# Review of the November 2000 Biological Opinion and Incidental Take Statement with respect to the Western Stock of the Steller seal lion

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Interim Report

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## Background

The November 30, 2000 Biological Opinion (BiOp) prepared by National Marine Fisheries Service (NMFS) pursuant to the Endangered Species Act, resulted in a finding of jeopardy to the Endangered western stock of Steller sea lions (SSL; *Eumetopias jubatus*) relative to three fisheries under management jurisdiction of the North Pacific Fisheries Management Council (Council). The BiOp sets forth a set of management measures (termed reasonable and prudent alternatives or RPAs) intended to alleviate jeopardy in 2001. Those measures are being implemented by NMFS under emergency rulemaking authority. The RPAs carry considerable economic and social costs for the pollock, Atka mackerel, and Pacific cod fisheries. There is considerable scientific debate regarding the conclusions of the BiOp, and the RPAs, owing to the nature of the evidence regarding food competition between SSL and these commercial fisheries, and other factors that might be limiting the recovery of SSL.

## Statement of Task

The North Pacific Fisheries Management Council tasked this panel of reviewers to review the BiOp and provide their generalized assessment of that document and its underlying science, assumptions, and hypotheses. More specifically, the team was to focus on the following three tasks:

1) Determine the types of information that should be collected and analyses necessary to demonstrate an unequivocal adverse affect of commercial groundfish fisheries on Steller sea lion mortality. Characterize the current availability of such information, the critical gaps and the impact of data limitations on the determination of fishery/Steller sea lion competitive interactions.

2) Recommend an appropriate experimental design to improve our understanding of the interactions between fisheries and Steller sea lions, and the efficacy of imposed management measures to promote recovery of the Steller sea lion population.

3) Review reports of stressed pinniped populations worldwide and compare and contrast characteristics of those populations with conditions observed for Steller sea lions.

In this interim report we have attempted to address partially each of the three tasks. We begin with an overall evaluation of the arguments put forward in the BiOp concerning the likelihood that the commercial fisheries for pollock, Atka mackerel, and Pacific cod are adversely affecting the abundance of western stock of SSL. Within this framework we assess current understanding of the population dynamics and foraging ecology of SSL, and the evidence that fishing results in reduced foraging efficiency of SSL through its effects on local prey abundance and levels of prey aggregation. We briefly also consider alternative hypotheses that have been proposed for the decline in SSL numbers. We then discuss the kinds of data that ought to be collected, and the types of analyses that could be done, to provide insight into the factors affecting trends in SSL abundance. Comparative studies are often useful in providing insight when data on a population of interest are not available. In this interim report we examine other situations where changes in the abundance of pinniped species have been attributed to local depletion of their prey. We review the evidence that has been used to infer this relationship and the way in which the pinniped population responded to changes in prey abundance. In the final report we will extend this comparative review to include a wide range of case studies where pinnipeds face potential competition from commercial fisheries or have been negatively affected by other factors, such as disease or large-scale environmental variability. Finally, we conclude with comments about the kinds of studies, monitoring, and management experiments that might be conducted to test hypotheses regarding the impacts of fisheries on SSL.

## Task 1 - Review of the BiOp

For the purpose of the interim report we have not provided a detailed evaluation of the arguments put forth in the BiOp. This will be done in the final report. Many of our comments in the final report will deal with statements that we feel are not well supported by evidence. However, for the most part, correcting these matters of fact or interpretation of the evidence will not alter our conclusion that there is great uncertainty about the effects of the groundfish fisheries on SSL. The evidence presented, so far, is almost entirely circumstantial. With respect to many of the key hypotheses, there are essentially no direct data bearing on specific mechanisms of the effects of fishing on SSL. For the most part, the arguments in the BiOp are constructed on the basis that such effects are possible, biologically imaginable, and are not contradicted by the available data. The weight that this argument of “plausibility” has carried in the decision process is a matter of legal and juridical interpretation of the Endangered Species Act and, perhaps secondarily, the “precautionary principle”.

### *Biology of Steller sea lions*

#### a) Population dynamics

There is no question that the number of SSL in the western stock has declined dramatically since the 1970s. The broad geographic extent of the decline and its duration over several decades are clearly causes for concern. However, there has been a marked change in the rate of decline and its spatial distribution over the past decade.

These changes in the rate and spatial extent of the decline in SSL numbers also suggests that the factors that contributed most strongly to the more rapid declines in the several decades prior to the 1990s may not be the most significant factors operating today. In fact, it is believed that directed take and incidental entanglement in active fishing gear played a large role in the earlier period, and both these factors are thought to be very minor now. Although the BiOp acknowledges the likely change in the nature of the causal factors, it does not develop this idea to help evaluate alternative hypotheses. We believe that considerably more information could be extracted from the count data by developing spatially explicit models using both the pup and non-pup counts at the level of individual rookeries or haulouts. Such models could help us understand how demography has changed in different areas over the course of the decline. This information could be used to evaluate; for example, hypotheses concerning which components of the population have recently been affected.

The current view that some aspect of food availability or quality may be responsible for the declines in SSL has gained popularity based largely on inferences drawn from a comparison of measurements from samples of SSL taken during the 1970s and another sample taken during the 1980s. These samples indicated, or in some cases simply suggested, a reduction in body growth rate, in late-term pregnancy rates, and in juvenile survival that were consistent with food limitation hypotheses. But these inferences are based on vital rates that applied more than 15 years ago (see York 1994), when the oceanographic regime, the fishery activities, and the rate of decline of the SSL population were quite different from now. There are good reasons for suspecting that these earlier vital rates are not representative of those currently being experienced by the population. The lack of current estimates of pregnancy rates and survival rates for the various segments of the population compromise the current population projections. The absence of more current data also constitute a missed opportunity, since such data could be used to test alternative hypotheses about the factors responsible for the current trends in numbers. This sort of modeling would, of course, be much more revealing if substantial data on movement patterns, and site fidelity of reproduction were incorporated in it. Such data, at the moment, are largely lacking.

**b) Foraging ecology**

Apart from travelling from one haulout or rookery to another, it can reasonably be assumed that SSL go to sea to forage. Currently, the distribution of SSL at sea is not well understood, but such knowledge is critical to understanding the potential effects of fisheries and environmental change on the foraging ecology of this species. Understanding the 3-dimensional use of the sea by SSL is also fundamental in identifying important habitats and in designing experiments and other studies to test hypotheses about the effects of local prey depletion by fisheries on SSL numbers.

NFMS and ADF&G had made good progress in instrumenting SSLs with satellite transmitters and data loggers. It is our understanding that to date some 80 SSLs (mainly adult females, pups, and juveniles) have been instrumented and that data have been collected from 53 of these individuals. However, despite the recognized importance of foraging distribution, there appears to have been relatively little analysis of these new data on SSL movements and diving behavior. In our view this is a serious limitation of the current BiOp. The data summaries from the satellite tagged animals given in the BiOp do not permit critical evaluation of how the analyses were done, and thus the conclusions drawn for current analyses cannot be properly assessed. The last published analysis of ranging behavior (Merrick and Loughlin 1997) was based on data collected during the period 1990-1993.

The BiOp repeatedly confuses the concepts of foraging and diet. Although clearly related, they are not the same and careless use of these terms can be misleading. Foraging refers to behaviors used in searching for, capturing and handling prey, and the ecological and prey characteristics that influence the decision to include a prey item in the diet. Diet is simply what was eaten. An example of the misuse of these terms is found in Table 4.2 where we are directed to foraging studies of SSL, but are presented with summaries of what was found in SSL stomach contents, i.e., diet. Although the confusion of these concepts may not seem important, it can be. Studies of what was found in the stomachs or scats of SSL (i.e., diet) are clearly important, but they provide little indication of where SSL forage, how often they dive, how deeply they dive, what fraction of the time they spend foraging, or how the composition in the diet relates to the spectrum of available prey items where and when the feeding took place. Each of these aspects of an animal's behavior could be used to shed light on how SSL might be affected by fishing, and by environmental change affecting prey availability.

There has been considerable effort to increase the understanding of the diet of SSL through broad-scale collections of scats. Diet estimation in pinnipeds is fraught with difficulties, and SSL are no exception. Nevertheless, the BiOp concludes that scats are a "reliable tool for monitoring seasonal and temporal trends in predator diets and eliminates the need to euthanize the animal." While the second point is true, the first is almost certainly not, in most situations. One of the many known problems with the use of scats is that one has little idea of the age or sex of the animals whose scats were collected. Thus, there is usually no way of knowing how representative the sample is with respect to different age and sex classes. The potential sources of bias in estimating species composition of the diet from scats are reasonably well understood in principle, although how they affect estimates of the diet of individual species is less well understood. NMFS and ADF&G scientists have used the split-sample frequency of occurrence (Olesiuk et al. 199) of different prey species in individual scats to characterize SSL diet, rather than other more sophisticated methods of diet reconstruction (e.g., Hall et al. 2000). This is understandable, since feeding studies of SSL have indicated that a high proportion of otoliths, which would normally be measured in order to reconstruct diet, are completely digested during their passage through the gut. However, it should be recognized that frequency of occurrence tends to over-emphasize the importance of rare prey species and is relatively insensitive to changes in the proportion of the most important prey species in the diet (Olesiuk et al. 1990). In addition, the statistical properties of frequency of occurrence estimates are not well understood (Merrick et al. 1997), which makes it difficult to detect significant changes in diet.

Another source of bias in the use of scats relates to the duration of foraging trips. VHF and SDR data indicate that female trips are relatively short during the summer, but can differ widely from 7.5 h to 39.1 h among rookeries (page 27, feeding ecology workshop 1999). Scat samples collected from females (or other age and sex classes) undertaking short foraging trips likely represent the diet of these animals in so far as such data can, but SSL undertaking trips longer than 24 h likely defecate at sea and thus scats collected at land sites may be biased towards the diet from the return trip in the immediate vicinity of haulouts. Winter foraging behavior could exacerbate this bias. Merrick and Loughlin's (1997) analysis of data from 1990-93 indicates that average trip duration of 5 adult females in winter was on the order of 8.5 d. If these data are representative, then scats collected at rookeries and haulouts are unlikely to be representative of winter diet. These points further underscore the importance of understanding the spatial and temporal characteristics of SSL foraging behavior.

The BiOp attempts an integration and synthesis of the current understanding of SSL foraging in section 4.8.6.6. This synthesis is summarized in seven points. Our comments on these points are as follows:

Point 1 - "Steller sea lions are land-based predators but their attachment to land and foraging patterns/distribution may vary …;"

This is a reasonable statement, evidence for which comes not only from studies of SSL, but from many other pinniped species.

Point 2 - "foraging sites relatively close to rookeries may be particularly important during the reproductive season when lactating females are limited by the nutritional requirements of their pups; "

Foraging sites close to rookeries are clearly important for lactating females, but all evidence to date suggests that during the first two months of lactation female SSLs are not food limited. The extent to which female foraging may be limited by the nutritional requirements of their pups during mid to late lactation is not known, but certainly pup fasting ability will place an upper limit on the duration of female foraging trips.

Point 3 - "Steller sea lions appear to be relatively shallow divers but are capable of (and apparently do) exploit deeper waters (e.g., to beyond the shelf break);"

This point clearly depends on what is considered "shallow". Shallow diving appears to mean < 200 m. By itself this statement is not terribly useful. Data on SSL dive depth would be more useful if they were linked to bathymetry such that one could then estimate the fraction of benthic habitat available to different age and sex-classes.

Point 4 - "at present, pollock, Atka mackerel appear to be their most common or dominant prey, but Steller sea lions consume a variety of demersal, semi-demersal, and pelagic prey;"

The importance of pollock and Atka mackerel in the diet of SSL seems accurate, subject to the caveats about the quality of frequency-of-occurrence data from scats (e.g., biases arising from differential or complete digestion of prey remains, and foraging range effects on prey remains) and the fact that variation of diet among age and sex classes is poorly known, Point 5 - "the availability of prey to an individual sea lion is determined by a range of factors …;"

This is a general statement that could be made about any pinniped species and therefore is not that useful from the point of synthesis about SSL foraging,

Point 6 - "diet diversity may also be an important determinant of foraging success and growth of Steller sea lion populations; and"

Diversity may indeed be important. However, this point is based on an observed correlation between diet diversity and rate of decline in different parts of the SSL range (Merrick et al. 1997). As noted in the BiOp, observed differences in diet diversity may simply reflect regional differences in prey availability that may have no direct effect on SSL demography. Thus, a more specific formulation and test of this hypothesis is needed before much significance can be attached to the observations.

Point 7 - "the broad distribution of sea lions sighted in the POP database indicates that sea lions forage at sites distant from rookeries and haulouts; the availability of prey at these sites may be critical …".

It is certainly quite likely that more distant foraging is important. The lack of analysis of existing satellite data, and the paucity of such data in winter, represent significant gaps in knowledge. As a result, the arguments about food availability advanced in the BiOp are largely speculative.

**c) Physiology**

*Captive studies* - "The Steller sea lion captive research program at the University of British Columbia uses a bioenergetic paradigm to empirically test hypotheses related to the population decline." This is an overstatement. However, it is true that this captive program has contributed to our understanding of the energetic requirements of SSL. These data will be useful both in designing studies to test hypotheses and in interpreting the results of such studies.

*Free-ranging studies* - Essentially these studies have failed to yield any insights into the causes of the decline in Steller sea lion numbers, a point acknowledged in the BiOp. These studies have focussed on the first 30-60 d of lactation, when females and pups can readily be sampled. Studies during mid-late lactation, when the energetic demands of lactation have increased, might have shed more light on the causes of the decline. However, such studies would have been more difficult to undertake because of reduced access to lactating females once they leave the rookeries in mid summer.

## *Effects of fisheries on Steller sea lions*

The BiOp argument for an effect of fisheries on SSL demography is summarized below:

1. **Fish abundance is finite**. **Fishery removals are substantial and spatially concentrated**. This can reduce, on a local scale and for short time periods, targeted fish biomass.

2. **The likelihood of depletion is higher for patchily distributed fish** (e.g., pollock and Atka mackerel), because fishing may reduce both the number of fish aggregations within a particular area, making them more difficult for SSL to locate, and the density of fish within an aggregation, making them less profitable for foraging SSL. The effect of this on SSL depends on the species foraging strategy. Although, SSL are probably adapted to foraging on the normal schooling behavior of pollock, it is also conceivable that SSL may be able to exploit fragmented fish schools more effectively. The proportion of fishing effort by the commercial pollock fishery within known SSL foraging areas has increased substantially since the 1970's.

3. Because so many fisheries have been conducted near SSL rookeries and haulouts **SSL may have had their foraging ability compromised**. Prey switching by SSL, which might be expected to occur with depletion of pollock, might be hampered by competition with other fisheries that also locally deplete their target stocks.

4. **These effects are** more significant the longer they last (i.e., they are cumulative) and **most significant during the winter for adult females and juvenile SSL**, for the following reasons:
   i. during winter SSL females have both the energetic demand of providing milk to their growing pup and of the developing foetus,
   ii. winter can be a time of harsh environmental conditions increasing daily metabolic requirements, particularly for small animals with thin blubber,
   iii. if pups are weaned during the winter they may be challenged energetically because their foraging skills are limited,
   iv. pups, being small, have greater metabolic and growth requirements per unit body mass.

   Spring may also be important energetically because it is just before pupping, and poor foraging conditions could affect pup birth weight and subsequent survival.

5. **SSL do not have large fat reserves** compared with other pinnipeds and require continuous access to food. Thus, they are susceptible to local depletion of prey by fisheries **and have shown the effect of food limitation through reduced growth and condition as well as a numerical response (i.e., declining numbers)**.

6. Besides resource competition between SSL and fisheries **there may be *interference competition***. The presence of vessels and gear can cause: disruption of feeding by SSL and abandonment of fishing areas by SSL.

7. **Indirect effects of fishing may reduce carrying capacity and effect the critical habitat** of SSL. In this context, critical habitat is defined as the geographic extent of environment needed for the recovery and conservation of a species, and carrying capacity is the maximum number of individuals that could be supported by available resources.

In this next section, we list and briefly review the evidence of the effects of fishing on SSL presented in the BiOp.

**a) Evidence for depletion of pollock and Atka mackerel**

1. Depletion of pollock – this has been cited from three areas: a) Bogoslof Island (AI), b) donut hole and c) Shelikof Strait – Fritz et al. (1995).

In Shelikof Strait, the fishery in 1970's developed to 300,000 mt/yr. By 1993, GOA pollock stock size was reduced from 3 million mt to 1 million mt. NRC (1997) stated that SSL counts on nearby rookeries declined dramatically and individuals showed signs of reduced growth (Calkins and Goodwin 1988, Lowry et al. 1989).

Uncertainties in these studies include the fact that prey density was rarely known in areas used by foraging SSL. This is because harvest rate is not necessarily a good indicator of prey availability. Using survey biomass estimates for a large region as an index of availability to SSL assumes a uniform distribution of prey in the area. in addition, the correlation between fish distribution and catch distribution is often poor (Fritz 1993).

2. Depletion of Atka mackerel: Fritz (unpublished ms.) showed that CPUE for Atka mackerel in some areas declined steeply during repeated trawling over relatively short periods (3 days to 17 weeks). He estimated that harvest rates ranged between 55% and 91%, suggesting that there was substantial local depletion of the exploitable biomass.

**b) Evidence for potential competition between fishery and SSL**

There are two lines of evidence here, competition by size and competition by depth. There is likely overlap in the size of fish taken in the pollock fishery and that consumed by adult SSL. However, not much is known about SSL feeding preferences and recent data on SSL diet does not include information on the size of prey eaten. There may be overlap in the depths used by foraging SSL and that trawled by fisheries. Some fish prey exhibit diel vertical migration, such that competition by depth between SSL and fisheries could occur at some times of the day but not others. Also, we still have a rather poor understanding of the foraging depths used by SSL of various age and sex classes at different times of the year.

**c) Evidence for winter season competition**

There are two lines of evidence bearing on this possibility. First, captive SSL increase their level of food intake in fall and early winter (Kastelstein et al., 1990). Second, although spawning aggregations of fish in late winter may provide higher energy and more reliable food source for SSL, the fishery, by trawling these aggregations, may reduce their availability. Neither of these arguments directly addresses whether or not competition does occur --only that it is possible.

**d) Evidence concerning interference competition**

The POP observation and observer program databases are equivocal on this issue. There are few observations of SSL from fishing ships in comparison to the amount of fishing activity. This could be because SSL are disturbed and avoid the vessels or because they are tolerant of fishing operations and just rarely sighted. The bycatch of SSL in the 1970's and 1980's implies that at least some SSL were tolerant of fishing activity in that era.

**e) Evidence concerning an energetic response of SSL in addition to a numerical response**

There are several lines of evidence that point to the effects of food limitation on the western stock of SSL:

York's (1994) analysis of samples collected in 1975-1978 and in 1985-1986 (Calkins and Goodwin 1988) showed:

- smaller animals in 1985
- later maturity in 1985
- fewer offspring of SSL in 1985
- SSL with pups were older in 1985
- SSL in 1985 with reported signs of anemia. (However, reported values were within the normal range for pups 2-3 weeks of age, NRC 1997),

In addition, juvenile survival apparently declined in eastern AI (Ugamak Is, Merrick et al., 1987) and in the GOA (Marmot, Is, Chumbley et al., 1999),

Pitcher, Calkins and Pendleton (1998) found an increased level of abortions and poorer condition for pregnant females collected during late gestation in 1985-86 compared with those collected in 1975-78 on rookeries, haulouts and coastal waters of the Gulf of Alaska. Successful gestation was directly proportion to condition (mass index).

On the other hand, studies that have compared SLL at rookeries in declining (western) and stable or increasing (eastern) populations have found little evidence of food stress:

- Rea et al., (1998) sampled 238 free-ranging pups < 1 month old during June and July 1990-1996 in the GOA, AI, and Southeast Alaska. They found no indication of nutritional stress in the declining populations;

- Castellini (unpublished data, SSL Research peer Review Physiology Workshop, Seattle, Feb, 1999) measured girth, length, and blood chemistry parameters of lactating female SSL between 1993 and 1997 from both increasing and declining populations. The results showed that individuals in the western population were rounder, longer and heavier compared with those from the eastern population,

- researchers at Texas A&M found no difference in energy intake of 40 pups at 5 rookeries in declining and stable populations sampled between 1993 and 1997 (unpublished data, SSL Research peer Review Physiology Workshop, Seattle, Feb, 1999).

Finally, the BiOp states that "The question of whether competition exists between the Steller sea lion and BSAL and GOA groundfish fisheries is a question of sea lion foraging success." This is a necessary but not sufficient basis upon which to draw conclusions. Poor foraging success may also be the result of environmental change; without additional information it is not possible to determine if fishing, the environment, or a combination of the two is the causal factor. Furthermore, as the evidence above clearly reveals, support for the BiOp argument is tenuous. Although local depletion of Atka mackerel by fishing has been demonstrated, a direct link between this and SSL foraging efficiency has not been established, let alone a link to the observed changes in SSL demography. The argument remains plausible but unsupported and the alternative hypothesis of climate changes has not been eliminated.

## Task 2 - Design of Field Experiments

NMFS has proposed to establish a "well-designed monitoring program that would be used to ascertain the extent to which the implemented measures [to] promote the recovery of sea lions."

### *Experimental design to determine effectiveness of RPAs*

It is our understanding that the design of the experiment(s) to test the effect of fishing on SSL is evolving and therefore somewhat of a moving target. Apparently, the design is being constrained by a number of considerations, which are not conducive to obtaining clear results. Among the apparent constraints is the desire to ensure that the design “alleviate jeopardy”, as judged by the BiOp for all management units. This presumably accounts for the somewhat surprising expectation, expressed at the top of page 295, that SSL populations in both the open and closed areas will respond positively during the period of the experiment. Certainly if fishing is a significant factor affecting sea lion numbers then we would expect a non-zero response in the areas closed to fishing. However, the planned experiment is being designed so that conditions for SSL in the areas open to fishing are also expected to improve. In effect, the experiment has two treatments and no control. Given the high degree of uncertainty that the proposed RPAs really will actually alleviate jeopardy, we think it is worthwhile to contemplate an experiment that has a real control, at least locally. Given that the present size of the SSL stock is over 30,000 animals and that the present rate of decline is small, there should be considerable scope for experimentation without undue risk.

The BiOp also states that both the experiment and other studies will be used to assess the efficacy of management measures, but there is no indication of the types of studies anticipated. Certainly tagging studies will be needed to determine to what extent the closed areas are actually used by foraging SSL. For example, if only 50% of animals use the treatment area intensively, the population response will only be about half that expected and one might incorrectly conclude that fishing was not a significant factor.

## *Design principles for ecological field experiments*

Although the specific design of the proposed field experiments have yet to be determined, there are certain principles that should apply rather generally to any such experiment. We briefly discuss some of these below to help focus the discussion about the merits of field experiments.

All experiments are based on the following logical model -

Observations → Models → Hypotheses (Predictions) → Alternative or Null hypotheses → Experiments → Interpretation of results

This framework (Underwood 1997) emphasizes that good experiments can only be designed and undertaken if there are adequate quantitative observations from which to reasonably construct alternative models (i.e., explanations) and predictions. Given the current state of our observations with respect to SSL foraging behaviour and the effects of fishing on prey behaviour at fine to meso scales, it might be considered somewhat premature to undertake large scale manipulative experiments. On the other hand, the importance of finding out if fishing really is having an impact on SSL may outweigh the desire to make additional preliminary studies as a prelude to desiging the best possible large-scale experiment.

It cannot be overemphasized how difficult it will be to conduct large scale field experiments to test hypotheses about the effects of fishing on SSL. To our knowledge experiments in the open ocean at this spatial scale have not been previously attempted. But, on the positive side, if the enormous fishing power of the ground fish fisheries really were at the disposal of the experiment, this too would be unprecedented.

Some of the issues that need to be resolved include -

1) number of replicates of the treatment and the control,
2) size of the experimental unit (individual rookery, clusters of rookeries),
3) response variable to measure (pups, non-pups, both, others) and what level of change should we expect to be able to measure,
4) duration of the experiment (there will be lags in the response variable),

5) how is the treatment to be measured (fishing days, biomass removed, number of tows, others?),
6) other response variables to measure (diet, foraging trip duration, birth mass, pup growth rate, others), and
7) what are the alternative hypotheses (e.g., climate effects, predation) and how will they be evaluated (i.e., does the experiment make unique preditions about the effects of fishing?).

Table 1 is an attempt to determine the direction of change in a number of response variables that might be expected under the hypotheses that have been proposed to explain the declines in the western stock of SSL. For some response variables, the direction of change under specific hypotheses is debatable. For other response variables, it is not clear to us how, or even if, the variable would change under some of the hypotheses. Nevertheless, it seem clear from Table 1 that quite similar changes are predicted under the fishery effects, fish predator competition, and climate effects hypotheses. We have not considered space explicitly in Table 1, however, we might expect different spatial signatures associated with some response variables under these three food hypotheses and this should be investigated further.

## *Smaller Scale Experiments*

We are moderately pessimistic about the prospects for resolving the critical uncertainties about the SSL decline from simply monitoring the response of the population to implementation of the RPAs (see Table 1). For this reason, we believe that the best hopes depend on a disciplined investment in specific smaller scale experiments to answer questions about the hypothesized mechanisms of the interaction between the fisheries and the SSL.

This will entail detailed measurements of the effects of fishing activities on the prey field and on the behavior of instrumented individual SSL. The spatial and temporal focus of such experiments should include the season and location that is thought to be the bottleneck for the SSL. Similarly, the sample of instrumented animals should include the age classes that are thought to be most severely affected. Although these experiments are smaller in scale than treating the RPAs as one grand experiment, they are still very substantial undertakings that will require a massive commitment of resources. It is our scientific judgement that this investment would be warranted.

## *Retrospective data analysis*

The historical count data of SSL is of high spatial resolution and provides an opportunity, independent of any manipulation experiment, to examine the relationship between SSL demography and possible influencing factors, such as fishery activity. Nonparametric regression models could be used to investigate the relationship between the rate of change of SSL numbers on any and all rookeries over various historical time periods and high resolution, spatially-explicit data on catch and effort for pollock and Atka mackerel close to the rookery over that time period. Other potential factors, such as catch of other species (e.g. herring), area of the rookery, and maximum historical SSL population on that rookery can also be used a covariates. Such analysis can also be done on haulouts or groups of rookeries over any time period for which high resolution fisheries data are available. The advantage of this approach over analysis of larger areas is that it affords larger sample size and more flexibility in the choice of spatial resolution and thus has a greater chance of identifying signals in the data.

## Task 3 - Responses of Other Pinnipeds

### *Comparisons with other species in the action area*

In assessing the causes of continuing declines of the western stock of SSL, the BiOp has made little use of data from other SSL populations, or from other pinniped species in the action area. Indeed, the BiOp pays little attention to the continuing and consistent increase in numbers of the SE Alaska stock of SSL. Many SSL foraging areas are also used by Northern fur seals, , at certain times of the year, and by harbour seals throughout the year in the case of the harbour seal. We believe that comparative data from these species could be used to help distinguish among alternative hypotheses, as we discuss below.

The BiOp notes on page 102 that the SSL population in the Russian territories had also declined to about one-third of historic levels by the late 1980s. Counts conducted in 1989, 1994, and 1999 indicate differing trends in different areas, but pup production overall has increased at about 2.7% annually over the 1990s. The sum of counts has increased, "but counts at repeated sites have declined indicating the trends in Russian cannot yet be described with confidence." We are not sure what this last sentence means. However, the important point here is that demography in the Russian population changed in the 1990s after a period of dramatic decline. Superficially, this would seem more consistent with a large-scale environmental effect than the effects of fishing, unless patterns of fishing within the Russian territories have changed or fishing effort was considerably reduced.

The dramatic decline in harbour seal numbers at Tugidak Island in the central GOA also seems to have halted during the 1990s and there is evidence of an increase in this population through 1999 (ADF&G personal comm.). There are population estimates of harbour seals elsewhere in the action area that could also be examined.

Fur seals use the action area only seasonally. Nevertheless, the number of pups born at St. Paul Island and St. George has been rather stable over the past decade, in contrast to earlier declines.

The point here is that by looking more broadly and considering the population trends of similar species in the action area, it may be possible to distinguish among competing hypotheses about the causes of decline in SSL.

### *Lessons from other seal populations*

In this section we review some case studies for other seal species in which the effect of local prey depletion on demography has been investigated, or changes in demography have been attributed to local prey depletion. For convenience, we divide the causes of prey depletion into three categories: fisheries-induced changes, environmentally-induced changes, and predator-induced changes.

**a) Fisheries-induced prey depletion**

There is, as far as we know, no direct evidence that prey depletion by fisheries has affected the demography of any seal population, whereas there are a number of cases in which seal populations have continued to increase exponentially following the complete collapse of an important prey stock as a result of overfishing (e.g., grey seals and Atlantic cod in the Northwest Atlantic and North Sea).

The only detailed study known to the panel of the effect of local depletion concerns the North Sea "industrial" fishery for small pelagic species, which are used as animal feed or to produce fish meal and oil. This includes a fishery for sand lance (mainly the lesser sand lance, *Ammodytes marinus*). Sand lance catches rose sharply from 1960 onwards and have varied between 540,000 and 970,000 tons since 1984 (Pedersen et al., 1999); they now account for nearly 50% by weight of all fish landings from the North Sea. Sand lance are an important prey species for many predatory fish, seabirds, and marine mammals. The sheer scale of this fishery has led to concerns about its impact on the entire North Sea ecosystem (e.g., Aikman, 1997). In particular, there is substantial spatial overlap between the fishery and foraging by seals and breeding seabirds on a series of major sandbanks off the Firth of Forth in Scotland. Sand lance fishing began in this area in 1990 and catches rose rapidly to more than 100,000 tons in 1993. They then fluctuated around 40,000 tons until the area was voluntarily closed to sand lance fishing in 1999. In most years, over 90% of the catch was taken in June, and most of that within a 10 day period. The effects of this local depletion on foraging and breeding performance of three seabird species (kittiwake, shag and common murre) and grey seals was investigated during 1997 and 1998 (Harwood 2000).

The total biomass of sand lance in 1998 was 15% less than in 1997, and there was a marked change in the age distribution of sand lance between the two years. Acoustic surveys indicated that the biomass of 0-group sand lance in June 1998 was less than half that in 1997 and individual fish were smaller. Total removals were similar in both years (69,000 tonnes in 1997 and 65,000 tonnes in 1998). Fish were the most important natural predator in both years. The fishery was responsible for 68% of all removals in 1998, compared to 34% in 1997.

Sand lance (mainly 1 year old and 3 year old fish) made up nearly 50% of the diet of grey seals in 1997, but only around 10% in 1998 (and in this year they were mostly 2-year-old fish). More cod and whiting were consumed in 1998. The proportion of sand lance in the diet of murres declined by 70% in 1998, with the alternative prey being clupeids. The diet of shags and kittiwakes showed much less change and was dominated by sand lance in both years. Both murres and shags spent more time diving and proportionally less time at the surface in 1998. In contrast, the surface feeding kittiwakes did not, or could not, change their foraging behavior.  Kittiwakes suffered an almost complete breeding failure in 1998, whereas the productivity of guillemots and shags was only slightly reduced.

The proportion of female grey seals not breeding in a particular year at the nearest rookery, and the number of breeding failures amongst marked animals at that colony was negatively correlated with sand lance CPUE in the southern North Sea over the period 1990 to 1997.  Female body condition was positively correlated with CPUE for the North Sea and the local stock area.  None of these relationships had a measurable effect on the total number of pups born at the colony, which increased steadily over the study period.

The conclusion from this study is that the impact of local depletion by fisheries depends intimately on the foraging strategy of the predators that may be affected. Grey seals murres and shags were able to make behavioural changes to compensate for the rapid reduction in the biomass of 1+ sand lance by the commercial fishery in June 1999, whereas surface feeding kittiwakes were not.  As a result, the observed response of most predators was relatively subtle and had no immediate effect on their demography.

Similarly, the relationships between grey seal breeding parameters (female condition, missed pregnancies, failed breeding) and sand lance abundance (as measured by CPUE) were also rather subtle and were only detectable because there was a sub-population of permanently marked females at the rookery whose performance was monitored each year. It should be noted that the year-to-year variations in sand lance abundance appear to be primarily a result of fluctuations in recruitment and not of the action of the fishery itself.

**b) Environmentally-induced depletion of prey**

The effects of ENSO (El Niño Southern Oscillation) events on the demography of a range of fur seal, sea lion and seal populations along the western seaboard of South and North America are well known (Trillmich and Ono 1991). However, there have been similar events in other parts of the world. For example, the intrusion of warm, low-oxygen content water into the northern Benguela system off the Atlantic coast of Namibia in late 1993 and early 1994 resulted in the virtual disappearance of many pelagic and epipelagic fish species from the continental shelf. This had a dramatic effect on Cape fur seals at Namibian colonies during the 1993/94 breeding season, summarized in Anon (1998). The initial effect was seen in a reduced growth rate of pups at Cape Cross (the northernmost colony of the Cape fur seal). This was followed by a mass mortality of pups at Cape Cross in the austral summer of 1993/94, and colonies further south were affected after a short delay.  From February/March 1994 onwards, all colonies north of Lüderitz (in southern Namibia) experienced the highest levels of pup mortality ever observed, due to abandonment and starvation.  By the end of May approximately 120,000 pups, out of a normal production of around 300,000, had died. Beginning in June and worsening through July, surviving females aborted their pups. It is estimated that 40,000 foetuses were aborted at Cape Cross alone. At the same time large numbers of emaciated adults of both sexes washed up along much of the Namibian coast. Pup production in 1994/95 was 50-70% lower than in 1992/93 and 1993/94. Mass of pups at birth and early pup survival in 1994/95 was the lowest ever recorded.

Capelin (*Mallotus villosus*) are normally the most important prey species for the harp seal population which breeds in the White Sea and feeds in the Barents Sea, making up more than 90% of the diet in some years. The Barents Sea capelin stock collapsed in 1985/87 and remained at very low levels until 1990. At about the same time, large numbers of harp seals began appearing off the northwest coast as Norway, and by 1987 they were reported as far south as the southern North Sea. Very large numbers of harp seals (up to 60,000 in 1987) were taken as bycatch in gillnets along the coast of Finnmark, Troms and Nordland during this period. These "invading" harp seals, particularly in the subadults, were reported to be thin and in very poor condition (Øritsland 1990 and Wiig 1988 in Haug & Nilssen 1995). These events must have resulted in large scale mortality of young animals because the 1986-1988 year classes are virtually absent from the age structure of Norwegian samples of molting harp seals taken since 1990 (Kjellqwist et al. 1995). Despite these dramatic changes, Haug and Nilssen (1995) are cautious about attributing the 1980s invasions of harp seals to local depletion of capelin in the Barents Sea, partly because the capelin stock collapsed again in 1992/93, but there was only a relatively small influx of harp seals into Norwegian waters at that time.

Antarctic fur seals breeding on the islands around South Georgia feed almost entirely on krill (*Euphasia supurba*). Breeding performance of fur seals and a number of seabird species on Bird Island which also prey on krill has been monitored annually since 1980. Performance of all krill predators increased up to the late 1980s but has declined steadily since then. Reid and Croxall (2001) interpret these changes as a response to decreasing availability of krill, possibly as a consequence of ocean warming and reduced sea-ice extent. The main responses by fur seals have been a decrease in the mean birth weight of pups and an increase in foraging trip duration (Boyd et al. 1994) during a year of particularly low krill abundance.

**c) Predator-induced depletion of prey**

The numbers of southern elephant seals breeding on Macquarie Island in the southern Indian Ocean have been declining steadily since the early 1970s. Hindell (1991) demonstrated that this was, at least in part, due to a dramatic decline in first-year survival from around 45% in the 1950s to less than 2% in the 1960s. He concluded that the population had temporarily exceeded the carrying capacity of the local environment and was demonstrating signs of delayed density-dependence. However, although first-year survival has now recovered to levels similar to, if not higher than, those observed in the 1950s, the population at Macquarie has continued to decline (McMahon et al. 1999).

On the basis of changes in the size structure of krill caught off South Georgia during the 1990s, and estimates of local krill mortality that were 50% higher than those recorded elsewhere in the species' range, Reid and Croxall (2001) concluded that Antarctic fur seals and seabirds from South Georgia were now "operating close to the limit of krill availability". As a consequence, there has been an "increase in the frequency of years where the amount of krill is insufficient to support predator demand", and abundance of all krill predators on Bird Island has declined since 1990.

### d) Lessons for SSL management

Two major lessons emerge from this brief review: 1. Changes in seal demography in response to a reduction in prey abundance are either so dramatic that they can be detected even without scientific study (Cape fur seals in Namibia, harp seals in Norway) or relatively subtle, requiring time series of monitoring data (North Sea grey seals, Antarctic fur seals, southern elephant seals); 2. A reduction in first-year survival was involved in all the examples listed above. A reduction in pup birth mass or growth rate was also often observed. The second point supports NMFS' contention that a reduction in juvenile survival is probably involved in the continuing decline of the western population of SSL. However, it should be recognized that no decline in SSL juvenile survival has been adequately documented, it has only been inferred from York's (1994) analysis of age-structure data which are now quite dated, and on observations of low survival from a very small sample of marked animals.

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Other references used in this interim report are given in the BiOp.

Table 1. Predicted direction of change in response variables under various hypotheses to explain the decline of SSL.

| | Hypothesis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Response variable | FE | CE | FPE | PRED | IT | SH | DI | PO | EN |
| Birth mass | R | R | R | ? | ? | NC | R | R | ? |
| Juvenile growth rate | R | R | R | NC | NC/I | NC | R | R | NC |
| Weaning mass | R | R | R | NC/R | NC | NC | R | R | NC |
| Body condition | R | R | R | NC | NC | NC | R | R | NC |
| Foraging trip duration | NC/I | NC/I | NC/I | NC/R | NC | NC | ? | NC | NC |
| Milk production | R | R | R | NC | NC | NC | R | R | NC |
| Diving behavior | I | I | I | NC/R | NC | NC | ?/R | ?/R | NC |
| Foraging areas | C | C | C | C | NC | NC | NC | NC | NC |
| Yearlings nursing (%) | ? | ? | ? | NC | NC | NC | ? | ? | NC |
| Dispersal | I | ? | ? | NC | NC | NC | R/? | R/? | NC |
| Diet composition | C | C | C | NC | NC | NC | C | C | NC |
| Diet diversity | I | ? | ? | NC | NC | NC | ? | ? | NC |
| Birth rate | R | R | R | NC | NC | NC | R | R | NC |
| Age at first birth | R | R | R | NC | NC | NC | R | R | NC |
| Juvenile survival | R | R | R | NC | NC | NC | R | R | NC |
| Adult survival | R | R | R | NC | NC | NC | R | R | NC |

FE - Fishery Effects on food
CE- Climate/Regime shift Effects on food
FPE - Fish predator effects (competition)
PR- Killer whale and shark predation
IT - Incidental take
SH - Subsistence harvest
DI - Disease
PO - Pollution
EN - Entanglement in fishing gear

R = reduced, I = increased, NC = no change, ? = uncertain