	**0.693**	**14.61%**
0 - 100 km	CPU2	**0.356**	**0.042**	**0.071**	**0.641**	**9.85%**
0 - 100 km	ind2	**0.449**	**0.009**	**0.177**	**0.721**	**17.56%**

Table 26. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.424**	**0.014**	**0.148**	**0.700**	**15.35%**
0 - 100 km	sum2	**0.427**	**0.013**	**0.151**	**0.702**	**15.58%**
0 - 100 km	ind2	**0.442**	**0.010**	**0.168**	**0.715**	**16.91%**
0 - 100 km	dur2	**0.410**	**0.018**	**0.133**	**0.688**	**14.15%**
0 - 100 km	CPU2	0.319	0.070	0.030	0.608	7.28%

Table 27. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.428**	**0.013**	**0.153**	**0.703**	**15.69%**
0 - 100 km	sum2	**0.429**	**0.013**	**0.154**	**0.704**	**15.77%**
0 - 100 km	dur2	**0.413**	**0.017**	**0.136**	**0.690**	**14.38%**
0 - 100 km	CPU2	0.317	0.072	0.029	0.606	7.17%
0 - 100 km	ind2	**0.444**	**0.010**	**0.171**	**0.717**	**17.13%**

Table 28. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.347**	**0.048**	**0.061**	**0.632**	**9.19%**
0 - 100 km	sum2	0.334	0.058	0.047	0.621	8.28%
0 - 100 km	dur2	**0.347**	**0.048**	**0.061**	**0.633**	**9.20%**
0 - 100 km	CPU2	0.307	0.083	0.017	0.596	6.48%
0 - 100 km	ind2	0.335	0.057	0.048	0.622	8.34%

Table 29. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.387**	**0.026**	**0.106**	**0.668**	**12.22%**
0 - 100 km	sum2	**0.377**	**0.031**	**0.095**	**0.659**	**11.42%**
0 - 100 km	ind2	**0.377**	**0.031**	**0.095**	**0.659**	**11.42%**
0 - 100 km	dur2	**0.384**	**0.027**	**0.103**	**0.665**	**12.01%**
0 - 100 km	CPU2	**0.347**	**0.048**	**0.061**	**0.632**	**9.17%**

Table 30. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	num2	**0.397**	**0.022**	**0.118**	**0.677**	**13.05%**
0 - 100 km	sum2	**0.391**	**0.025**	**0.111**	**0.671**	**12.54%**
0 - 100 km	dur2	**0.392**	**0.024**	**0.112**	**0.672**	**12.67%**
0 - 100 km	CPU2	**0.360**	**0.040**	**0.076**	**0.644**	**10.15%**
0 - 100 km	ind2	**0.384**	**0.027**	**0.102**	**0.665**	**11.97%**

Table 31. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	num2	**0.350**	**0.046**	**0.064**	**0.635**	**9.40%**
20 - 30 km	sum2	0.331	0.060	0.044	0.619	8.10%
20 - 30 km	dur2	**0.348**	**0.047**	**0.062**	**0.633**	**9.27%**
20 - 30 km	CPU2	0.312	0.077	0.023	0.601	6.83%
20 - 30 km	ind2	0.336	0.056	0.050	0.623	8.45%
0 - 50 km	num2	**0.361**	**0.039**	**0.077**	**0.645**	**10.23%**
0 - 50 km	sum2	0.336	0.056	0.049	0.623	8.44%
0 - 50 km	dur2	0.339	0.053	0.053	0.626	8.66%
0 - 50 km	ind2	0.339	0.053	0.053	0.626	8.65%
0 - 100 km	num2	**0.510**	**0.002**	**0.248**	**0.772**	**23.65%**
0 - 100 km	sum2	**0.464**	**0.007**	**0.194**	**0.733**	**18.97%**
0 - 100 km	dur2	**0.502**	**0.003**	**0.239**	**0.766**	**22.84%**
0 - 100 km	ind2	**0.463**	**0.007**	**0.193**	**0.733**	**18.89%**

Table 32. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1991 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	num2	0.316	0.073	0.027	0.605	7.08%
20 - 30 km	sum2	0.297	0.094	0.006	0.587	5.86%
20 - 30 km	dur2	0.317	0.072	0.029	0.606	7.18%
20 - 30 km	ind2	0.303	0.086	0.013	0.593	6.27%
0 - 50 km	num2	**0.349**	**0.046**	**0.064**	**0.635**	**9.36%**
0 - 50 km	sum2	0.322	0.067	0.034	0.611	7.50%
0 - 50 km	dur2	0.326	0.064	0.038	0.613	7.71%
0 - 50 km	ind2	0.323	0.067	0.035	0.611	7.56%
0 - 100 km	num2	**0.457**	**0.007**	**0.186**	**0.728**	**18.34%**
0 - 100 km	sum2	**0.407**	**0.019**	**0.128**	**0.685**	**13.84%**
0 - 100 km	dur2	**0.446**	**0.009**	**0.174**	**0.719**	**17.33%**
0 - 100 km	ind2	**0.403**	**0.020**	**0.124**	**0.681**	**13.52%**

Table 33. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	num2	0.314	0.076	0.024	0.603	6.92%
20 - 30 km	sum2	0.293	0.098	0.002	0.584	5.63%
20 - 30 km	dur2	0.314	0.075	0.025	0.604	6.98%
20 - 30 km	ind2	0.300	0.090	0.010	0.591	6.07%
0 - 50 km	num2	0.348	0.048	0.062	0.633	9.24%
0 - 50 km	sum2	0.322	0.067	0.034	0.611	7.50%
0 - 50 km	dur2	0.324	0.066	0.036	0.612	7.59%
0 - 50 km	ind2	0.323	0.067	0.035	0.611	7.54%
0 - 100 km	sum2	**0.408**	**0.018**	**0.131**	**0.686**	**14.00%**
0 - 100 km	dur2	**0.449**	**0.009**	**0.177**	**0.721**	**17.56%**
0 - 100 km	ind2	**0.405**	**0.019**	**0.127**	**0.683**	**13.70%**

Table 34. Ranked Small/Non-Pelagic Trawl, Spring, Pacific Cod Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	num2	**0.355**	**0.043**	**0.071**	**0.64**	**9.80%**
20 - 30 km	sum2	**0.361**	**0.039**	**0.077**	**0.65**	**10.22%**

Table 34. Continued.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	dur2	**0.362**	**0.039**	**0.078**	**0.65**	**10.28%**
20 - 30 km	CPU2	**0.357**	**0.041**	**0.072**	**0.64**	**9.92%**
20 - 30 km	ind2	**0.362**	**0.038**	**0.079**	**0.65**	**10.34%**
0 - 50 km	num2	**0.343**	**0.05**	**0.057**	**0.629**	**8.94%**
0 - 50 km	sum2	0.23	0.198	-0.066	0.526	2.24%
0 - 50 km	dur2	0.323	0.067	0.034	0.611	7.52%
0 - 100 km	num2	**0.527**	**0.002**	**0.268**	**0.785**	**25.40%**
0 - 100 km	dur2	**0.527**	**0.002**	**0.268**	**0.786**	**25.45%**

Table 35. Ranked Small/Non-Pelagic Trawl, Spring, Pacific Cod Fishing From 1991 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	num2	0.339	0.054	0.05	0.63	0.0861
20 - 30 km	sum2	0.335	0.057	0.05	0.62	0.0836
20 - 30 km	ind2	0.338	0.055	0.05	0.62	0.0854
20 - 30 km	dur2	0.333	0.059	0.05	0.62	0.0819
0 - 50 km	num2	**0.412**	**0.017**	**0.134**	**0.689**	**14.27%**
0 - 50 km	sum2	**0.411**	**0.017**	**0.133**	**0.689**	**14.22%**
0 - 50 km	dur2	**0.406**	**0.019**	**0.128**	**0.684**	**13.79%**
0 - 50 km	CPU2	**0.401**	**0.021**	**0.122**	**0.680**	**13.37%**
0 - 100 km	num2	**0.495**	**0.003**	**0.231**	**0.760**	**22.08%**
0 - 100 km	dur2	**0.490**	**0.004**	**0.225**	**0.756**	**21.57%**

Table 36. Ranked Small/Non-Pelagic Trawl, Spring, Pacific Cod Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	num2	0.324	0.066	0.035	0.61	7.58%
20 - 30 km	sum2	0.337	0.055	0.05	0.62	8.48%
20 - 30 km	dur2	0.333	0.058	0.046	0.62	8.25%
20 - 30 km	CPU2	0.329	0.061	0.042	0.62	7.96%
20 - 30 km	ind2	0.336	0.056	0.049	0.62	8.41%
0 - 100 km	num2	**0.497**	**0.003**	**0.232**	**0.761**	**22.24%**
0 - 100 km	dur2	**0.491**	**0.004**	**0.226**	**0.757**	**21.71%**

Table 37. Ranked Small/Non-Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	num2	0.429	0.013	0.154	0.704	15.80%
0 - 50 km	sum2	0.425	0.014	0.149	0.701	15.41%
0 - 50 km	dur2	0.430	0.013	0.155	0.705	15.85%
0 - 50 km	CPU2	0.407	0.019	0.129	0.685	13.86%
0 - 50 km	ind2	0.411	0.017	0.134	0.689	14.23%

Table 38. Ranked Small/Non-Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991 - 2001(no 50's) Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	num2	0.412	0.017	0.134	0.689	14.27%
0 - 50 km	sum2	0.411	0.017	0.133	0.689	14.22%
0 - 50 km	ind2	0.406	0.019	0.127	0.684	13.76%
0 - 50 km	dur2	0.406	0.019	0.128	0.684	13.79%
0 - 50 km	CPU2	0.401	0.021	0.122	0.680	13.37%

Table 39. Ranked Small/Non-Pelagic Trawl, Winter, Pollock Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	num2	0.413	0.017	0.136	0.690	14.37%
0 - 50 km	sum2	0.412	0.017	0.134	0.689	14.26%
0 - 50 km	dur2	0.407	0.019	0.129	0.685	13.88%
0 - 50 km	CPU2	0.400	0.021	0.121	0.679	13.26%
0 - 50 km	ind2	0.407	0.019	0.129	0.685	13.90%

Table 40. Ranked Small/Non-Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	num2	0.439	0.011	0.165	0.712	16.65%
0 - 50 km	sum2	0.478	0.005	0.210	0.745	20.35%
0 - 50 km	dur2	0.430	0.013	0.155	0.705	15.83%
0 - 50 km	CPU2	0.504	0.003	0.241	0.767	23.03%
0 - 50 km	ind2	0.453	0.008	0.181	0.724	17.95%

Table 41. Ranked Small/Non-Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991 - 2001(no 50's) Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 50 km	num2	**0.415**	**0.016**	**0.138**	**0.692**	**14.59%**
0 - 50 km	sum2	**0.460**	**0.007**	**0.190**	**0.731**	**18.65%**
0 - 50 km	dur2	**0.405**	**0.019**	**0.127**	**0.684**	**13.74%**
0 - 50 km	CPU2	**0.486**	**0.004**	**0.220**	**0.752**	**21.20%**
0 - 50 km	ind2	**0.452**	**0.008**	**0.181**	**0.724**	**17.88%**

Table 42. Ranked Small/Non-Pelagic Trawl, Winter, Pacific Cod Fishing From 1991 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 50 km	num2	**0.416**	**0.016**	**0.139**	**0.693**	**14.65%**
0 - 50 km	sum2	**0.462**	**0.007**	**0.193**	**0.732**	**18.85%**
0 - 50 km	dur2	**0.406**	**0.019**	**0.128**	**0.684**	**13.79%**
0 - 50 km	CPU2	**0.486**	**0.004**	**0.219**	**0.752**	**21.12%**
0 - 50 km	ind2	**0.455**	**0.008**	**0.184**	**0.726**	**18.17%**

Both offshore fishing activity and offshore fish abundance, as measured by the fishery, from 1991 – 2000 are consistent, significant, positive, predictors of SSL population trend from 1991 – 2001. This relationship is particularly evident using winter and spring trawl fishing for pollock and Pacific cod.

<u>1977 – 2000 Fishing as a Predictor of 1991 – 2001 SSL Population Trend</u>.
Fishing over the entire time period, 1977 – 2000, is a significant positive predictor of SSL population trend from 1991 – 2001. All of the significant regressions used distance variables greater than 20 km from SSL rookeries.

Table 43. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.422**	**0.014**	**0.146**	**0.698**	**15.16%**
0 - 100 km	Tsum	**0.456**	**0.008**	**0.184**	**0.727**	**18.19%**
0 - 100 km	Tdur	**0.437**	**0.011**	**0.163**	**0.711**	**16.45%**
0 - 100 km	TCPU	0.337	0.055	0.050	0.623	8.47%
0 - 100 km	Tind	**0.458**	**0.007**	**0.188**	**0.729**	**18.46%**

Table 44. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.421**	**0.015**	**0.145**	**0.697**	**15.09%**
0 - 100 km	Tsum	**0.447**	**0.009**	**0.175**	**0.720**	**17.41%**
0 - 100 km	Tind	**0.454**	**0.008**	**0.182**	**0.725**	**18.03%**
0 - 100 km	Tdur	**0.429**	**0.013**	**0.154**	**0.704**	**15.81%**
0 - 100 km	TCPU	0.299	0.091	0.008	0.589	5.99%

Table 45. Ranked Large/Pelagic Trawl, Winter, Pollock Fishing From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.426**	**0.013**	**0.150**	**0.701**	**15.50%**
0 - 100 km	Tsum	**0.450**	**0.009**	**0.178**	**0.722**	**17.70%**
0 - 100 km	Tdur	**0.433**	**0.012**	**0.159**	**0.708**	**16.16%**
0 - 100 km	TCPU	0.295	0.096	0.004	0.586	5.74%
0 - 100 km	Tind	**0.457**	**0.008**	**0.186**	**0.728**	**18.31%**

Table 46. Ranked Winter, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	0.298	0.092	0.007	0.589	5.94%
20 - 30 km	Tdur	0.306	0.084	0.016	0.596	6.41%
0 - 50 km	Tnum	**0.364**	**0.037**	**0.08**	**0.647**	**10.43%**
0 - 50 km	Tdur	**0.38**	**0.029**	**0.098**	**0.661**	**11.65%**
0 - 100 km	Tnum	0.297	0.093	0.006	0.588	5.88%
0 - 100 km	Tsum	**0.464**	**0.006**	**0.195**	**0.734**	**19.04%**
0 - 100 km	Tdur	**0.367**	**0.035**	**0.084**	**0.651**	**10.70%**
0 - 100 km	TCPU	**0.354**	**0.043**	**0.069**	**0.639**	**9.73%**

Table 46. Continued.

0 - 100 km	Tind	**0.473**	**0.005**	**0.204**	**0.741**	**19.83%**

Table 47. Ranked Winter, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 50 km	Tnum	0.343	0.051	0.056	0.629	8.88%
0 - 50 km	Tdur	**0.354**	**0.043**	**0.069**	**0.639**	**9.71%**
0 - 100 km	Tsum	**0.456**	**0.008**	**0.185**	**0.727**	**18.26%**
0 - 100 km	Tind	**0.465**	**0.006**	**0.196**	**0.735**	**19.11%**
0 - 100 km	Tdur	**0.349**	**0.046**	**0.064**	**0.635**	**9.36%**
0 - 100 km	TCPU	0.341	0.052	0.054	0.627	8.75%

Table 48. Ranked Winter, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 50 km	Tnum	**0.347**	**0.048**	**0.061**	**0.632**	**9.18%**
0 - 50 km	Tdur	**0.359**	**0.040**	**0.075**	**0.643**	**10.10%**
0 - 100 km	Tsum	**0.460**	**0.007**	**0.189**	**0.730**	**18.58%**
0 - 100 km	Tdur	**0.355**	**0.043**	**0.070**	**0.640**	**9.77%**
0 - 100 km	TCPU	0.340	0.053	0.053	0.626	8.70%
0 - 100 km	Tind	**0.468**	**0.006**	**0.199**	**0.737**	**19.42%**

Table 49. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.360**	**0.040**	**0.076**	**0.644**	**10.16%**
0 - 100 km	Tsum	**0.345**	**0.049**	**0.059**	**0.631**	**9.06%**
0 - 100 km	Tdur	0.332	0.059	0.045	0.620	8.19%
0 - 100 km	TCPU	0.306	0.084	0.016	0.596	6.43%
0 - 100 km	Tind	0.328	0.063	0.040	0.615	7.86%

Table 50. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.385**	**0.027**	**0.104**	**0.666**	**12.04%**
0 - 100 km	Tsum	**0.379**	**0.029**	**0.098**	**0.661**	**11.62%**
0 - 100 km	Tind	**0.354**	**0.043**	**0.069**	**0.639**	**9.71%**
0 - 100 km	Tdur	**0.359**	**0.040**	**0.075**	**0.644**	**10.11%**
0 - 100 km	TCPU	0.339	0.054	0.052	0.625	8.62%

Table 51. Ranked Large/Pelagic Trawl, Winter, Pacific Cod Fishing From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
0 - 100 km	Tnum	**0.393**	**0.024**	**0.113**	**0.673**	**12.69%**
0 - 100 km	Tsum	**0.392**	**0.024**	**0.111**	**0.672**	**12.61%**
0 - 100 km	Tdur	**0.368**	**0.035**	**0.085**	**0.651**	**10.74%**
0 - 100 km	TCPU	**0.350**	**0.046**	**0.065**	**0.636**	**9.45%**
0 - 100 km	Tind	**0.365**	**0.037**	**0.081**	**0.648**	**10.51%**

Table 52. Ranked Winter, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.405**	**0.020**	**0.126**	**0.683**	**13.66%**
20 - 30 km	Tsum	**0.420**	**0.015**	**0.144**	**0.696**	**14.99%**
20 - 30 km	Tdur	**0.369**	**0.034**	**0.086**	**0.652**	**10.84%**
20 - 30 km	TCPU	**0.393**	**0.024**	**0.112**	**0.673**	**12.68%**
20 - 30 km	Tind	**0.420**	**0.015**	**0.143**	**0.696**	**14.96%**
0 - 50 km	Tnum	**0.405**	**0.020**	**0.126**	**0.683**	**13.67%**
0 - 50 km	Tsum	**0.485**	**0.004**	**0.218**	**0.751**	**21.02%**
0 - 50 km	Tdur	**0.401**	**0.021**	**0.122**	**0.680**	**13.35%**
0 - 50 km	TCPU	**0.409**	**0.018**	**0.132**	**0.687**	**14.08%**
0 - 50 km	Tind	**0.468**	**0.006**	**0.199**	**0.737**	**19.43%**
0 - 100 km	TCPU	0.329	0.061	0.042	0.617	7.98%

Table 53. Ranked Winter, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.372**	**0.033**	**0.089**	**0.654**	**11.02%**
20 - 30 km	Tsum	**0.377**	**0.03**	**0.095**	**0.659**	**11.47%**

Table 53. Continued.

20 - 30 km	Tind	**0.383**	**0.028**	**0.101**	**0.664**	**11.88%**
20 - 30 km	Tdur	0.339	0.053	0.053	0.626	8.65%
20 - 30 km	TCPU	0.322	0.068	0.033	0.61	7.46%
0 - 50 km	Tnum	**0.391**	**0.024**	**0.111**	**0.671**	**12.55%**
0 - 50 km	Tsum	**0.461**	**0.007**	**0.19**	**0.731**	**18.69%**
0 - 50 km	Tind	**0.451**	**0.008**	**0.179**	**0.723**	**17.77%**
0 - 50 km	Tdur	**0.384**	**0.027**	**0.103**	**0.665**	**11.97%**
0 - 50 km	TCPU	**0.365**	**0.037**	**0.081**	**0.648**	**10.49%**

Table 54. Ranked Winter, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.370**	**0.034**	**0.087**	**0.652**	**10.87%**
20 - 30 km	Tsum	**0.375**	**0.031**	**0.093**	**0.657**	**11.30%**
20 - 30 km	Tdur	0.340	0.053	0.053	0.626	8.68%
20 - 30 km	TCPU	0.314	0.075	0.025	0.603	6.94%
20 - 30 km	Tind	**0.381**	**0.029**	**0.100**	**0.663**	**11.78%**
0 - 50 km	Tnum	**0.393**	**0.024**	**0.113**	**0.673**	**12.70%**
0 - 50 km	Tsum	**0.461**	**0.007**	**0.191**	**0.732**	**18.75%**
0 - 50 km	Tdur	**0.389**	**0.025**	**0.108**	**0.669**	**12.36%**
0 - 50 km	TCPU	**0.357**	**0.042**	**0.072**	**0.641**	**9.92%**
0 - 50 km	Tind	**0.453**	**0.008**	**0.181**	**0.724**	**17.95%**

Table 55. Ranked Spring, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.443**	**0.010**	**0.170**	**0.716**	**17.04%**
20 - 30 km	Tsum	**0.509**	**0.003**	**0.246**	**0.771**	**23.47%**
20 - 30 km	Tdur	**0.434**	**0.012**	**0.160**	**0.709**	**16.26%**
20 - 30 km	TCPU	**0.351**	**0.045**	**0.066**	**0.636**	**9.49%**
20 - 30 km	Tind	**0.524**	**0.002**	**0.264**	**0.783**	**25.08%**
0 - 50 km	Tnum	**0.394**	**0.023**	**0.114**	**0.674**	**12.79%**
0 - 50 km	Tsum	**0.391**	**0.025**	**0.110**	**0.671**	**12.53%**
0 - 50 km	Tdur	**0.390**	**0.025**	**0.109**	**0.670**	**12.44%**
0 - 50 km	Tind	**0.478**	**0.005**	**0.211**	**0.746**	**20.39%**

Table 56. Ranked Spring, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	Tnum	**0.393**	**0.024**	**0.113**	**0.673**	**12.72%**
20 - 30 km	Tsum	**0.471**	**0.006**	**0.202**	**0.739**	**19.63%**
20 - 30 km	Tind	**0.482**	**0.004**	**0.215**	**0.749**	**20.76%**
20 - 30 km	Tdur	**0.394**	**0.023**	**0.114**	**0.674**	**12.78%**
20 - 30 km	TCPU	0.342	0.052	0.055	0.628	8.83%
0 - 50 km	Tnum	**0.358**	**0.041**	**0.073**	**0.642**	**9.97%**
0 - 50 km	Tsum	**0.348**	**0.047**	**0.062**	**0.633**	**9.25%**
0 - 50 km	Tind	**0.446**	**0.009**	**0.173**	**0.718**	**17.29%**
0 - 50 km	Tdur	**0.353**	**0.044**	**0.068**	**0.638**	**9.63%**

Table 57. Ranked Spring, Pacific Cod Fishing (All Gear Types) From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	Tnum	**0.388**	**0.026**	**0.107**	**0.669**	**12.32%**
20 - 30 km	Tsum	**0.464**	**0.007**	**0.194**	**0.734**	**19.01%**
20 - 30 km	Tdur	**0.391**	**0.024**	**0.111**	**0.671**	**12.57%**
20 - 30 km	TCPU	0.330	0.061	0.042	0.617	8.00%
20 - 30 km	Tind	**0.477**	**0.005**	**0.209**	**0.744**	**20.21%**
0 - 50 km	Tnum	**0.353**	**0.044**	**0.068**	**0.638**	**9.64%**
0 - 50 km	Tsum	0.343	0.051	0.057	0.629	8.90%
0 - 50 km	Tdur	**0.349**	**0.046**	**0.064**	**0.635**	**9.37%**
0 - 50 km	Tind	**0.442**	**0.010**	**0.168**	**0.715**	**16.91%**

Table 58. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	Tnum	**0.369**	**0.035**	**0.086**	**0.652**	**10.84%**
0 - 50 km	Tsum	0.343	0.051	0.057	0.629	8.93%
0 - 50 km	Tdur	**0.400**	**0.021**	**0.121**	**0.679**	**13.26%**
0 - 50 km	Tind	**0.353**	**0.044**	**0.069**	**0.638**	**9.67%**
0 - 100 km	Tnum	0.322	0.068	0.033	0.610	7.46%
0 - 100 km	Tsum	**0.468**	**0.006**	**0.199**	**0.737**	**19.42%**
0 - 100 km	Tdur	**0.362**	**0.038**	**0.078**	**0.646**	**10.30%**
0 - 100 km	Tind	**0.486**	**0.004**	**0.219**	**0.752**	**21.11%**

Table 59. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	Tnum	**0.353**	**0.044**	**0.068**	**0.638**	**9.66%**
0 - 50 km	Tsum	**0.349**	**0.047**	**0.063**	**0.634**	**9.33%**
0 - 50 km	Tind	**0.364**	**0.037**	**0.080**	**0.647**	**10.44%**
0 - 50 km	Tdur	**0.386**	**0.027**	**0.105**	**0.667**	**12.15%**
0 - 100 km	Tsum	**0.438**	**0.011**	**0.165**	**0.712**	**16.60%**
0 - 100 km	Tind	**0.457**	**0.008**	**0.186**	**0.728**	**18.32%**
0 - 100 km	Tdur	0.304	0.086	0.014	0.594	6.29%

Table 60. Ranked Large/Pelagic Trawl, Spring, Pollock Fishing From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
0 - 50 km	Tnum	**0.353**	**0.044**	**0.068**	**0.638**	**9.60%**
0 - 50 km	Tsum	**0.353**	**0.044**	**0.068**	**0.638**	**9.62%**
0 - 50 km	Tdur	**0.384**	**0.027**	**0.103**	**0.665**	**11.98%**
0 - 50 km	Tind	**0.367**	**0.036**	**0.084**	**0.650**	**10.66%**
0 - 100 km	Tsum	**0.441**	**0.010**	**0.168**	**0.715**	**16.88%**
0 - 100 km	Tdur	0.304	0.085	0.014	0.594	6.33%
0 - 100 km	Tind	**0.459**	**0.007**	**0.188**	**0.729**	**18.49%**

Table 61. Ranked Spring, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991(50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R²
20 - 30 km	Tnum	**0.411**	**0.017**	**0.133**	**0.689**	**14.22%**
20 - 30 km	Tsum	**0.363**	**0.038**	**0.080**	**0.647**	**10.41%**
20 - 30 km	Tdur	**0.415**	**0.016**	**0.138**	**0.692**	**14.53%**
20 - 30 km	Tind	**0.357**	**0.041**	**0.072**	**0.641**	**9.92%**
0 - 50 km	Tnum	**0.368**	**0.035**	**0.085**	**0.651**	**10.73%**
0 - 50 km	Tsum	0.342	0.051	0.056	0.628	8.87%
0 - 50 km	Tdur	0.331	0.060	0.043	0.618	8.06%
0 - 50 km	Tind	**0.346**	**0.049**	**0.060**	**0.631**	**9.11%**
0 - 100 km	Tsum	**0.501**	**0.003**	**0.238**	**0.765**	**22.71%**
0 - 100 km	Tdur	0.340	0.053	0.053	0.626	8.69%
0 - 100 km	TCPU	**0.439**	**0.011**	**0.166**	**0.713**	**16.70%**

Table 61. Continued.

0 - 100 km	Tind	**0.498**	**0.003**	**0.234**	**0.762**	**22.42%**

Table 62. Ranked Spring, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991(no 50's) - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.374**	**0.032**	**0.092**	**0.657**	**11.24%**
20 - 30 km	Tsum	0.340	0.053	0.054	0.627	8.72%
20 - 30 km	Tind	0.334	0.057	0.047	0.621	8.30%
20 - 30 km	Tdur	**0.381**	**0.029**	**0.099**	**0.662**	**11.74%**
0 - 50 km	Tnum	**0.343**	**0.050**	**0.057**	**0.629**	**8.95%**
0 - 50 km	Tsum	0.325	0.065	0.037	0.613	7.71%
0 - 50 km	Tind	0.331	0.060	0.043	0.618	8.05%
0 - 50 km	Tdur	0.314	0.076	0.024	0.603	6.93%
0 - 100 km	Tsum	**0.461**	**0.007**	**0.190**	**0.731**	**18.68%**
0 - 100 km	Tind	**0.467**	**0.006**	**0.198**	**0.737**	**19.31%**
0 - 100 km	Tdur	0.308	0.081	0.019	0.598	6.59%
0 - 100 km	TCPU	**0.410**	**0.018**	**0.132**	**0.688**	**14.12%**

Table 63. Ranked Spring, Pollock Fishing (All Gear Types) From 1977 – 2000 vs. 1991 - 2001 Slope Estimates.

distance	fish var	Slope coefficient (β)	p-value (slope)	LCI	UCI	adj. R^2
20 - 30 km	Tnum	**0.370**	**0.034**	**0.087**	**0.653**	**10.92%**
20 - 30 km	Tsum	0.338	0.054	0.052	0.625	8.59%
20 - 30 km	Tdur	**0.378**	**0.030**	**0.096**	**0.660**	**11.55%**
20 - 30 km	Tind	0.332	0.059	0.045	0.620	8.18%
0 - 50 km	Tnum	0.343	0.051	0.057	0.629	8.90%
0 - 50 km	Tsum	0.325	0.065	0.037	0.613	7.68%
0 - 50 km	Tdur	0.315	0.074	0.026	0.604	7.03%
0 - 50 km	Tind	0.330	0.061	0.042	0.617	7.99%
0 - 100 km	Tsum	**0.462**	**0.007**	**0.192**	**0.732**	**18.85%**
0 - 100 km	Tdur	0.310	0.080	0.020	0.599	6.67%
0 - 100 km	TCPU	**0.409**	**0.018**	**0.131**	**0.687**	**14.05%**
0 - 100 km	Tind	**0.469**	**0.006**	**0.200**	**0.738**	**19.49%**

Offshore fishing activity from 1977 – 2000 is a consistent, significant, positive predictor of SSL population trend from 1991 – 2001. This relationship is most apparent using winter and spring large/pelagic trawl fishing for pollock, and winter and spring Pacific cod fishing with all gear types, as predictors.

Multiple Linear Regression and Principal Components Analysis

1977 – 1991 Fishing as a Predictor of YFC – 1991 SSL Population Trend. There are several variables describing fishing. Many of these variables are highly correlated. Principal components analysis (PCA) is useful in situations where there are many predictor variables relative to the number of observations and when those predictor variables are highly correlated (Rencher 1995) (see appendix D for a discussion of PCA).

The results of the simple linear regressions show that the strongest interactions between fishing and SSL population decline before 1991 occur at 10 – 20 km from SSL rookeries, during summer and fall, and with pollock, Pacific cod and Atka mackerel, small/non-pelagic trawl fishing, when the fishing variable values are ranked. The results of a PCA on the data from these specific seasons, gear types, and species, at 10 – 20 km from SSL rookeries are shown in the following tables.

Table 64 shows the relative contribution of each principal component in explaining the total variation in the data set. There are 24 variables, num1, sum1, dur1 and CPU1 for 1 gear type, 2 seasons, 3 species and 1 distance, indicating that

there are 24 total eigenvalues in this PCA. Only those eigenvalues that account

for more than 1.0 % of the total variation in the data are included in table 64.

Table 64. Eigenvalues from the PCA of Ranked, Summer and Fall, Small/Non-Pelagic Trawl Fishing for Pollock, Pacific Cod and Atka Mackerel at 10 – 20 km From SSL Rookeries, From 1977 - 1991.

Eigenvalue	% of Total Variation
16.53	71.00%
1.882	8.10%
1.612	6.90%
1.009	4.30%
0.651	2.80%
0.425	1.80%
0.375	1.60%
0.228	1.00%

Table 64 shows that the first 5 principal components account for 93.1% of

the total variation in the dataset. The component scores from all principal

components that accounted for more than 2% of the total variation in the data

were included in a multiple linear regression (MLR). Every possible combination

of those 5 principal component scores was used to predict SSL population trend

from YFC – 1991. The results were ranked by adjusted R^2. Table 65 shows the

results of the MLR that yielded the highest adj. R^2 value when each of the YFC –

1991 SSL population trend estimates were the response variable. Any slope

coefficients that were significant at the $\alpha = 0.05$ level are in bold.

Table 65. The Results of MLR Models Using Principal Component Scores as Predictors of Each YFC - 1991 SSL Population Trend Estimate.

YFC (50's) - 1991 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**-0.535**	**0.001**	**32.32%**
PC4	-0.273	0.071	

YFC (no 50's) - 1991 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**-0.533**	**0.001**	**26.69%**
PC4	-0.160	0.298	

1977 - 1991 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**-0.466**	**0.003**	**34.32%**
PC3	**0.404**	**0.009**	

In each case, the scores from the first principal component were a significant predictor of SSL population trend in the MLR model. Principal component 1 (PC1) accounts for 71.0% of the total variation in the fishing data. Scores from principal components 3 and 4 were also accepted into different models. However, only the scores from PC3 were a significant predictor of SSL population trend. PC3 and PC4 account for 6.9% and 4.3% of the total variation respectively. The eigenvectors corresponding to principal components 1, 3 and 4 are shown in table 66.

Table 66. Eigenvectors Corresponding to Principal Components 1, 3 and 4.

PC1	PC3	PC4	variable
0.212	-0.165	0.089	num1, pl_wt, summer , smtrl, 10-20 km
0.218	-0.192	0.084	sum1, pl_wt, summer, smtrl, 10-20 km

Table 66. Continued.

0.214	-0.196	0.006	dur1, pl_wt, summer, smtrl, 10-20 km
0.184	-0.227	0.177	CPU1, pl_wt, summer, smtrl, 10-20 km
0.213	-0.075	-0.26	num1, pl_wt, fall, smtrl, 10-20 km
0.215	-0.12	-0.195	sum1, pl_wt, fall, smtrl, 10-20 km
0.213	-0.101	-0.263	dur1, pl_wt, fall, smtrl, 10-20 km
0.192	-0.264	-0.001	CPU1, pl_wt, fall, smtrl, 10-20 km
0.215	-0.065	0.21	num1, cd_wt, summer, smtrl, 10-20 km
0.217	-0.086	0.203	sum1, cd_wt, summer, smtrl, 10-20 km
0.219	-0.03	0.181	dur1, cd_wt, summer, smtrl, 10-20 km
0.195	-0.144	0.219	CPU1, cd_wt, summer, smtrl, 10-20 km
0.213	-0.093	-0.233	num1, cd_wt, fall, smtrl, 10-20 km
0.22	-0.099	-0.15	sum1, cd_wt, fall, smtrl, 10-20 km
0.211	-0.099	-0.193	dur1, cd_wt, fall, smtrl, 10-20 km
0.209	-0.141	-0.105	CPU1, cd_wt, fall, smtrl, 10-20 km
0.185	0.342	-0.246	num1, am_wt, summer, smtrl, 10-20 km
0.195	0.353	-0.15	sum1, am_wt, summer, smtrl, 10-20 km
0.181	0.265	-0.253	dur1, am_wt, summer, smtrl, 10-20 km
0.188	0.318	-0.186	CPU1, am_wt, summer, smtrl, 10-20 km
0.192	0.283	0.22	num1, am_wt, fall, smtrl, 10-20 km
0.197	0.244	0.315	sum1, am_wt, fall, smtrl, 10-20 km
0.193	0.267	0.21	dur1, am_wt, fall, smtrl, 10-20 km
0.198	0.202	0.338	CPU1, am_wt, fall, smtrl, 10-20 km

The eigenvector values of PC1 show that most of the variation in PC1 is due to the fact that each of the fishing variables is positively correlated with each other variable. SSL rookeries that have high component scores in PC1 will tend to have generally high fishing variable ranks. Sites that have low PC1 scores will have generally low ranks in most of the fishing variables. The eigenvector values of PC3 indicate that PC3 is picking up the variation in the data that is due to negative correlations between Atka mackerel fishing variables and pollock and Pacific cod variables. SSL rookeries that have high component scores in

component 3 will tend to have high ranks in Atka mackerel variables, coupled with low ranks in both Pacific cod and pollock variables. Sites with low PC3 scores will generally have low ranks in Atka mackerel variables coupled with high ranks in both Pacific cod and pollock variables. Sites with near 0 PC3 scores will generally show little difference between their Atka mackerel, and pollock and Pacific cod ranks. Finally, the eigenvector values of PC4 show that PC4 is picking up variation in the data set that is due to negative correlations between Pacific cod plus pollock fall fishing, along with Atka mackerel summer fishing, and summer Pacific cod plus pollock fishing along with fall Atka mackerel fishing. SSL rookeries that have high component scores in component 4 will tend to show high ranks in Pacific cod and pollock fall fishing, as well as Atka mackerel summer fishing, and low ranks in summer Pacific cod and pollock fishing, as well as fall Atka mackerel fishing. Sites with low scores on PC4 will tend to have the opposite arrangement of ranks.

1977 – 1991 Fishing as a Predictor of 1991 - 2001 SSL Population Trend. SLR showed that single 1977 – 1991 fishing variables are not generally significant predictors of 1991 – 2001 SSL population trend. The SLR with the highest R^2 values used variables derived from large/pelagic trawl pollock fishing in all seasons, and spring Pacific cod fishing using all gear types, both at 0 – 50 km from SSL rookeries. Table 67 shows the eigenvalues from a PCA on those variables.

Table 67. Eigenvalues from the PCA of Ranked, Large/Pelagic Trawl Fishing for Pollock in All Seasons, and Spring Pacific Cod Using All Gear Types at 0 – 50 km From SSL Rookeries, From 1977 - 1991.

Eigenvalue	% of Total Variation
5.52	71.10%
1.143	14.70%
0.67	8.60%
0.245	3.10%
0.124	1.60%
0.044	0.60%
0.012	0.20%
0.008	0.10%

Table 67 shows that the first 8 principal components account for 100% of the variation in the data. The component scores from all principal components that accounted for more than 2% of the total variation in the data were included in a multiple linear regression (MLR). Every possible combination of those 4 principal component scores was used to predict SSL population trend from 1991 - 2001. The results were ranked by adjusted R^2. Table 68 shows the results of the MLR that yielded the highest adj. R^2 value when each of the 1991 - 2001 SSL population trend estimates were the response variable. Any slope coefficients that were significant at the $\alpha = 0.05$ level are in bold.

Table 68. The Results of MLR Models Using Principal Component Scores as Predictors of Each 1991 - 2001 SSL Population Trend Estimate.

1991 (50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.370**	**0.029**	**16.37%**

Table 68. Continued.

PC3	0.281	0.093

1991 (no 50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.373**	**0.029**	**14.66%**
PC3	0.246	0.143	

1991 - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.379**	**0.027**	**14.85%**
PC3	0.24	0.151	

In each case, the scores from the first principal component were a significant predictor of SSL population trend in the MLR model. Principal component 1 (PC1) accounts for 71.1% of the total variation in the fishing data. Scores from principal component 3 were also accepted into each model, but were not a significant predictor of SSL population trend. PC3 accounts for 8.6% of the total variation in the data. The eigenvectors corresponding to principal components 1 and 3 are shown in table 69.

Table 69. Eigenvectors Corresponding to Principal Components 1 and 3.

PC1	PC3	variable
0.389	-0.248	num1pl_wtlgtrl_ALL_00-50
0.387	-0.120	sum1pl_wtlgtrl_ALL_00-50
0.386	-0.228	dur1pl_wtlgtrl_ALL_00-50
0.301	0.265	CPU1pl_wtlgtrl_ALL_00-50
0.345	-0.214	num1cd_wtsprin_ALL_00-50
0.376	0.183	sum1cd_wtsprin_ALL_00-50
0.338	-0.238	dur1cd_wtsprin_ALL_00-50
0.290	0.816	CPU1cd_wtsprin_ALL_00-50

The eigenvector values of PC1 show that most of the variation in PC1 is due to each of the fishing variables being positively correlated with each other. SSL rookeries that have high component scores in PC1 will tend to have generally high ranks in most fishing variables. Sites that have low PC1 scores will have generally low ranks in most of the fishing variables. The eigenvector values of PC3 indicate that PC3 is picking up the variation in the data that is due to negative correlations between the CPU variables, as well as the summed, spring, weight of Pacific cod, using all fishing gear at 0 – 50 km from SSL rookeries, and the rest of the variables included in this analysis. The high eigenvector value associated with the CPU of spring Pacific cod fishing with all gear at 0 – 50 km, indicates that a high rank in that variable might drive a site's PC3 score up, regardless of the ranks in other variables. However, the sites with the highest PC3 scores will be those with positive correlations between the two CPU variables and the sum variable mentioned above, as well as large differences between the ranks of those variables and the rest of the fishing variables.

1991 – 2000 Fishing as a Predictor of 1991 - 2001 SSL Population Trend. The fishing variables that produced the highest R^2 values in SLR using 1991 - 2000 fishing to predict 1991 – 2001 SSL population trend were: pollock and Pacific cod, winter and spring, and small/non-pelagic trawl and large/pelagic trawl gear at 0 – 100 km from SSL rookeries. The results of a PCA on the data from these

specific seasons, gear types, species, and distance from SSL rookeries are shown

in the following tables.

Table 70 shows the relative contribution of each principal component in

explaining the total variation in the data set. There are 32 variables, num1, sum1,

dur1 and CPU1 for 2 gear types, 2 seasons, 2 species and 1 distance, indicating

that there are 32 total eigenvalues in this PCA.

Table 70. Eigenvalues from the PCA of Ranked, Winter and Spring,
Large/Pelagic Trawl Fishing for Pollock and Spring, Small/Non-Pelagic Trawl
Fishing for Pacific Cod at 0 – 100 km from SSL Rookeries, as well as Winter,
Small/Non-Pelagic Trawl Fishing for Pollock and Pacific Cod, at 0 – 50 km from
SSL Rookeries, From 1991 - 2000.

Eigenvalue	% of Total Variation
10.361	53.40%
3.495	18.00%
1.727	8.90%
1.613	8.30%
0.684	3.50%
0.56	2.90%
0.363	1.90%
0.23	1.20%

Table 70 indicates that the first 8 principal components account for 98.1%

of the total variation in the data. All principal components that accounted for

more than 2% of the total variation in the data were included in a multiple linear

regression (MLR). Every possible combination of those 6 principal components

was used to predict SSL population trend from 1991 - 2001. The results were

ranked by adjusted R^2. Table 71 shows the results of the MLR that yielded the

highest adj. R^2 value when each of the 1991 - 2001 SSL population trend

estimates were the response variable. Any slope coefficients that were significant

at the $\alpha = 0.05$ level are in bold.

Table 71. The Results of MLR Models Using Principal Component
Scores as Predictors of Each 1991 - 2001 SSL Population Trend Estimate.

1991 (50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.482**	**0.001**	**43.26%**
PC2	0.200	0.145	
PC3	**0.325**	**0.022**	
PC5	**-0.322**	**0.023**	
PC6	0.153	0.261	

1991 (no 50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.454**	**0.003**	**37.55%**
PC2	0.187	0.192	
PC3	**0.291**	**0.047**	
PC5	**-0.324**	**0.029**	
PC6	0.171	0.232	

1991 - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.454**	**0.003**	**37.93%**
PC2	0.190	0.183	
PC3	**0.292**	**0.046**	
PC5	**-0.326**	**0.027**	
PC6	0.169	0.236	

In each case scores from principal components 1, 2, 3, 5, and 6 were

accepted into the MLR model with the highest adj. R^2 value. Only the scores from

PC 1, 3 and 5 were significant predictors of SSL population trend in each model.

PC1, PC3, and PC5, account for 53.4%, 8.9%, and 3.5% of the total variation,

respectively. The eigenvectors corresponding to principal components 1, 3 and 5

are shown in table 72.

Table 72. Eigenvectors Corresponding to Principal Components 1, 3 and
5.

PC1	PC3	PC5	variable
0.188	-0.129	-0.127	num2pl_wtwintelgtrl0-100
0.190	-0.098	-0.075	sum2pl_wtwintelgtrl0-100
0.199	-0.187	-0.106	dur2pl_wtwintelgtrl0-100
-0.024	0.639	-0.046	CPU2pl_wtwintelgtrl0-100
0.222	0.098	-0.065	num2pl_wtsprinlgtrl0-100
0.197	0.155	0.118	sum2pl_wtsprinlgtrl0-100
0.213	0.064	-0.014	dur2pl_wtsprinlgtrl0-100
-0.049	0.577	0.283	CPU2pl_wtsprinlgtrl0-100
0.256	-0.099	0.459	num2cd_wtsprinsmtrl0-100
0.257	-0.065	0.255	sum2cd_wtsprinsmtrl0-100
0.258	-0.131	0.463	dur2cd_wtsprinsmtrl0-100
0.046	-0.051	-0.290	CPU2cd_wtsprinsmtrl0-100
0.258	0.161	-0.132	num2pl_wtwintesmtrl00-50
0.279	0.014	0.022	sum2pl_wtwintesmtrl00-50
0.265	0.135	-0.078	dur2pl_wtwintesmtrl00-50
0.269	-0.140	0.141	CPU2pl_wtwintesmtrl00-50
0.265	0.173	-0.138	num2cd_wtwintesmtrl00-50
0.279	0.074	-0.192	sum2cd_wtwintesmtrl00-50
0.267	0.149	-0.119	dur2cd_wtwintesmtrl00-50
0.213	-0.063	-0.422	CPU2cd_wtwintesmtrl00-50

The eigenvector values of PC1 are either positive or relatively small in

magnitude. Positive correlations between most of the fishing variables used in

this PCA account for the variation explained by PC1. SSL sites that have high

PC1 scores will have generally high ranks in most fishing variables, while sites

that have low PC1 scores will generally have low ranks in most fishing variables.

The strongest signal in PC3 comes from a positive correlation between the CPU

of winter, large/pelagic trawl pollock fishing at 0 – 100 km and its spring

counterpart. PC3 is also picking up some variation due to differences between

winter, large/pelagic trawl pollock fishing at 0 – 100 km plus spring, small/non-

pelagic trawl Pacific cod fishing at 0 –100 km plus the CPU of winter, small/non-

pelagic trawl pollock fishing at 0 – 50 and spring, large/pelagic trawl pollock

fishing at 0 – 100 km plus the winter, small/non-pelagic trawl pollock fishing

activity variables at 0 – 50, plus winter, small/non-pelagic trawl Pacific cod

fishing at 0 – 50 km (the 2 CPU variables mentioned earlier fit in on this side of

the correlation, see table 72). SSL rookeries that score highly on PC3 are likely to

have high ranks in both the CPU of winter, large/pelagic trawl pollock fishing at 0

– 100 km and its spring counterpart, although they may also have rank differences

that fit the rather complex pattern described above. Sites with low scores in PC3

probably have low ranks in both the CPU of winter, large/pelagic trawl pollock

fishing at 0 – 100 km and its spring counterpart. PC5 is picking up residual

variation that is due to differences between the CPU of spring, large/pelagic trawl

fishing for pollock at 0 – 100 km, plus spring, small/non-pelagic trawl fishing for

Pacific cod at 0 – 100 km and the CPU of spring, small/non-pelagic trawl fishing

for Pacific cod at 0 – 100 km.

1977 – 2000 Fishing as a Predictor of 1991 - 2001 SSL Population Trend.

Fishing variables describing the entire time period were significant predictors of

SSL population trend, as long as they were measured at some distance offshore.

The SLR with the highest R2 values used winter and spring, pollock and Pacific

cod fishing variables at distances greater than 20 km from SSL rookeries. Table

73 shows the eigenvalues from a PCA on those data.

Table 73. Eigenvalues from the PCA of Ranked, Winter and Spring,
Large/Pelagic Trawl Fishing for Pollock at 0 – 100 km From SSL Rookeries, as
Well as Winter Fishing for Pacific Cod, Using All Gear Types, at 0 – 50 km From
SSL Rookeries, and Spring Fishing for Pacific Cod Using All Gear Types at 20 –
30 km From SSL Rookeries, From 1991 - 2000.

Eigenvalue	% of Total Variation
7.615	49.00%
3.107	20.00%
1.35	8.70%
1.044	6.70%
0.82	5.30%
0.581	3.70%
0.496	3.20%
0.25	1.60%

Table 73 indicates that the first 8 principal components account for 98.2%

of the total variation in the data. The principal component scores were used in

MLR as described earlier, as predictors of SSL population trend from 1991 –

2001. Table 74 shows the results of the MLR that yielded the highest adj. R^2

value when each of the 1991 - 2001 SSL population trend estimates were the

response variable. Any slope coefficients that were significant at the $\alpha = 0.05$

level are in bold.

Table 74. The Results of MLR Models Using Principal Component
Scores as Predictors of Each 1991 - 2001 SSL Population Trend Estimate.

1991 (50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.524**	**0.001**	**40.20%**
PC2	0.199	0.158	
PC3	**0.328**	**0.024**	
PC4	0.233	0.099	
PC5	-0.142	0.308	

1991 (no 50's) - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.487**	**0.002**	**36.67%**
PC2	0.171	0.236	
PC3	**0.324**	**0.029**	
PC4	0.251	0.086	
PC6	-0.179	0.213	

1991 - 2001 SSL decline			
Variable(s)	Slope coefficient (β)	p-value	adj R^2
PC1	**0.488**	**0.002**	**36.27%**
PC2	0.162	0.262	
PC3	**0.323**	**0.03**	
PC4	0.250	0.088	
PC6	-0.179	0.217	

Principal components 1, 2, 3, and 6 were included in each MLR. PC5 and

PC 6 also are included in different MLR. In each case PC1 and PC3 are

significant predictors of SSL population trend. PC1 and PC3 account for 49.0%,

and 8.7% of the total variation, respectively. The eigenvectors corresponding to

principal components 1 and 3 are shown in table 75.

Table 75. Eigenvectors Corresponding to Principal Components 1, and 3.

PC1	PC3	variable
0.297	-0.018	Tnumpl_wtwintelgtrl0-100
0.287	0.068	Tsumpl_wtwintelgtrl0-100
0.287	-0.004	Tdurpl_wtwintelgtrl0-100
0.022	0.669	TCPUpl_wtwintelgtrl0-100
0.315	-0.069	Tnumpl_wtsprinlgtrl0-100
0.303	0.129	Tsumpl_wtsprinlgtrl0-100
0.317	-0.082	Tdurpl_wtsprinlgtrl0-100
-0.033	0.656	TCPUpl_wtsprinlgtrl0-100
0.249	0.133	Tnumcd_wtsprin_ALL_20-30
0.243	0.073	Tsumcd_wtsprin_ALL_20-30
0.264	0.153	Tdurcd_wtsprin_ALL_20-30
0.007	-0.014	TCPUcd_wtsprin_ALL_20-30
0.287	-0.133	Tnumcd_wtwinte_ALL_00-50
0.295	-0.102	Tsumcd_wtwinte_ALL_00-50
0.290	-0.093	Tdurcd_wtwinte_ALL_00-50
0.098	0.074	TCPUcd_wtwinte_ALL_00-50

The variation in PC1 is once again due to positive correlation between

most of the fishing variables used in this PCA. Sites with high PC1 scores will

generally have high ranks in most fishing variables, while sites with low PC1

scores will generally have low ranks in most fishing variables. The variation in

PC3 is mainly due to positive correlation between the CPU variables for pollock.

High PC3 scores probably indicate high ranks in both pollock CPU variables,

while low ranks could come from low pollock CPU ranks.

Discussion

There are 3 different estimates of each of 3 SSL population parameters. None of the three estimates are ideal. The estimates that include the 1950's data, introduce a geographic bias in that only the eastern segment of the western stock range was sampled in the 1950's (figure 15, appendix C). However, the methods used for those samples are similar to the ones used today (Mathison '63) and are probably fairly accurate. The pre-1991 slope estimates derived from the data set that includes the 1950's data tend to be less steep than the other estimates. This is due to the fact that the 1950's estimates tended to be lower than estimates made in the 1960's and early 1970's (figure 15, appendix C). This could be due to a growing sea lion population, or a systematic sampling bias. For example, ocular counts might consistently overestimate the actual population. The slope estimates made using the data set that excludes the 1950's data produce steeper pre-1991 slopes and do not have the same geographic bias as the 1950's estimates do (figure 2, appendix 1). However, the sampling procedures over this period have many detractors (Merrick 1987, for example) and, as mentioned before, are generally considered less accurate. The data set that uses 1977 as a starting point has no obvious geographic biases and includes almost entirely photographic data. However, the SSL population was already declining rapidly at that point and the slope estimates derived from this period tend to be very steep (figure 17, appendix C). While these estimates fit the data well, they are not useful for extrapolating backward to earlier years. Steep slope estimates will result in high intercept

estimates for any extrapolated pre-1977 year. The 1977 - 1991 estimates are an accurate snap shot of the SSL population declining at its steepest rate, but might not capture the entire decline period. Since each of the different SSL population trend estimates have associated problems, it may be best to look at all three when considering the relationship between SSL and fishing in the Bering Sea and Gulf of Alaska.

Tables 2 - 22 show a general pattern of SSL population trend being negatively correlated with fishing near SSL rookeries. Correlation does not imply cause and effect. The relationship between fishing and SSL population trend does not necessarily mean that fishing near SSL rookeries during the years 1977 - 1991 caused the decline of SSL that we see from YFC - 1991, though that is one possible explanation. The relationship could mean that fewer SSL caused better fishing, which attracted more effort, or that some other factor or factors have caused both the population of SSL to decline faster and more fishing to occur near some rookeries. Without further analysis, it is not possible to state that one or the other of these possibilities represents the truth, but it is possible to speculate.

The negative relationship between fishing activity variables and SSL population could be explained in a number of ways. One possibility is that repeated fishing in an area severely depleted the sea lion's near-rookery prey base over time, making it hard for SSL to satisfy their caloric requirements (Loughlin and Merrick 1988). Trites and Donnelly (2003) have recently concluded that SSL were probably nutritionally stressed during the decline.

If nutritional stress was indeed a major driver of the SSL decline, why are the fish abundance variables also negatively correlated with SSL population growth? CPU reflects the abundance of fish present *before* the fishing took place. The fish abundance after fishing is unknown. It could be that fishing in a rich prey field caused localized depletions of frequently used SSL foraging patches, which might cause SSL to have longer search times and thus greater energy requirements.

Another possibility is that SSL were being caught and killed along with the fish (Loughlin and Nelson 1986), or simply shot from fishing boats during this period (*ibid*). In this case, all of the fishing metrics measured here are merely reflecting the number of SSL being killed as a result of fishing related activities. That is, higher fishing activity and higher fish abundance are merely proxies for the frequent presence of fishermen, which might indicate high direct SSL mortality.

The geographic limit of the statistically significant relationship between YFC-1991 slope and the raw 1977-1991 fishing variables appears to be 20km from each rookery. Consider Table 2, where the 1977 - 1991 fishing data is used to predict the YFC - 1991 (no 50's) SSL data. All 4 fisheries variables are significant at $0 - 20$ km and 3 of the 4 are significant or near significant at $0 - 10$ km and $10 - 20$ km distance from SSL rookeries. While num1 is significant at $0 - 30$ km, it is not significant in the area greater than 20 km and less 30 km away from rookeries. This implies that the 0 - 20 km area drives the significance of the

0 - 30 km test. However, this geographic limit is less apparent when the ranked

fishing variables are used as predictors. Tables 5 - 7 indicate that the negative

relationship between fishing measures (particularly num1), may extend further out

to sea.

The strongest relationships generally occur at the 10 – 20 km distance and

these relationships are the focus of the remaining comparisons between 1977 –

1991 fishing and YFC – 1991 SSL population trend. It should be noted that the

fisheries data analyzed here probably do a poor job of describing the fishing from

0 – 10 km offshore. Vessels smaller than 60 feet in length do not generally

contract for NMFS observers (Lowell Fritz pers. comm. 2002). It is reasonable to

conclude that these vessels do some of their fishing in relatively near-shore

waters, due to range limitations and the need to be close to sheltering bays and

breakwaters in case of severe weather. While the over-all removals of fish by

these vessels is generally considered to be negligible (except in the case of

sablefish) (*ibid*) their impact near-shore may be relatively important.

Furthermore, the waters out to 3 nm from shore are controlled by Alaska state

agencies, specifically the Alaska Department of Fish and Game (ADF&G) and

ADF&G observer data were not included in this analysis. Therefore, the absence

of a pattern near shore may be due to lack of data, rather than lack of differences

between rookeries.

Tables 8 - 10 and tables 14 - 16 indicate a consistent and relatively strong

relationship between summer small/non-pelagic trawl fishing for pollock and

Pacific cod and SSL population trend. This relationship is uniformly negative, meaning that high ranks in fishing measures are associated with the most severe SSL population declines. June and July are SSL breeding months, during which reproductive males generally fast (Gisiner 1985). Heavy fishing around SSL rookeries during the summer may lead to localized depletions of fish, making successful foraging for males, weakened by territorial fighting and extensive fasting, difficult. Females are nursing during these months and may require extra forage to produce sufficient milk. If the increased caloric requirements of nursing females are not met, young SSL may show reduced growth rates. This phenomenon has been seen in other pinniped species (Trillmach and Limberger, 1985, Trillmach and Dellinger 1991). Trites and Donnelly (2003) review evidence indicating that juvenile growth rates of SSL were probably reduced during the 1980's.

Tables 11 - 13 and tables 17 – 22 indicate a consistent and relatively strong relationship between *fall* small/non-pelagic trawl fishing for pollock, Atka mackerel and Pacific cod and SSL population trend. This relationship is also uniformly negative. Lowered juvenile survival has been posited as a contributing cause for the SSL decline (York 1994). Though juveniles are generally still nursing at the time, the fall months may be critical to juvenile survival in particular. Young SSL are just learning to forage during this period (Gentry 1970, Sandegren 1970) and readily available prey may be an important dietary supplement for them. Younger, smaller SSL cannot travel as far or dive as deeply

as older, larger SSL (Loughlin et al 2003), making the availability of near-shore

prey particularly important to them. If growing juvenile SSL depend entirely on

milk for their increasing caloric demands, readily available prey will be extremely

important for nursing females. Therefore, localized depletions of fish caused by

intense fishing activity around SSL rookeries could be deleterious to juvenile SSL

survival. Milette and Trites (2004) and Andrews et al. (2002) found evidence of

shorter foraging times for females at Seguam and Sugarloaf Islands (rookeries in

the declining western stock range), when compared to Forrester Island, which is

in the eastern stock range and supports a stable population of SSL. Seguam

Island did have generally high ranks in most fishing variables before 1991, but the

study took place in 1997 and may not accurately reflect the foraging conditions of

the late 1970's and early 1980's. The study on Sugarloaf Island took place in

1994 and 1995 and may have been a slightly better reflection of the foraging

conditions before 1991. However, Sugarloaf had generally low ranks in most

fishing variables and prey availability might not have been adversely affected by

fisheries removals.

PCA analysis of pollock, Pacific cod and Atka mackerel, small/non-

pelagic trawl fishing, during the summer and fall at 10 – 20 km from SSL

rookeries between the years 1977 and 1991, supports the conclusions found in

tables 8 - 22. The first principal component is made up of positive correlations

between all the variables and explains 71.0% of the variation in the data. A high

rank in one measure of fishing is positively correlated with a high rank in any

other fishing measure. The MLR results in table 65 show that in each case,

regardless of the YFC, scores from PC1 are a significant and negative predictor of

SSL population trend before 1991. Sites that score highly on PC1 will tend to

have high ranks in most fishing variables.   Therefore, the negative slope

coefficient corresponding to PC1 indicates that sites with high fishing variable

ranks are associated with steep SSL declines.

Scores from PC4 are included in the MLR using YFC (50's) – 1991 and

YFC (no 50's) – 1991 SSL population trend estimates as response variables. PC4

is not a significant predictor in either case. PC3 is included in the MLR using the

1977 – 1991 SSL population trend estimate as the response variable. PC3 score is

a significant predictor. PC3 describes variation due to differences between rank

in pollock and Pacific cod fishing and Atka mackerel fishing. Sites with high

PC3 scores will generally have relatively high Atka mackerel ranks and relatively

low pollock and Pacific cod ranks. The slope coefficient associated with PC3 is

positive, indicating that high Atka mackerel fishing variable ranks and relatively

low pollock and Pacific cod ranks are associated with less severe SSL declines.

PC3 is significant only in the MLR that uses 1977-1991 SSL slope as the response

variable. Differences between Atka mackerel fishing and fishing for other species

may be worth investigating further, but this analysis will focus on results that are

consistent across all three SSL population trend estimates.

PC1 demonstrates that most of the variation in the 1977 – 1991 fishing

data can be explained by the extent to which the various measures of fishing are

correlated to each other. Table 65 shows that PC1 score, in combination with one other component score, can explain about 30% of the between rookery variation in SSL population trend before 1991.

The nature of the relationship between fishing and the SSL decline is dramatically different when the SSL population trend estimates after 1991 are used as the response variable. Tables 23 - 63 show that the significant relationships result from comparisons of offshore (>20 km) fishing and that the significant slope coefficients in these regressions are uniformly positive, indicating that high ranks in fishing measures are associated with less severe SSL declines over this time period. One possible explanation for the positive slope coefficients is that an area of high yield for fisherman may indicate an extremely rich prey field for SSL. That is, competition is reduced because the resource supply outstrips the needs of both fishery and SSL. In this case both the SSL and the fisherman would do well in those areas. The fact that the significant relationships occur offshore is interesting as well. Tables 23 - 63 indicate that no significant relationships were found inside of 20 km from shore. Offshore fishing events are probably less likely to involve interactions with SSL. One reason for this is simple geometry. The area described by a circle increases exponentially with increasing radius, and the depth of the ocean generally increases as one moves offshore. During months in which SSL are typically hauled out, they are leaving from and returning to the same location repeatedly. The likelihood that SSL will occur near their haulout site is therefore much

greater than the likelihood that they will occur in any particular place offshore (assuming they do not always forage in the same place). There is much greater opportunity for fishermen and SSL to avoid one another in a larger area. If an SSL/fisherman interaction is likely to result in the injury or death of the SSL, or simply in competition for shared resources, then it is probable that offshore fishing is less harmful to SSL than near shore fishing for the simple reason that there is probably less interaction.

MLR using principal component scores derived from PCA analysis of fishing variables from 1977 – 1991, 1991 – 2000, and 1977 - 2000, reinforce the findings described above. The MLR using principal component scores from 1991 – 2000 fishing data produces the highest adj. R^2 values, though the 1977 – 2000 component scores produce similar adj. R^2 values, and the results from all three MLR are similar.

When 1991 – 2000 fishing is used to predict 1991 – 2001 SSL population trend, the slope coefficients corresponding principal components 1 and 3 are significant and positive, while the slope coefficient corresponding to PC5 is significant and negative, in each of the MLR models with the highest adj. R^2 values (table 71). PC1 is a component describing the positive correlations between all of the fishing variables and explains 53.4% of the total variation in the fishing data. Sites with a high PC1 score will tend to have high ranks in most of the fisheries variables, while sites with a low PC1 score will generally have low ranks in most of the fisheries variables. Therefore, a positive relationship

between PC1 score and 1991 - 2001 SSL population trend represents a positive relationship between fisheries variables and SSL population trend over that period.

PC3 explains 18.0% of the variation in the dataset. PC3 is picking up variation that is largely due to positive correlations between the CPU of large/pelagic trawl fishing for pollock in winter and the CPU of large/pelagic trawl fishing for pollock in spring, both at 0 – 100 km from SSL rookeries. Sites with high PC3 scores will tend to have high ranks in both those variables, while sites with low (negative) scores will have low ranks in both variables. Sites with near zero PC3 scores will tend to have large differences between the CPU of large/pelagic trawl fishing for pollock in winter and the CPU of large/pelagic trawl fishing for pollock in spring. The slope coefficient for PC3 is positive, indicating that areas of high offshore pollock abundance in winter and spring are associated with less severe SSL declines.

The slope coefficient for PC5 score is significant and negative. PC5 is picking up variation in the data that is due to a negative correlation between CPU of large/pelagic trawl fishing for pollock in spring, and the num, sum and dur variables for small/ non-pelagic trawl fishing for Pacific cod in spring, all at 0 – 100 km from SSL rookeries on 1 side, and the CPU of small/ non-pelagic trawl fishing for Pacific cod in spring at 0 – 100 km, together with the sum and CPU variables for small/non-pelagic trawl fishing for Pacific cod at 0 – 50 km on the other side. High scores in PC5 result from high ranks in the CPU of large/pelagic

trawl fishing for pollock in spring, and the num, sum and dur variables for small/ non-pelagic trawl fishing for Pacific cod in spring all at 0 – 100 km, coupled with low ranks in the CPU of small/ non-pelagic trawl fishing for Pacific cod in spring at 0 – 100 km, and the sum and CPU variables for small/non-pelagic trawl fishing for Pacific cod at 0 – 50 km. Low PC5 scores would result from the opposite configuration. The slope coefficient associated with PC5 is negative, indicating that sites that show high ranks in offshore pollock abundance in spring and high ranks in offshore, small/non-pelagic trawl Pacific cod fishing activity, coupled with low ranks in offshore, spring, Pacific cod abundance and offshore winter Pacific cod abundance as well as low ranks in total small/non-pelagic trawl catch, are associated with steeper SSL declines. This result is interesting in that one could imagine that low fish abundance in winter coupled with high fishing activity in spring would be likely to result in localized depletions of Pacific cod. The high abundance of pollock might lead to more fishing in spring and yet more reduction in Pacific cod (perhaps taken as bycatch) levels. PC5 explains only 3.5% of the total variation in the fishing data, indicating that the pattern is not particularly strong within the fisheries records. However, further exploration of the effect of reduced offshore Pacific cod abundance in spring, on SSL population trend might be warranted, as removing PC5 from the regression reduces the adj. R^2 value by about 9%, regardless of which SSL population trend estimate is used. Furthermore, most measures of fishing are either uncorrelated or positively correlated with SSL population trend over this time period. A negative

correlation may indicate an aspect of fisheries related SSL management that could be improved upon.

One common interpretation of adjusted R^2 value is that it represents the amount of variation in the response variable that can be explained by the predictor variable. Under this interpretation, an R^2 value of 20% - 30% is not particularly compelling. That is, if differences in the fishing variables around rookeries explain only 30% of the observed difference in SSL population decline, what about the other 70%? However, that interpretation of R^2 can be misleading. To get an idea of the size of the effect quantified by a regression, one must consider both the R^2 and the slope coefficient associated with the predictor variables. The reason for this is that R^2 can be adversely affected by noise in the data. Even if a variable perfectly predicts the behavior of a response variable, measurement error in either variable can reduce the R^2 value in a regression comparing the two. This is easily demonstrated by plotting a straight line on a graph where $x_1 = y_1 = 0.1$, $x_2 = y_2 = 0.2$, etc. A regression in which x is used to predict y will yield an R^2 value of 100%. If each point in this plot is slightly perturbed in either the x, or y direction, the R^2 value will decrease. There is no reason to think that the data discussed in this paper are free of noise. The SSL data used are 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 course fashion to approximate that total. A lower R^2 value would be expected under these conditions.

How strong is the actual signal? An examination of the slope coefficients found in this analysis can give a more complete answer. The slope coefficients shown in tables 2 - 63 can be thought of as the change in SSL population trend per unit of fishing increase (unit refers to the particular variable being used). Figure 1 shows a plot of the ranked number of fishing events from 1977 – 1991 vs. SSL population trend from 1977 – 1991. Both variables have been standardized.

Figure 11. Ranked Fishing at 0 - 20 km from SSL Rookeries vs. 1977–1991 SSL Population Trend Estimate.
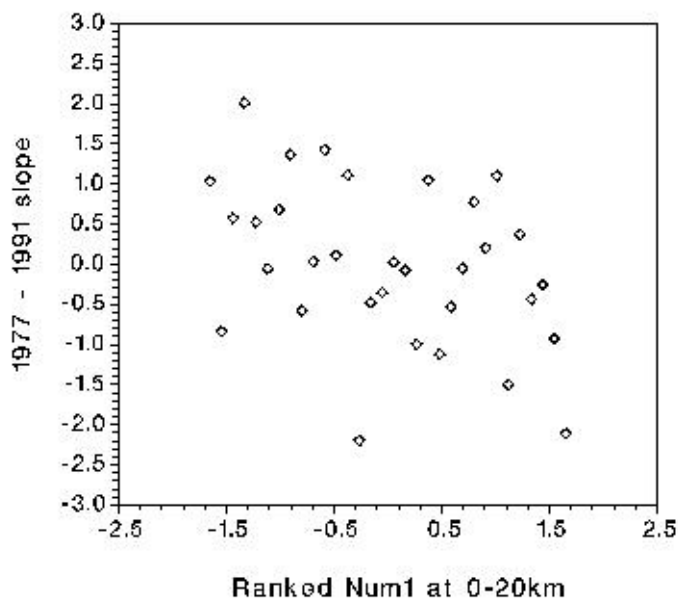
Figure 11 indicates that the difference in SSL population trend between areas of high fishing intensity and low fishing intensity is meaningful. The average population trend estimate for the 12 sites that had less then 100 fishing events within 0 – 20 km between 1977 and 1991 is approximately -0.0517 (using the 1977 – 1991 SSL population trend estimate), while the average for the 20 rookeries which had more than 100 fishing events within 0 – 20 km is about -0.1187. A decline rate of -0.1187 represents a loss of about 12% of the population per year. At that rate, a population of 100 animals would drop to less than 2 individuals in 31 years. Compare that to a decline rate of 5% a year, in which the same starting population of 100 animals would take 73 years to fall to under 2 individuals.

Furthermore, the YFC-1991 trend estimates that are associated with low fishing variable ranks are consistent with the SSL population trend estimates for the years 1991 – 2001. That means that all SSL rookeries show a post-1991 decline rate that is approximately equal to the decline rate associated with low fishing pressure before 1991.

What might have occurred in 1991 to alter the relationship between SSL and fisheries? The changes are widespread. They can be seen across most of the different fishing variables examined. Near-shore fishing activity and fish abundance were negatively correlated with SSL population trend before 1991 and uncorrelated with SSL population trend after 1991. Offshore fishing activity and SSL population trend were uncorrelated before 1991 and positively correlated

after.   Summer and fall fishing activity and fish abundance, were negatively

correlated with SSL population trend before 1991 and uncorrelated after. Winter

and spring fishing activity and fish abundance, were uncorrelated with SSL

population trend before 1991 and positively correlated after. Small/non-pelagic

trawl fishing activity and fish abundance, were negatively correlated with SSL

population trend before 1991 and positively correlated after. Large/pelagic trawl

fishing activity and fish abundance, were uncorrelated with SSL population trend

before 1991 and positively correlated after 1991.

One possible explanation for the alterations in the relationship between

SSL population trend and fishing, are the regulatory changes that went into place

in and around 1991 (see chapter 5). The observer program operated exclusively

on foreign and joint venture fishing vessels until 1986 and the coverage of

domestic vessels was minimal until 1990. This means that the bulk of the

fisheries observer data used in these correlations comes from foreign vessels. The

Bering Sea/ Gulf of Alaska fishery is currently a largely domestic enterprise

(NMFS 2000a). The domestic fishery has been subject to many regulation

changes in the way it operates, including exclusion zones around rookeries,

reduction of deliberate and incidental take, and spreading out the spatial and

temporal impact of fisheries, through seasonal and geographic quotas (NMFS

2000a). Several of these changes were first instituted (since modified) in 1991, in

response to the listing of SSL under the Endangered Species Act. They were

regulations designed specifically for the purpose of helping the SSL population to recover.

The links between the regulatory changes put in place in 1991, and the changes in the relationship between SSL and the BS/GOA fisheries are hard to dismiss. For example, in mid 1990 aggressive enforcement of protective regulations, especially as they relate to the intentional killing of SSL, began, a 3 nm "no-approach" buffer zone was established around important rookeries, and incidental take quotas were reduced. In 1992 trawl fishing within 10 nm was prohibited around 37 rookeries in the GOA and Bering Sea Aleutian Islands (BSAI). These changes could have driven the near-shore to offshore switch seen in the statistically significant fishery/SSL relationship. They could also have contributed to the shift seen in the relationship between small/non-pelagic trawl fishing and SSL population trend. In 1991, some alterations in the pollock management plan were implemented. The basic idea behind them was to spread out the pollock TAC over time and space (NMFS 2000a). This and subsequent changes to the Atka mackerel FMP (see chapter 5), may have lead to the alterations seen in the seasonal relationship between SSL and fisheries. Finally, fishermen shot an unknown number of SSL before 1991 and almost none have been shot since (Loughlin pers. comm. 2004). This change alone may have been sufficient to cause the shift in the categorization of the fisherman/SSL relationship from negative to positive.

Other explanations are possible. For example, ongoing climate change has probably altered the composition of the BS/GOA ecosystem in a way that affected both SSL and the commercial fishery (see chapter 3). It is impossible, given the data used in this study, to conclude that environmental change is not responsible for the patterns seen here. The mechanism through which the regime shift of 1989 could have slowed the SSL population decline is unclear, however. The regime shift of 1989 did not increase the population sizes of "forage fish", such as herring and Atka mackerel (which are thought to be of higher caloric value to SSL) it seems to have decreased them (Hare and Mantua, 2000). Decreases in the pollock and large flatfish populations, which might reduce competition pressure on SSL seem to have started before 1989. Regime shift appears to be a less likely explanation for the observed changes in the SSL/fisheries relationship than changes to the rules governing fishing.

There is the possibility that the pattern relating SSL population decline to fisheries activity is due not to SSL mortality, but to SSL movement. There is a chance that the declines seen at individual rookeries are the result of animals moving from one rookery to another, rather than animals actually dying. However, there are several reasons why this is unlikely.

SSL and other otariid seals appear to prefer to breed at the same location where they were born (Calkins and Goodwin, 1986, Raum-Suryan et al. 2002, Baker et al. 1995). There is some evidence that SSL do occasionally breed at a different rookery from the one they were born at, but this appears to be the

exception rather than the rule (Raum-Suryan et al. 2002, Calkins and Pitcher 1982, Bickham et al. 1996). Even if the dispersal away from natal rookeries is more prevalent than previously thought, there is only 1 documented case of a sexually mature female moving from 1 rookery to another, after she has given birth (as of 2002) (Raum-Suryan et al. 2002). Since no assumptions were made about the birth origins of SSL observed at each rookery, the lack of observed dispersal of females once they have chosen a breeding site is probably more important to this analysis than natal site fidelity. This analysis does assume that once an animal is counted at a rookery, it either continues to attend that rookery, or dies. As long as female SSL are counted at only one site for the majority of their lives, animal movement probably cannot explain the trends seen here. The counts used in this study are counts of adults and juveniles, on land during breeding season. The majority of SSL seen on rookeries during breeding season are of breeding age (Sandegren 1970, Gentry 1970). An unknown proportion of the observed animals are juveniles. In order for the observed decline of SSL at a rookery to be explained by animal movement, that proportion of juveniles would have to have systematically decreased over the period the decline. While such a systematic decrease is possible, to my knowledge it has not been documented and it is unlikely to have occurred without many of the numerous scientists monitoring the population remarking on it. Finally, dispersal of non-breeding animals away from their natal rookeries would soon decrease the population of that rookery, but it would have to increase the population at another. The western

stock of SSL, as a whole, is declining (NMFS 2000a). Unless SSL are migrating

entirely out of the western stock range, and this appears unlikely based on genetic

analysis and movement studies (Bickham et al. 1996, Raum-Suryan et al. 2002),

they are dying. However, small-scale movements of SSL could exaggerate the

apparent affect of fishing on individual rookeries. If intense fishing were

associated with SSL migration, rather than mortality, the patterns seen here would

would still be interesting from a managerial perspective. If heavy fishing activity

has indeed been inciting animals to move from one place to another, it stands to

reason that fishing and SSL were engaged in exploitative competition (as defined

in Pianka 1994), a situation that would require careful monitoring under the

auspices of the Endangered Species Act.

Another possibility is that the decline of SSL has taken the population

below a critical threshold level for exploitative competition with fisheries. That

is, the fish resource not removed by the fisheries is enough to satisfy the foraging

needs of the remaining SSL. Using this analysis, it is impossible to say that a

critical SSL population size for exploitation competition does not exist. However,

the existence of a threshold population size for exploitation competition assumes

that exploitation competition exists above that threshold. In that case, restricting

the interaction between the fishery and SSL is certainly a good management

strategy, if the target population size of SSL is above that threshold.

CHAPTER 8

CONCLUSIONS

This analysis was designed to determine whether or not the protective regulations instituted by NMFS have helped the SSL population to recover from its decline. Those regulations were enforced around all major rookeries in the western stock range. Since there were no sites left unprotected, a comparison between "treatment" and "control" units was not possible. Therefore, a conclusive cause and effect relationship between fishing and SSL population trend cannot be determined. However, the available data on both fishing and SSL comprise a long time series that encompasses several years before and after the enforcement of the SSL protection measures. Thus, while it is impossible to say that some coincident third factor was not responsible for the patterns seen in fishing and SSL population, it is possible to determine whether those patterns changed after the onset of protective measures.

The early relationship between SSL and fisheries was negative. That is, rookeries where high levels of fishing occurred tended to show steeper declines in SSL population. This relationship was spatially limited to areas within 30 km of shore and strongest during the summer and fall when SSL are breeding or caring for young pups, and are generally found near shore. Small trawl fishing operations tended to have the strongest negative association with SSL.

The possibilities for explaining this relationship are legion. Since SSL and fisheries often target the same species and size of fish, it has been postulated that inhibitory competition exists (Alverson 1991, Baraff and Loughlin 2000). This hypothesis is one facet of the more general idea that SSL have been nutritionally stressed, which has contributed to their decline (Trites and Donelly 2003). Another possibility is that the interactions between SSL and fisheries have led to the death or injury of SSL. This could result from incidental capture of sea lions in fishing gear, or the intentional killing of sea lions by fishermen, either for bait or in defense of gear and catch. There are other, indirect modes of competition that might exist as well. For example, fisheries activity might disperse schools of fish, making hunting more difficult for SSL. None of these hypotheses has received much popular support due to a lack of experimental evidence sustaining them. There were very few experiments conducted on SSL prior to their listing as 'threatened' under the ESA in 1991. We therefore have an incomplete picture of the ecological situation during the peak of the decline.

The protection measures instituted during or near 1991, were designed to ease the pressure many scientists believed fisheries were putting on SSL (Braham et al. 1980, Lowry 1982, Merrick et al. 1987, Loughlin and Merrick 1988, Alverson 1991). The protection measures stopped intentional killing, and instituted quotas in the amount of allowable indirect mortality of SSL caused by fishing gear. They also moved the fishery offshore, away from the waters

immediately surrounding rookeries. Finally, the regulations attempted to spread out fishery removals over both time and space.

Since the implementation of these protections, the nature of the relationship between SSL and fisheries has reversed. The statistically significant correlations between fisheries and SSL were positive after 1991. That is, rookeries that had high levels of fishing around them tended to have less steep population declines. This relationship was spatially limited to areas further than 30 km from shore and strongest during the winter and spring. Pelagic trawl operations tended to have the strongest positive association with SSL population trend over this time period.

There are several possible explanations for why the statistically significant relationship between SSL and fisheries became positive, moved offshore, and shifted to different seasons and gear types. It is conceivable that a climatic shift occurred at some point near 1991 and that changes in the ecosystem affected both SSL and fisheries. The composition of the prey species population has undergone many changes in the years following the climate regime shift of the late 1970's (NMFS 1992, Benson and Trites 2002). This shift in prey species composition has been posited as a contributing factor in the SSL decline, in the form of the "junk food hypothesis" (see Trites and Donnelly 2003) and direct competition from large gadids and flatfish (Trites et al. 1999). It is possible that those changes resolved into a combination of species that is more favorable for SSL around 1991. There was another, less apparent regime shift in 1989, but it appears

unlikely that this event alone could have positively affected the SSL population

trajectory (see chapter 3). Other possibilities include threshold hypotheses. For

example, SSL population size might have reached a critical threshold level near

1991. In this scenario, the decline of SSL dropped below a new carrying capacity

(possibly set by environmental changes), thus slowing the decline. Both of these

hypotheses require that some event or threshold level be reached at or near 1991.

A far more parsimonious postulation is that the changes seen in the relationship

between SSL and fisheries were driven by the implementation of protection

measures that began in 1991.

Perhaps the single most important protection afforded SSL under the ESA,

was the cessation of intentional killing. If SSL/human interaction frequently led

to the death or injury of SSL, then a near shore negative relationship would be

expected. A negative relationship would result from the fact that more

interactions occur where more fishing occurs. SSL would be more likely to be

seen near shore since they are arriving at and leaving from the same place

repeatedly, whereas off shore they are likely to visit a variety of locations to

forage. There is also more opportunity for SSL and fishermen to avoid

interactions offshore, since the area concerned (in this analysis, a circle with

expanding radius) is much greater. The months of the summer and fall, when

SSL are more likely to be found near shore would probably contribute to this

pattern as well.

Alterations were made to the pollock and Atka mackerel Fishery Management Plans following the "listing" of SSL in 1991. These changes were designed to spread out fisheries removals over the course of the year. Before the implementation of these plans, summer and fall fishing showed the strongest negative relationship with SSL population decline. After the 1991, summer and fall fishing were unrelated to the SSL decline and winter and spring fishing produced the strongest positive relationship with SSL population trend.

Another possibly critical protection was the institution of a 3 nm, later expanded to a 10 nm, trawl exclusion zone. Before the establishment of these exclusions, near shore, small trawl vessels produced the strongest negative association with SSL population trend (of any gear type and distance), following the protection, that relationship was no longer significant. Instead, offshore, pelagic trawlers had the strongest positive association with SSL population of any gear type and distance.

The negative association with small trawl vessels is simple to explain if, as discussed before, the association is simply due to the fact that more interactions led to more deaths and injuries for SSL. Small trawl fishing was the most common gear type employed inside the 0 – 30 km range, which would indicate the probability of a small trawl vessel encountering SSL was probably higher than for other gear types. It is also possible that small trawler fishing gear directly killed more SSL than other gear types (Perez and Loughlin 1991). Furthermore, small trawlers may have caused localized depletions of fish populations near

rookeries. These aggregations may be critical to the foraging success of lactating females and juveniles.

The positive association with offshore pelagic trawl gear after 1991 could be an indicator of particularly rich prey fields. That is, an area productive enough to support the needs of both SSL and the commercial fishery. This positive relationship indicates that commercial fisheries, as they are currently prosecuted, are probably not hindering the SSL recovery. However, it is important to note that SSL are currently at a depressed level. If their population begins to expand, the relationship between fisheries and SSL may change again.

In conclusion, the characterization of the pre-1991 relationship between SSL population trend and the Bering Sea/Gulf of Alaska Fishery is different, in almost every way measured, from the post 1991 relationship. Although the analysis presented here shows only correlation, the data support a logical and parsimonious hypothesis: the protection measures implemented by NMFS designed to mitigate the potentially inhibitory affects of the Bering Sea/Gulf of Alaska commercial fishery on the recovery of the Steller sea lion, are effective.

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APPENDICES

APPENDIX A

FISHERIES GEAR AND TECHNOLOGY

Trawl Netting

Trawl nets come in many shapes and sizes and have been used in the North Pacific since 1876 (Forrester et al. 1978). The most basic trawl nets are conical in shape. The net is dragged along with the base of the cone forward. Fish enter through an opening there and cannot escape out of the narrow end of the net (codend) which is closed. The net has to be pulled at a pace sufficient to keep fish from swimming out of the open end. The earliest trawls were paranzella nets and beam trawls. Two boats in tandem, called pair trawlers, fished paranzella nets. Each boat would pull one side of the net and the two would stay side by side throughout the tow. The paranzella net mouth was held open by "spreaders", a combination of a short rod and net rigging that kept the net mouth from closing vertically, and the width created by separation between the two vessels, which kept the net from closing horizontally. Beam trawls had the relative advantage of being fishable by a single boat. The mouth of the net was held open by a large metal beam. Beam trawls were effective, but unwieldy (*ibid*).

Otter board trawls were introduced in the North Pacific in 1906 (Forrester et al. 1978). The mouth of an otter board trawl is held open by water pressure, which is directed into the net mouth by two large boards that sit on either side of it. Outriggers, or poles that extend laterally out from the ship help keep otter trawls spread open. Although the shape of the trawl doors (otter boards) and rigging has changed over the years, otter board trawls are still the dominant type

of bottom trawl used today (Von Brandt 1984, Waitling and Norse 1998, Ocean Studies Board 2002).

The development of the stern trawler in the 1950's made fishing in any weather possible (Von Brandt 1984). Instead of nets being hauled over the side, where manpower was needed in addition to winches, they were pulled up a chute in the stern of the vessel, entirely by winch. The technological boom post WWII brought in bigger, more powerful boats, which meant that bigger trawl nets could be used.

A major distinction in trawl net fishing is whether the trawl is designed to fish the ocean bottom, or mid-water depths. Bottom or demersal trawls typically have a smaller opening (Von Brandt 1984). They are weighted with steel weights called bobbins, which, when placed along the bottom edge of the net opening, keep the net on the sea floor. The upper horizontal section of the net mouth is strung with floats, which help keep the net open. Otter trawls are extremely heavy, often weighing over 1 mt when empty (Waitling and Norse 1998). They can be over 12 m tall and stretch 100 m between the doors (OSB 2002). Beam trawls do not require additional weight to stay on the bottom, as they can weigh over 10 mt when empty (Waitling and Norse 1998). The opening of a beam trawl can be 15 - 20 m wide and (OSB 2002). Historically, bottom trawls worked only on smooth, sandy or muddy-bottomed areas, in order to avoid damage to gear. Since the mid 1980's bottom trawls have expanded to any and all substrates with use of rockhoppers (OSB 2002). Rockhoppers are large molded rubber, or steel

discs that can bounce over rough terrain, while holding the more fragile net above

sharp potentially damaging snags. Trawl nets are also often equipped with

ticklers, which are chains that run across in front of the net opening to scare fish

off the sea floor and into the net. The addition of rockhoppers and the ever

increasing size and power of the fishing fleets in the North Pacific has given

fishermen access to the seabed in waters over 2000 m deep (Norse and Waitling

1999).

The dragging of heavy trawl gear over the sea floor has probably had an

effect on the benthic ecosystem (Waitling and Norse 1998). The physical

structure of the benthos is important for benthic biodiversity (Norse and Waitling

1999). Benthic structure provides hiding places from predators and feeding

patches for demersal fish and other species. Observed disturbances resulting from

trawl activity include, loss of surface sediment, reduced structural complexity,

damage to corals, bryozoans, sponges and other sessile organisms (*ibid*).

Mid-water trawls are used to catch pelagic species like pollock. Mid-

water trawl nets are larger than bottom trawls. The larger the net opening, the

larger the "area swept", which generally results in larger catches. The most

important technological innovation in mid-water trawling has been fish detecting

devices like echographs, through which fisherman can detect the location and

depth of aggregations of fish (Von Brandt 1984). A device called a "netsonde"

allowed fishermen to accurately detect the depth of the top and bottom of the

mouth of the mid-water trawl net, and thus, to align the net relative to the targeted

fish aggregation (*ibid*). It is also important for pelagic trawls to have low

resistance. Fish can detect the swell of water that is pushed out in front of a

moving net with high resistance, and dodge away from its mouth. Pelagic trawls

therefore have very wide mesh opening in the forward section of the net, which

reduces the resistance. Pelagic trawls probably do not have as much of an impact

on the marine ecosystem as bottom trawls, though they can remove large amounts

of locally concentrated biomass (Fritz *In Prep*). According to NMFS Fisheries

Observer data, pelagic trawls have taken single hauls of pollock that include over

600,000 fish and weigh over 550 mt.

Purse Seine Netting

Purse seines are used to catch pelagic fish near the surface. They are

made of long walls of netting, sometimes stretching several km in length (Von

Brandt 1984). Purse seines have metal rings strung along their bottom edge with

a line running through them. To catch fish with a purse seine net, a school of

target fish needs to be encircled quickly, to prevent horizontal escape. Once the

fish are surrounded, the line strung along the bottom of the net is tightened, which

cinches the bottom of the net almost closed and hampers vertical escape. The net

can then be towed on board as in trawl fishing. Purse seining requires less towing

power and fuel than trawl fishing, but targets only fish that occur near the surface.

Purse seines were first used in the North Pacific around 1863 (Von Brandt

1984). The most important technological advance in purse seine fishing was the

introduction of the power block in the 1950's (*ibid*).   Purse seines traditionally

required an excessive amount of man, or winch power to be towed on board.

Power blocks are essentially pulleys suspended above the deck of the boat at a

steep angle. They greatly reduce the amount of torque needed to haul the net

(*ibid*).   Today, in American fisheries, purse seining is mainly used in the eastern

tropical Pacific for catching tuna (*ibid*).

Gillnets, Driftnets and Tangle Nets

Gillnets are nets made of mesh. As fish attempt to swim through a gillnet

they get hung up in the mesh, usually getting the area behind their gills caught. If

fish are too big to fit into the mesh of the gillnet, they can still become entangled

in it. Gillnets are generally shaped like a wall, with floats on the top edge and

weights on the bottom edge maintaining the alignment. Gillnets are usually set

across the path of migrating fish, so that they attempt to swim through the mesh

(Von Brandt 1984). The effectiveness of a gillnet depends on several factors.

The net must be somewhat slack and the filaments that make up the mesh must be

as thin as possible. The reason for this is that fish generate a displacement of

water as they swim. The fish can sense the reflection of that water off of any

solid object, which helps them navigate (*ibid*). Reducing the reflective properties

of a net therefore reduces the chances that a fish will detect it in time to avoid it.

The color of a net can also help disguise it. The introduction of monofilament

line has been extremely important in the gillnetting industry (ibid). Monofilament
is very thin and strong and can be almost transparent.

There are a number of different types of gillnets used in fisheries. Gillnets
can be set on the bottom, to catch demersal fish. There are anchored nets that
float at some distance off the bottom. There are surface nets, used in the North
Pacific to catch herring (Alverson 1991), and there are also free drifting gillnets,
called driftnets. Driftnets in the North Pacific have mainly been employed by the
Japanese to catch salmon and other schooling fishes (Alverson 1991, Von Brandt
1984). Driftnets are often fished in "fleets" or "gangs", a large row of drift nets
that can cover several km of water at once, thus catching even widely scattered
schools of fish (Von Brandt 1984).

One of the major ecological problems that has resulted from the North
Pacific driftnet fishery is ghost fishing. Ghost fishing occurs when lost or
discarded fishing gear continues to catch and kill marine organisms. L. Davis
(1991) reporting on NMFS estimates, states that over 1000 km of driftnet are lost
each year in the North Pacific. The amount of biomass lost to ghost fishing each
year is unknown, but driftnets have been known to catch and kill a number of
non-fish species, including pinnipeds (Henderson 1984).

Another type of mesh net used in the North Pacific is the tangle net
(Alverson 1991). Tangle nets are mainly used to catch crustaceans (Von Brandt
1984). Tangle nets have been used to catch crabs in the BS and GOA (Alverson
1991). Japanese tangle nets for king crab were set vertically and held down by

weights. Floats on the upper edge held the net's alignment, as in gillnetting.

Crabs become entangled as they enter the net and then struggle to get out. One of

the major problems with tangle nets is that struggling crustaceans easily damage

them. In order for a tangle net fishery to be profitable, the catch needs to be both

valuable and plentiful (Von Brandt 1984). As king crab catches declined in the

BS and GOA in the late 1960's, the Japanese tangle net fishery declined as well.

By the early 1970's most king crab fishermen in the BS and GOA used pots.

Pot Trap Fishing

Fish traps come in many shapes and sizes. In general, traps have large

openings on one end and small partial enclosures on the other. A fish enters

through the opening and is drawn to the small end, usually by bait or force of

current. Once the fish enters the smaller end of the trap it is stuck there by water

pressure, or the design of the trap, which makes it confusing or otherwise difficult

for fish to find a way out. Pots are fully enclosed traps. They are usually baited

and used as bottom gear (Von Brandt 1984). Pots in the BS and GOA have been

used to catch Pacific cod and various crab species (NMFS 2001). King crab pots

used off the coast of Alaska are often made of steel bars welded into a

rectangular, pyramidal, or conical shape and then covered with wire or net mesh

to make the trap (Alaska Department of Fish and Game (ADFG) at: www.cf.adfg.

state.ak.us).

Pots can also contribute to ghost fishing mortality when they are lost. However, once the bait is lost (which can take a long time if fish continue to be caught and die inside the trap), their effectiveness at catching fish decreases (ADFG: www.cf.adfg.state.ak.us).

Longline Fishing

The concept of longline fishing is simple. Many hooks, up to thousands (Von Brandt 1984), are strung along a single long line. The hooks are individually baited and set apart from each other by spreaders, or leaders. Depending on conditions longlines can be set on or off of the sea floor using a combination of floats and weights. Longlines are used in the North Pacific to catch halibut, sablefish, cod and other species (Alverson 1991). There are no significant bycatch or ghost fishing problems associated with longline fishing (*ibid*).

APPENDIX B

STOCK HISTORY AND DESCRIPTION OF IMPORTANT FISH SPECIES

Walleye Pollock

The BS/GOA walleye pollock fishery currently represents one of the largest single species fisheries in the world (Springer 1992). It is the dominant species of fish in the eastern BS and the second most common groundfish in the GOA (NMFS 2001). Pollock is used to make minced fish, or *surimi*, which is used to make fake crab and fish cakes in Japan. Pollock is also the main ingredient in US products like fish sticks and fast food fish patties. Landings of pollock in the BS peaked in 1972 at 1,874,534 mt, and in 1984 in the GOA at 307,400 mt (NMFS 2000b).

Pollock are a semidemersal schooling fish, widely distributed throughout the North Pacific. They typically occur at depths of 100 –300 m, near shore in the summer and further off shore, in waters as deep 1000 m, in winter. Juvenile pollock are pelagic and feed mainly on copepods and euphausiids (NMFS 2000b). As pollock age, they rely increasingly on fish for food and are cannibalistic (Springer 1992). Smaller pollock can make up a major portion of their diet (Livingston and Lang 1997). Pollock reach a maximum-recorded age of 22 years (NMFS 2000b).

Pollock biomass in the eastern BS has been estimated by NMFS since 1979 (NMFS 2000b). The biomass estimates are based on the triennial surveys mentioned in chapter 4. Figure 12 shows the available biomass estimates and fisheries removals in the eastern BS.

Figure 12. Estimated Pollock Biomass and Fisheries Catch in the Eastern Bering Sea, by Year.
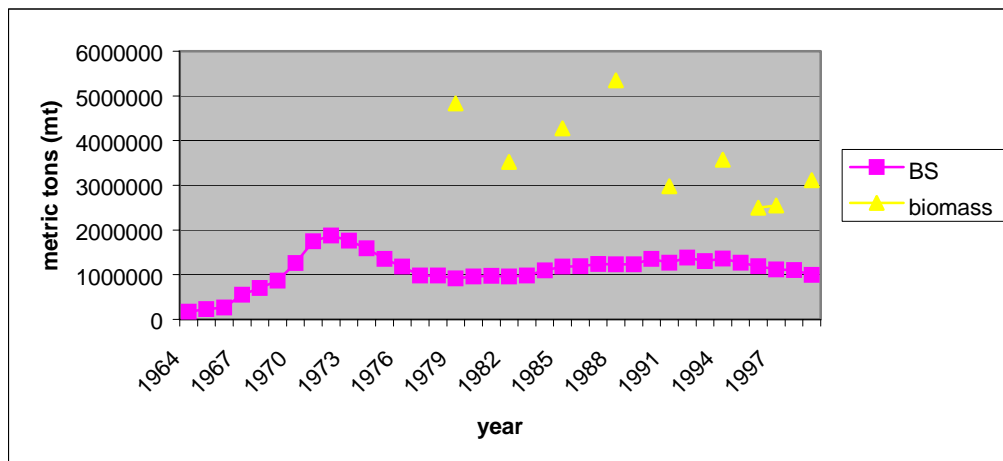
<div align="center">Pacific Cod</div>

The Pacific cod fishery is the second largest Alaskan groundfish fishery (NMFS 2000b). Pacific cod are a demersal species. They occur on the continental shelf throughout the North Pacific (*ibid*). Pacific cod migrate long distances and congregate in relatively small areas in order to breed. Known breeding grounds in the BS/GOA area include, the Shumigan Islands, in between Unimak and Unalaska Islands and southwest of the Pribolof Islands (NMFS 2001).

Pacific cod eat invertebrates when they are young and are mainly piscivorous when they are adults. Their most important prey items by weight for Pacific cod are, pollock, fishery offal and yellowfin sole (NMFS 2001).

Pacific cod biomass in the eastern BS has been estimated by NMFS since 1979 (NMFS 2000b). The biomass estimates are based on the annual bottom

trawl surveys mentioned in chapter 4. Figure 13 shows the available biomass

estimates and fisheries removals in the eastern BS.

Figure 13. Biomass Estimates and Catch of Pacific Cod in the Eastern Bering Sea, by Year.
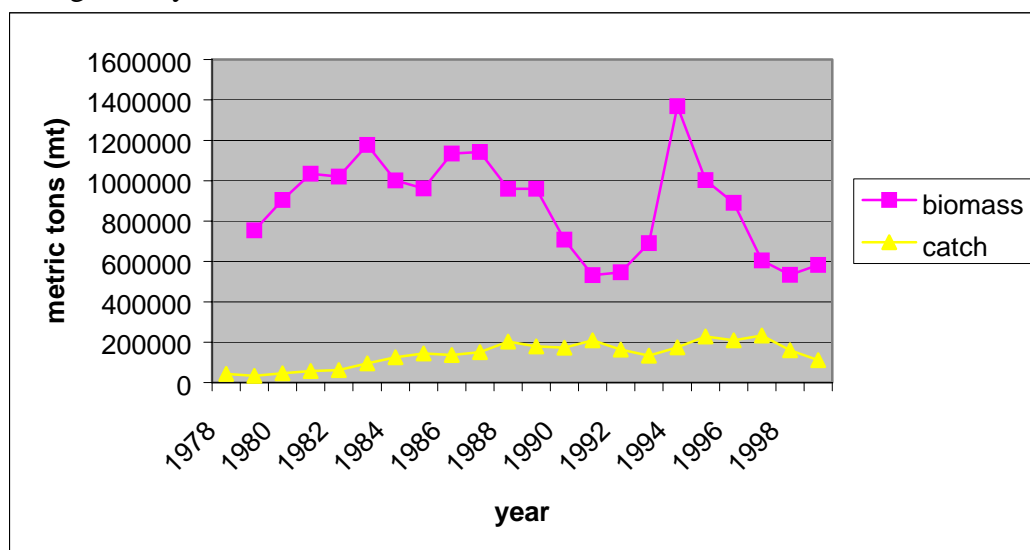
Atka Mackerel

Atka Mackerel are semipelagic and occur throughout the Aleutian Islands

and into the BS and GOA to southeastern Alaska (NMFS 2001). Adults spend

most of the year in relatively shallow water (< 200 m) over the continental shelf

(*ibid*). They migrate into shallower water in summer to breed. Females deposit

eggs in rocky crevices, which are guarded by the males until the eggs hatch (*ibid*).

Atka mackerel reach a maximum weight of about 1 kg, length of about 65 cm and

recorded age of 15 years (NMFS 2000b).

Atka mackerel apparently eat mainly invertebrates, though they also eat squid, pollock and their own eggs (NMFS 2001).

Atka mackerel are a difficult species to survey because they do not have a swim bladder, making them a difficult target for hydroacoustic surveys (NMFS 2000b). They also tend to congregate in rocky, topographically complex areas, which make bottom trawl surveys difficult. Finally, they school in very large aggregations and occur irregularly throughout their range. All of these factors contribute to biomass estimates with high variances (*ibid*).

Atka mackerel biomass in the eastern BS has been estimated by NMFS since 1979 (NMFS 2000b). The biomass estimates are based on cooperative US – Japanese trawl surveys (*ibid*). Figure 14 shows the available biomass estimates and fisheries removals in the Aleutian Islands.

Figure 14. Biomass Estimates and Catch of Atka Mackerel in the Aleutian Islands, by Year.
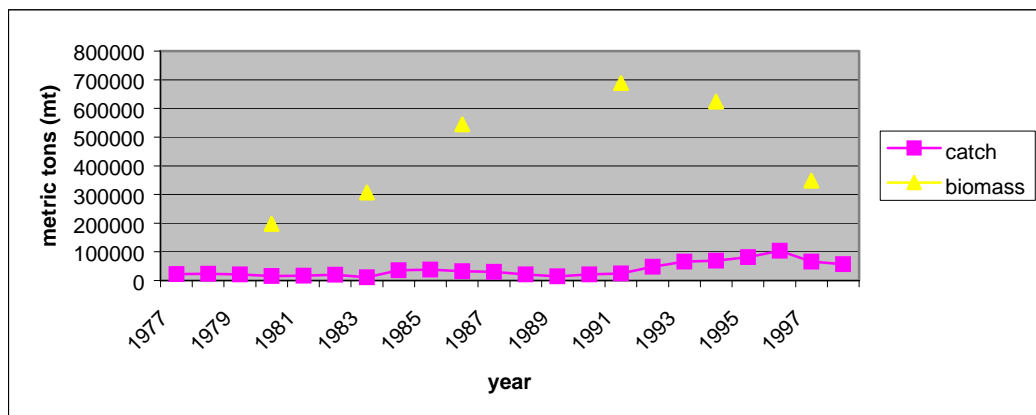
APPENDIX C

STELLER SEA LION POPULATION TREND MODELS

This appendix contains three figures, which are collections of simple

scatter plots of the natural log of SSL index counts against the year in which that

count was made. The fit produced by the two-stage regression model mentioned

in chapter 7, is shown as a line through the points. The figures are meant to

illustrate the differences in slope estimates that derive from using varying subsets

of the available SSL data. Note that sites that did not have adequate index counts

(at least 3 per time period) were excluded from the analysis.

The requirement of 3 counts per time period is derived using Gerrodette

(1987), which provides a method for estimating the probability of detecting

upwards or downwards trends in abundance using linear regression. His example

deals specifically with aerial counts of California sea otters. The method

described in his paper is directly applicable, because the technique used here, for

determining the trends in the SSL population, involves linear regression of aerial

adult count data. Gerrodette (1987) requires that the relationship between the

coefficient of variation (cv) of the abundance estimates and the abundance

estimates be known (or at least approximated). The aerial surveys of SSL

rookeries could be considered point counts, which are a method of distance

sampling. Gerrodette (1987) points out that in distance sampling, the cv of

abundance does not depend on abundance. Therefore, to reduce 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, (both are 0.05) and the cv can be estimated from existing SSL 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, basically a measure of the observation error). Using the method described above and a cv estimate of 0.0271 (derived from replicate counts), the minimum number of counts required to detect a trend of minimum size $r = -0.02$ (a very conservative estimate of the SSL decline), is 3.

Figure 15. Slope Estimates Using All Available Data From 1956 – 2001.
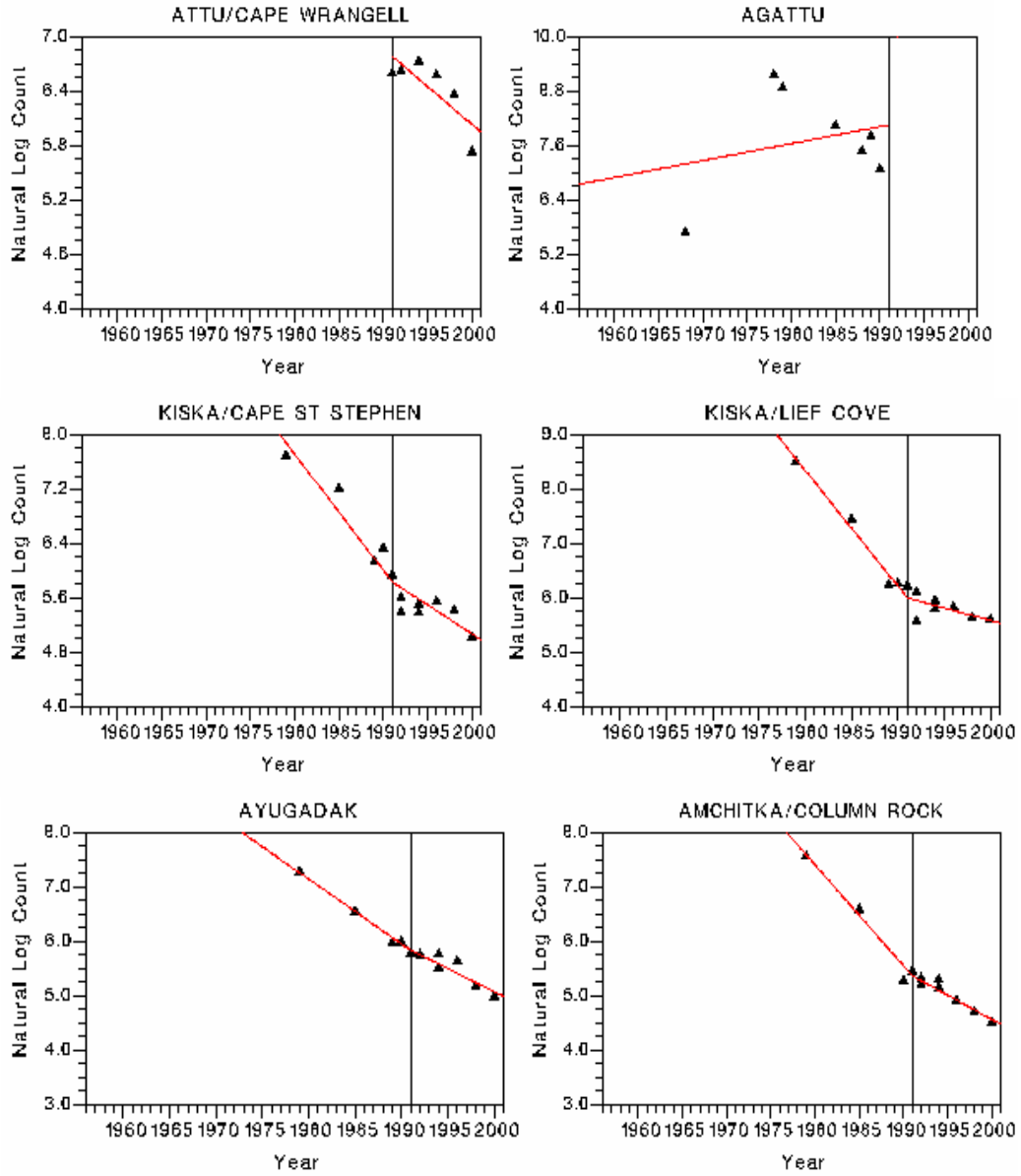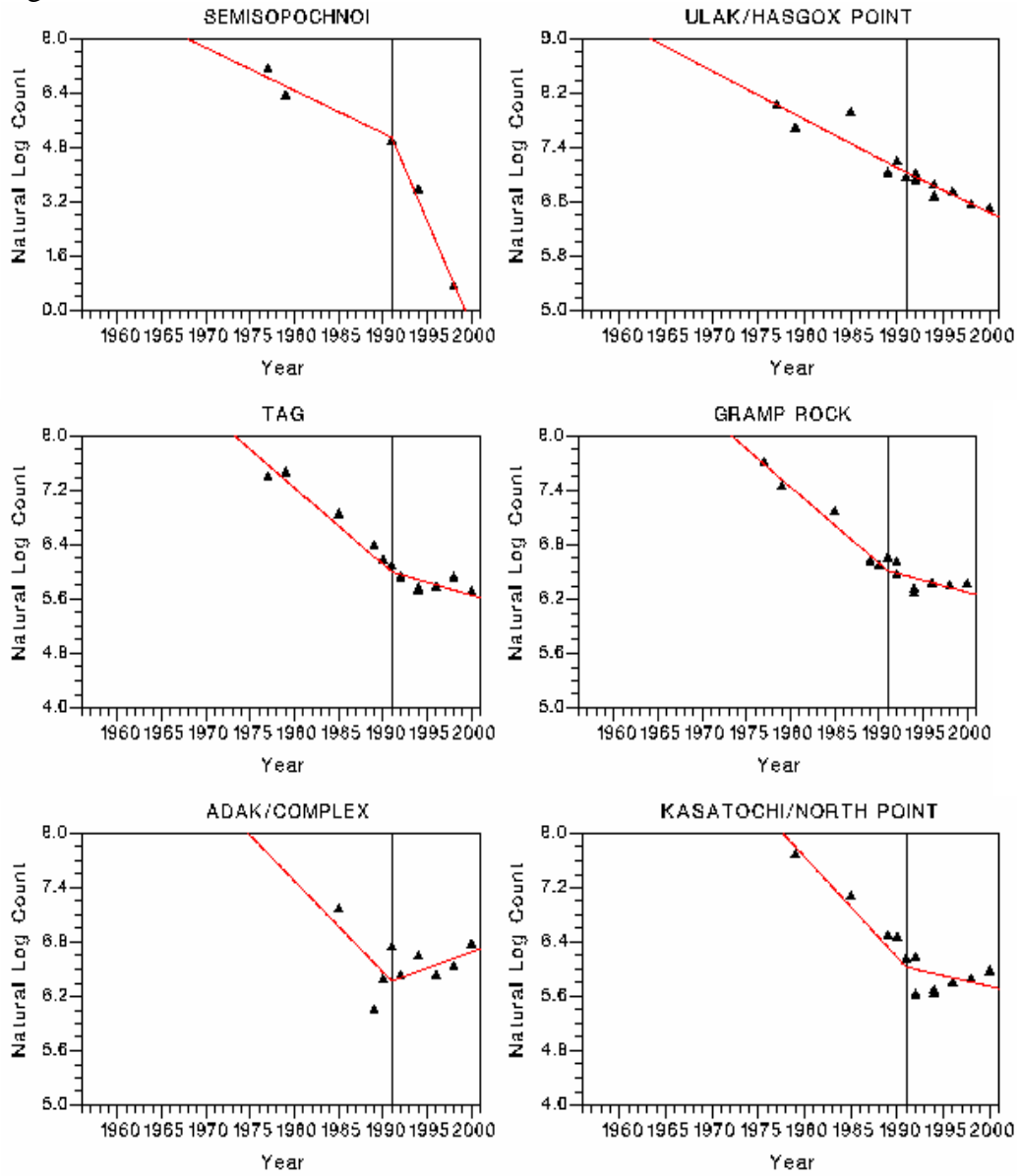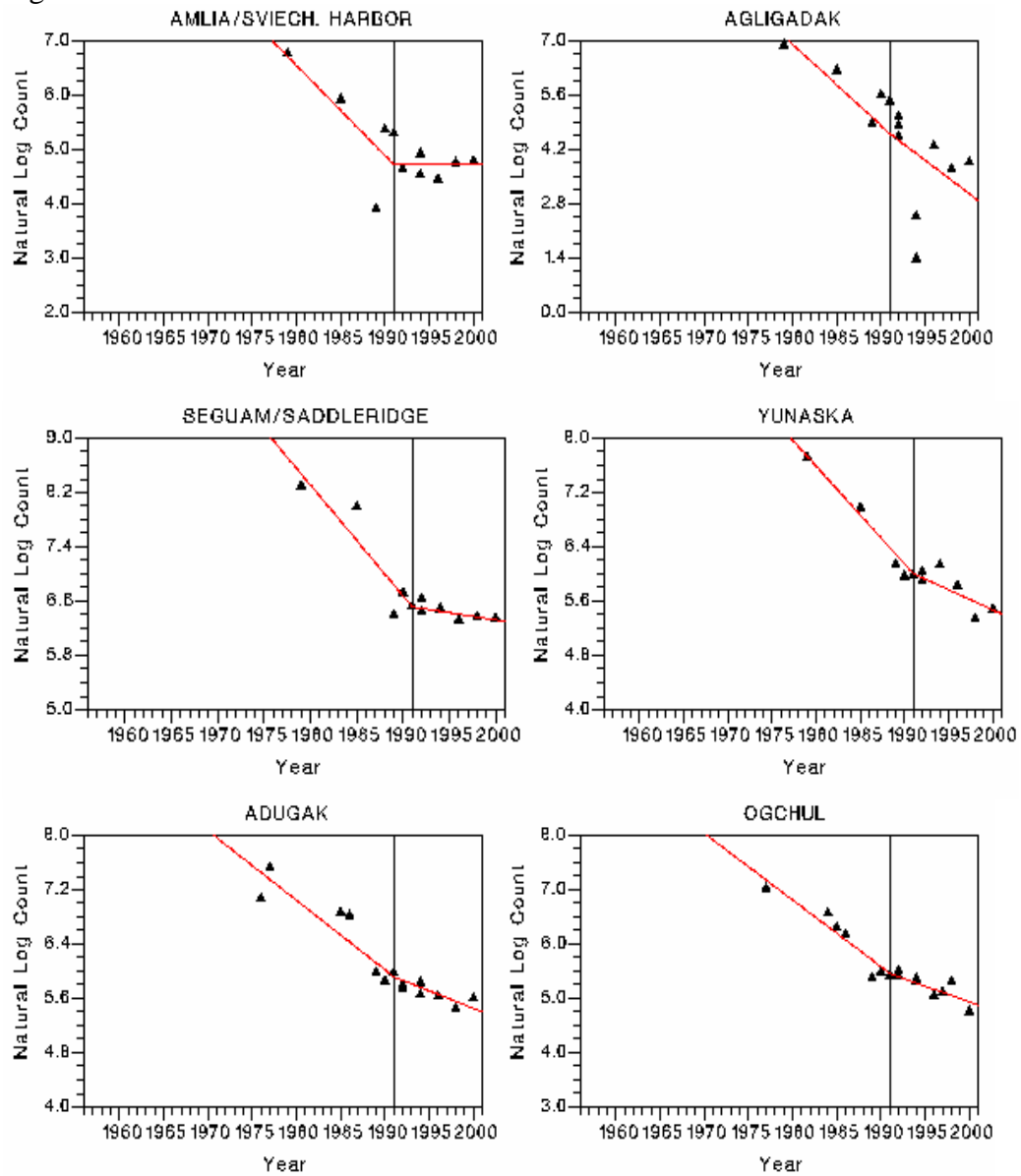
Figure 15. Continued.
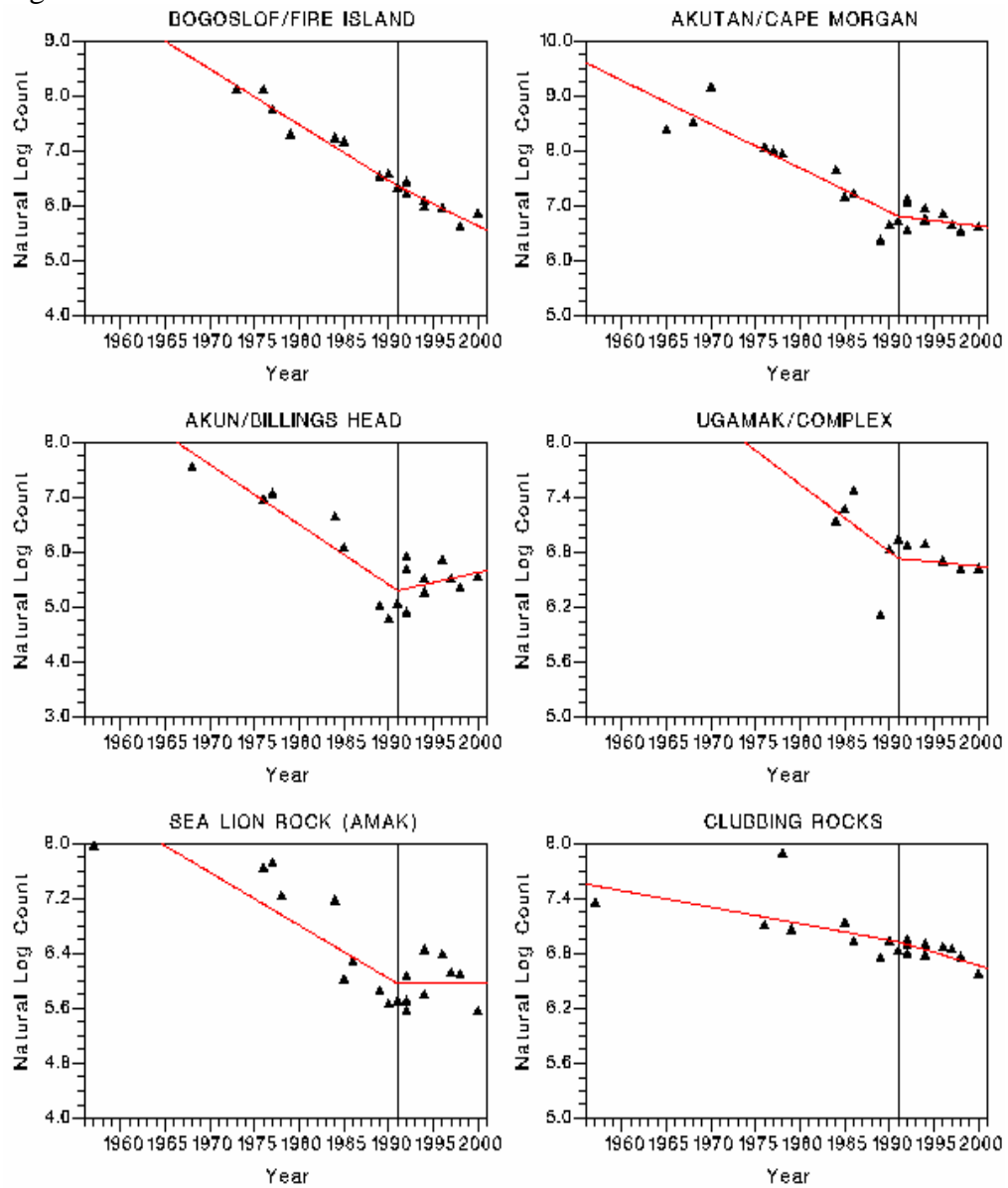
Figure 15. Continued.

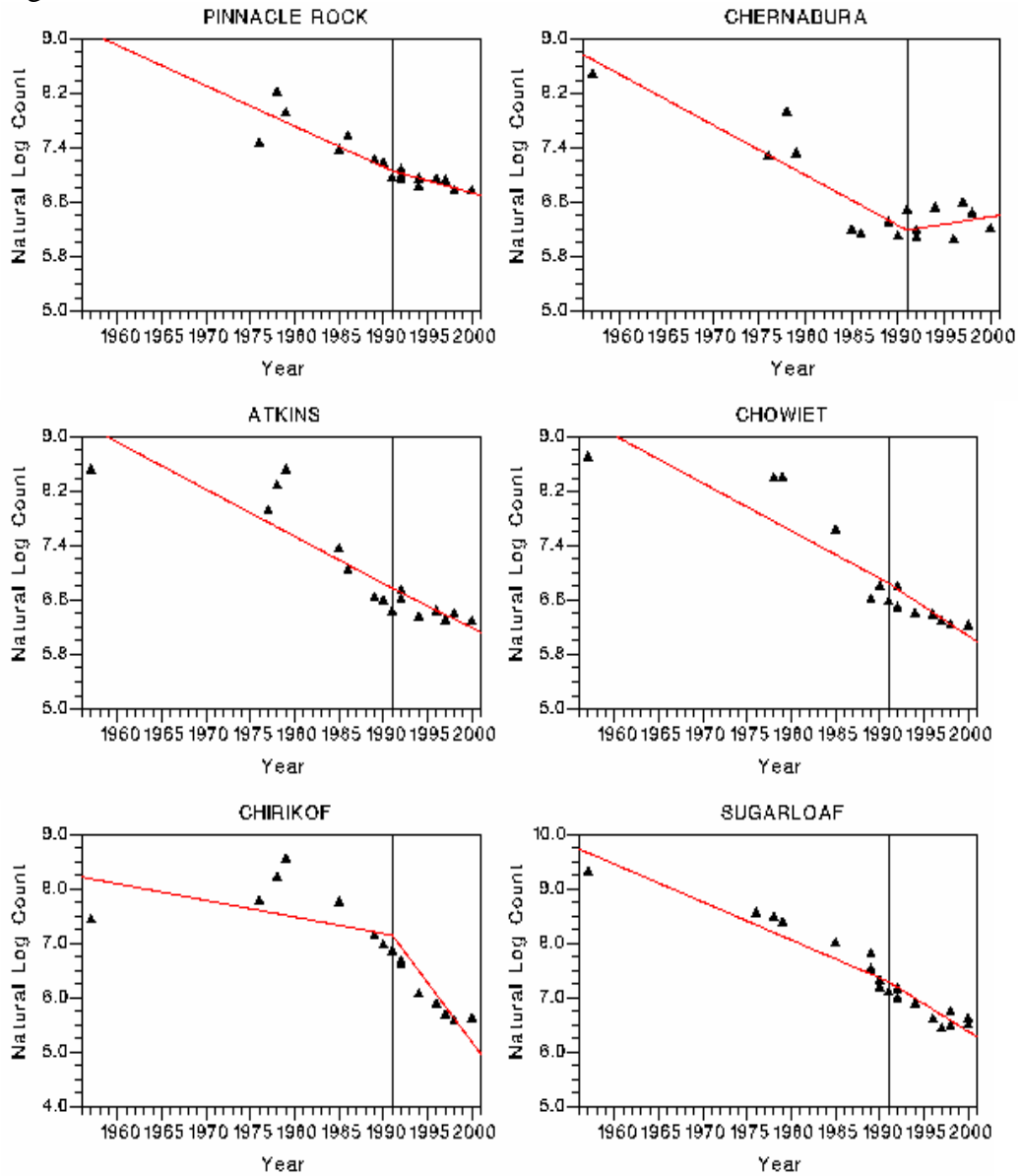Figure 15. Continued.

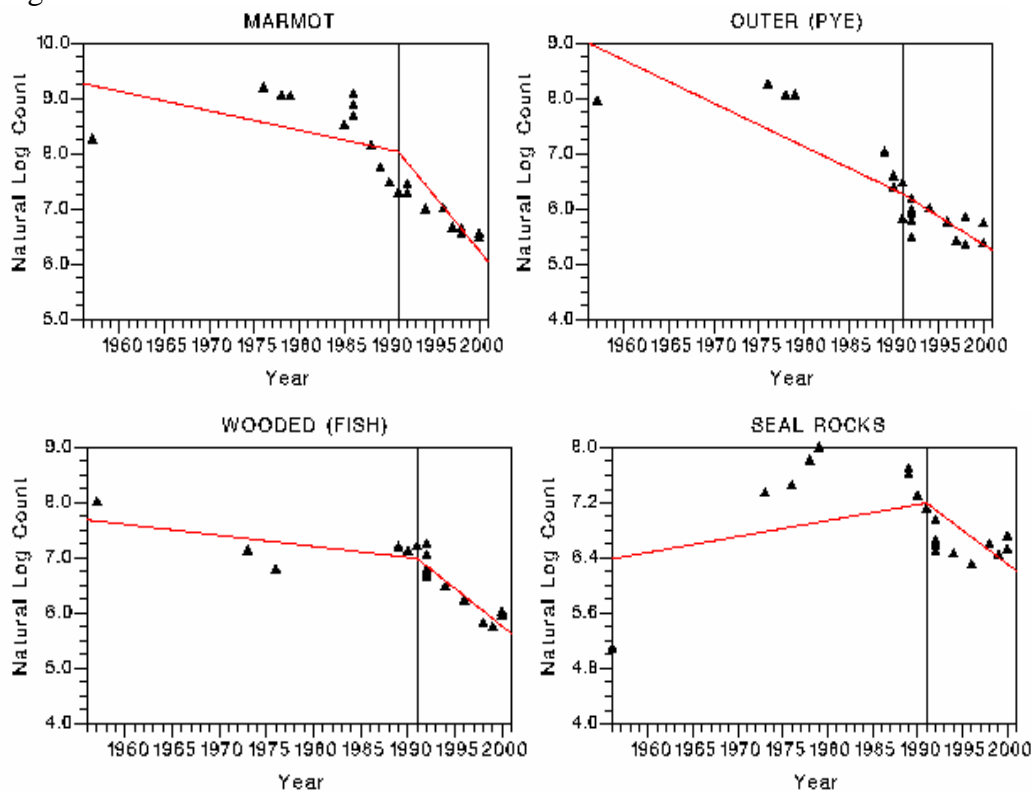Figure 15. Continued.

Figure 15. Continued.

Figure 16. Slope Estimates Using All Available Data From 1960 – 2001 (Only Sites that had Different Slope Estimates From the Data Set that Included the 1950's Index Counts are Shown).
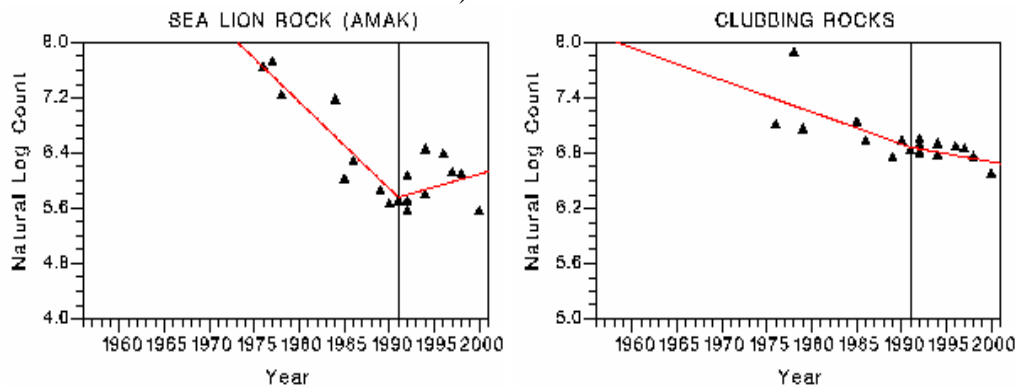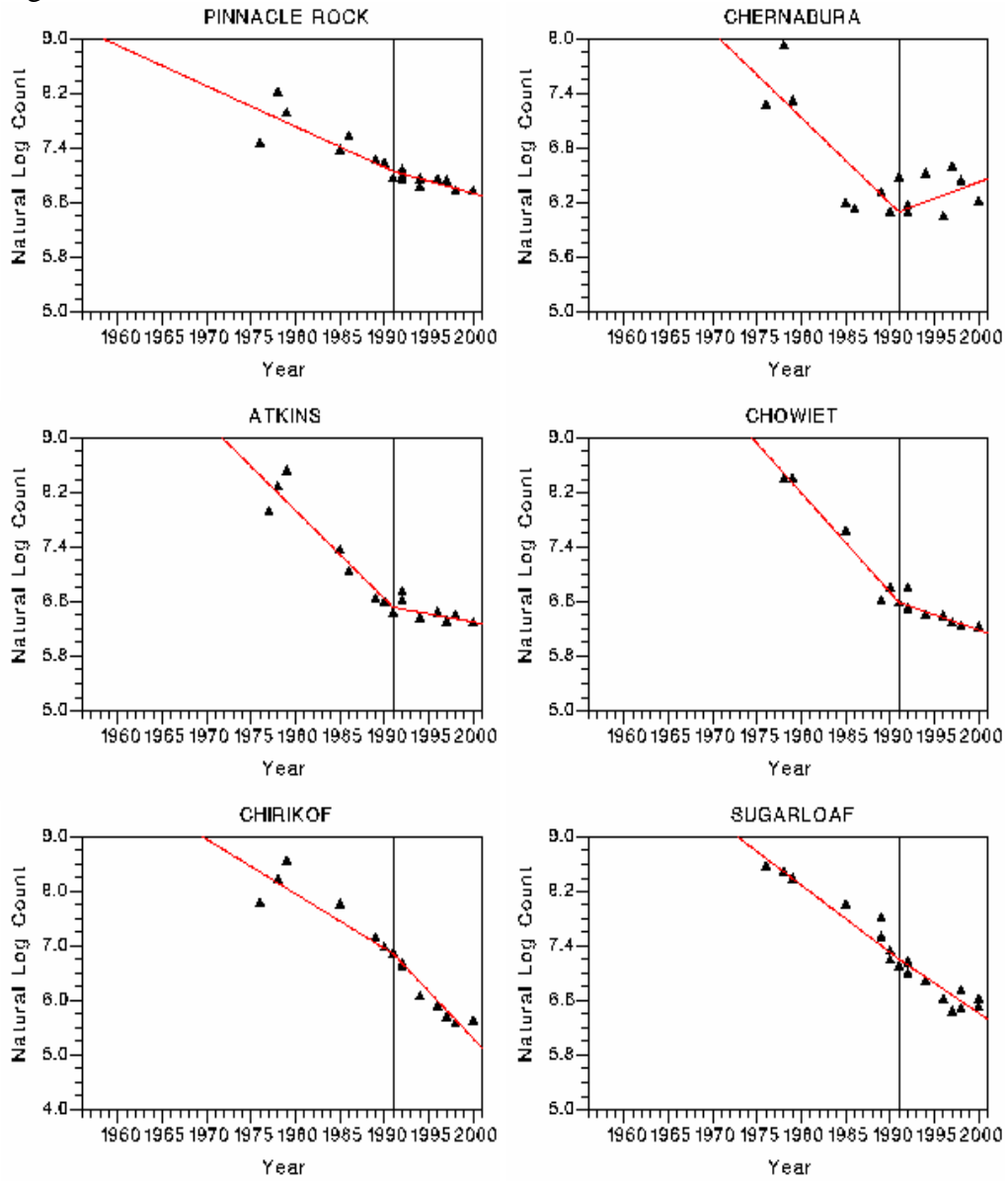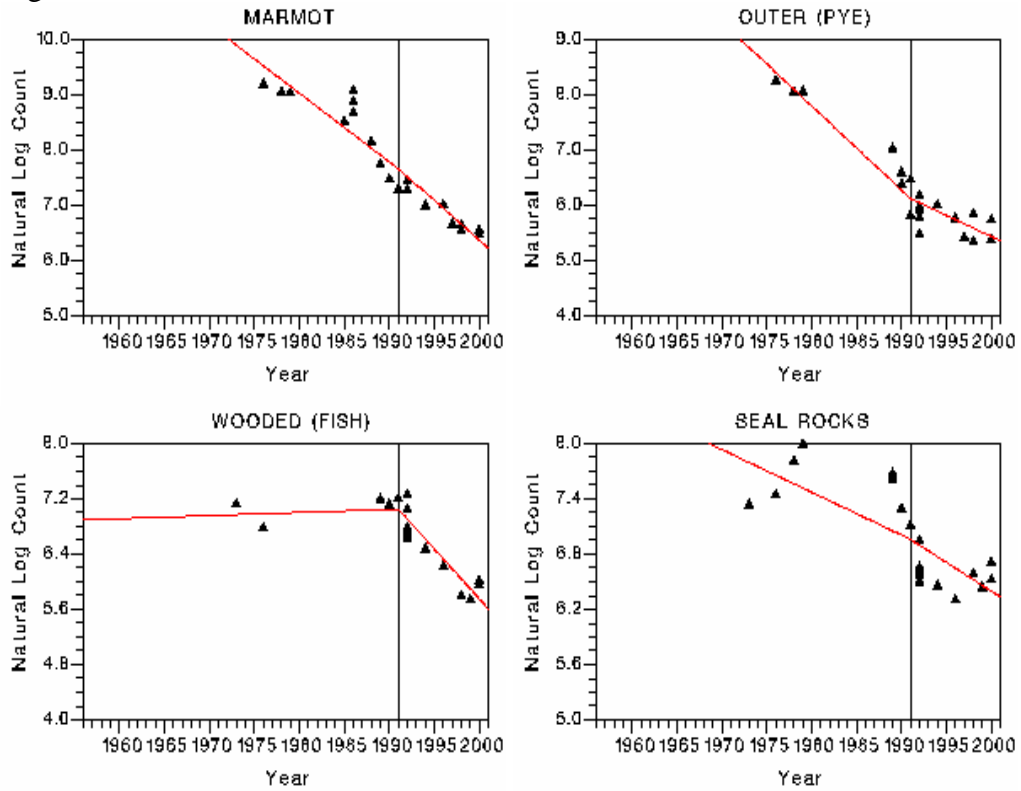
Figure 16. Continued.

Figure 16. Continued.

Figure 17. Slope Estimates Using All Available Data From 1977 – 2001.

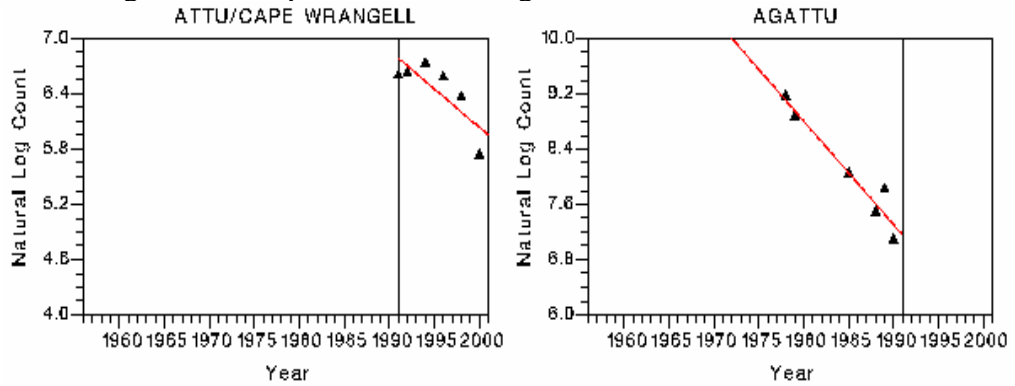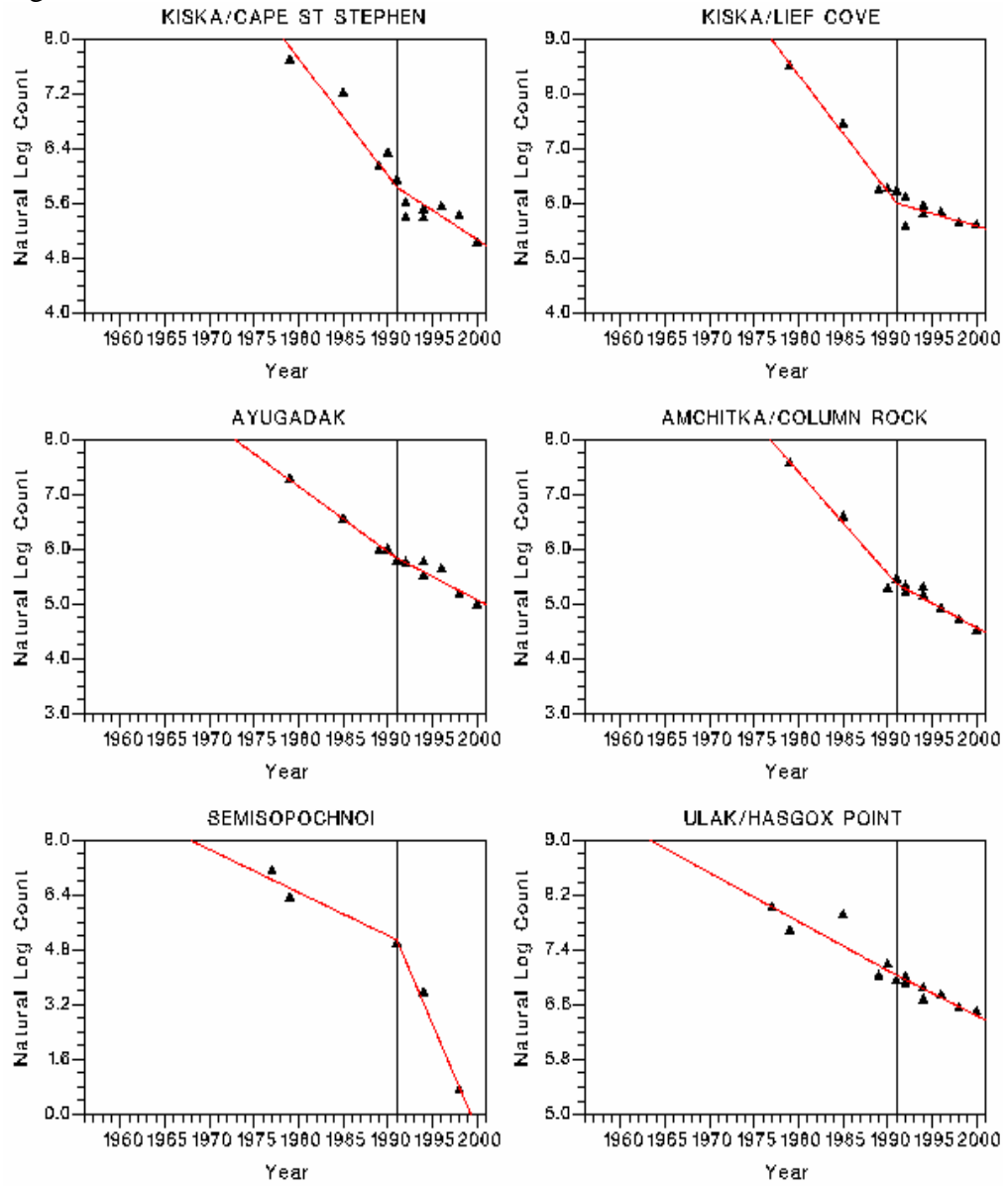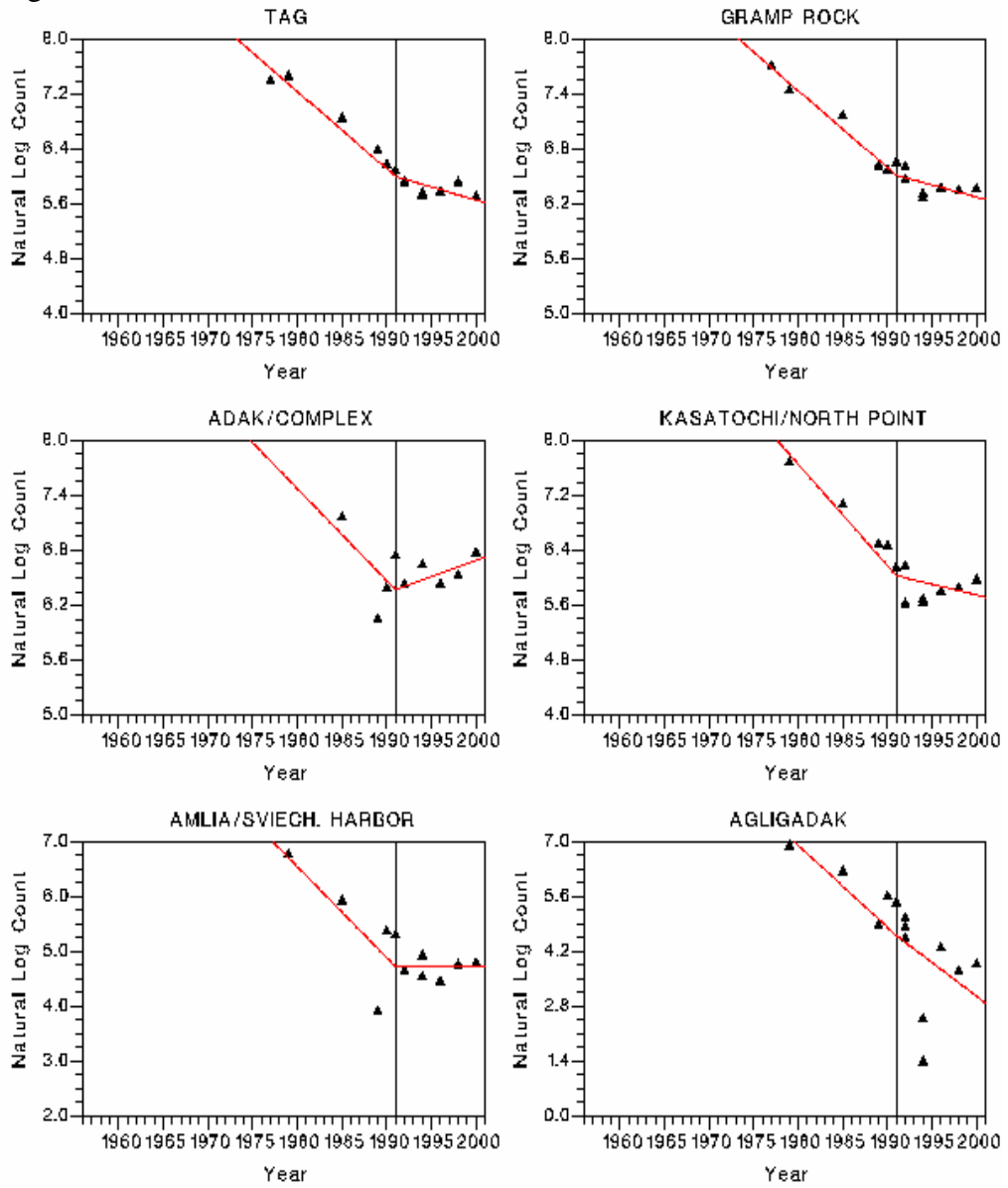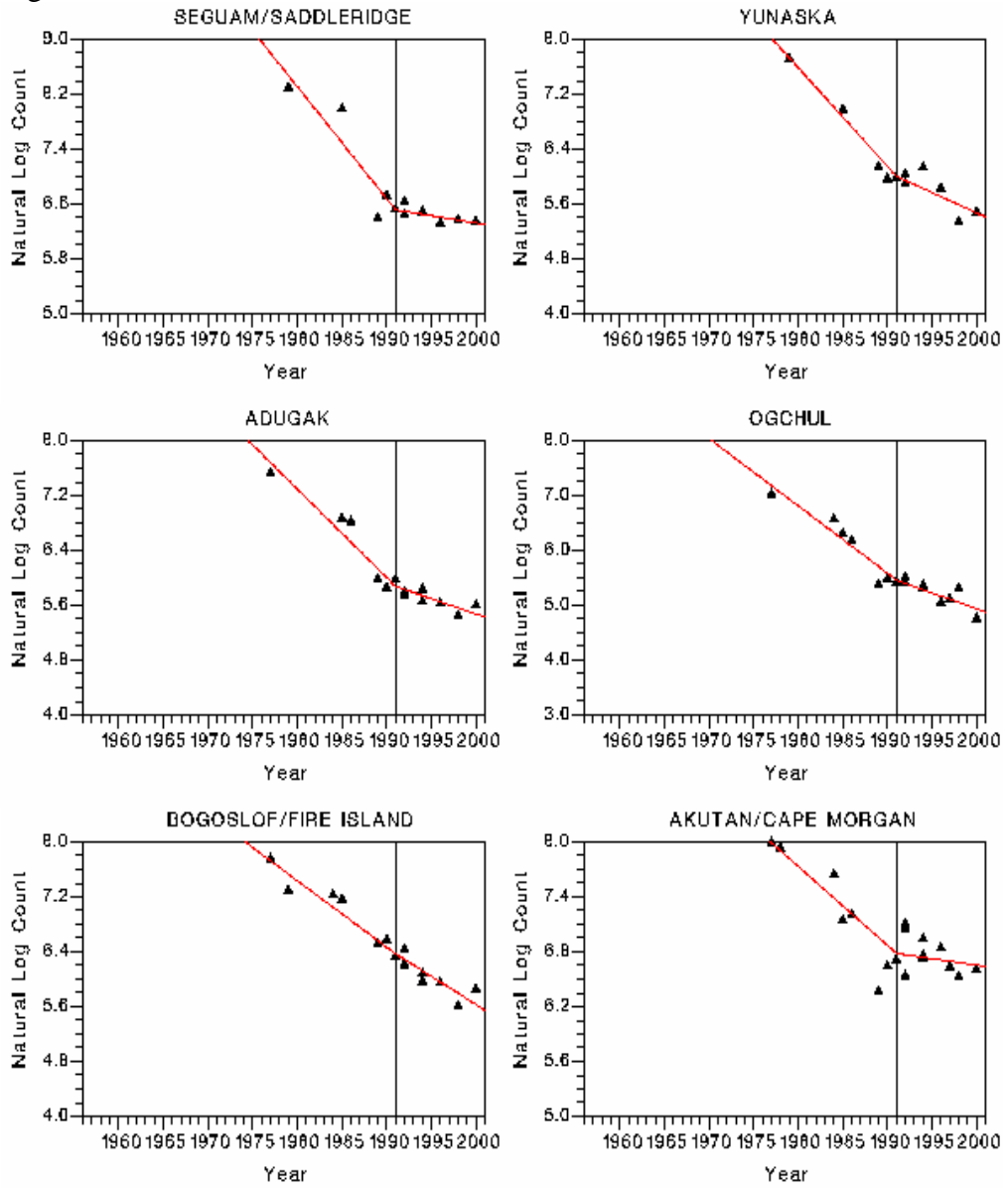Figure 17. Continued.

Figure 17. Continued.

Figure 17. Continued.
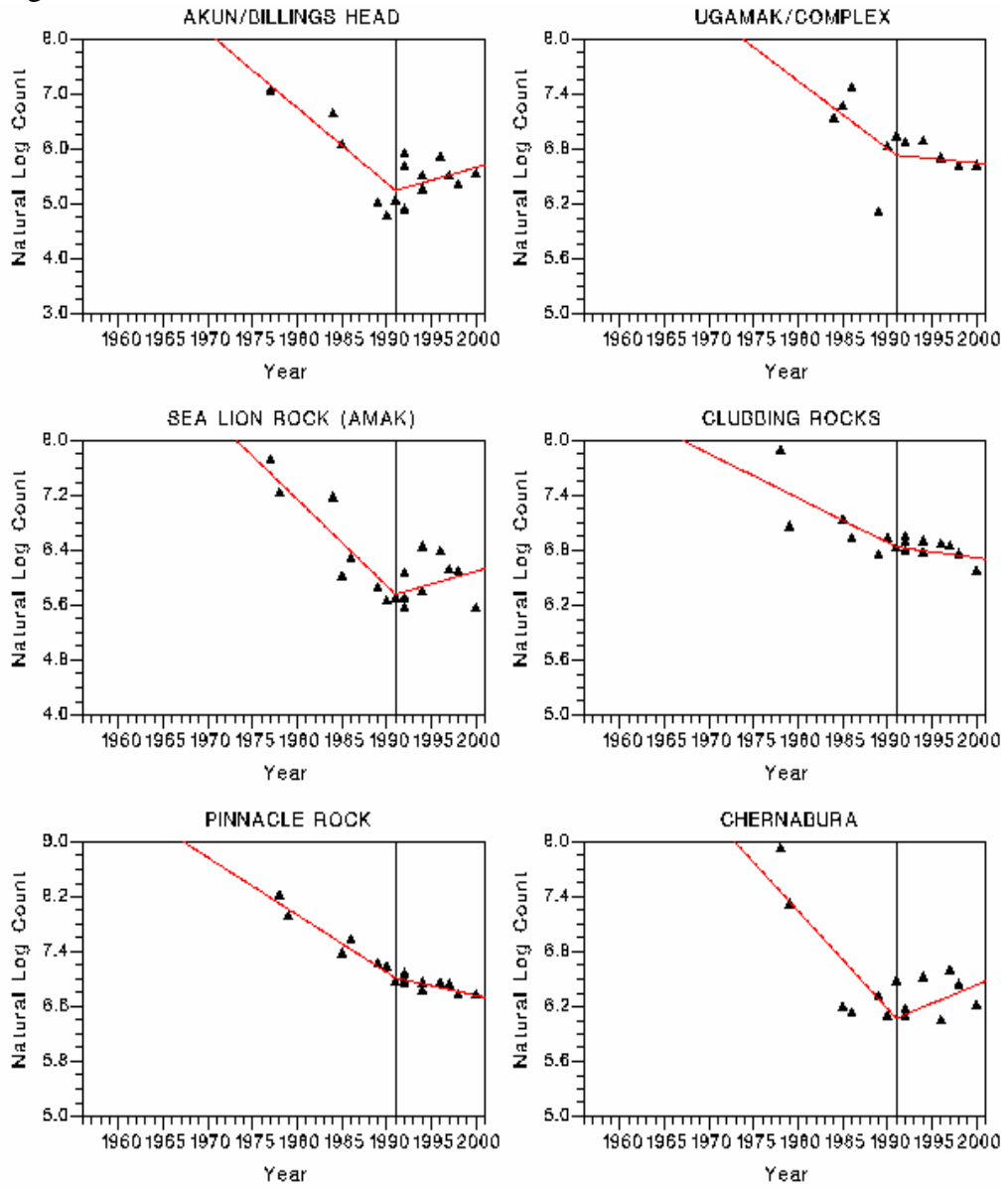
Figure 17. Continued.
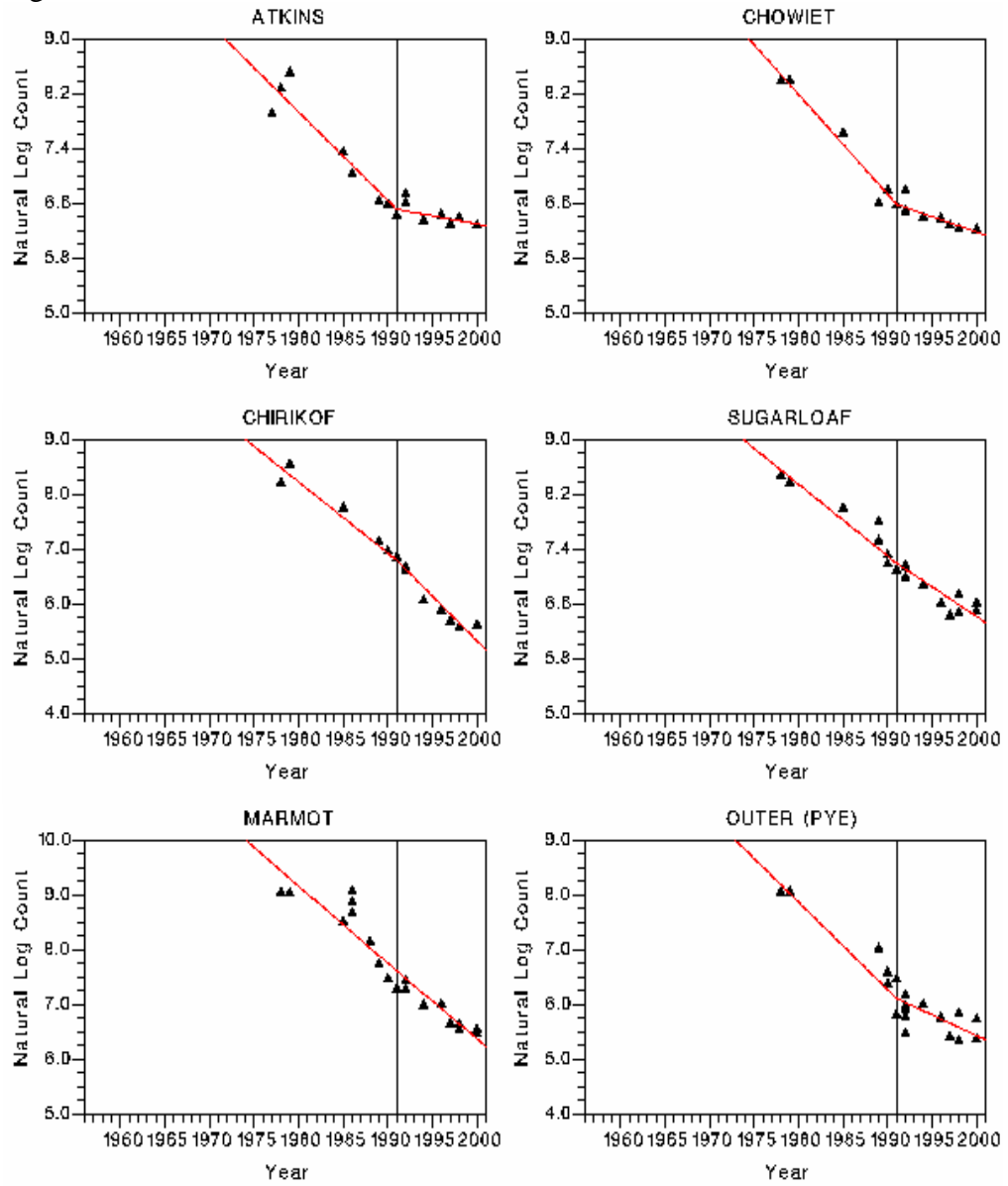
Figure 17. Continued.

Figure 17. Continued.
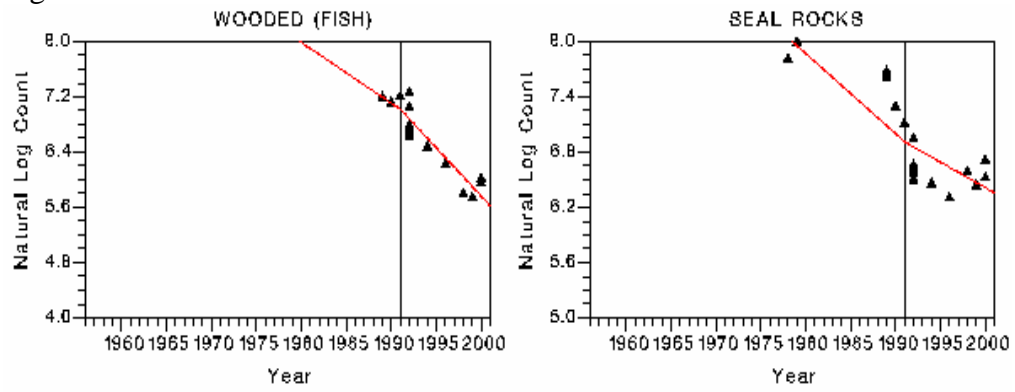
APPENDIX D

PRINCIPAL COMPONENTS ANALYSIS (PCA)

Much of the discussion in this document assumes a basic understanding of PCA. This appendix is intended as an aid to readers who may be unfamiliar with, or have a limited understanding of PCA. If you are familiar with PCA please disregard this appendix.

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 Σ_x. Do an eigenvector/eigenvalue decomposition on Σ_x. Because Σ_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 marginal distributions. Seeing a football shape in two oblong marginal distribution plots might be difficult. 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 1 has a large positive coefficient,

variable 2 is near zero and variable 3 has a large negative coefficient, variables 1

and 3 are negatively correlated and variable 2 plays very little roll in determining

the variation along principal component 1. 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 1. 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 1. Component scores can be

very useful in elucidating spatial or temporal patterns. For example, if the data

points which score highly on principal component 1 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:

Figure 18. An Example Plot of Eigenvector Values.
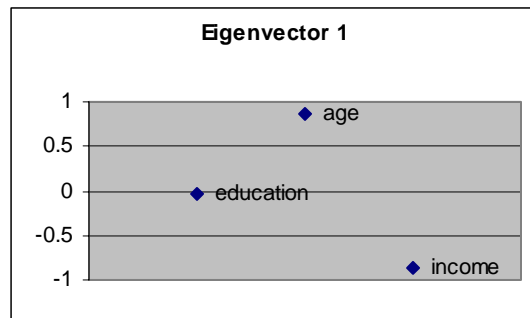
The coefficients for age and income are much closer to 1.0 than the coefficient

for education. This means that they account for much more of the variation in

principal component 1. 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 regular variable in other statistical analyses allows you to capture information about both age and income (and a tiny bit about education) in one variable. Principal component scores also come with the added benefit of being uncorrelated with one another, which reduces the problems associated with using a procedure like multiple linear regression on correlated variables.

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.

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