
Chapter 22

The Status of Stocks of Pacific Seals

Northern Fur Seals

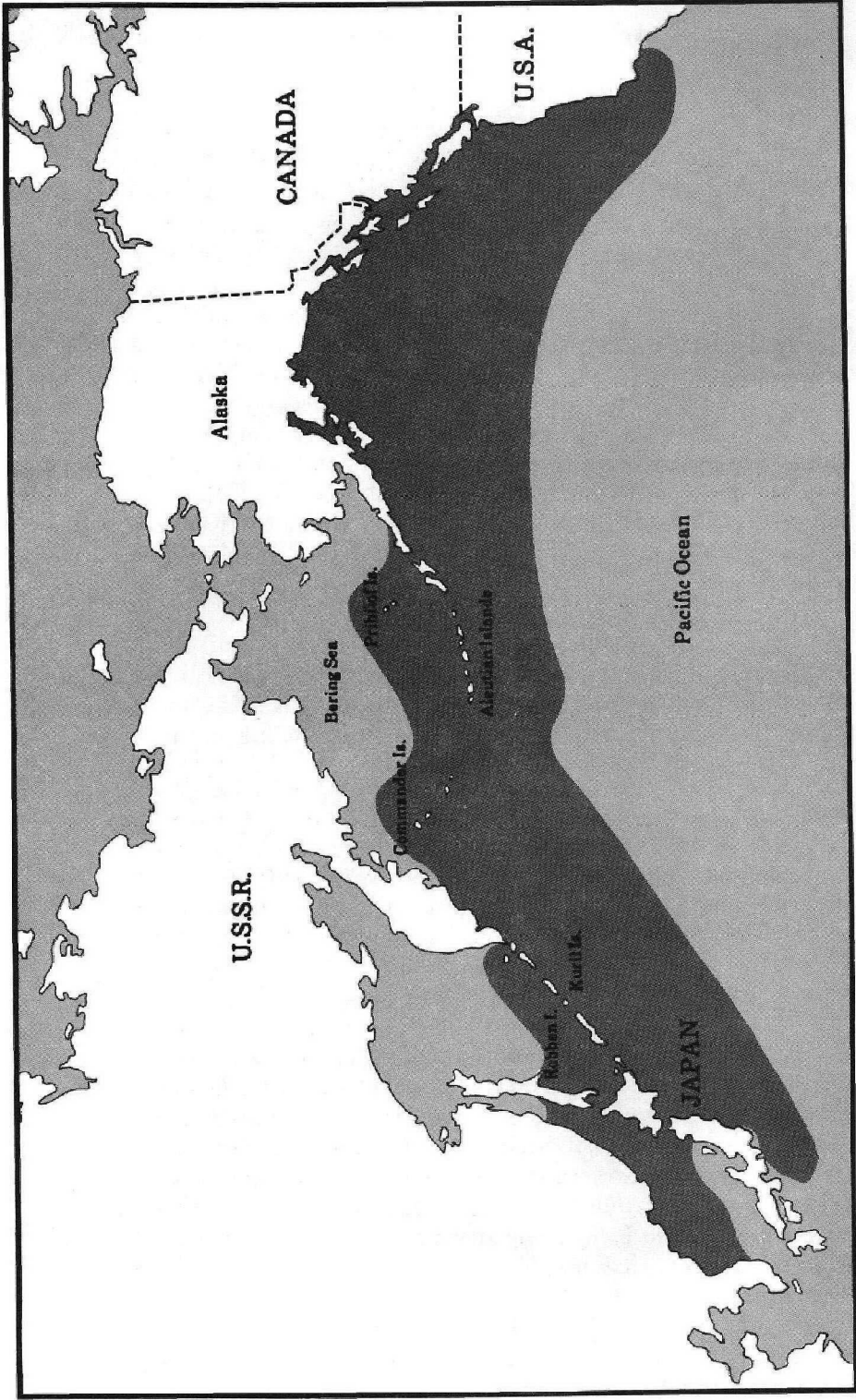
The northern fur seal does not breed in Canadian waters, but does breed principally on the American Pribilof Islands in the eastern Bering Sea (Figure 22.1). Smaller numbers breed on the Russian Commander Islands in the western Bering Sea and on Robben Island and the Kurile Islands in the western Pacific Ocean. A very small group breeds on the San Miguel Islands off California.

The present population is approximately 1.2 million. At the 1984 meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission and at a 1985 meeting of representatives of Canada, the United States, the U.S.S.R. and Japan, the numbers breeding on the various island groups were estimated as follows:

Bering Sea: U.S. territory	819,000
Bering Sea and Western Pacific: U.S.S.R. territory	350,000
San Miguel Islands: U.S. territory	4,000
	<hr/>
	1,173,000

Most fur seals belonging to the northern populations remain in the vicinity of the breeding islands between June and October, but young females and males of up to about five years, particularly those one and two years old, spread widely through the north Pacific Ocean during the late winter and spring (Kajimura, 1984). The females move as far south as about 33°N off California, but the males do not travel as far. On the eastern side of the Pacific, the southward movement seems to take place mainly within 300 kilometres of the coast, but it appears that on the return journey many of the females travel in a fairly direct line back to the Bering Sea, although some move along the coast. Most older males remain in the Bering Sea throughout the year, although it seems that some may winter in the Gulf of Alaska and on the north Pacific Ocean.

Figure 22.1
Distribution of Northern Fur Seals



Source: King (1968).

Canadian interest in the present status of the stock derives from two factors. First Canada, with the United States, the U.S.S.R. and Japan, has been a member of the North Pacific Fur Seal Commission, the international body established to regulate harvesting of the fur seal stock. Canada has therefore shared a responsibility to ensure that harvesting activities are managed in an acceptable manner. Canada has also received some direct benefit in the form of 15% of the pelts harvested. This Canadian involvement had its roots in the very active Canadian participation in the pelagic, or high seas, hunt for fur seals which took place from about 1866 until it was banned under the first international agreement in 1911.

Secondly, Canada has an interest in the northern fur seal because many of these animals pass through, and sometimes linger in, Canadian coastal waters in the course of their regular southward migrations during the winter. They feed vigorously at this time, and much of their food consists of commercially important fish, particularly herring.

Early History

The numbers of northern fur seals have undergone very large variations since the islands on which they breed were first discovered in the late 18th century. These fluctuations have, until recently, been brought about almost entirely by changes in the levels of hunting. Until the United States purchased Alaska from Russia in 1867, the hunt was under Russian jurisdiction. There was no attempt to regulate the take until 1821, when catch limits were imposed, and in some years, commercial, as distinct from subsistence, hunting was prohibited. Busch (1985) has researched the history of this hunt and estimates that from its commencement in about 1786 until the sale of Alaska in 1867, about four million fur seals were killed on the islands. The earlier uncontrolled hunting apparently reduced the population to a very low level by about 1800, but subsequent regulation of the kill, although largely on a trial and error basis, seems to have allowed the numbers to rebuild. Busch states: "By 1867 and Alaska's sale, the seal population had probably returned to nearly the pre-exploitation level of roughly three million (only four-fifths of which is . . . based on the Pribilofs)." Although there are many uncertainties in the records, Busch's estimate of a total kill of four million seals in the entire Bering Sea area between 1786 and 1867 seems reasonable.

After the United States took possession of the Pribilofs, hunting was placed on a new basis. Two companies were successively granted a monopoly

of the hunt. The first, the Alaska Commercial Company, is recorded as taking just over two million seals between 1870 and 1890. From 1890 to 1910, the North American Commercial Company held the lease, but was able to take only about 360,000 seals.

A new threat to the seal herds developed in the late 1860s. The Indians of the west coast of North America had traditionally hunted the migrating seals off their coasts for subsistence, but about 1866, other groups saw an opportunity for a commercial hunt. This hunt built up rapidly during the 1880s, and at its peak in 1892, 124 vessels are known to have engaged in it. It declined quickly as the seals became scarce, and by its end in 1910, only four vessels participated. From the California and B.C. coasts, the pelagic sealers gradually spread their operations throughout the north Pacific and into the Bering Sea. The hunt was dominated by U.S. and Canadian vessels, although some boats from other countries took part; the Japanese pelagic sealing industry was slower to develop, but later played a major role.

Because pelagic sealing operations were diffuse, it is difficult to obtain reliable data on the numbers of seals taken. Busch (1985) quotes three estimates; two for total takes of 982,000 and 1,311,000 seals, and a third for 394,000 skins landed in British Columbia from 1889 to 1910. Busch's own estimate of 1,300,000 total landings from 1870 to 1910 seems reasonable. In considering the effect on the population, however, the number of animals killed, rather than the number of skins sold, is important. For the pelagic hunt, unlike the operations on the islands, these figures are very different because of the large proportion of animals killed but not recovered. Contemporary estimates of the proportion recovered quoted by Busch range all the way from 2% or 3% to 66% (for a good hunter). Busch adopts an average recovery rate of 33% in calculating a total kill of about four million animals. This figure seems optimistic, and it appears possible that the efficiency of recovery was as low as 16%, giving a total kill of about eight million seals.

Another important effect on the seal population is the likelihood that outside the Bering Sea, the majority of animals killed were females, while on the islands the take, even in most of the early years, was probably mainly males. Furthermore, it is impossible to be sure what proportion of the seals killed by the pelagic hunt came from that part of the population breeding on the Pribilof Islands, although two factors suggest that these animals made up most of the kill. First, in recent years the animals breeding on these islands have amounted to about 70% of the total population (Fowler, 1985b). Secondly, most of the pelagic operations were based in North American ports, and although large kills were made in the western Bering Sea and off

Japan, particularly in later years, it is likely that the greater part of the catch was taken in the eastern part of the region. We may conservatively assume that at least two-thirds of the pelagic kill, or 2,500,000 to 5,000,000 animals, were taken from the Pribilof stock.

Thus between 1866 and 1910, the total kill from this stock was probably between 5,000,000 and 7,500,000 animals, an average of 120,000 to 170,000 a year. This kill reduced the population on the Pribilof Islands from between two and three million – a figure which is not far below the unexploited level (Busch, 1985; United States, 1985) – to about 300,000 (United States, 1985).

The Recent Regime

The deteriorating condition of the Pribilof seal herds between 1890 and 1910 brought the U.S. and British governments to the realization that drastic action was needed to save the populations. It would be necessary to reduce the land kill and, if possible, end the pelagic hunt. International rivalries and the entrenched position of the U.S. sealing company aborted these efforts; furthermore, efforts to stop pelagic sealing seem to have had the unwanted effect of stimulating the Japanese operations in the western Bering Sea (Busch, 1985).

Finally, in 1911, a treaty was signed among Britain (in behalf of Canada), the United States, Russia and Japan. This agreement banned pelagic sealing and gave a compensating share of the financial return from the land take to Canada and Japan. It also placed a five-year moratorium on the taking of seals except for food. The treaty lapsed in 1941, when Japan withdrew, but it was revived in modified form in 1957, when the North Pacific Fur Seal Commission was established to manage the hunt. The Fur Seal Commission was very recently terminated.

Both before and during the regime of the Fur Seal Commission, the declared objective of international management was to work towards maintaining the populations at a level of maximum productivity. The Fur Seal Commission recommended, but did not have power to set, catch levels for the United States and the Soviet Union. Its recommendations were normally based on the advice of its Standing Scientific Committee.

In accordance with the aim of allowing the population to rebuild to a productive level, kills were restricted to slow increases on the Pribilofs after the expiry of the initial moratorium; they were also restricted to immature

males, and no females or harem bulls could be taken. Under this regime the population increased steadily until about 1940, when it seems to have levelled off. From 1912 to the late 1930s, the kill was steadily increased until it passed the 60,000 mark in 1939; up to that year a total of 876,000 seals were killed, giving an annual average of 31,000. From 1939 to 1955, a further 1,038,000 seals were taken for an annual average of nearly 65,000.

In the 1950s, the concept of management for maximum sustainable yield (MSY) became widely adopted as a basis for fisheries management. This development led to the belief that the maximum production of pups would be obtained by reducing the female population substantially below the unexploited equilibrium level, although this belief was not based on any specific evidence. In an attempt to accomplish this reduction, regular harvesting of females was begun in 1956, and it continued through 1968; a total of about 320,000 females was taken, an average of 25,000 a year. Scientific advice proved incorrect, however, and the female harvest led to a drastic decline in the size of the seal population. The herd on St. Paul Island, which comprised about 80% of the Pribilof total, declined from about 1,800,000 in the early 1950s to 930,000 in 1970 (United States, 1985).

The female kill was stopped in hopes that the population would soon rebuild, since it stood at about the same level as in the early 1930s, when it grew rapidly in spite of a male harvest of about 50,000 animals a year. These hopes, too, proved unfounded, and the population has continued to show a generally downward trend despite temporary upward fluctuations in 1966 – 1967 and 1975 – 1976. This has happened in spite of a reduction in the size of the immature male harvest to about 25,000 a year. Causes of this decline will be considered later in this chapter.

Scientific Data Base

Few scientific data exist concerning the northern fur seal herds prior to 1911. Official records of the numbers of fur seals killed on the islands seem to be satisfactory (Busch, 1985), although the data on the pelagic take are much less complete. Still, the estimates of the size of the herds are extremely weak; the first experienced scientist to attempt an estimate seems to have been D. Starr Jordan, who estimated the Pribilof population at 400,000 in 1897 (Busch, 1985). Since 1911, however, when the seal hunt came under international control, an almost continuous program of data collection has been in operation. As a result, the northern fur seal is one of the best documented of all marine mammals. The major kinds of data collected have been (Smith and Polacheck, 1984):

- counts of pups born from 1911 to 1924;
- estimates of numbers of pups born from 1950 to 1985;
- estimates of harem and "idle" bulls on the islands since 1911, based first on counts and then on markings;
- counts of pups found dead from 1914 to 1922 and since 1941;
- age determinations of males harvested since 1947;
- pelagic samples of seals from 1958 to 1961.

It is not possible to make accurate counts of the total fur seal population based on direct observation, but the estimates of harem bulls and pups born provide indices which can be related fairly simply to overall population size. The data for the harem bulls are probably the more accurate, since these animals are large and conspicuous, and there are relatively few of them. The estimates of numbers of pups born in the early years when numbers were low are probably fairly accurate. Counting became more difficult later, up to 1924, when numbers were larger, but the results are considered acceptable (Fowler, 1985b). Early tagging experiments (1947-1968) encountered problems, and their results are subject to some criticism (Trites, 1984); later experiments when the animals were marked by shearing were regarded as more satisfactory.

Population Trends

Pup Production

In 1911, 70,000 pups were counted on the beaches of St. Paul Island. When regular observations ended in 1924, the count was 172,500 (Smith and Polacheck, 1984), although there is some doubt about the validity of this figure. Estimates are next available for 1940 (York, 1985a) and 1950 (Eberhardt, 1981) of 442,620 and 450,000 respectively, and the count remained close to this level until 1957. For the periods 1911-1924 and 1924-1940, the average annual rates of increase are about 7.2% and 6.1% respectively. The two estimates for 1940 and 1950 are consistent with the view that the population had reached stability by about 1940. A lower growth rate from 1924 to 1940 than from 1911 to 1924 is not unexpected.

The true rate would have slowed down as the population approached stability, and the population may have reached stability and growth stopped completely some time before 1940.

After the beginning of the female harvest in 1956, the number of pups declined quite rapidly to about 280,000 by 1962. The subsequent history of pup production could be described either as a period of approximate stability with some fluctuations until 1976 and then a fairly rapid decline, or as a continuing but erratic decline over the whole period from 1962 to the present. The average count for the years 1982–1984 has been 181,000, which is 40% of the 1950 figure. Since 1975, the average rate of decrease has been about 6% per year (Smith and Polacheck, 1984; Trites, 1984).

Mature Bulls

Since 1911, separate counts have been made on St. Paul Island of harem bulls and of "idle" bulls, which are animals of mature age (seven years or more) not occupied with harems. The numbers of harem bulls rose steadily from 1,090 in 1912 to 10,000 in 1936, a growth rate of 9.7% per year, and then remained fairly constant to 1961. The total number of mature bulls rose steadily, apart from a check between 1940 and 1950, from 1,300 in 1911 to a peak of 23,000 in 1961, an average annual rate of 5.9%.

After 1961, the number of harem bulls and the total of all bulls on St. Paul Island fell rapidly to a low of about 3,700 and 6,100 respectively in 1972. These numbers rose again for a few years to peaks of about 6,500 and 11,000 in 1978. Recently there has been a further decline, and in 1983 and 1984, about 4,800 harem bulls and a total of 9,000 bulls have been counted. The number of harem bulls thus stands at about 48% of the 1936–1962 level.

Thus the general changes in numbers of bulls have followed those of the pups, although, as is to be expected, they have lagged by several years. The sharp decline which took place following the female hunt of 1956–1968 occurred from 1957 to 1962 for pups and from 1961 to 1971 for mature bulls.

The Current Situation

Current populations on St. Paul Island, expressed in terms of pup production and of numbers of harem bulls, are about 40% and 48%, respectively, of the apparently stable levels of the 1950s. Somewhat similar

changes have taken place on St. George Island, the other major island in the Pribilof group.

Both pup production and numbers of harem bulls are declining, in spite of the fact that the kill (of immature males only) has averaged only 25,000 since 1961 as compared to 48,000 in the 1950s. Expressed as a percentage of the total number of pups born three years earlier, the kill from 1975 to 1984 represents about 10% as against 8.8% in the 1950s.

The two most important questions posed for any attempt to manage the Pribilof fur seal herd are therefore:

- How does the present population level relate to any identifiable target level at which management may be aimed?
- What causes have prevented the herd increasing to the 1950s level as it did after 1911?

Relation to Target Levels

The principles now accepted as underlying the management of marine living resources are reviewed in Chapter 27. That review explains the concept of maximum sustainable yield (MSY) and of the population level at which MSY is available. It also relates the MSY population level to other definitions of optimum or target-population levels, such as that defined under the United States *Marine Mammal Protection Act of 1972*. This section relates these general principles to the particular circumstances of the northern fur seal.

Ability to Increase

The history of the Pribilof Islands fur seals shows clearly that until about 1960, the herd had a natural ability to increase when its numbers were reduced below its unexploited stable level. The average annual rates of increase in the numbers of pups were, as was shown earlier, about 7.2% and 6.1% in the periods from 1911 to 1924 and from 1924 to 1940 respectively. Since no females were harvested, these figures represent the total rate of increase in the population. Chapman (1981) fitted a regression line to the pup counts from 1912 to 1924 and obtained a rate of increase of 8.2%.

A crude calculation can be made of the natural rate of increase in operation over the period when the population declined from an unexploited level in 1868 to the depleted level in 1910. If the range of likely values of the initial population was two to three million, and the depleted population was 300,000 while the total catch was five million, the average natural rate of increase was about 5%–9%. However, if the total catch was 7.5 million, the rate of increase was 10%–15%. These figures are more or less consistent with the more reliable values for the later years. This method calculates the average rate of natural increase from initial and final population size and total catch. (See Appendix 22.1.)

Density Dependence

If a population is able to achieve a natural rate of increase in response to a reduction in its numbers, some factors affecting the natural recruitment and/or the mortality rates must behave in a density-dependent manner.

Fowler (1986) examined the extent to which density dependence occurs in a number of characteristics of the northern fur seal. He found positive evidence of this effect in:

- survival of pups prior to leaving land;
- survival of males up to two to three years of age (comparable data are not available for females);
- age at reproductive maturity;
- growth rate as measured by a number of factors, including pup weight at two months, length and weight of males and females collected both on land and at sea, and tooth weight.

Concerning density-dependent growth and age at maturity, Fowler notes:

It is well-known that among many animal species it is often easier to predict the timing of first reproduction . . . on the basis of size than on the basis of age.

MSY Level Relative to Unexploited Level

For Overall Harvest

Direct determination of the population level (relative to the unexploited level) at which the sustainable yield is a maximum (the MSY level) would require masses of accurate data on the rate of increase at various population levels. These data are not now available for fur seals, nor are they likely to be available in the foreseeable future. Indirect approaches to determining the MSY level are, however, possible. It is now generally accepted that for large mammals, the MSY level is above, and sometimes well above, 50% of the unexploited equilibrium level.

Fowler (1984b) states that the MSY level for the northern fur seal is 0.6 of the unexploited level. This figure is based largely on a general study conducted by Smith (1973) and on an analysis made by Eberhardt (1981) of the relation between northern fur seals' survival to three years of age and the numbers of pups born. Examination of Eberhardt's analysis, however, reveals several problems. First, as Eberhardt points out, while the data lead to a definite conclusion that the female pup level giving maximum net recruitment on St. Paul Island is fairly close to 200,000, they give little indication of the number of pups at the unexploited equilibrium. Secondly, in the data series used, all the points for numbers of female pups between 100,000 and 200,000 were for years between 1958 and 1965; as will appear later, it is likely that in this period extraneous factors were reducing the rate of survival to three years of age. Compensation for this effect would tend to reduce the estimate of the relative MSY level. Thirdly, Eberhardt's analysis deals only with the effect of density-dependent changes in the rate of survival to age three; as will be seen later, there is evidence that other factors may contribute to density-dependent changes in net rate of increase. There are no quantitative data on these effects.

Fowler (1984b) also shows that for a wide range of animals there is a fairly linear relationship between the maximum net recruitment level and the logarithm of the maximum rate of increase per generation time. Applying this relationship to a maximum rate per generation time of 0.88 (derived from Smith, 1973; Eberhardt, 1981) gives an MSY level for the fur seal in about the range of 0.55–0.75.

Fowler notes that most of the density-dependent relations he examined are non-linear, with the most rapid change in the parameter occurring

not far below the maximum population level. Again, this finding is consistent with the maximum net recruitment occurring at a population above 50% of the unexploited level.

It seems likely that the MSY population level for fur seals is between 50% and 100% of the unexploited equilibrium level. The precise level may best be described by a statement of an expert working group which considered this problem in 1979 in relation to tropical Pacific porpoises.

Opinion within the group is that the MNPL (maximum net productivity level) is likely to be in the range of 65 to 80% of the equilibrium unharvested population level (carrying capacity or largest supportable population). In the absence of better information, all levels within this range were treated as being equally likely; the midpoint (72.5%) cannot be regarded as "the most likely value" (Smith, 1979, p. 6).

For Male Harvest

The population level giving maximum natural increase is not, however, a good indicator of the level giving maximum yield unless harvesting is spread evenly over the population at, and above, the age to which recruitment is measured. While many marine animals, including fish and baleen whales, meet this condition, the fur seal does not because harvesting is almost entirely confined to males of two to four years. A close parallel is provided by the sperm whale, which also breeds through harems, and for which harvesting in many of the major fisheries has been largely restricted to males. The principles underlying the identification of population level and structure in the sperm whale have been extensively studied (e.g., Allen, 1980, p. 84) and are essentially applicable to the northern fur seal. For both these animals it is necessary to consider the females and the males separately.

The aim of management is now to achieve the maximum number of males of harvestable age in excess of those required to fertilize the females. To produce this number, the number of mature females should be quite close to that which exists in an unexploited population, but the number of males will be much smaller. These guidelines imply a continuation of the present policy of a minimal female kill. The precise level for males depends on the

values of the various vital parameters such as harem size, number of mature males and pregnancy rate, and the way they change with population size; in particular:

- the most desirable harem size;
- any need to have a reserve of mature males to replace periodically those holding the harems;
- the effect on female pregnancy if the ratio of the number of mature males to the number of harems drops below the optimum.

For sperm whales, most combinations of likely values for the various parameters lead to MSY population levels of about 85%–95% of the unexploited level for females and 35%–50% for males.

No detailed data seem to have been published on harem size in northern fur seals. Taking the number of pups as a minimal estimate of the number of breeding females, the published counts of pups and of harem bulls lead to estimates of the average harem size in a year as generally ranging between 25 and 60 animals, and most commonly between 35 and 45. However, Fowler (1985c) advises that the current view among biologists is that the natural harem size of northern fur seals is between 12 and 15 adult females per breeding territory-holding male. No significant variations in harem size over time have been identified.

The population levels supporting a maximum continuing yield cannot be identified from the available data. Under conditions existing up to 1958, the population levels between 1936 and 1958 were capable of sustaining a high level of pup production. From 1940 to 1957, the number of pups produced on St. Paul Island remained fairly constant at about 450,000 a year, and few females were being killed. The number of harem bulls also remained fairly constant during this period. It is reasonable to consider these population levels as close to the maximum productivity levels for harvesting three- and four-year-old bulls under the environmental conditions that existed at that time. Since the number of idle bulls (and therefore the total number of bulls of mature age) continued to increase at least until 1957, pups could probably have been maintained at 1940–1957 levels, with a slightly larger kill of young males, at least during the latter part of this period.

In the absence of any real data pertaining to the original size of the unexploited fur seal populations, it seems best to take the 1940–1957 popula-

tion levels on the Pribilof Islands as a lower bound of the maximum production level of an unexploited fur seal population.

Relation to Optimum

Chapter 27 shows that while the population levels corresponding to maximum sustainable yield or maximum net recruitment (MNR) may be defined at least conceptually, the optimum population level may lie within a wide range, depending on the combination of factors it is desired to optimize. Definitions under the United States *Marine Mammal Protection Act of 1972* place the optimum population level in the range between the maximum net recruitment level and the unexploited level. Recognition of the intrinsic value of living seals also places the optimum population level above the MSY or MNR level, as does economic optimization of any harvesting process, provided that costs for a given harvest decrease as the population increases. On the other hand, if social or economic costs related to the abundance of seals are taken into account, such as damage to gear or removal of parasites from fish, the optimum population figure is moved downwards relative to the MSY or MNR level.

As long as management of the northern fur seal remained within the ambit of the North Pacific Fur Seal Commission, its aim was defined as that of maintaining the population at levels "which will provide the greatest harvest year after year". This is a definition which approximates quite closely to the MSY level.

Costs to Canada from the presence of fur seals are treated in Chapter 29. They appear to be minor, and the method of harvesting involves no direct cost to Canada. Thus, as long as Canada is primarily interested in the fur seal as a harvestable resource, the optimum population level of fur seals will be about the MSY level or, preferably, somewhat higher to allow for risks of error and to take account of intrinsic values.

Present Levels

The population figures of pups and harem bulls now stand at about 40% and 50%, respectively, of 1940-1957 levels and are continuing to decline. If the environment remains unchanged, these figures would indicate that the population is now well below the optimum level, however defined, and that management policies should be adjusted accordingly. There is evidence, however, that the current situation is the result of a new

source of mortality. If this is so, it is impracticable to try to define what the optimum population levels would be if the new conditions persist. The appropriate strategy appears to be to try to stabilize the situation while accumulating additional knowledge, rather than to move the population towards any predefined level.

Possible Causes of Failure to Rebuild

Food Supply

When it became evident that the fur seal population was not rebuilding as expected after the end of the female kill in 1968, suspicion was directed towards a possible reduction in food supply resulting from the large commercial fishery which had developed in the Bering Sea. It now seems likely that this was not the cause. Some density-dependent vital parameters, believed to operate through the availability of food, now stand at values similar to those prevailing in the 1920s, when the fur seal population was about the same size as it is at present (Fowler, 1985b). These parameters include the weight of pups at birth, the survival rate of pups on land, measures of growth such as the length and weight of harvested males, and the weight of their teeth.

This view is supported by more direct evidence concerning the quantities of food available to the fur seals. The fur seal, like most seals, is an opportunistic feeder, taking a wide variety of species of fish and squid according to what is available to it. Thus it can compensate for scarcity of one food source by changing to another, more readily available form. It is recorded as feeding on fish of 17 families in the Bering Sea, and in its southern migrations its principal prey changes from area to area as it travels along the coast (Kajimura, 1984). In addition, there is little evidence of any significant current shortage of the principal prey species as a result of the Bering Sea fishery. The fur seal's most important prey in the Bering Sea are capelin, walleye pollock, Pacific herring, Atka mackerel and two or three species of squid. Of these, the capelin has not been fished in these waters, the Pacific herring fishery is of minor importance, and the squid and mackerel fisheries began in the eastern Bering Sea in 1977 and 1978, and are still fairly small.

The walleye pollock is the most important species as it is both much the most abundant commercial species in the Bering Sea and a major food of fur seals, especially in the vicinity of the Pribilof Islands. Pollock were subject to a very heavy fishery in the early 1970s and, according to Kajimura

(1984), suffered a decline in abundance which was arrested when the United States placed restrictions on foreign fishing. Since that time the biomass has remained fairly stable (Bakkala et al., 1984). The biomass of pollock, however, appears to have been lower since about 1970 than it was during the preceding 30 years, when the fur seal population reached stability at a high level. It is not known whether the more abundant fur seal population of that time affected the size of the pollock stock. Although it seems unlikely that shortage of food has contributed seriously to the failure of the fur seals to rebuild their numbers since 1968, further examination is needed of the relation between the seal population and the pollock stock.

Exploitation

The average number of male fur seals killed on St. Paul Island during the last seven years is 24,500, less than half that taken between 1931 and 1935 (52,800 annually), when the population was about the same size and growing rapidly. Data are not available to support a comparison of the number killed with the number of pups born between 1931 and 1935, but the number killed in the 1950s, when the population was apparently stable, represented about 9% of the pups born three years earlier, compared to 10% of those born from 1975 to 1984. These figures do not suggest that the population is currently overexploited as compared with the past.

Of course, the regular kill of a substantial number of animals must affect the size and composition of the population, but it seems that some new factor is causing the population to stabilize at a lower level or to decline under a harvesting regime which previously allowed an increase in a population of similar size. This view is supported by the fact that the smaller fur seal population on St. George Island, where no killing has taken place since 1972, is also decreasing. There is some argument as to whether the proportional rate of decrease is as great on St. George Island as on St. Paul Island, since the results of statistical comparisons depend on which series of years is examined. Nevertheless, some decrease is taking place on St. George Island.

The suggestion merits consideration that cessation or reduction of the male harvest would increase the proportion of males to females, and that this change might bring about an increase in pup mortality on land. If it is true, "termination of the harvest could impede a recovery of the population to higher levels" (United States, 1983). Swartzman (1984) has examined statistical data bearing on this problem. The results are conflicting: for St. Paul Island, multiple regression shows that pup mortality is positively corre-

lated both to pup production and to the ratio of adult males to females, although pup production is a much higher contributor; on St. George Island, only pup production shows a significant correlation to mortality. Concerning the Russian sites, neither variable shows correlation on Robben Island, while on the Commander Islands both variables are significantly correlated, the larger contribution being made by the sex ratio. While further work might show a real relationship, the effect is likely to be small, and it is unlikely that discontinuance of the male harvest would materially slow any build-up of the fur seal population.

Loss of Breeding Beaches

Trites (1985) has pointed out that the limited size of the breeding beaches may restrict the size of the fur seal populations and cause density-dependent effects. If the beaches are overcrowded, adults may bite and trample young pups, causing increased mortality. These circumstances may provide a mechanism for the density-dependent effect on pup mortality noted by Fowler (1986). It has been suggested that one effect of the female kill from 1956 to 1968 was to denude some of the beaches of their breeding populations, and because females tend to return to the beaches where they were themselves born, reoccupation may have been slow to take place. Such a process could slow down or prevent population recovery after the female kill. Two factors indicate, however, that the loss of breeding beaches is not the primary cause of the present situation: first, while this occurrence could slow down recovery, it would not produce the further decline which is now taking place; secondly, the survival rate of the pups in the first few weeks is now high and not at the low level which would be expected if the beaches in use were overcrowded.

Juvenile Mortality

Although none of the preceding possibilities seems likely to account for the current decline in the numbers of fur seals, there is good evidence about the stage in the life of the seals at which the critical change has taken place. Since about 1970, there has been a decrease in the survival rate of the young males. Since the females do not return to the islands while immature as the males do, they cannot be counted at this age, and comparable estimates of mortality rates are not available. There are theoretical grounds for thinking that a similar change has taken place for females. There are indications (Lander and Kajimura, 1982; Eberhardt, 1981) that prior to the

female kill, the male juvenile survival rate was to some degree density dependent. Since 1968, however, the survival rate has not increased as the population diminished, but has remained at a level substantially lower than that of most years since 1950 (Trites, 1985; Fowler, 1985a).

While there is some discussion concerning the way in which these survival rates should be calculated (e.g., Eberhardt, 1981; Trites, 1985), the differences between the rates calculated in different ways are not significant in their effect on the overall population trend. Trites (1985) has assumed that young males and females have the same survival rates. He has used a simulation to show that a combination of the known catches, including those of females from 1957 to 1968, and the estimated year-to-year survival rates to age two will account quite closely for the decline in the number of pups since 1957, and for the failure of the numbers to recover in recent years. If it is assumed that the survival rates of the older males were higher in the 1950s than in the following two decades, the results also follow closely the changes in the total numbers of mature bulls.

Predators

The question then arises of the cause of increased mortality rates of juvenile animals in recent years. No evidence suggests any increase in disease or parasitization which could produce increased mortality rates for young fur seals. Possible predators on juveniles in the Bering Sea are killer whales and Steller sea lions. It is not known whether the numbers of killer whales are changing. There do not seem to be any indications of a significant increase in the numbers of Steller sea lions anywhere within the eastern range of the northern fur seal. A marked decline is, in fact, occurring in the numbers of Steller sea lions in part of the Aleutian chain (Braham et al., 1980; Loughlin, 1984). On the coast of British Columbia, the numbers of Steller sea lions breeding on the rookeries have not recovered as expected after the discontinuance of hunting in 1964. However, there has been an increase in the numbers of these animals breeding on the adjacent Alaskan coast, and the total numbers feeding in the region may have increased somewhat, although they are still well below the 1956 level. Recent changes in the numbers of Steller sea lions are discussed later in this chapter.

Abiotic Factors

Abiotic factors, such as changes in oceanic circulation patterns and associated variations in local temperatures and salinities, could influence

the abundance of fur seals in a number of ways. Such relationships can be difficult to identify and still more difficult to explain. Up to now, no strong relationships have been found. Roppel et al. (1963) and Vladimirov (1974) quoted by Trites (1985) found statistically significant correlations between pup survival on land and weather conditions on St. Paul Island and on Robben Island. However, more detailed studies made by Trites (1985) on St. Paul Island over a longer period did not confirm such a relationship. Trites compared the physiological needs of the pups and the annual weather pattern on the island to show that the fur seal is well adapted to conditions in the area. The annual weather cycle provides the right conditions at exactly the time of year when the pups are ashore. York (1985b) demonstrated a small, but statistically significant, correlation between the harvest rate of fur seal cohorts on St. Paul Island (itself dependent largely on the survival rate of fur seals to ages three and four) and the mean temperature over the previous four years at Pine Island on the B.C. coast. A variety of explanations of such an effect could be postulated but as York has said, "it suggests that the survival of young fur seals may be partially regulated by oceanic conditions in the north Pacific Ocean." These results emphasize the need for further studies to determine the nature and degree of environmental factors in long-term fluctuations in the abundance of fur seals. There is no evidence now to link the apparent declining trend in the population in recent years with any environmental effect.

Entanglement

Seals, like many other marine animals, are exposed to the risk of becoming entangled and killed in fishing gear which is now widely spread throughout the oceans. This risk is from gear which is in working order and actively fishing, and from fragments of broken and discarded gear which are adrift. The question of the incidental capture of seals in the process of fishing operations is discussed in Chapter 23. The main source of this kind of mortality among northern fur seals is the Japanese drift-net fishery for salmon in the north Pacific Ocean. The problem seems, however, to be a fairly minor one, since only a few thousand seals are killed in this way each year.

Entanglement in fragmented and discarded gear and in plastic debris from other sources appears to be a much more serious problem. It affects fur seals, other seals, whales, dugongs, turtles and seabirds. (See Chapter 23.) The effects on fur seals have been reviewed extensively by Fowler (1982, 1984a, 1985a). They were first observed in relation to northern fur seals in 1936. However, in the 1960s, when the use of plastic in

fishing nets and packing materials became common and the large groundfish fishery in the Bering Sea developed, entanglement began to occur on a significant scale. Since about 1970, some 0.4% of the returning harvestable male fur seals have been entangled in pieces of plastic.

Fowler has reviewed evidence relating to entanglement and has concluded that a significant proportion of young males die from this cause after leaving the breeding islands and before returning as two- or three-year-olds. Evidence supporting this conclusion includes the following:

- There is a relatively low ratio of large to small pieces of netting on returning seals, compared to the ratio in netting washing up on beaches; it is therefore assumed that animals entangled in small pieces generally survive, while those entangled in large pieces die.
- A similar comparison applies to the relative amounts of netting of all kinds and of packing bands on seals and on beaches, suggesting that netting pieces are more destructive to seals than packing bands.
- Originally the survival rate of young males from the time of departure from the islands till their return showed a good correlation with the survival rate of the same pups prior to departure. Recently, the survival rate at sea has been less than that expected from this correlation, and the extent of the deficiency has a positive correlation with the proportion of the same animals that were entangled in netting on their return.
- The annual rates at which the numbers of pups and the numbers of harem bulls have been declining in recent years show positive correlations with the entanglement rate at the appropriate number of years earlier.
- The proportion of returning three-year-old males entangled is only 54% of the proportion of two-year-olds entangled. This circumstance suggests that excess mortality of entangled animals has occurred in the interval.

Fowler (1985a) has pointed out that the use of these relationships to estimate the extent of mortality caused by entanglement involves several assumptions which have not yet been fully tested. These assumptions relate, for example, to the size composition of the debris in which seals become entangled, the mortality rate of animals entangled in small pieces of debris, and the extent to which females become entangled. Nevertheless, it is clear that entanglement has increased in recent years, and that it does contribute

to the deaths of juvenile fur seals; no other cause of additional mortality since about 1970 has been identified. The relation found by Fowler (1985a) between the departure of the survival rate from the value expected from the regression on survival on land and the entanglement rate forecasts a decrease of 0.15 in the survival rate to first return at age two or three for the average current entanglement rate of 0.4%. The other indicators of the effect of entanglement on survival suggest values not inconsistent with this figure. Such a decline in juvenile survival would apparently be sufficient to cause the observed decline in pup production. It is therefore reasonable to consider, at present, that entanglement is probably a major contributor to the post-1970 failure of the fur seal population to rebuild. Entanglement is not necessarily the only factor responsible for this problem, and further studies to identify other possible factors are needed. Such studies should examine both abiotic factors, such as climatic changes and pollution, and biotic factors, including food supply, predation and disease.

The general question of the threat posed by plastic debris to a wide variety of marine vertebrates is reviewed briefly in Chapter 23. Other kinds of seals, including Steller sea lions (Calkins, 1984) and monk seals (Henderson, 1984), become entangled, but the phenomenon has been most fully studied in the case of the northern fur seal, and it seems likely that this species is one of those most seriously affected. Japanese experiments with fur seals in tanks (Yoshida and Baba, 1984; North Pacific Fur Seal Commission, 1984, p. 39) confirmed the tendency for the animals to become entangled in pieces of netting placed in the water. Entanglement resulted when seals charged into the netting at high speed and when young animals played with it. Females as well as males became entangled. This observation is important, since all the data on entanglement in the wild population refer to males.

If entanglement in plastic debris does emerge as the principal cause of the failure of the fur seals to recover their population levels, there may be some chance of alleviation of the situation in the long term; this might come about, for example, through changes in technology or as the result of a deliberate effort to reduce the amount of plastic debris in the ocean. Signs already exist that the amount of plastic debris may be decreasing; Merrell (1984) records a 37% reduction, between 1974 and 1982, in the amount of trawl web coming ashore on Amchitka Island in the Aleutians, an area which is well within the normal range of the Pribilof fur seals. The proportion of entangled returning fur seals rose rapidly from 1967 to reach a peak in 1975, but fell again in the next two years and seems to have been fairly constant since 1978 (Fowler, 1985a).

Awareness of the damage caused by plastic marine debris to seals, other marine mammals, other vertebrates and especially to seabirds, is growing rapidly. It has led to pressure in the United States for action to reduce the amount of such material in the ocean (Wallace, 1984), and pressure of this sort seems likely to spread. The fishing industry is the principal source of the problem and could act to improve the situation. The simplest and most important step would be to reduce the throwing overboard of plastic debris of all kinds, but particularly of netting fragments, damaged nets, plastic wrapping bands and ropes. Probably an equally valuable measure would be to retain on board material of this kind brought up in nets. Organized work to clean up material washed up on beaches has already been started in some places, and its extension would be valuable. A vigorous program of public education and of appropriate regulatory measures will probably be required to bring about any substantial and continuing improvement. In the long term, it may be practicable to introduce technological changes towards the use of biodegradable materials in certain parts of fishing gear such as hanging twines. (See Chapter 23.)

International Management

As was noted earlier in this chapter, management of the northern fur seal was placed on an international basis with the signing of the Fur Seal Treaty of 1911 between Great Britain (in behalf of Canada), the United States, Russia and Japan. The Fur Seal Treaty lasted from 1911 to 1941, when it was abrogated by Japan. From 1941 to 1957, the Pribilof herd was protected under a provisional agreement between Canada and the United States.

The Interim Convention on Conservation of North Pacific Fur Seals, which came into force in 1957, was signed by Canada, Japan, the United States and the U.S.S.R. It was extended by protocols which took effect in 1964, 1969, 1976, and 1980. It was this Convention that established the North Pacific Fur Seal Commission. A 1984 protocol was to have extended the Convention until 1988. A statement attached to it included:

- recognition of the need for further research on the entanglement problem;
- agreement to take all appropriate measures to halt the discarding of net and gear at sea, in accordance with the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention);

- provision for action in unforeseen circumstances;
- agreement to review the Convention within two years to determine if modifications or renegotiation are necessary.

However, the protocol was not ratified by the United States. The Convention expired in October 1984, and the North Pacific Fur Seal Commission has been terminated.

In 1985, interim measures in the United States placed harvesting on the Pribilof Islands under the control of the local people, but limited the harvest to between 3,000 and 15,000 animals to be taken for subsistence purposes only (Associated Press, 1985).

Policy Options

In the short term, management of fur seals will be the responsibility of the individual countries within their 200-mile limits. It is to be hoped that there will be some international sharing of information to assist in each country's management efforts.

In the longer term it may be advantageous to include the fur seals in the scope of a broader treaty for the management of the marine living resources of the north Pacific Ocean and the Bering Sea. Negotiation of any international fur seal or broader convention will likely include consideration of three of the points covered by the 1984 protocol: research on entanglement, efforts to stop discard of plastic debris, and provision for action in unforeseen circumstances.

If any new arrangements are negotiated for the international management of fur seals in the north Pacific, the objectives at which management should be aimed will require careful consideration. The previous Convention stated its goal to be:

... to take effective measures towards achieving the maximum sustainable productivity of the fur seal resources of the north Pacific Ocean so that the fur seal populations can be brought to and maintained at levels which will provide the greatest harvest year after year, with due regard to the productivity of other living marine resources of the areas.

This statement, which clearly recognizes the harvest as the main objective of the Convention is now unacceptable to many animal-protection organizations. These organizations would certainly take the opportunity to press the case for terminating the hunt. The above definition of the target population is also incompatible with the definition of optimum population level under the United States *Marine Mammal Protection Act of 1972*. Pressure has already been brought to bear on the U.S. government to make management of fur seals compatible with the Act. It is impossible to predict the positions that governments will take in discussions relating to the future management of fur seals, but it is obvious that the above issues will be considered.

Canada's Relation to the Commission

Canada (represented by Great Britain) was an essential member of the Fur Seal Commission as originally established because of its active involvement in the pelagic hunt. The material benefit which Canada has gained from the Commission was 15% of the sealskin take, which it receives in compensation for refraining from hunting seals on the high seas. Financially, this benefit has been quite small, even before the collapse of the sealskin market; the average net revenue for the years 1976–1982 was about \$300,000.

The only other effect of fur seals on the Canadian economy seems to be through the damage done by the seals to the west coast fishing industry, discussed in Chapters 24 and 25. Fur seal damage seems to be relatively small compared to that caused by the sea lions and harbour seals in the same area.

Whether Canada is currently in receipt of any direct economic effect from the fur seals or not, the seals exist as a potentially exploitable resource in which Canada has identifiable interests. These interests stem both from the fact that a substantial part of the population spends a vital, although fairly short, period in Canadian waters and from Canada's traditional participation in the seal fishery.

Regardless of economic benefits, the northern fur seals constitute one of the great marine mammal populations of the world. The waters they inhabit are generally within Canada's area of interest and, seasonally, a significant part of their population lives within the Canadian fishing zone.

For all these reasons it is appropriate for Canada to take an active part in any international management of the fur seal populations. Canada's

efforts should be directed towards replacing the North Pacific Fur Seal Commission by some international arrangement which will provide effective management.

Benefits of the Commission

The primary benefits derived from the Fur Seal Commission were that it provided a mechanism for regulating the exploitation of the fur seals which has proved very effective in the past; it also stimulated a large and well-coordinated research program. Since the Commission has been disbanded, it seems possible that funding for the large U.S. research program and for the smaller but valuable Canadian program could be cut back or even terminated. The Royal Commission believes that support for the Canadian research program should be maintained at the present level.

The Commission's presence was particularly important because it prohibited pelagic hunting of fur seals, apart from a strictly limited take for research purposes. With the Convention lapsing, pelagic hunting could possibly be resumed, perhaps by a country that was not a member of the recent Convention. Such a development could pose a very serious danger to the seal herds. The take might be uncontrolled, and the kill would be impossible to measure even if landing statistics were kept, since the recovery rate could not be checked. Furthermore, a large proportion of the kill, particularly if taken outside the Bering Sea, would be likely to be females, and history has already shown the catastrophic effect of such a kill. Canada will maintain a ban on pelagic sealing (Goodman, 1986).

The Royal Commission believes that it is also important for the statements attached to the 1984 protocol, relating to research on entanglement and the prevention of the dumping of plastic material, to receive the strongest possible support in any future national or international management efforts.

The Objectives of Management

As long as Canada's interest in the fur seals is based primarily on these animals as a resource, it is appropriate to define a target level for management as somewhat above the MSY level. Under present conditions, however, it is impossible to define this level in numerical terms. In these circumstances it might be appropriate for any new management guidelines

to include the principle that no harvest should be taken which would cause the net productivity of the fur seal population to decrease.

Inclusion of Fur Seals in a More General Agreement

There would be advantages in bringing the management of fur seals into the ambit of an international body having general responsibilities for the marine living resources of the Bering Sea and north Pacific Ocean. These advantages include better provision for examination of the relation between the seals and the rest of the marine ecosystem, particularly other exploitable resources, and a wider scientific contribution to discussion of seal-management problems. These benefits are presented in more detail in Chapter 28 of this Report. The possibility of establishing a more general body for this region has been under discussion for many years. The Royal Commission suggests that the Canadian government take steps to promote this proposal and to ensure that fur seals are brought within the purview of such a body if it is established. Nevertheless, in the light of past experience, the Royal Commission is not confident that such an international agreement will be achieved within the next few years. The Royal Commission therefore considers that Canada should actively support any moves to establish a special international arrangement for the management of fur seals in the north Pacific.

Conclusions

1. There can be no doubt that the Pribilof Islands fur seal herd is far below its original unexploited level – probably, indeed, standing at less than 50% of that level – and that it has been decreasing over the last decade both where males are harvested (on St. Paul Island) and where they are not harvested (on St. George Island). It is likely, but not certain, that the decline is continuing at the present time.
2. In the 1950s, the population was apparently stable with a high level of yield. It may have been close to the MSY level, since no females had been harvested for many years. Thus the restoration of the 1950s level would appear at first sight to be an appropriate target, whether the objective is to achieve a high continuing yield or to bring the population to some less definite optimum level, such as that defined under the United States *Marine Mammal Protection Act of 1972*. It is not clear, however, whether under present conditions, the population could rebuild to this level even if it were fully protected.

3. The only hypothesis relating to the cause of the recent decline that is supported by much evidence is that the decline results from an increase in the mortality rate of young animals, probably over their first two to three years after they go to sea.
4. The weight of the evidence suggests that the harvesting of immature males at current levels is not contributing to the decline in population, measured either in terms of pups born or in terms of numbers of mature bulls. It follows that discontinuance of hunting would not facilitate or accelerate the population-rebuilding process. Nor is discontinuance likely to slow down population recovery to any material extent.
5. Since the increase in juvenile mortality rate appears to be the result of extraneous causes, a reduction in that mortality rate could occur only from a modification of these causes. If the major cause lies in the natural environment – in climatic changes, for example – human intervention is not practicable, and there is little to do but hope for a beneficial natural change in the future and adopt a cautious approach to measures which might affect the recovery of the population. However, no significant relationship with any climatic factor has yet been identified.
6. There is quite persuasive evidence to support the hypothesis that the principal, but not necessarily the only, cause of the increased mortality rate of young fur seals is their entanglement in lost or discarded netting and other plastic debris. Such debris increased rapidly with the introduction of synthetic netting materials, and the proportion of seals entangled rose sharply in the mid-1970s. It has apparently stabilized in the last few years, and it is to be hoped that no further increase will occur. Conservation of fur seals, and probably of other pinnipeds, is one of many reasons to support any measures which can be taken to reduce the amount of plastic debris adrift in the oceans.
7. It is desirable that Canada work at an international level to ensure that, as quickly as possible, the Interim Convention on the Conservation of the North Pacific Fur Seals is replaced by some international arrangement to provide effective management of fur seals. Such a body is necessary to maintain the existing effective regulatory and research programs. It is particularly needed to ensure that pelagic hunting of fur seals is not resumed, since such a development could well have a disastrous effect on the fur seal populations. In the longer

term it may be useful to bring the fur seals within the ambit of any international body which may be established to exercise responsibility for the marine living resources of the north Pacific Ocean and Bering Sea as a whole.

8. In any future negotiations concerning fur seal management it will be important to provide for a commitment to expanded research on the entanglement problem and to the adoption of adequate measures to prevent the discarding at sea of netting and other plastic debris.
9. The Royal Commission considers that the objective of management of the seal herds that was defined in the preamble of the Convention is compatible with the present policy of the Canadian government and with the views of this Commission concerning the use of seals as a resource for the benefit of humankind, provided that this management is carried out with the minimum of cruelty and without endangering the survival of the fur seal populations.
10. In any future fur seal management objectives, the target level of the population should be defined not as the maximum productivity level, but as a figure somewhat above this level.

In order to provide guidance under present conditions, in which the maximum productivity level cannot be identified in numerical terms, a provision should be incorporated to the effect that no harvest be taken which would cause the net productivity of the fur seal population to decrease.

11. There would be advantages in the establishment of an international body with general responsibilities for the living resources of the Bering Sea and north Pacific Ocean. The Canadian government should take appropriate steps to support the establishment of such a body.

Sea Lions

The ranges of the two species of sea lions which inhabit the north Pacific Ocean overlap on the B.C. coast. The Steller sea lion is a northern species most abundant in Alaskan waters, and the California sea lion is most numerous off California and Mexico. Both species are common on the B.C.

coast, but only the Steller sea lion is resident. The California sea lion visits in winter when the males, but not the females, migrate north from their breeding grounds. Until about 1970, the California sea lion had been almost unknown on the Canadian coast, but since then the number of visitors has increased substantially.

For most of the information relating to the history and present status of both species on the B.C. coast, the Royal Commission is indebted to Dr. M.A. Bigg of the Department of Fisheries and Oceans Pacific Biological Station. Bigg's (1985a) study is based on the results of regular aerial surveys of the sea lion population carried out from 1971 to 1984, and on the collection and analysis of all available data on numbers of sea lions seen, and on numbers killed, from 1892 to 1984, by different individuals and organizations (Bigg, 1984). Counts of sea lions on the B.C. coast up to 1956 were previously reviewed by Pike and Maxwell (1958).

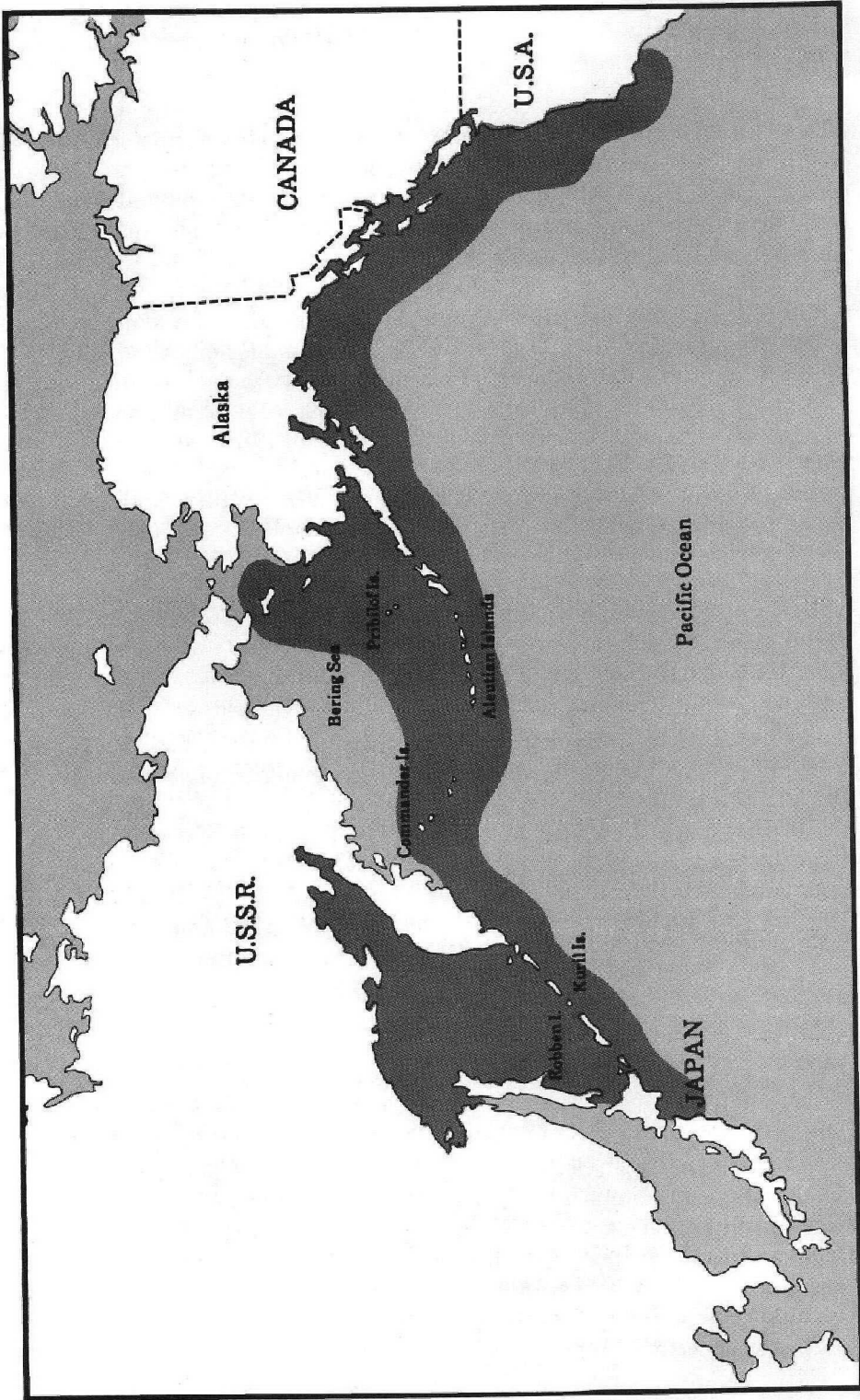
Steller Sea Lions

The range of the Steller sea lion extends over the coasts of the north Pacific, from California in the east into the Bering Sea and to the Okhotsk Sea and the Kurile Islands in the west (Figure 22.2). Loughlin et al. (1984) reviewed the available data on the size and distribution of the population. In total there are about 230,000 animals; about 25,000 are found on the Asiatic coast, about 100,000 in the Aleutian Islands and the Bering Sea, a further 100,000 in the Gulf of Alaska and southeast Alaska, and the remainder between British Columbia and California. The Canadian population makes up less than 5% of the total.

Data Base

Counting of Steller sea lions is simplified by the fact that this species comes ashore in numbers at only a few regular sites. The most important sites are the rookeries where all the breeding takes place. The population on the rookeries is at a maximum during June and July, when virtually all the births occur. Then the animals, including the pups, gradually disperse. Only a few remain in the winter. Nine rookeries on the B.C. coast are known to have been occupied for some period.

Figure 22.2
Distribution of Steller Sea Lions



Source: King (1983).

Bigg (1985a) distinguishes two other categories of hauling-out sites: year-round non-breeding sites, of which 12 were identified, and 28 sites occupied only during the winter. Attempts to estimate the sea lion population by direct counting must allow for the movements of animals among the different sites. Estimating local movements is further complicated by evidence that during the winter male Steller sea lions, like the California, migrate to B.C. waters from more southerly rookeries in California and Oregon, and may also migrate north from B.C. into Alaskan waters in summer. It is probable, too, that sea lions disperse into B.C. waters in winter from a very large rookery on Forrester Island just across the border in Alaska.

Although a great deal of data has been accumulated on the numbers of animals on the rookeries and other hauling-out sites, particularly from 1971 to 1984, these counts always underestimate the population. At any given time, some animals will be at sea and others ashore at sites outside British Columbia, or at sites frequented by only a few animals and not included in the survey. However, the counts, when critically examined, are believed to be sufficiently related to the actual population size to give a good measure of changes in population size over time. The best relative index of breeding population size is probably the number of pups counted, since these are virtually all produced on the rookeries. Few pup counts, however, were made early in the century, when most counts were of the total population. Counts made about mid-July are most complete because all pups have been born, and few animals have yet dispersed from the rookeries. Bigg (1985a) has developed a method of adjusting counts made earlier in the summer to allow for the pups not yet born. The adjusted early season counts appear to be acceptable estimates of total pup production.

Numbers Killed

The number of Steller sea lions on the B.C. coast appears to have fluctuated substantially since the early 1800s. Bigg (1985a) believes that during much of the 19th century, sea lion numbers were kept to a reduced level by Indians hunting for meat, hides, oil and other products. By the end of the century there were fewer Indians, and they were probably less dependent on sea lions for subsistence, with the result that fewer sea lions were killed, and their numbers began to increase. Bigg cites Newcombe et al. (1918) as stating that fishermen believed that sea lions were more abundant in 1913 than in the early days of the salmon fishery, that is, in the late 1800s.

This apparent increase led to organized hunting in 1912 and 1913, when about 7,400 sea lions were killed. After these episodes the sea lions were apparently left in peace until 1922. From 1922 until the beginning of the Second World War in 1939, sea lions were officially hunted quite vigorously; about 30,000 animals were reportedly killed, and the group of rookeries which was chiefly attacked was virtually eliminated (Bigg, 1984, 1985a). For the next 20 years the numbers of sea lions killed in official hunts were small (a few hundred per year), except in 1950, when about 2,000 animals were killed. Bigg believes that "substantial" although uncounted kills were made by the navy and air force during the Second World War in efforts to help the fishermen.

"Management" hunting under government control was resumed in 1958, and in the following year 3,388 kills were recorded. Hunting gradually tapered off after that year and finally ceased after 1968. The number of kills officially recorded during this period was about 11,000. Fisheries officials consider the number of kills reported an overestimate (Bigg, 1984, 1985a). Unlike the practice in commercial and research operations, kills were not always confirmed by recovering the carcasses; it is likely that many animals reported killed were missed or only wounded.

Relatively few sea lions have been taken in commercial hunts on the B.C. coast for their skins and meat as compared to those killed for management purposes. A few hundred animals were taken from 1913 to 1915 and from 1936 to 1939, but the principal commercial hunt took place between 1955 and 1966, when nearly 7,000 sea lions were killed. Animals killed for research purposes have totalled fewer than 700, and most of these were taken between 1958 and 1961. Fishermen have killed some sea lions throughout the whole period, but no estimate of the numbers exists. Table 22.1 lists the various kills, omitting the periods when few animals were taken.

Population Estimates

Between 1913 and 1916, several counts were made on most of the major rookeries, and the total number of Steller sea lions inhabiting them at that time was probably 11,000–14,000 (Bigg, 1985a; Pike and Maxwell, 1958). No further counts were made until 1938. By that time the population had been subject to kills of about 7,400 animals in 1912–1915, and 17,000 in 1922–1935, and the more intense killing of 1936–1939 was still in progress. Most hunting was concentrated on particular rookeries at any one time, and

Table 22.1
Major Kills of Steller Sea Lions on the B.C. Coast, 1912–1968

	Management	Commercial	Research	Average Total Per Year
1912–15	7,400	500	–	2,000
1922–35	17,000	–	–	1,200
1936–39	11,000	–	–	2,700
1940–45 ^a	–	–	–	substantial
1950	2,000	–	–	2,000
1958–68	11,000	7,000	700	1,700

Source: Adapted from Bigg (1984, 1985a).

a. Substantial but undocumented kills by the armed forces.

consequently, effects were somewhat localized. From 1922 to 1935, hunting was concentrated on two rookeries in the Sea Otter Group of islands at about the centre of the B.C. mainland coast. By the end of the 1930s, these breeding colonies had been destroyed, although the sites are still occupied as non-breeding haul-out sites.

The intensive hunting which began in 1936 was concentrated on the offshore Scott Islands, to the north of Vancouver Island. The numbers of Steller sea lions on these rookeries had apparently been increasing between 1915 and 1936, but were reduced by the hunting carried out from 1936 to 1939. By 1938, the overall population on the rookeries seems likely to have been about the same as in 1913, that is, about 12,000 animals, although the numbers declined seriously on the Sea Otter Group (Bigg, 1985a).

There were further recorded kills in 1939 and 1950, as well as the uncounted kills conducted by the armed forces. The next counts were made in 1955 and 1956, and by that time the estimated numbers on the rookeries had dropped to 9,000–11,000. The rookeries on the Sea Otter Group had vanished, but there was a compensating new rookery on Sartine Island in the Scott Islands and an apparent increase in numbers at Cape St. James on the Queen Charlotte Islands. It has been suggested that the Sartine Island rookery was established by animals that hunting had driven off the other

rookeries, such as those on the Sea Otter Group. Heavy hunting occurred from 1958 to 1968, and by the time of the next counts, in 1961 and 1971, the estimated total numbers of Steller sea lions on the rookeries were reduced to about 4,600 and 3,500 respectively.

After hunting stopped in 1968, an increase in the size of the sea lion population might have been expected. No such increase appears to have taken place. Bigg's (1985a) count in 1982 recorded only 3,970 animals on rookeries.

On the counts of pups over this period Bigg (1985a) comments:

A comparison of pup production in British Columbia between 1971 and 1982 suggests that an increase in breeding stock may have occurred between 1977 and 1982 following stable pup production in 1971-77. However, no increase in postpups was recorded between 1977 and 1982 which suggests that the increase in pup numbers in 1982 may not be indicative of a true increase in breeding stock size. It is possible that pup survival in 1982 was better than usual.

The principal counts of animals on the rookeries reported by Bigg (1985a) are summarized in Table 22.2.

If we use the pup counts as the best index of population size, then the relative size of the 1977-1982 population compared to that of 1956 is 1200/3250, representing a decrease to about 37%. The estimate of the total population in 1956 is 9,400 as compared with 11,000-14,000 in 1913, or a decrease to about 67% to 85%. If we ignore any changes in the proportion of pups to the total population between 1913 and 1956, these figures imply that the 1977-1982 population was about 25%-31% of the population in 1913.

The 1956 and 1971-1982 counts recorded the number of pups as about one-third of the total animals seen, but as noted earlier, counts on the rookeries underestimate the total population. Calkins and Pitcher (1982) have used available data on the age composition of the population, age at maturity, pregnancy rate and sex ratio, to draw up life tables for Steller sea lions. These tables can be used to estimate the ratio of pups to total population in an ideal situation. They indicate a total population of about 4.5 animals of both sexes and all ages (including pups) for each pup produced.

Table 22.2
Counts of Steller Sea Lions, British Columbia and Forrester Island,
1913-1982

	Total Steller Sea Lions			Pups	
	B.C.	Forrester Island	Forrester Island + B.C.	B.C.	Forrester Island
1913	11-14,000 ^a	50-100	11-14,000	-	-
1938	12,000	-	-	-	-
1956	9,400	-	-	3,250	-
1961	4,600	2,400	7,000	2,000	1,100
1971-73	3,500	6,200	9,700	1,050	2,400
1977-82	4,000	5,500	9,500	1,200	-

Source: Bigg (1985a).

a. For rookeries and non-breeding sites.

The tables are based on a very small number of animals so that the estimates of mortality rates used contain large sampling errors. The estimates are very sensitive to assumptions about the variation of the mortality rate with age and to the method used to fit the survival curve to the data. Furthermore, the basic data were obtained from sea lions in the Gulf of Alaska. It does not seem likely that any significant errors will arise from this cause; the distances involved are not great, and some migration between Alaskan and B.C. waters is known to occur.

Examination of the original data kindly provided by Calkins and Pitcher suggests that the likely range of the ratio of total population to pups is 4.0 to 5.5. Thus the decrease in pups counted from 3,250 in 1956 to 1,200 in 1982 corresponds to a change in total population from about 13,000-17,800 to 4,800-6,600.

The Current Situation

Between 1913 and the late 1960s, the number of Steller sea lions breeding on the rookeries on the coast of British Columbia declined to about

one-quarter of the 1913 level. This decline was the result of an erratic series of government-sponsored kills undertaken to benefit the fishing industry. Since protection was applied in 1969, however, the rebuilding of the B.C. rookeries which might have been expected has failed to materialize. The causes of this failure are of particular importance to any attempt to assess the future of the Steller sea lion population on the B.C. coast.

Under present regulations, fishermen may kill sea lions if these animals are actively interfering in fishing operations. The regulations permit the individual fisherman to exercise considerable discretion. The Royal Commission does not know how many sea lions are killed under this dispensation, but the numbers killed are probably too few to be the main cause of the failure of the population to rebuild since protection was established. It seems desirable to require fishermen to provide a record of the number of sea lions they kill to the Department of Fisheries and Oceans.

The first point to be considered is the degree of change there has been in the total number of Steller sea lions frequenting, and using the food resources of, the B.C. coast. It is likely that this number, as distinct from the number breeding, has increased because of the growth, during the 1950s and 1960s, of the very large rookery on Forrester Island, just across the Alaskan border. Some of the animals from this rookery feed in B.C. waters, thus competing with the animals from Canadian rookeries. As Table 22.2 shows, the combined total for B.C. and Forrester Island rookeries increased by the 1970s, and may now be not very much less than the 1913 level.

Secondly, the California sea lion population visiting the southern coast of British Columbia has increased substantially since 1965 and may have influenced the Steller sea lion population through competition. There are a number of reasons for thinking that any such effect would be of minor significance:

- Most of the increase in California sea lions on the B.C. coast has occurred since 1980.
- The spread of California sea lions has been largely limited to the southern part of the B.C. coast.
- The California sea lions are only present on the B.C. coast for about half the year (Bigg, 1985a).
- The biomass of California sea lions in B.C. waters is small compared to that of Steller sea lions. The average weight of Steller sea lions is about

180 kilograms on the basis of weight-at-age data in Calkins and Pitcher (1982) and on age-distribution data provided by Pitcher (1985). Taking the central estimates of the total populations in 1956 and 1982 as 15,400 and 5,700 animals respectively, the biomass estimates are 2,772 and 1,026 tonnes. The most recent estimate is that 4,500 California sea lions are present for less than half the year. Allowing for the fact that only males visit British Columbia, the mean individual weight is about 180 kilograms (Mate, 1985), which is equivalent to an average biomass over the whole year of about 400 tonnes. This is small compared to the decline, since 1956, of about 1,750 tonnes in the biomass of the Steller sea lion population based on the B.C. rookeries.

No evidence has been found, as discussed in Chapter 23, that the carrying capacity of B.C. waters for sea lions has decreased as a result of reduction in the food supply. The principal food of Steller sea lions in this area is octopus, which is not subject to any commercial fishery, and there is no reason to believe that the numbers of sea lions have declined from any other cause. The main commercial species preyed on by sea lions (Chapter 24) are the Pacific herring and the various kinds of salmon. The herring declined temporarily between 1965 and 1970, but have since recovered, and populations have been generally at or above the 1951-1965 levels (Haist et al., 1985). A decline in the number of herring off southern British Columbia since 1980 is too recent to contribute to the post-1969 continuation of the low sea lion population. There is no reason to believe that there has been any reduction in the availability of salmon that would have a limiting effect on sea lions. Nor is there any good evidence of serious disease or pathological effects of pollution on Steller sea lions. In fact, there are more reported occurrences of this kind affecting the California sea lion off California, despite which that population continues to increase.

Another possible cause of recent mortalities has been noted in the discussion of the status of the northern fur seal. Entanglement in lost or discarded netting and other plastic debris is apparently contributing to a failure of the Pribilof Islands' fur seal population to rebuild as expected. There are also indications of adverse effects from the same cause on the Hawaiian monk seal. Bigg (1985a) reports seeing Steller sea lions with plastic debris around their necks, and the possibility of adverse effects on B.C. sea lions cannot be ignored. Reports do not suggest, however, that entanglement of sea lions occurs with sufficient frequency to make this possibility a strong hypothesis.

Comparison with adjacent areas presents a rather confusing picture. The Forrester Island rookery in southern Alaska has increased greatly since

the 1950s, although the 1983 count was slightly, perhaps not significantly, less than that of 1973 (Bigg, 1985a). In the central Aleutian Islands, on the other hand, Steller sea lions have been decreasing since 1960 at a rate of about 6% per year (Loughlin et al., 1984; Loughlin, 1984). Further west on the Aleutian chain, however, their numbers appear to be increasing.

No satisfactory explanation of the decline of Steller sea lions in the central Aleutians has been found. Some degree of population redistribution may be taking place. Braham et al. (1980) speculate that causes of the Aleutian decline may include a pathogen, the commercial harvesting of pups between 1970 and 1972, and interactions with commercial fishing activities.

The public impression of an increase in sea lions on the B.C. coast in recent years, despite the virtual stability of the Steller population, has arisen from the increase in the numbers of California sea lions and from a real increase in the numbers of Steller sea lions wintering in the waters off southeastern Vancouver Island, an area where the animals are much exposed to the public view. Since 1972, a number of new winter haul-out sites have been established in this region, and the numbers of sea lions counted on them in the month of February rose from 71 in 1972 to a peak of 983 in 1982; in 1984, the number had fallen to 328. This increase is the result of a shift in the distribution of wintering animals and not of any real increase in the population. Bigg (1985a) considers two possible explanations. One is an increase in food supply following the recovery of the herring stock after the crash in the numbers of that species in the 1960s. This view is supported by the fact that numbers of sea lions on some haul-out sites have declined again, between 1982 and 1984, coincident with a sharp decrease in the abundance of herring in this area (Haist et al., 1985). Bigg (1985a) states, "An alternative explanation . . . may be that the control programs kept many animals away up to the late 1960s. The species was frequently hunted in this populated region." It does not seem possible at this stage to determine to what extent either or both of these possible causes contributed to the increase in winter numbers of sea lions in this area.

Conclusions

1. The number of Steller sea lions occupying Canadian rookeries declined from 11,000–14,000 in 1913, when it was near its maximum, to about 4,500 in the early 1960s. The drop was a result of extensive hunting undertaken mainly for the purpose of "managing" the stock

for the benefit of the fisheries. The total Canadian population has declined from about 13,000–18,000 in 1956, to about 4,800–6,600 in 1985.

2. Since the cessation of hunting in 1969, the expected recovery in the breeding population of Steller sea lions has not taken place. The population remains at about 25%–30% of the 1913 level. A system should be introduced to require that records be kept by fishermen of their kills of sea lions that are interfering with fishing operations.
3. A very large rookery has developed on Forrester Island, just across the Alaskan border. If this rookery is taken into account, the combined B.C.–Forrester Island population is now similar to, or a little less than, the 1913 B.C. population.
4. It seems most likely that it is the large increase in the numbers of Steller sea lions breeding on Forrester Island that has, by increasing consumption of the available food supply, prevented recovery of the numbers breeding on B.C. rookeries since 1969.
5. It does not seem likely that the northward expansion of California sea lions as winter visitors to B.C. waters has had a major effect on the Steller sea lion population.
6. There is no evidence that decline in food supply, caused, for example, by commercial fishing, has limited recovery of the population breeding on B.C. rookeries.
7. There is no evidence that disease or pollution has adversely affected the B.C. population of sea lions.
8. There is evidence that some Steller sea lions are becoming entangled in discarded or lost netting and other plastic debris, but it is not enough to indicate whether entanglement is causing mortalities on a sufficient scale to limit population as it apparently does for northern fur seals.
9. The apparent increase in the numbers of sea lions in B.C. waters, which has attracted much public attention, is partly the result of the spread northwards of California sea lions as winter visitors and partly of a redistribution of Steller sea lions southwards in winter. Both have moved into waters more frequented by people, that is, Georgia

Strait and around southern Vancouver Island. This redistribution may be a response to an increase in the abundance of herring in the area.

10. It seems likely that the Steller sea lion population in the region of British Columbia and the southern tip of Alaska is close to the area's carrying capacity. If so, further expansion (say, by more than 25%-50%) seems unlikely in the near future.

California Sea Lions

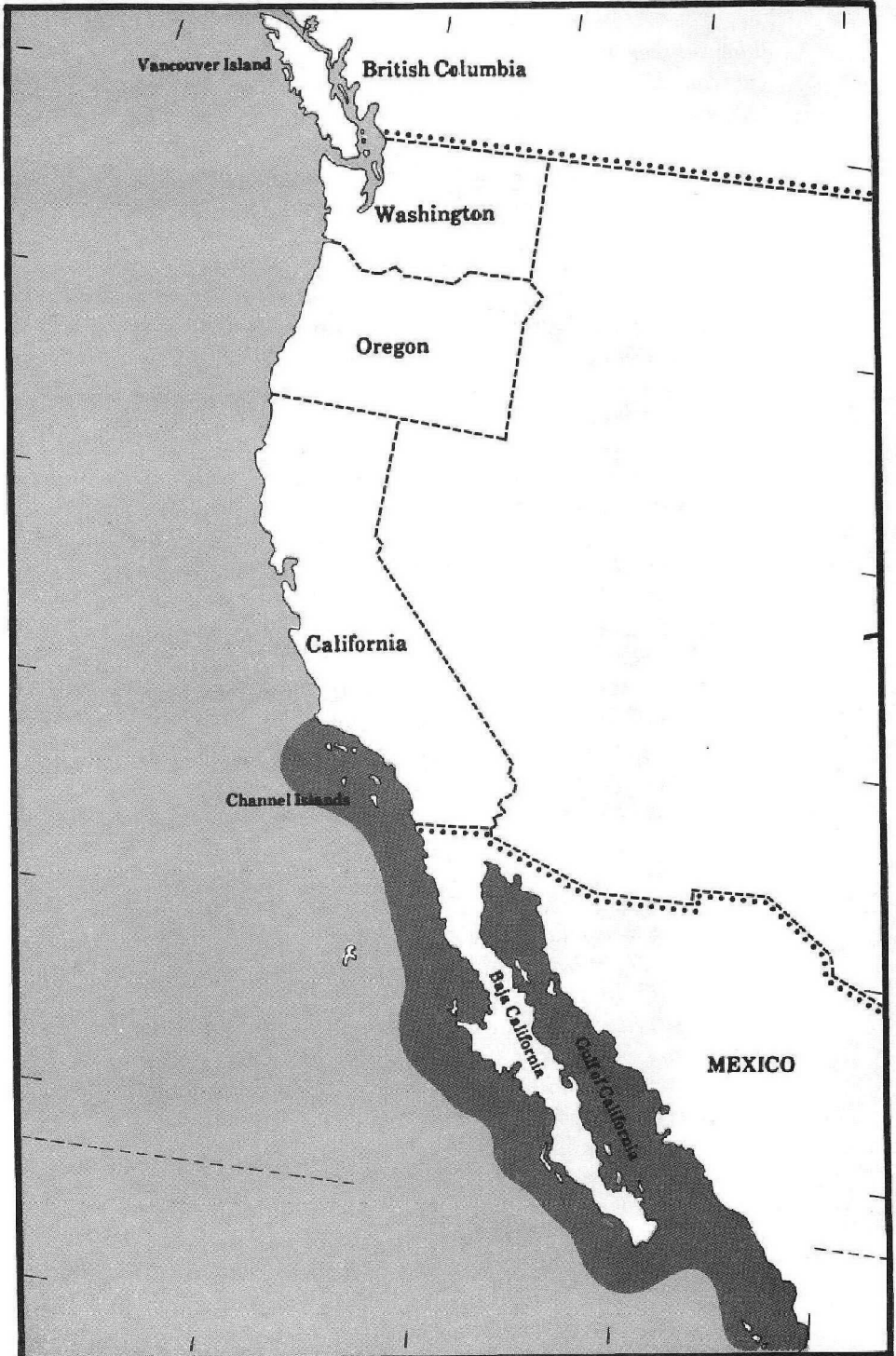
The Current Situation

The history of the California sea lion on the coast of British Columbia is very different from that of the Steller sea lion. While there are a few isolated records of the former species' appearance during the 1800s and early 1900s, it does not seem to have been seen regularly until about 1965, when a small haul-out site was established on Race Rocks in Juan de Fuca Strait. Especially since 1980, the numbers of California sea lions have increased, and by 1984, about 4,500 of these animals were counted in aerial surveys (Bigg, 1985a). Distribution is concentrated at the southern third of Vancouver Island, although there is one regularly occupied site as far north as Solander Island on the west coast. California sea lions seem to have increased sharply in numbers between 1982 and 1984, while the number of Steller sea lions wintering round southeastern Vancouver Island declined during this period.

The appearance of California sea lions in recent years is not, however, an extension of the breeding range of the species, which continues to be limited to California and Mexico (Figure 22.3). The animals in B.C. waters are all males that migrate northward after the breeding season. Most of these animals arrive between October and December, and they have nearly all gone by May; in a local movement, a number of animals have been recorded entering the Fraser River in early May in pursuit of spawning eulachon.

Bigg (1985a) has reviewed the background of this increase in the California sea lion in the waters off British Columbia, as follows.

Figure 22.3
Breeding Range of California Sea Lions



Source: King (1983).

The Status of Stocks of Pacific Seals

The number of California sea lions off Vancouver Island increased 10-fold between 1972 and 1984, with most of the increase apparently taking place since 1980. The species did not increase the northern range in association with the sharp increase in numbers since the late 1970's. None was seen during an aerial survey for Steller sea lions around northern Vancouver Island, from Denman Island to Solander Island, during 7 March 1984. Presumably, not all individuals present off Vancouver Island were counted. Some may have been at sea feeding or swimming between sites. The censuses hence provided an estimate of minimum numbers, and annual trends.

An increase in the number of California sea lions off Vancouver Island was expected over the past 50 years, because the breeding population off California has grown steadily. Only about 400-1,000 California sea lions were seen off southern California during the early 1930s, following severe depletion for commercial purposes (Bonnot 1928; Barthomolew and Boolootian 1960). Thus, few animals could have migrated into southern British Columbia early in this century. By 1975, the population off southern California had increased to at least 27,000 (Mate 1977), and since then has continued to increase at a rate of about 5%/yr (DeMaster et al. 1982).

The increase observed off Vancouver Island during the 1980's was much larger than the annual rate of increment for the breeding population off California. Hence, a sudden shift to a more northern migration appears to have occurred in the southern population. One possible explanation is that the population in wintering areas south of British Columbia grew past a critical level of crowding or competition for food and as a result suddenly some males shifted their winter distribution northward. DeMaster et al. (1982) suggested growth of the breeding stock may be slowing due to density dependent factors. Perhaps in approaching maximal numbers, the population expanded the use of the northern range. If this explanation is correct, then the size of the population

in British Columbia can be expected to remain large, or perhaps continue to increase in the future if the breeding population off California continues to increase in size. Another possibility is that recent increases in coastal water temperatures encouraged the species to move more northward. Bartholomew (1967) suggested that the northern limit of the breeding range of the species was restricted to southern California by warmwater distribution. In 1982-83, the El Niño current caused a more northerly flow of warm water from tropical areas to the coast of British Columbia (Tabata 1984). A longer warming trend also took place along coastal waters of British Columbia between about 1972 and 1981 (Dodimead 1984). Temperature could influence the winter distribution of California sea lions through changes in food supply, or changes in the metabolic costs of thermoregulation. If increased water temperatures caused the numbers of this species to increase in British Columbia, then numbers should decrease over the next few years. El Niño is now diminishing, and a decreasing trend in the long-term temperature of coastal waters is expected.

It is thus not possible to forecast whether the large numbers of California sea lions off British Columbia will be maintained, increase or even decrease. If the increase in their numbers has been the result of temperature effects, a decrease in the near future is likely as the El Niño current dies away and the present trend reverses. If, however, the additional animals have been pushed northward by the expansion of the breeding population in California and Mexico, the numbers are likely to stabilize or possibly even to increase.

If for any reason, however, it becomes desirable to reduce the numbers of California sea lions in B.C. waters, attempts to do so by hunting would be less likely to be effective than they have been in the past for the Steller sea lion. It has been possible to reduce or even destroy breeding colonies of the latter animals by killing the breeding females. For California sea lions, only a part (perhaps 20%) of the male, and none of the female, population would be exposed to hunting here. It is impossible to be sure what the effect on overall pup production would be of removing a proportion of the males and no females, but it is unlikely to be great.

Conclusions

1. Male California sea lions have become conspicuous winter visitors to the southern B.C. coast in the last few years; up to about 4,500 have been counted.
2. It is likely that the expansion of the main breeding population off California and Mexico is the main cause of their abundance off British Columbia, but climatic conditions, including the recent El Niño phenomenon, may have contributed.
3. Since California sea lions do not breed in Canada, and only a small proportion of the male population visits B.C. waters, no actions taken in Canada are likely to have significant effect on the numbers of visitors, except possibly on a localized basis and within the season in which action is taken.

Harbour Seals

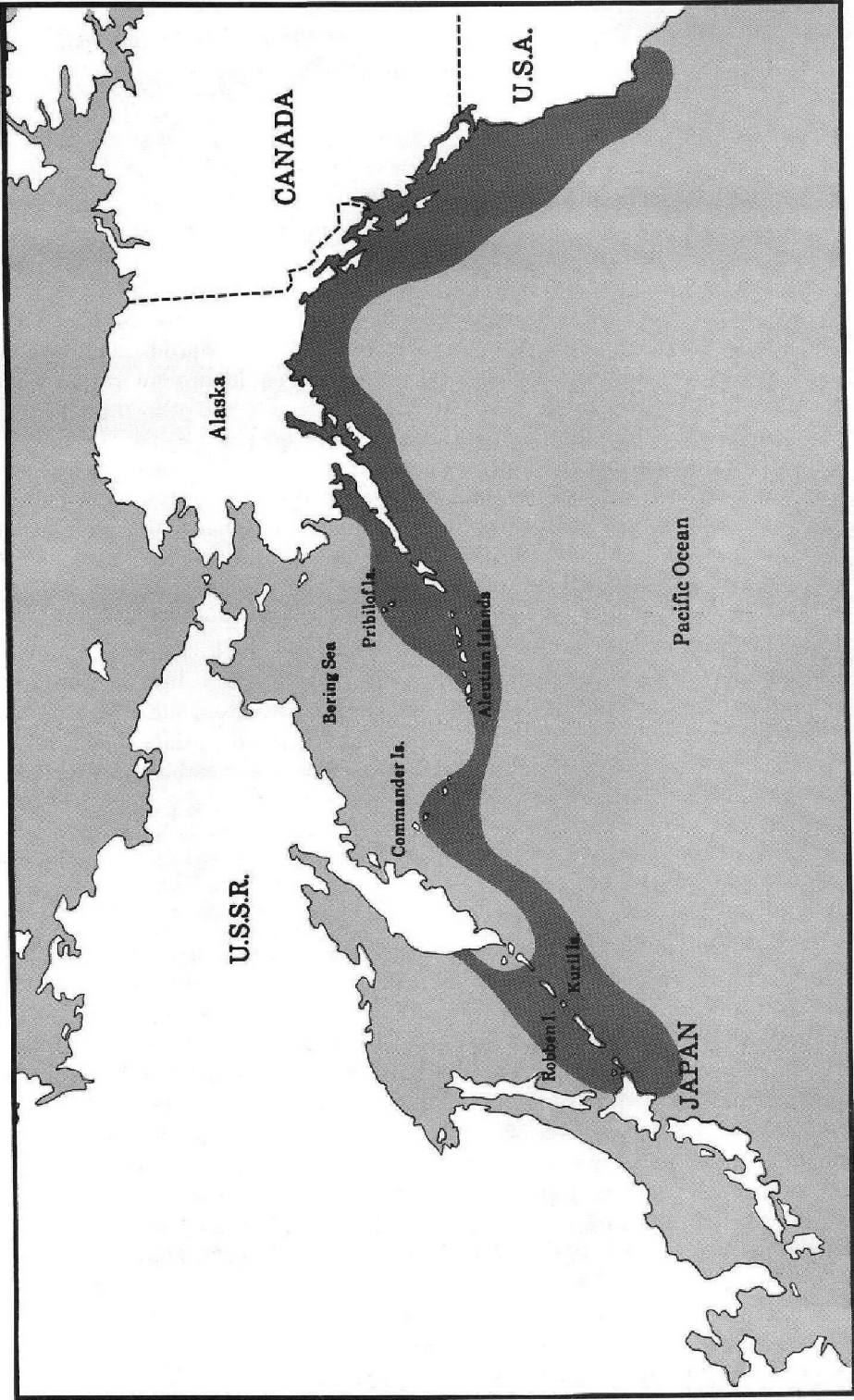
The harbour seal is widely distributed throughout the temperate regions of the Northern Hemisphere. (See also Chapter 21.) It is essentially a coastal animal rarely found more than 15 kilometres from land (Fisher, 1952). It does enter fresh water, particularly when following migrating fish such as salmon, and groups may become established in rivers and lakes as far as 300 kilometres from salt water (Fisher, 1952).

Exploitation

Bonner (1979) has assembled published information on the numbers of harbour seals recorded in the various ocean areas. These seals total about 380,000–400,000 animals excluding those in the Baltic Sea, Greenland, the eastern United States, and the Asiatic coast of the Pacific Ocean. On the eastern Pacific coast, harbour seals extend from northern Alaska to Baja California (Figure 22.4). The greatest number (260,000) are to be found in Alaska (Bonner, 1979), but these seals are numerous as far south as Oregon.

On the B.C. coast, harbour seals have fluctuated in numbers, probably as a result of varying levels of killing by fishermen and hunters. Fishermen anxious to protect their gear and catches of fish have probably been

Figure 22.4
Distribution of Harbour Seals in the North Pacific



Source: King (1983).

killing some harbour seals since the early days of European settlement. No useful data are available concerning the number of seals killed in this way. From 1914 to 1918, 1928 to 1934, 1936 to 1940 and 1941 to 1964, the Canadian government operated a bounty scheme in response to demands made by the fishermen. Bounties claimed each year from 1928 to 1964 have ranged between 2,000 and 6,000 and averaged just over 3,000 (Bigg, 1969). Bigg estimated from experience and on the basis of conversations with hunters and DFO officers that an equal number of seals were killed for which no bounties were claimed, either because they could not be retrieved or because no effort was made to obtain the bounty. On the other hand, Fisher (1952) observed that some bounties may have been fraudulently claimed, either by substituting sea lion noses (on which no bounty was paid) or by importing noses from areas in the United States where no bounty, or smaller bounties, were paid. Such cases were probably few, however, compared to the numbers of harbour seals killed without the payment of bounties.

From 1964 to 1969, there was also a commercial hunt for harbour seals on the coast of British Columbia to take pelts for the European market. The numbers of pelts taken are not known with certainty, but they probably amounted to about 10,000 (Bigg, 1985a). Large kills were made in 1964 and 1965; after these years the number of kills declined rapidly, because of a decline in the markets. Since 1970, the harbour seal has been protected on the west coast of Canada.

Population Estimates

Harbour seals can be counted by aerial surveys because they habitually haul out on reefs and inter-tidal sandbars at low tide. Difficulties in basing absolute population estimates on such counts are the result of uncertainties about the proportion of animals hauled out in a given area at the time the count is made. A number of experiments have aimed at obtaining data on this point through observing radio-tagged animals. Pitcher and McAllister (1981) observed 35 animals in Alaska over a period of several months. They found that the proportion of the days on which a seal hauled out varied for different groups of animals from 16% to 80%, and they concluded that the "average number of seals hauled out . . . probably represented between about 35% and 60% of the population." They found these figures consistent with other researchers' observations. Harvey (1984) found that radio-tagged animals in Oregon were visible only 9% of the time. He considers this low figure a consequence of the small size of the sample and believes that in general counts would represent about half of the animals

present (Harvey, 1985). It seems that there are great differences in the proportions of harbour seal populations hauled out, both from time to time and in different areas. It is not appropriate, therefore, to apply any single standard figure in calculating population estimates from direct counts. Bigg (1985b) considers that around southeastern Vancouver Island, where there are a great many haul-out sites, most of the animals will be seen, but that in the long steep-sided inlets of the mainland coast, there are few haul-out sites and consequently few seals will be seen hauled out, although they may be observed in the water.

Bigg (1985b) stated that substantial data have been gathered by the Pacific Biological Station on counts of harbour seals on the B.C. coast. These data relate to two areas, one off southeastern Vancouver Island and the other off the Skeena River on the northern B.C. coast. For southeastern Vancouver Island, Bigg estimates that about 2,000 seals of all ages were hauled out by the end of the pupping season in 1973, and that by 1983, numbers had increased to 6,300. These estimates were derived from taking a composite of regions within the study area, as well as a combination of years, and by giving consideration to abundance trends. As mentioned above, Bigg believes that in this area, under the conditions of the study, almost all the seals would have hauled out so that the numbers actually present would not greatly exceed the numbers counted. The 1983 population could be as high as 7,500.

Off the Skeena River, the counts of harbour seals of all ages totalled 400 near the end of the pupping season in 1977; they totalled 660 in 1983. It does not seem possible to use these figures to obtain useful estimates of the true population size in the study area, but the figures do indicate the relative change in the numbers of harbour seals between 1977 and 1983. Bigg (1985b) provided an estimate of the total B.C. population of these animals, based on the southeastern Vancouver Island counts. In so doing he used the following reasoning:

At least 6,300 animals were seen here in 1983. Let's assume that the density of seals here was the same in other areas of British Columbia, which is a possibility. Based on having flown over much of the coast of British Columbia many times, and hunted or observed seals in many areas, I don't think that density, if it varies, is greater in other areas. Additional support for this possibility comes from a comparison between areas of kills

per distance of coast-line. Fisher (1952, p. 50) indicated that during 1942-1947 about 15% of the total kills in British Columbia came from southeastern Vancouver Island. This figure is about the same proportion that the coastal distance around southeastern Vancouver Island is of the total coast-line of British Columbia. Thus, using the multiplier, a total current population of about 42,000 is suggested.

He points out, too, that if the number of harbour seals in this study area was actually 7,500, the total population estimate would rise to about 50,000. Similar reasoning would provide an estimate of the total B.C. harbour seal population of 13,300-16,000 animals in 1973.

Several other more indirect methods of obtaining estimates of the B.C. harbour seal population have been used. The earliest attempt to establish an estimate was made by Spalding (1964). On a rough assumption of an average of one harbour seal per mile of coastline, he estimated a population of 17,000 seals. He also quotes some professional bounty hunters as estimating the harbour seal population at 20,000.

Bigg (1969) used another method to estimate the harbour seal population. This method was based on the assumption that over the 50-year period (1914-1964) when a bounty kill was taken, the seal population reached and maintained stability. This assumption is reasonable, since the age and fecundity structure of the population is such that generation time (mean age of female when a pup is born) is about 8.5 years (Bigg, 1969), so that five or six generations elapsed during the period in question, and the number of animals killed annually did not vary greatly. If it is further assumed that the number of unrecorded kills and the annual natural mortality of the harbour seals were each equal to the bounty kill, the total number of deaths would be about 9,000 a year. Using the data on the proportion of females that are mature (55%), the proportion of mature females that are pregnant (88%), and the proportion of females in the total population (53%), Bigg calculated that the population would have comprised about 3.9 animals for each pup born. Since the number of deaths and the number of pups born would be equal, this figure corresponds to a total population of about 35,000 harbour seals during the stable period of roughly the late 1950s and the early 1960s.

These figures correspond to a total instantaneous mortality rate (Z in standard fisheries science notation) of about 0.3. Since it is assumed that

natural deaths cause one-third of the mortality, the corresponding instantaneous natural mortality rate (M) would be 0.1. This is virtually the same value as that obtained by Pitcher and Calkins (1979) for male and female harbour seals in samples in which the animals' ages were determined when they were taken in Alaska. It is also the same as the central value identified in Chapter 21 for the harp seal, which has been more extensively studied. The two species are similar in size, although the harbour seal is slightly smaller, and the average weight of adult west coast harbour seals is about 70% of that of the average harp seal. Since there is a general tendency in marine animals (Ohsumi, 1979, for cetaceans; Pauly, 1980, for fish) for natural mortality rates to increase as the average size decreases, one might expect the harbour seal to have a slightly higher mortality rate than the harp seal. This difference would probably be small compared to the degree of uncertainty in the estimates of the mortality rate for harp seals. The assumptions used to determine this estimated mortality rate are thus reasonably consistent with what is known of the more extensively studied harp seal.

Another estimate of the size of the harbour seal population is based on observations of the rate of population increase after bounty and commercial hunting were discontinued at the end of the 1960s. The figures cited above show an average annual rate of increase of 12% off southeastern Vancouver Island between 1973 and 1983, and a corresponding rate of 9% off the Skeena River between 1977 and 1983. These increases reflect the survival of animals that would previously have been killed. The number of bounties paid (3,000 a year) underestimates this number, but the total number of animals believed killed by hunters and fishermen (6,000 a year) would probably represent an overestimate of the increase in survival, since some killing probably still occurs despite legal protection. On this basis, assuming an average annual rate of increase of 10%, the population size in the stable period before protection began in 1969 would amount to 30,000–60,000 harbour seals. The estimate of 42,000 given above, which was based on different data, falls in the middle of this range and thus is not inconsistent with it.

Population Trends

The population estimates reported in the preceding section are summarized in Table 22.3. Allowing for the tenuous basis of the Spalding estimate, there is no great discrepancy among the three figures relating roughly to 1960. It is difficult, however, to reconcile these figures with the 1973 and

Table 22.3
Harbour Seal Population Estimates, 1960–1983.

Year	Estimate (1000s)	Method	Source
c. 1960	17–20	Average number/mile	Spalding (1964)
c. 1960	35	Recorded deaths and population structure	Bigg (1969)
1960s	30–60	Recorded deaths and rate of increase	Present Report
1973	13–16	Extrapolation from 1973 count	Present Report
1983	42–50	Extrapolation from 1983 count	Bigg (1985b)

1983 estimates. The latter indicate a rate of population increase of about 10% between 1973 and 1983, and at first sight it is reasonable to extrapolate this back to 1969, when the species came under protection. If this is done, the 1960 estimates are too high compared with those for 1973 and 1983.

The greatest uncertainty in the derivation of the second and third estimates for 1960 lies in the number of harbour seals killed; the other main components – the population structure and the rate of population increase after hunting was discontinued – are both based on fairly direct observations. Bigg's (1969) estimate of the total hunting kill is twice the number of bounties claimed. A minimum estimate of the kill would be the 3,000 bounties paid. Using this figure would reduce the population estimate to 23,400. For the third 1960 estimate, the corresponding figure is 30,000, as shown in Table 22.3. Since this adjustment does not entirely remove the discrepancy, we must consider the level of uncertainty in the rate of increase in the population. The independent estimates for the rates of increase of the Vancouver Island and Skeena River segments of the harbour seal population are not very different; nor are they inconsistent with estimates for other seal

populations. For example, estimates of natural rates of increase for northern fur seals of about 8% and for northern elephant seals of about 10%, are reported elsewhere in this chapter. The estimate of the annual rate of increase thus seems likely to be subject to relatively smaller uncertainties than is the estimate of numbers killed prior to protection.

There are also uncertainties relating to the period over which the increase has operated. A proportional change of population size by a factor of 3.15 was observed off southeastern Vancouver Island between 1973 and 1983. For the Skeena River area, the corresponding factor was 1.65 between 1977 and 1983; this factor, if projected, would be equivalent to 2.3 between 1973 and 1983.

Assuming that these figures are approximately correct, we can only speculate concerning the reasons for the discrepancy when comparisons are made with the 1960 population estimates. Possible contributing factors include:

- errors in the population estimates, particularly for 1960;
- a population decline, possibly by a factor of about 2, between 1960 and the discontinuance of hunting in 1969;
- a lag in the commencement of population expansion after 1969;
- changes over time in the ratio of the harbour seal population of southeastern Vancouver Island to the total B.C. population.

Considering the various uncertainties, any statement about past and present populations of harbour seals on the B.C. coast should be limited to the following:

- in the 1960s the population probably consisted of 20,000 to 30,000 animals;
- the current population probably stands at 45,000 to 60,000 animals.

Whether or not harbour seals are currently increasing at about 10% per annum, they cannot continue to do so indefinitely even in the absence of hunting. If information had been available on the numbers of harbour seals in the early days of European settlement before serious hunting began, or before the bounty scheme was started in 1914, it might have been possible to

use those figures to estimate the potential expansion of the population in the absence of hunting or other adverse effects. Unfortunately, no such data are available.

Future Prospects

Natural factors which could influence the equilibrium level include changes in numbers of predators, in incidence of disease, and in climatic conditions. No evidence has been adduced suggesting that any of these changes have occurred on a significant scale.

There are also at least three ways in which human activities could adversely affect the harbour seal population. The rate at which that population has been increasing, at least during the 1970s, suggests that none of these factors caused by human activities has had any major effect as yet.

The first possible factor is the influence of fishing on the food supply of the seals. Harbour seals, however, are opportunistic feeders, able to change to other foods as particular prey species become scarce; moreover, about half their food on the B.C. coast consists of animals of little commercial importance. The two main commercial groups on which the harbour seals feed are salmon and herring. There is no indication that there has been any significant decrease in the overall abundance of salmon since the end of the 1960s (Archibald and Graham, 1981), when harbour seals increased rapidly. Herring have generally been as abundant since 1970 as they were prior to a temporary decline which occurred in the late 1960s, in part, at least, as a result of over-fishing (Haist et al., 1985).

Secondly, there is reason to suppose that northern fur seals have been seriously affected by entanglement in discarded fishing nets and other plastic debris. It is also possible that sea lions have been affected in the same way, although to a lesser extent. There are few records, however, of harbour seals becoming caught in such debris, perhaps because of differences in their behaviour or in the abundance of debris in the waters they inhabit. At present, it seems unlikely that harbour seals are significantly affected by this debris.

A third and more serious cause for concern may be pollution, particularly by chlorinated hydrocarbons. In some relatively enclosed waters such as the Baltic Sea and parts of the North Sea, adverse effects of pollution on the reproduction of harbour seals are well documented (Van Haaften, 1974).

Adjacent to the B.C. coast is Puget Sound, where birth defects and pup mortality in harbour seals, possibly as a result of PCBs and DDT, have been recorded (Calambokidis et al., 1978). No direct evidence of effects of this kind has been found on the B.C. coast. Fortunately much of this coast is bathed by oceanic waters and is not subject to concentrations of localized origin. However, the distribution of pollutants is so widespread in the ocean that long-term effects on the harbour seals cannot be deemed impossible.

Conclusions

1. The current population of harbour seals is large and possibly growing; it is probably in the range of 45,000-60,000 animals.
2. Unless it has stabilized very recently, the population is still increasing, probably by about 10% per annum.
3. It is not possible to determine at what level the population will stabilize if it continues to be protected.
4. Hunting for bounties and hunting by fishermen in the years prior to 1970 did not endanger the harbour seal population, since it remained capable of a rapid natural increase when hunting ceased.
5. Unless the population has already been affected by changed environmental conditions, it can sustain an annual kill of at least 3,000 animals, and perhaps as many as 6,000, without risk.
6. The environmental effect caused by humans which seems most likely to have an adverse impact on the harbour seal population is pollution, particularly by chlorinated hydrocarbons, but there is no evidence of any significant effect of these pollutants at present.

Northern Elephant Seals

The northern elephant seal does not breed on the Canadian Pacific coast and rarely comes ashore there. It now breeds on offshore islands along the coast from central Baja California to central California. It disperses extensively along the coast from the breeding grounds in a northward direction. Guiget (1971) reported that the northern elephant seal was still rare off

the B.C. coast, although its numbers were increasing. The Department of Fisheries and Oceans stated in its submission to the Royal Commission that young of the year are seen off the west coast of Vancouver Island in late winter and spring, and that adult males are seen throughout coastal regions in summer (Canada, DFO, 1985).

Population Status

The species was originally abundant off the coasts of Baja California and California. From about 1800, it was heavily exploited for oil from the blubber and, by 1892, was on the verge of extinction; the number of animals surviving was not more than 100 and may have been much lower (Le Boeuf, 1979). It was then left in peace, and by about 1975, the numbers had built up again to about 45,000, at an average rate of increase of about 10% per year (Le Boeuf, 1979). It provides a good example of the ability of some species of seals to rebuild their populations from very low levels if they are not hunted.

Protection

No northern elephant seals have been killed off the coast of British Columbia for commercial or control purposes during this century, and these animals have been protected under the federal *Fisheries Act* since 1970. It is, of course, possible that some animals have been killed by fishermen, but no evidence is available on this point.

Conclusions

The northern elephant seal does not breed in Canadian waters, and only small numbers visit. It has no discerned impact on local fisheries and is currently protected. There seems no need for any further action at present.

Appendix

Appendix 22.1. Method of Calculating Average Rate of Increase from Initial and Final Population Size and Total Catch for Northern Fur Seals

The model assumes that the fur seal population changes over the period of observation by a constant instantaneous rate (Z). This rate is made up of two components, an instantaneous fishing (or hunting) rate (F) and the rate at which the population is "trying" to increase; that is, the rate (I) at which it would increase if there were no killing. If one assumes that these processes are continuous over a period of years, one can apply standard population-dynamics procedure. If the population changes from N_0 to N_t in a time period t during which a catch C is taken, then we can write:

$$\begin{aligned} Z &= \ln(N_0/N_t)/t \\ C &= F(N_0 - N_t)/Z \\ F &= CZ/(N_0 - N_t) \\ I &= F - Z \end{aligned}$$

The following table, indicating population and catch sizes in 1,000s, shows the values used in calculating the figures given in this report, (the p is 42 years for the period 1868–1910):

N_0	N_t	C	Z	F	I
2	.3	5.0	.045	.133	.088
2	.3	7.5	.045	.199	.154
3	.3	5.0	.055	.102	.047
3	.3	7.5	.055	.152	.097

References

- Allen, K.R. 1980. Conservation and management of whales. University of Washington Press, Seattle.
- Archibald, D.M., and C.C. Graham. 1981. Populations of Pacific salmon in British Columbia, 1970–1979. Can. Ms. Rep. Fish. Aquat. Sci. 1616.

The Status of Stocks of Pacific Seals

- Associated Press. 1985. Message date-lined Anchorage, Alaska, 17 July 1985.
- Bakkala, R.G., V.G. Wespestad, and J.J. Traynor. 1984. Pollock. In R.G. Bakkala and L.L. Low (ed.) Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984. Northwest and Alaska Fish. Center, Natl. Mar. Fish. Serv., NOAA.
- Bartholomew, G.A. 1967. Seal and sea lion populations of the California Islands, p. 229-244. In R.M. Philbrik (ed.) Proc. symp. on the biology of the California Islands. Santa Barbara Botanic Garden, Cal.
- Bartholomew, G.A., and R.A. Boolootian. 1960. Numbers and population structure of the pinnipeds on the California Channel Islands. *J. Mammal.* 41: 366-375.
- Bigg, M.A. 1969. The harbour seal in British Columbia. *Bull. Fish. Res. Board Can.* 172.
- Bigg, M.A. 1984. Sighting and kill data for the Steller sea lion (*Eumetopias jubatus*) and California sea lion (*Zalophus californianus*) in British Columbia, 1892-1982, with some records from Washington and southeastern Alaska. *Can. Data Rep. Fish. Aquat. Sci.* 460.
- Bigg, M.A. 1985a. Status of the Steller sea lion (*Eumetopias jubatus*) and California sea lion (*Zalophus californianus*) in British Columbia. *Can. Spec. Pub. Fish. Aquat. Sci.* 77.
- Bigg, M.A. 1985b. Pacific Biological Station, Nanaimo, B.C. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Bonner, W.N. 1979. Harbour (common) seal, p. 58-62. In Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. *Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians.* FAO, Rome.
- Bonnot, P. 1928. Report on the seals and sea lions of California. *Fish. Bull.* 14.
- Braham, H.W., R.D. Everitt, and D.J. Rugh. 1980. Northern sea lion population decline in the eastern Aleutian Islands. *J. Wildl. Manage.* 44: 25-33.
- Busch, B.C. 1985. The war against the seals: a history of the North American seal fishery. McGill-Queen's University Press, Kingston.
- Calambokidis, J., K. Bowman, S. Carter, J. Cabbage, P. Dawson, T. Fleischner, J. Schuett-Hames, J. Skidmore, B. Taylor, and S.G. Herman. 1978. Chlorinated hydrocarbon concentrations and the ecology and behavior of harbour seals in Washington State waters. Evergreen State College, Olympia, Wash.

The Status of Stocks of Pacific Seals

- Calkins, D.G. 1984. Steller sea lion entanglement in marine debris. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/4.
- Calkins, D.G., and K.W. Pitcher. 1982. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. U.S. Dept. of Interior, Bur. Land Manage., Outer Environ. Assess. Progr. Final Rep., Res. Unit 243 Contract 03-5-022-69.
- Chapman, D.G. 1981. Evaluation of marine mammal population models. *In* C.W. Fowler and T.D. Smith (ed.) Dynamics of large mammal population models. John Wiley, New York.
- Canada. Dept. of Fisheries and Oceans (DFO). 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. Ottawa.
- DeMaster, D.P., D.J. Miller, D. Goodman, R.L. DeLong, and B.S. Stewart. 1982. Assessment of California sea lion/fishery interactions, p. 253-264. *In* Trans. 47th N. Am. Wildl. Nat. Resour. Conf.
- Dodimead, A.J. 1984. A review of some aspects of the physical oceanography of the continental shelf and slope waters of the west coast of Vancouver Island, British Columbia. *Can. Ms. Rep. Fish. Aquat. Sci.* 1773.
- Eberhardt, L.L. 1981. Population dynamics of the Pribilof fur seals. *In* C.W. Fowler and T.D. Smith (ed.) Dynamics of large mammal population models. John Wiley, New York.
- Fisher, H.D. 1952. The status of the harbour seal in British Columbia, with particular reference to the Skeena River. *Bull. Fish. Res. Board Can.* 93.
- Fowler, C.W. 1982. Entanglement as an explanation for the decline in northern fur seals of the Pribilof Islands. Background paper to 25th Ann. Meet. St. Sci. Comm. of North Pacific Fur Seal Comm.
- Fowler, C.W. 1984a. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/AB-II/3.
- Fowler, C.W. 1984b. Density dependence in cetacean populations, p. 373-387. *In* Reproduction in whales, dolphins and porpoises. Spec. Pub. Int. Whal. Comm.
- Fowler, C.W. 1985a. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. Background paper to 28th Ann. Meet. St. Sci. Comm. of North Pacific Fur Seal Comm.

The Status of Stocks of Pacific Seals

- Fowler, C.W. 1985b. Status review: northern fur seals (*C. ursinus*) of the Pribilof Islands, Alaska. Background paper to 28th Ann. Meet. St. Sci. Comm. of North Pacific Fur Seal Comm.
- Fowler, C.W. 1985c. National Marine Mammal Laboratory, Seattle, Wash. Personal communication with K.R. Allen, of Royal Commission on Seals and the Sealing Industry in Canada.
- Fowler, C.W. 1986. Density dependence in northern fur seals (*Callorhinus ursinus*). In J. Croxall and R.L. Gentry (ed.) Proceedings of the first international symposium on fur seal biology. Held 24-27 April, 1984, Cambridge, U.K. U.S. Dept. of Commerce, Nat. Mar. Fish. Serv., NOAA Tech. Rep. (in press).
- Goodman, D. 1986. Dept. of Fisheries and Oceans, Ottawa. Personal communication with C.E. Tull, Royal Commission on Seals and the Sealing Industry in Canada.
- Guiget, C.J. 1971. An apparent increase in California sea lion, *Zalophus californianus* (Lesson), and elephant seal, *Mirounga angustirostris* (Gill) on the coast of British Columbia. Syesis 4: 263-264.
- Haist, V., M. Stocker, and J.F. Schweigert. 1985. Stock assessments for British Columbia herring for 1984 and forecasts of the potential catch in 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1365.
- Harvey, J.T. 1984. Abundance and activities of harbour seals along the central Oregon coast. Final Rep. to Oregon Dept. of Fish and Wildlife.
- Harvey, J.T. 1985. Marine Science Center, Oregon State University, Newport, Oregon. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Henderson, J.R. 1984. A review of Hawaiian monk seal entanglements in marine debris. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/6.
- Kajimura, H. 1984. Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the eastern north Pacific Ocean and eastern Bering Sea. NOAA Tech. Rep. NMFS no. SSRF-779.
- King, J.E. 1983. Seals of the world. 2nd ed. British Museum (Natural History) and Oxford University Press, London.

The Status of Stocks of Pacific Seals

- Lander, R.H., and H. Kajimura. 1982. Status of northern fur seals, p. 319-345. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. IV, Small cetaceans, seals, sirenians, and otters. FAO, Rome.
- Le Boeuf, B.J. 1979. Northern elephant seal, p. 110-114. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians. FAO, Rome.
- Loughlin, T.R. 1984. Northern sea lion population continues rapid decline. U.S. Dept. of Commerce, NMFS, Northwest and Alaska Fish. Center (July-Sept.): 18-19.
- Loughlin, T.R., D.J. Rugh, and C.H. Fiscus. 1984. Northern sea lion distribution and abundance: 1956-80. *J. Wildl. Manage.* 48: 729-740.
- Mate, B.R. 1977. Aerial censusing of pinnipeds in the eastern Pacific for assessment of population numbers, migratory distributions, rookery stability, breeding effort, and recruitment. Final Rep. to U.S. Marine Mamm. Comm. Report No. MMC - 75/01.
- Mate, B.R. 1985. Oregon State University, Newport, Oregon. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Merrell, T.R., Jr. 1984. Fish nets and other plastic litter on Alaska beaches. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-1/5.
- Newcombe, C.F., W.H. Greenwood, and C.M. Fraser. 1918. British Columbia sea lion investigation. Part 1. Preliminary report of the Commission on the sea lion question, 1915. Part 2. Report and conclusions of the sea lion investigation, 1916. *Can. Contr. Can. Biol., Fish.* [1917-1918]: 1-39.
- North Pacific Fur Seal Commission. 1984. Workshop on population trends in northern fur seals, p. 34-41. *Proc. of 27th Ann. Meet. of North Pacific Fur Seal Comm.*
- Ohsumi, S. 1979. Interspecies relationships among some biological parameters in cetaceans and estimation of the natural mortality coefficient of the Southern Hemisphere minke whale. *Rep. Int. Whal. Comm.* 29: 397-406.
- Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. int. Explor. Mer* 39 (2): 175-192.

The Status of Stocks of Pacific Seals

- Pike, G.C., and B.E. Maxwell. 1958. The abundance and distribution of the northern sea lion (*Eumetopias jubata*) on the coast of British Columbia. *J. Fish. Res. Board Can.* 15 (1): 5-17.
- Pitcher, K.W. 1985. Alaska Dept. of Fish and Game, Anchorage, Alaska. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Pitcher, K.W., and D.G. Calkins. 1979. Biology of the harbour seal *Phoca vitulina richardsi*, in the Gulf of Alaska. U.S. Dept. of Interior, Bur. Land Manage. Outer Continental Shelf Environ. Assess. Progr. Final Rep.
- Pitcher, K.W., and D.C. McAllister. 1981. Movements and haulout behavior of radio-tagged harbour seals, *Phoca vitulina*. *Can. Field Naturalist* 95 (3): 292-297.
- Roppel, A.Y., A.M. Johnson, R.D. Bauer, D.G. Chapman, and F. Wilke. 1963. Fur seal investigations Pribilof Islands, Alaska, 1962. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. Ser. 454.
- Smith, T. (ed.) 1979. Report of the status of porpoise stocks workshop, La Jolla, California, 27-31 August. Southwest Fish. Center, Admin. Rep. LJ-79-41.
- Smith, T.D. 1973. Variable population matrices: theory and application of the evaluation of harvesting strategy. Ph.D. thesis. Univ. Washington, Seattle.
- Smith, T.D., and T. Polacheck. 1984. The population dynamics of the Alaska fur seal: what do we really know? NWAFC Rep. 84-15.
- Spalding, D.J. 1964. Fur seal, sea lion and harbour seal on the British Columbia coast. *Bull. Fish. Res. Board Can.* 146.
- Swartzman, G.L. 1984. Factors bearing on the present status and future of the eastern Bering Sea fur seal population with special emphasis on the effect of terminating the subadult male harvest on St. Paul Island. U.S. Mar. Mamm. Comm. Rep. No. MMC-83/03.
- Tabata, S. 1984. Anomalously warm water off the Pacific coast of Canada during the 1982-1983 El Niño. *Tropical Ocean-Atmosphere Newsl.* 24: 7-9.
- Trites, A.W. 1984. Population dynamics of the Pribilof Islands north Pacific fur seal (*C. ursinus*). M. Sc. thesis. Univ. British Columbia, Vancouver.
-

The Status of Stocks of Pacific Seals

- Trites, A.W. 1985. The impact of weather conditions at St. Paul Island on the dynamics of the northern fur seal (*Callorhinus ursinus*). Background paper to 28th Ann. Meet. St. Sci. Comm. of North Pacific Fur Seal Comm.
- United States. 1983. Draft environmental impact statement on the Interim Convention on Conservation of North Pacific Fur Seals. Dept. of Commerce and Dept. of State, Washington, D.C.
- United States. 1985. Environmental impact statement on the Interim Convention on Conservation of North Pacific Fur Seals. Dept. of State and Dept. of Commerce, Washington, D.C.
- Van Haaften, J.L. 1974. [Seals of the Dutch coastal waters.] *K. Ned. Natuurhist. Ver. Wet. Meded.* 101: 1-36.
- Vladimirov, V.A. 1974. [Role of climatic factors in mortality of juveniles in fur seals (*Callorhinus ursinus*).] *Zool. Zh.* 53(9): 1385-1390.
- Wallace, N. 1984. Solutions to debris entanglement or, "think of it as a big fish bowl!". Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/BP/5.
- York, A.E. 1985a. Estimations of the size of the 1940 year class. *In* P. Kozloff (ed.) Fur seal investigations. NOAA Tech. Mem. NMFS-F/NWC-71: 20.
- York, A.E. 1985b. Forecast of 1985 harvest on St. Paul Island. Northwest and Alaska Fish. Center, Nat. Mar. Fish. Serv., NOAA.
- Yoshida, K., and N. Baba. 1984. The problem of entanglement of fur seals in marine debris. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/12.

Chapter 23

Indirect Effects on Seals

Most of the interactions between humans and seals arise directly or indirectly because both are functioning as top-level predators in the same environment. Two of the most direct interactions occur when humans function as predators, using seals as a resource, and when human predation on other marine resources is affected by the competing predatory activities of seals. These interactions are discussed at some length in other chapters. This chapter considers other ways in which human activities may be exercising an effect on seals. The four questions which seem to require most consideration are the following:

- What effect has human exploitation of fish stocks on the seal populations preying on those stocks?
- What effect does the incidental killing of some seals in fishing operations have on seal populations?
- What effect has environmental pollution of human origin on seal populations?
- What impacts on seal populations could arise from development in the Arctic?

Reduction of Fish Stocks

Competitive Effects

Many commercial fisheries have seriously reduced the abundance of the fish against which they operate, sometimes sufficiently to destroy the fishery itself. At first sight it would appear that such reductions would seriously affect any marine mammals, including seals, which fed on these fish. In practice, however, no substantial evidence of any such effects has been forthcoming. Beverton (1985), for example, comments on the conclusions of a major international workshop on marine mammals and fisheries, held at La Jolla, California in 1981, under the auspices of the International Union for

the Conservation of Nature and Natural Resources (IUCN) and the United Nations Environment Programme (UNEP): "The Workshop was unable to find a case in which a fish-eating marine mammal had been adversely affected at the population level by interaction with a fishery." It cannot be assumed, however, that because no such cases have been identified, it must follow that they do not occur. As Northridge (1984) points out, we not only need to obtain much more data on the food of marine mammals, but we also need to know more about their feeding strategies as they respond to changes in the nature and distribution of their potential prey, and more about the inter-species population dynamics of the species concerned.

Nevertheless, there are several reasons why reduction in the abundance of certain prey species by commercial fishing may not necessarily have an identifiable effect on a seal population. In the first place, most seals are opportunistic feeders, able to turn to other available fish or invertebrates if one of their principal food species is reduced in abundance by human or natural causes. Secondly, migrating species, such as the harp and northern fur seals, may feed on different prey at different stages during their seasonal wanderings. Thirdly, neither the seals nor the commercial fisheries usually take only a single species; both take a variety of species which also sustain predator-prey relationships among themselves. Thus, part of the effect of the commercial fishery may be to remove predators on a prey species which is important to seals and so benefit them; a variety of such relationships is possible (Beverton, 1985). Fourthly, the seals and the fishery may be concentrating on the prey at different life stages; the seals may actually benefit if the fishery takes older fish that prey on younger age groups which are also eaten by the seals. This seems to happen with northern fur seals feeding on walleye pollock in the Bering Sea. Fifthly, provided prey abundance remains above a certain level, the individual seal may be able to obtain as much as its feeding behaviour will enable it to take, and any reductions in prey abundance above that level may have little effect on the amount that the individual consumes, and therefore on the benefit obtained by the seals.

Thus the Royal Commission can only conclude that while reduction in the abundance of fish that are important to seals as food may, in some circumstances, have an adverse effect, such negative relationships do not necessarily occur, and they have not been clearly identified among marine mammals as a whole.

Harp Seals

Some studies on this question have been undertaken for two of the most important seal species within the Commission's area of interest. Lavigne (1982) refers to evidence of a marked decrease in stored energy (blubber) in whelping female harp seals since the collapse of the capelin in the northwest Atlantic in the late 1970s. Recent studies have suggested that part of the decrease in capelin biomass is due to natural changes in year-class strength (Leggett et al., 1984) rather than to heavy fishing. Bowen (1985), in reviewing the situation in the light of additional data on fluctuations in the abundance of capelin, concluded that "the hypothesis that increased commercial fishing for capelin was responsible for a decrease in female [harp seal] condition is not supported by available data," and that "there is no evidence that commercial fishing in the 1960's and 1970's had a significant detrimental effect on the food available to harp seals, and hence on population growth."

Northern Fur Seals

The possible effect on the northern fur seal of the large fisheries which developed in the Bering Sea in the 1970s, especially for walleye pollock, has been considered in Chapter 22 on the status of the northern fur seal: there is no evidence to suggest that the fishery has contributed to the current declining trend in the fur seal population through any effect on the available food supply. If such an effect had been occurring, the density-dependent population parameters of growth and mortality would have taken values appropriate to a population at its carrying capacity. On the contrary, a number of these parameters are now at about the same values that they stood at in the 1920s, when the population was growing rapidly (Fowler, 1985).

The walleye pollock is unusual, but by no means exceptional, in that large and medium-sized pollock are among the most important predators on medium-sized and small pollock. Swartzman and Haar (1983) have shown that in the early stages of the development of the fishery, in the mid-1960s, the most abundant age groups were four- and five-year-old fish, but that by 1974 the most abundant age groups were two- and three-year-old fish. Apparently, the later age composition represents not only a change in relative abundance, but also a real increase in the abundance of the younger fish as a result of reduced cannibalism by the older fish. This change provided a larger food supply for the fur seals, which eat mainly younger fish.

Since 1980, the situation has changed again; Bakkala et al. (1984) report that, following poor recruitment of young fish into the population, older fish are again dominant.

Harwood (1983) also points out that a commercial fishery which tends to reduce the average size of the fish in the population may benefit those marine mammal populations which prefer smaller prey than do commercial fishermen. This generality applies to most seals. Even in such a heavily fished area as the North Sea, the total biomass of fish has changed little, despite the very heavy fishing intensity (Hempel 1978). The main effect of fishing has been to deplete the most valuable or most vulnerable species of fish, and to shift the size composition of these populations downwards to smaller fish.

Effects of Fisheries on Seal Predators

There is one other way in which a commercial fishery may possibly exercise a fairly direct and beneficial effect on a seal population. This is where the fishery reduces the numbers of a major predator on seals. Only one such possibility has come to the Commission's attention. Brodie and Beck (1983) have pointed out that the numbers of large sharks, especially of white sharks, off the east coast of Canada have probably decreased as a result of their capture, both in direct shark fisheries and incidentally in longlining for swordfish. This probable decrease is a fairly recent development, beginning about 1960, and the authors suggest that it may have contributed to the concurrent increase in grey seals, particularly on Sable Island, which lies at the centre of the area of the shark fisheries. Sharks are known by direct observation to be frequent predators on grey seals near Sable Island.

Incidental Kill of Seals in Fishing Operations

Chapter 25 deals with the fishing industry's losses of fishing gear caused by seals trying to take fish caught in nets or on lines. Some of these seals are killed as a result of this activity; they may become entangled in the gear and drown, or they may be killed deliberately by fishermen. Seals may also be accidentally entangled in fishing gear even when they are not trying to take fish. This section reviews what is known about the significance to the maintenance of seal populations of incidental mortality due to active

fishing gear. Mortality from abandoned and lost gear is reviewed in a later section of this chapter. Unfortunately, very little useful data on this problem seem to be available. Studies aimed at collecting quantitative data on the losses that seals cause to fishermen generally do not include records of the number of seals killed in the process. This applies, for example, even to the very thorough study undertaken by the Eastern Fishermen's Federation (Farmer and Billard, 1985). In particular, the Royal Commission has received no useful information on the numbers of grey seals that die in the course of encounters with fishing operations, in spite of the widespread prevalence of such encounters.

Harp Seals

Several witnesses, in their briefs to the Royal Commission, stated that following the great curtailment of the harp seal hunt in the last few years there had been an increase in the numbers of young harp seals becoming entangled in fishing nets (Rompkey, 1985; Barker, 1985; Wilderness Society of Newfoundland and Labrador, 1985). Such evidence is anecdotal – for example, one fisherman caught 38 seals in his nets in one day – and does not provide a basis for an estimate of the total numbers of seals killed in this way. Lien (1985), in a letter to the Royal Commission, provided some rather more detailed information. On the basis of information obtained incidentally to surveys of whale and shark entrapments, he estimates that the incidental kill of harp seals by Newfoundland and Labrador fishermen rose from about 1,000 per year in 1979–1982 to about 5,000 in 1984. This suggested fivefold increase may be compared with the population estimates treated in Chapter 21. The best estimate of harp seal pup production in 1978 was about 300,000–350,000, and no major change is likely to have occurred since that time. From 1973 to 1982, the number of pups killed in the Front and Gulf regions combined ranged between 98,000 and 178,000, with a mean of 130,000 (Cooke et al., 1986, Appendix, Table 4). From a pup production of 300,000 to 350,000, the number of survivors after a kill of 24,000 (that of 1984) would be 1.5 to 1.6 times that after a kill of 130,000. The reported increase in young harp seals becoming entrapped in nets in the last few years is therefore considerably greater than would have been expected on the basis of the population estimates. Since no detailed records of the numbers becoming entrapped are available, it is not possible at present to pursue the matter further. No information at all is available on the numbers of harp seals being caught in fishing gear on parts of the Canadian coast other than Newfoundland and Labrador.

In the review in Chapter 25 of the damage caused by seals to fishing gear and catches, it is noted that an estimated 10,000 harp seals were drowned in gill nets off northern Norway each year in the 1979-1981 period (Bjørge et al., 1981). Another source (Wilderness Society of Newfoundland and Labrador, 1985) stated that annual deaths in 1984 probably amounted to 15,000 on the Finnmark coast of Norway. All the estimates of the numbers of incidental deaths of harp seals are small compared to the numbers that used to be killed annually in the hunt and to the natural rate of increase of this stock.

Pacific Coast Seals

The Royal Commission received no useful information about the mortality of Pacific coast seals in Canadian waters caused by fishing gear, although certainly some harbour seals and sea lions, and possibly a few fur seals, die in this way. DeMaster et al. (1982) provide an estimate of the annual kill of California sea lions off the California coast. This kill amounted to about 1,500 animals, of which 60% were caught in shark gill nets and nearly all the remainder in halibut gill nets and on salmon troll gear. Since pup production of this species amounts to about 20,000 annually, the incidental kill, as a proportion of the total population, seems likely to be much higher for this species than for harp seals. The numbers of California sea lions have been increasing in recent years in spite of this kill.

Although there is good evidence of mortality in northern fur seals caused by entanglement in discarded netting and other plastic debris, there is much less evidence of their becoming entangled in operational fishing gear. Some are caught in the very extensive Japanese gill-net fishery for salmon in the north Pacific Ocean, but it seems unlikely that they total more than a few thousand. Lander and Kajimura (1982) quote Fukuhara (1974) and Nishiwaki (pers. comm.) as estimating the kill at 3,150-3,750 and 7,000 respectively. Fowler (1982), however, on the basis of more recent data, reports estimates in the range 100-1,000 and suggests that this figure is probably declining as a result of shifts in the areas fished. This mortality seems to be small compared either to the commercial harvest of males or, apparently, to the numbers of fur seals dying as a result of entanglement in discarded netting and other plastic debris.

Environmental Pollution

Three types of pollution of the marine environment can be identified as having possible effects on seal populations. They are:

- underwater noise pollution;
- chemical pollution;
- pollution with plastic debris.

Underwater Noise Pollution

Underwater noise pollution derives from such sources as ships' engines and the detonations used in seismic sounding. It seems to be of relatively little significance to seals, although it cannot be entirely ignored. It almost certainly has much less effect on seals than on the other large group of marine mammals, the cetaceans (whales, porpoises and dolphins). The reason is that seals depend less on sound for determining their position, for finding their food, and for communicating with one another than do cetaceans. Nevertheless, seals cannot be unaffected by some of the stronger sound effects which humans inflict on the marine environment. As Bonner (1982) says, "Seals within the range of underwater detonation used in seismic surveys must suffer acute discomfort if not physical damage." Terhune et al. (1979), quoted by Bonner (1982), have shown that there is a marked decrease in harp seal underwater vocalizations after a vessel with running engines arrives in the vicinity. The significance of these vocalizations to the seals is not known, and it is therefore impossible to assess the nature of the impact of the vessel's noise on these animals. Man-made noise, however, may also be beneficial to seals; there is anecdotal evidence of sea lions, and possibly other species of seals, apparently using the sound of a fishing boat's engines to locate the boat and take fish from the vessel's gear.

The Royal Commission concludes, therefore, that at present, underwater sound pollution has no widespread or continuing adverse effects on Canadian seal populations. However, sound pollution is one of the problems which may become more serious if there is a great increase in vessel traffic in the Arctic.

One other form of physical pollution of marine environments may be mentioned, but it is of no practical significance to seal populations. It is heat

pollution caused, for example, by the cooling water of thermal and nuclear power stations. The local effects of pollution of this kind are significant to many animals, but seals and other marine mammals are little affected, if at all, both because their wide-ranging habits enable them to avoid uncomfortable localities, and because they, like other warm-blooded animals, are able to tolerate much wider temperature ranges than are cold-blooded forms of animal life (Warren, 1971).

Chemical Pollution

During much of the present century humans have been pouring into the oceans vast quantities of substances, some of which never existed before, that in a variety of ways adversely affect the creatures living in the seas. The marine mammals, including the seals, have not been immune from these effects. Four groups of substances must be considered here because of their potential for harmful effects. These are radioactive substances, heavy metals and trace elements, petroleum compounds and organochlorine compounds.

Radioactive Substances

A variety of radio-isotopes has been entering the marine environment over the last 40 years, both as products of nuclear explosions and from other sources. Some of these radio-isotopes pass into the tissues of seals. Risebrough (1979) reports the presence of radioactive cesium and strontium in harp seals in the Gulf of St. Lawrence and of cesium in unspecified seals from the Northwest Territories. He states that the values found may be considered low, although above background levels for the environments in which the species evolved. He concludes: "An increase in levels of marine radioactivity would most likely result e.g. in an increase in mutation rates in marine mammals, but would not necessarily increase genetic variability. It is not therefore viewed as a serious threat to marine mammal populations."

It appears, therefore, that the potential risks to seal populations from the present levels of radioactive pollutants in the marine environment are not of serious concern.

Heavy Metals and Trace Elements

Since about 1970, the presence of high levels of mercury in the flesh of long-lived carnivorous fish such as sharks and swordfish has raised prob-

lems related to human health. The possibility of toxic effects from mercury in seals and other fish-eating mammals has therefore come under consideration. A considerable number of analyses of the mercury content of seal tissues have been made (Risebrough, 1979), and a great range of values has been found, exceeding three orders of magnitude. It is now generally accepted, however, that for the most part the mercury is of natural origin (Bonner, 1982). This finding does not exclude the existence of some locally high concentrations of mercury of industrial origin, although local "hot spots" of natural mercury also occur. For instance, the liver of a bearded seal from the Northwest Territories, far from any artificial source of mercury, is recorded as containing the very high level of 420 parts per million of mercury which, presumably, must ultimately have been derived from a natural source (Risebrough, 1979). There is also good evidence that seals have physiological mechanisms which help to protect them against adverse effects from mercury they ingest. Mercury in fish is found in the highly toxic methylmercury form, but only a little of this form is found in seals. Most of the mercury found in seals is in relatively harmless forms (Bonner, 1982) in a complex that includes selenium and bromine (Risebrough, 1979).

High concentrations of cadmium have been found in the kidneys both of seals and of whales (Wageman and Muir, 1984), and nickel has been associated with stillbirths in seals (Hyvarinen and Sipila, 1984).

No evidence has been found that any other heavy metal or trace element has any adverse effects on seals under natural conditions (Risebrough, 1979).

Petroleum Compounds

Since the tanker *Torrey Canyon* went aground in 1967, the risks of environmental catastrophe following a massive oil spill have been well recognized. Seals, as inhabitants of coastal waters, are among the animals which might be subject to serious damage on such an occasion, and it is important to know how susceptible they would be to such effects. Three possible ways in which an oil spill might affect seals are identified by Risebrough (1979). These are oiling of the pelage, which has an adverse effect on insulation; poisoning by ingested oil; and long-term sublethal effects arising from accumulation of persistent compounds in the ecosystem.

A number of observations and experiments with seals that are dependent primarily on their blubber for insulation (i.e., hair seals such as

grey seals and harp seals) have led to the conclusion that oiling of the pelage has little serious effect on survival (Risebrough, 1979; Bonner, 1982; Hofman and Bonner, 1985). The risk, however, seems to be considerably greater for fur seals, whose insulation could be seriously damaged by oil. Risebrough (1979) quotes Gentry et al. (1976), who found that the heat flux through experimentally oiled pelts of northern fur seals increased by a factor of 2, and that the metabolic rate of experimentally oiled fur seals increased 1.5 times. Fortunately there has not yet been a serious oil spill in the vicinity of a fur seal colony.

A few experiments have been done on the effects of ingested oil by dosing ringed and harp seals with oil. Seals store ingested oil in their blubber until it is metabolized, and there is some evidence that mobilizing this unique pathway to clear oil may lead to adreno-cortical imbalance, anorexia, lethargy and reduced ability to survive stress (Engelhardt, 1982, 1983; Geraci and Smith, 1976). In any case, oiling causes seals intense distress and at least temporary eye ulceration (Smith and Geraci, 1975). However, Bonner (1982) concludes that "oil contamination or ingestion in quantities that might reasonably be expected in the course of a spill is unlikely to be irreversibly harmful to a healthy seal population."

In general, the Royal Commission accepts Bonner's conclusion, but the Commissioners believe that, if by some misfortune a major oil spill occurred in an area where northern fur seals were concentrated, serious immediate damage could be done through deaths of animals with contaminated pelage even though in the long term this damage might prove reversible and the population might recover to the level allowed by other environmental factors.

Ringed seals, too, may be particularly susceptible to the effects of an oil spill because of the conditions under which they live. Although they are known to avoid oil slicks when possible (Engelhardt, 1983; Smith and Geraci, 1975), these seals, when wintering in the sea ice, would be vulnerable because of their dependence for respiration on a few small breathing holes, leads and cracks. The toxic aromatic fractions of crude oil persist in arctic cold, and may accumulate along these ice edges (Engelhardt, 1983).

The Royal Commission did not find any useful studies on the question of whether long-term environmental degradation following a catastrophic or low-level continuing oil spill could adversely affect seal populations.

Organochlorine Compounds

Since the Second World War, organochlorine compounds, which never existed in nature, have become widely distributed through both the marine and the terrestrial environments with devastating effects on many biological communities. The substances of greatest concern are DDT and its derivatives, which are used primarily as insecticides, and polychlorinated biphenyls (PCBs), which have a great variety of industrial uses. By 1964, DDT had been detected in crabeater and Weddell seals in the Antarctic, although in fairly low concentrations (Risebrough, 1979). There are no parts of the world's oceans which are now entirely free of these compounds, although there are only a few areas where their concentrations are high enough to cause serious effects on seals. None of these areas is in Canadian waters, although one, Puget Sound, is closely adjacent. The occurrence of birth defects and pup mortality in harbour seals in this area, possibly as a result of relatively high levels of DDT and PCBs (Risebrough, 1979), has been noted in the material relating to the status of the harbour seal. (See Chapter 22.)

Other areas in which there are strong indications that organochlorine compounds have contributed to decline or mortalities in seal populations are San Francisco Bay (harbour seals), southern California (California sea lions), the Baltic Sea (ringed seals and grey seals), the Netherlands and West German coasts (harbour seals), and the Farallon Islands (Steller sea lions) (Risebrough, 1979). The effects operate generally through the reproductive system, and the chief results are prematurely born pups, which invariably die; birth defects in pups; and pathological changes in the uterus. The particular results depend upon the species of seal and the locality. The phenomenon has been well studied among California sea lions of southern California, but even there it is not entirely clear how far, and in what way, DDT and PCBs contribute to the problem. Three possible mechanisms have been discussed (Risebrough, 1979):

- High levels of DDT derivatives, with or without a contribution from PCBs, disturb the biochemical mechanisms controlling pregnancy.
- DDT derivatives, with or without a contribution from PCBs, lower the resistance of the seals to two pathogens which cause premature birth.
- The pathogens alone, without contributions from DDT and PCBs, cause premature births.

It is evident that the situation is complex and that, while it is virtually certain that organochlorine compounds, when present above critical concentrations, may cause serious difficulties for the survival of seal populations, much remains to be discovered about the mechanisms involved.

The Royal Commission has seen recent reports (Anonymous, 1985) that the deaths of a number of belugas in the St. Lawrence River are believed to be the result of poisoning with PCBs, DDT and another organochlorine insecticide (Mirex). Very large amounts of these chemicals are reported to have been found in the blubber and milk of the belugas. (These chemicals accumulate in the fat of animals.) No reports of dead seals are mentioned, but the mortality occurred near the mouth of the Saguenay River, which Sergeant (1973) identifies as a feeding area for adult harp seals. The Royal Commission is concerned, therefore, about the potential effects of the pollutants in this area on the harp seal population.

As noted above, only a few localities have been found where organochlorine compounds seem to be seriously affecting seal populations, and none of these is in Canada. Fortunately, there is reason to believe that in the long term this problem will diminish rather than increase. The use of DDT has greatly declined since the 1960s, when the world became aware of the threat that it was posing to many kinds of wildlife. PCB manufacture has declined rapidly since about 1970, although the environmental impact of this chemical may not have been reduced until much later (Addison et al., 1984). Addison et al. (1984) compared DDT and PCB concentrations in grey seals from Sable Island in 1974, 1976 and 1982; and in harp seals from the Gulf of St. Lawrence in 1971 and 1982. They concluded that their data "show convincingly that concentrations of the DDT group of insecticides in eastern Canadian seals have declined appreciably during the 1970s but that PCB concentrations have fallen much less, if at all." The differences in the trends of DDT and PCB compounds may be partly the result of a greater decline in recent years in environmental concentrations of DDT than of PCBs, and partly to some ability of seals to degrade and eliminate DDT compounds, but not PCBs. In the Bering Sea, however, Calambokidis and Peard (1985) found that DDT levels in northern fur seals on the Pribilof Islands in 1980 were at about the same levels as had been observed in 1968 and 1969; they were unable to rule out the possibility that some increase had occurred. While PCBs were measured in 1980, no comparable data for 1969 are available for comparison. Calambokidis and Peard (1985) note that the levels of PCBs and DDE (the main DDT derivative) were well below the levels detected in other pinnipeds showing reproductive dysfunctions.

Pollution with Plastic Debris

Concern about the great quantities of plastic material of diverse kinds which is now adrift in the oceans has been growing since the early 1970s. It particularly relates to the adverse effects on many species of marine animals, including both commercially important fish and species of significant public interest such as seabirds, turtles and endangered marine mammals. Plastic debris has also directly threatened human life when ships have had their intakes blocked or their propellers fouled (Hammond, 1984), or when divers have become entangled in it.

As one result of this concern the U.S. government organized a scientific workshop to examine the problem and discuss possible actions; this workshop was held in Honolulu in November 1984 (Anonymous, 1984). It dealt with the kinds and amounts of debris entering the oceans, its fate, the effect on marine resources, and actions which could be taken to mitigate the problems. Scientists from a number of other countries besides the United States were present. Interest was concentrated mainly on the Pacific Basin and particularly the north Pacific Ocean, although data from some other areas were also presented. The following summary has been drawn largely from the material presented at this workshop.

The Amount of Debris

The amounts of plastic material entering the ocean annually are very great; most of this material comes from fishing operations and from waste discarded by merchant ships. It also includes small plastic granules which may be of industrial origin, but this material is of much less significance to seals than it is to other marine animals, especially seabirds.

A recent estimate is that 145,000 pieces of netting, large and small, are lost or deliberately discarded annually in the Bering Sea alone (Wallace, 1984). This figure does not seem surprising when it is compared with the 15,000 miles of gill nets (Wallace, 1984) which are set daily in the north Pacific Ocean and with an average fishing effort by large trawlers in the Bering Sea-Gulf of Alaska area of over 2,000 vessel-months annually (Low et al., 1984). Another estimate is that in the whole world 350 million pounds of material are discarded or lost annually by the fishing fleet (Wallace, 1984). No data seem to be available at present relating to the amount of plastic debris originating from the fishing industry in the other area of direct concern to Canada, the northwest Atlantic Ocean; however, little informa-

tion has come before the Royal Commission to suggest that seals in this area are being adversely affected by entanglement to any significant extent.

The limited amount of data available in the matter of the amount of plastic material that is discarded by merchant ships suggests that, for the world as a whole, it is probably of about the same order as that produced by the fishing industry. In the north Pacific area, however, it is likely to be much less when the relative distributions of the two activities are compared. Further, the kinds of material which most frequently entangle seals are netting scraps, pieces of line and packing bands, and the first two of these are derived almost entirely from the fishing fleets.

It is true, of course, that other objects which have been found entangling seals, such as canned drink packs, may well come from any kind of vessels. It seems likely, however, that seabirds and some other marine animals may be relatively more vulnerable to debris of non-fishing origin than are the seals.

The Fate of Debris

Although it is the non-biodegradable nature of plastic materials that has given rise to the existing problem, the material does actually disappear gradually, and there is no occasion to fear an infinite build-up of plastic debris in the oceans as more is added each year and none is removed. Much of this material is washed ashore, where it may be buried naturally or can be removed by humans. Thus, if the amount of material entering the sea can be reduced, the quantity of drifting material and its harmful effects should also decline. On Amchitka Island in the Aleutians, for example, between 1974 and 1982, there was a decrease of 37% in the weight of trawl netting coming ashore (Merrell, 1984). This decrease is attributed to a reduction in the number of boats fishing off the area.

The amount of debris coming ashore on particular stretches of coast can vary greatly from place to place, even within a limited area depending, apparently, on local currents, and wind and wave effects. At sea, there is evidence that debris tends to be most abundant in certain areas, again as the result of the concentrating effect of the oceanic circulatory system.

Effects on Seals

There is substantial evidence that plastic debris has caused serious mortality in juvenile northern fur seals in the Bering Sea. This has been discussed in detail in Chapter 22.

Instances of entanglement in pieces of netting and other plastic debris have been observed in a number of other seal populations, but no other studies seem to have been undertaken to relate this entanglement to population structure and change in abundance. However, Dr. G. Stander (1985), Director of the Sea Fisheries Research Institute, Cape Town, South Africa provided the Royal Commission with an interesting set of data for the Cape fur seal. These data enable a comparison to be made between the proportion of animals observed to be entangled and the estimated rate at which the colony is increasing for a series of fur seal colonies along the South African coast. At first sight this comparison reveals a tendency for the rate of increase to be highest where the proportion entangled is lowest and vice versa. The correlation is not significant when tested by a Spearman rank test and, more important, the data themselves contain uncertainties. Some of the samples on which entanglement rates are based are small, and the Royal Commission has been advised that further modelling studies may change the estimated relative growth rates of some of the colonies. It appears, therefore, that these data, while not inconsistent with the hypothesis that entanglement contributes to seal mortality, cannot be regarded as giving the theory any definite support.

Entanglement in fishing gear – netting scraps and lines – has been observed in sea lions, northern elephant seals and harbour seals on the U.S. west coast. In the largest series of observations that the Royal Commission has found, samples of 13,000 sea lions and 11,000 northern elephant seals on the southern California coast both recorded 0.08% animals entangled (Stewart and Yochem, 1984). This figure is well below the observed figures for northern fur seals in the Bering Sea (0.4%) (Scordino, 1984) and probably reflects a lower intensity of commercial fishing in the area.

Other species which have been recorded as entangled are the Hawaiian monk seal (Henderson, 1984), the South American sea lion off Argentina (Wallace, 1984), the New Zealand fur seal off New Zealand (Cawthorn, 1984), and the Steller sea lion off Alaska (Calkins, 1984).

Entanglement can apparently cause the death of seals and other marine mammals in at least three ways, depending on the size of the netting fragment. Large pieces may cause the animal to drown; medium-sized

pieces may cause death from exhaustion and starvation as a result of the drag; and small fragments, if they form a loop round the animal, may cut through the tissues, particularly as a young animal grows, and cause lethal injuries (Wallace, 1984). There is abundant evidence, however, that many animals which have been entangled escape, sometimes quite quickly and without experiencing lasting harm. This evidence has been taken both from direct observation of individual identifiable animals (Scordino, 1984) and from the numerous records of animals bearing scars caused by previous entanglement.

Ameliorative Measures

Although there are indications that the amount of plastic debris in the sea may be decreasing in some areas (e.g., Merrell, 1984), the effects on seals and other marine animals are so serious that consideration must be given to introducing more specific measures to alleviate the problem. This might be achieved in the long term by a combination of deliberate efforts to reduce the amount of such material that is discarded and technological changes aimed at reducing the biological threat from material that does go adrift.

The Honolulu workshop pointed out that if the amount of material discarded were to be reduced, there was a need not only for appropriate regulatory measures, but also for educational campaigns aimed at informing the crews of merchant and fishing vessels, and the general public as well, about the damage caused by plastic debris and the importance of taking whatever steps are possible to minimize it.

The fishing industry is not only a major source of the problem but is also directly affected by its consequences. It should therefore be particularly involved in steps to improve the situation.

The simplest and most important of these steps would be to reduce the throwing overboard of plastic debris of all kinds, but particularly of netting fragments, damaged nets, plastic wrapping bands and ropes. The workshop pointed out, too, that a simple procedure like cutting packing bands before discarding them could save an animal's life, since the band could no longer encircle it.

Technological advances may be possible through development of the use of biodegradable materials in fishing gear so that lost and discarded fragments will ultimately break up and cease to be a threat to marine life.

There is likely to be difficulty, however, in achieving this advance without imposing additional costs on the industry. The possibilities of further recycling net material may also merit investigation (Anonymous, 1984).

Further, there is need for much more research to provide a basis for effective measures to mitigate the effects of plastic debris. Among the problems which should be addressed are:

- more detailed assessment of the impact on seals, fish, seabirds and turtles;
- determination of the sources and distribution of debris;
- determination of the fate of this material once it enters the marine environment; and
- development of means of identifying the origins of debris found in the sea and on shore.

Potential Effects of Arctic Development

The Arctic is, without doubt, the area in which the existing possibilities of development constitute the most serious threat to the seal populations and the people dependent on them. The ringed seal is the species whose future gives rise to the greatest concern, both because of its abundance and significance to the subsistence of the Inuit, and because some features of its breeding behaviour make it particularly vulnerable.

The aspects of arctic development which seem most likely to give rise to threats to the seal populations are surface mining of minerals, petroleum exploitation and large-scale ship traffic through the ice to service either or both of the primary developments. Some effects of these developments on the hunting activities of the Inuit and on the availability of the seals to them are considered in Chapter 13. The present chapter deals with the direct effects on the seals themselves.

The Laurentian Shield extends into the Arctic as far north as Ellesmere Island, offering lead, zinc and iron prospects. A number of sites are already under lease, and there are operating lead-zinc mines on Bathurst Island and northern Baffin Island. Coal fields are being explored in the high Arctic, chiefly on Ellesmere Island. Shipping supplies and ore through Lan-

caster Sound and Baffin Bay ice could affect seals. In addition, any contamination of surface waters with the toxic heavy metals commonly associated with lead-zinc ores would eventually enter the sea and could adversely affect the seals in ways mentioned earlier in this chapter.

Petroleum exploitation appears to pose a relatively minor direct threat to the seal populations of the Arctic. However, much of the area now being explored for oil and gas lies quite close to grounds traditionally hunted by the Inuit for ringed seals (see Figure 13.4, Chapter 13), and any serious spill could have an adverse effect, even if temporarily, on the level of seal populations.

Ship transport associated with petroleum or mineral development might well constitute a greater threat to the seals than the direct risks from spills. Ice-breakers may crush ringed seals in their birthing lairs under the snow and propagate wider ice displacements, affecting habitat conditions (Boles et al., 1983; Mansfield, 1983). Full development of the Sverdrup field could involve a fleet of more than 50 tankers, with a transit of Lancaster Sound every five to 10 hours, depending on time of year (Mansfield, 1983). Based on estimates of the density of lairs in relatively stable offshore ice (e.g., Alliston and MacLaren, 1981; Finley, 1978) and the fact that ringed seals quickly colonize ice-breaker tracks, it appears that thousands of seal lairs could be crushed each season. Ringed seal pups in lairs may be particularly susceptible to such impacts.

Engine noise would be nearly continuous if a 50-vessel tanker fleet were operating. It could mask seals' vocalizations and reduce the distances over which they could communicate (Mansfield, 1983; Terhune et al., 1979; Terhune and Ronald, 1975). Ringed seals do not appear to disperse when ice-breakers pass because their winter mobility is extremely limited (Alliston, 1980, 1981), but they may eventually abandon persistently noisy areas (Freeman, 1976; Mansfield, 1980, 1983; Boles et al., 1983; Smith and Hammill, 1981; Labrador Inuit Association, 1985).

The potential effects on seals of any form of arctic development, particularly if it involves large-scale ship transport through the ice, appear to be sufficiently serious to make it important that they should be carefully examined before any decision is taken to permit development.

In the Atlantic region, there does not seem to be the same degree of concern about the potential impacts on seals from offshore oil and gas exploration and exploitation. This is because the seals in question are hair

seals and, as stated earlier, oiling of the pelage of these species has little serious effect on their survival. As well, the species found in this region do not maintain breathing holes in ice, and therefore, the potential impacts of ice-breaker traffic and oil contamination on breathing holes do not arise.

Conclusions

1. Reduction in the abundance of fish by commercial fisheries may possibly have an adverse effect on seal populations in some situations, but no such cases have been clearly identified either for seals or for other marine mammals.
2. Where commercial fisheries take fish which prey either directly on seals or on smaller fish which are eaten by seals, the impact of the fishery may actually be beneficial to the seal population.
3. Some seals are killed by becoming entangled in fishing gear either accidentally or when trying to take fish from the gear. There are no Canadian estimates of the numbers of seals dying in this way, but the limited evidence suggests that they are small compared either to some past commercial kills (harp seals) or the natural rate of increase of some populations (harp seals and grey seals).
4. There is no evidence that underwater sound pollution such as that from ships' engines or seismic sounding has at present any continuing or widespread effects on Canadian seal populations. However, if large-scale ship transport develops in the Arctic, the noise may tend to drive the seals away from the areas affected.
5. Radioactive pollution does not seem to be a serious threat to Canadian seal populations.
6. Any mercury occurring in seals in significant quantities is of natural origin, and no other heavy metals have adverse effects on seals under natural conditions.
7. The principal danger to seals in the event of a major oil spill in an area they inhabit would be to northern fur seals as a result of loss of thermal insulation because of oiling of the pelage. All other Canadian seals, which depend mainly on their blubber for insulation, seem to be much less vulnerable in this respect; however, ringed seals could be vulnerable if oil were to accumulate at their breathing holes.

8. Organochlorine compounds, mainly PCBs, and DDT and its derivatives, appear to have had serious effects on seal populations in a few areas such as the southern North Sea, southern California and Puget Sound. No evidence has been seen of significant effects on seals in Canadian waters, although organochlorine compounds appear to have killed belugas in an area of the St. Lawrence River where harp seals feed. Present indications are that the incidence of DDT is declining in some areas, but the picture for PCBs is less clear.
9. Plastic debris adrift in the oceans, particularly lost or discarded fishing nets and pieces of nets, causes the deaths of many seals, as well as the deaths of other marine mammals and birds. The most serious effects at present seem to be on the northern fur seal, and it is likely that they are the principal cause of the decline in this population since the 1960s. There is a need for active intervention to try to alleviate this problem.
10. Serious adverse effects on seals, particularly ringed seals, in the Arctic could result from development in the form of surface mining for minerals, oil/gas exploration and exploitation and, particularly, large-scale sea transport through the ice in association with these enterprises.

Recommendations

1. The Canadian government should work both domestically and internationally to reduce the amount of netting and other plastic material being discarded at sea. It should also support studies aimed at developing modifications to fishing gear which will reduce the hazard to seals and other marine life caused by the lost nets.
2. The Canadian government should not permit development in any part of the Arctic without a thorough investigation and disclosure of the potential environmental impacts on seals and sealing communities.

References

- Addison, R.F., P.F. Brodie, and M.E. Zinck. 1984. DDT has declined more than PCBs in eastern Canadian seals during the 1970s. *Environ. Sci. Technol.* 18: 935-937.

- Alliston, W.G. 1980. The distribution of ringed seals in relation to winter icebreaking activities near McKinley Bay, N.W.T., January–June 1980. Rep. by LGL Ltd. (Toronto) to Dome Petroleum Ltd., Calgary.
- Alliston, W.G. 1981. The distribution of ringed seals in relation to winter icebreaking activities in Lake Melville, Labrador. Rep. by LGL Ltd. (Toronto) to Arctic Pilot Project, Calgary.
- Alliston, W.G., and M.A. McLaren. 1981. The distribution and abundance of ringed seals in western Coronation Gulf, Prince Albert Sound and Minto Inlet, N.W.T., June 1980. Rep. by LGL Ltd. (Toronto) to Polar Gas Project.
- Anonymous. 1984. Workshop on the fate and impact of marine debris, Honolulu, 26–29 November 1984. Executive summary.
- Anonymous. 1985. Saving beluga whales next Greenpeace goal. *Globe and Mail*, 20 September 1985, p. 4.
- Bakkala R.G., V.G. Wespestad, and J.J. Traynor. 1984. Pollock. In R.G. Bakkala and L.L. Low (ed.) Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984. Northwest and Alaska Fish. Center, Natl. Mar. Fish. Serv., NOAA.
- Barker, A. 1985. Testimony before the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of the Bonavista South Development Corp. St. John's, 23 May 1985. Vol. 3, p. 561–576.
- Beverton, R.J.H. 1985. Analysis of marine mammal fisheries interaction, p. 3–33. In J. Beddington, R.J.H. Beverton and D.M. Lavigne (ed.) *Marine mammals and fisheries*. George Allen and Unwin, London.
- Bjørge, A., I. Christensen, and T. Øritsland. 1981. Current problems and research related to interactions between marine mammals and fisheries in Norwegian coastal and adjacent waters. *ICES CM 1981/N: 18*.
- Boles, B., L. Jackson, and M.A. Mackey. 1983. Breaking the ice: seal and seal harvesting patterns and benefits in relation to navigational ice breaking in Lake Melville, Labrador. Rep. by Labrador Inst. North. Studies, Memorial Univ. Newfoundland, for Dept. Develop., Gov. Newfoundland Labrador, and Dept. Regional Economic Expansion.
- Bonner, W.N. 1982. *Seals and man: a study of interactions*. University of Washington Press, Seattle.

- Bowen, W.D. 1985. Harp seal feeding and interactions with commercial fisheries in the northwest Atlantic, p. 135-152. *In* J. Beddington, R.J.H. Beverton and D.M. Lavigne (ed.) Marine mammals and fisheries. George Allen and Unwin, London.
- Brodie P., and B. Beck. 1983. Predation by sharks on the grey seal (*Halichoerus grypus*) in eastern Canada. *Can. J. Fish. Aquat. Sci.* 40: 267-271.
- Calambokidis, J., and J. Peard. 1985. Chlorinated hydrocarbons in tissues of northern fur seals from St. Paul Island, Alaska. Fur seal investigations, 1982. NOAA Tech. Mem. NMFS-F/NWC-71.
- Calkins, D.G. 1984. Steller sea lion entanglement in marine debris. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/4.
- Cawthorn, M.W. 1984. Entanglement in, and ingestion of, plastic litter by marine mammals, sharks, and turtles in New Zealand waters. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/7.
- Cooke, J.G., A.W. Trites, and P.A. Larkin. 1986. A review of the population dynamics of the northwest Atlantic harp seal (*Phoca groenlandica*). Technical Report 1, Royal Commission on Seals and the Sealing Industry in Canada. Deposited with DFO Headquarters Library, Ottawa.
- DeMaster, D.P., D.J. Miller, D. Goodman, R.L. DeLong, and B.S. Stewart. 1982. Assessment of California sea lion fishery interactions, p. 253-264. *In* Trans. 47th N. Am. Wildl. Nat. Resour. Conf.
- Engelhardt, F.R. 1982. Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, *Phoca hispida*. *Comp. Biochem. Physiol.* 72 (1): 133-136.
- Engelhardt, F.R. 1983. Petroleum effects on marine mammals. *Aquat. Toxicol.* 4: 199-217.
- Farmer, P., and A. Billard. 1985. Gear damage in the Nova Scotia inshore fishery. *Can. Industry Rep. Fish. Aquat. Sci.* 156.
- Finley, K.J. 1978. Behaviour and density of ringed seals *Phoca hispida* during haul-out in the high Arctic, June 1977. Rep. by LGL Ltd. (Toronto) to Polar Gas Project.
- Fowler, C.W. 1982. Interactions of northern fur seals and commercial fisheries, p. 278-292. *In* Trans. 47th N. Am. Wildl. Nat. Resour. Conf.
- Fowler C.W. 1985 Status review: northern fur seals (*C. ursinus*) of the Pribilof Islands, Alaska. Background paper to 28 Ann. Meet. St. Sci. Comm. of North Pacific Fur Seal Comm.

- Freeman, M.M.R. (ed.) 1976. Inuit land use and occupancy study. Minister of Supply and Services Canada, Ottawa.
- Fukuhara, F.M. 1974. Estimated mortality of seabirds, fur seal and porpoise in Japanese salmon drift net fisheries and sea lions in the eastern Bering Sea trawl fishery. NOAA/NMFS, Seattle.
- Gentry, R.L., J.H. Johnson, and J. Holt. 1976. Unpublished observations, quoted in Fur seal investigations, 1976. Northwest Fisheries Center Processed Report. National Marine Fisheries Service, Seattle.
- Geraci, J.R., and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. J. Fish. Res. Board. Can. 33: 1976-1984.
- Hammond, C. 1984. Derelict gill net reported to National Marine Fisheries Service, Alaska Region in 1983. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984: FIMD/84/BP/7.
- Harwood, J. 1983. Interactions between marine mammals and fisheries. Adv. Applied Biol. 8: 189-214.
- Hempel, G. (ed.) 1978. North Sea fish stocks and their changes. Rapp. P. -v. Réun. Cons. int. Explor. Mer 172.
- Henderson, J.R. 1984. A review of Hawaiian monk seal entanglements in marine debris. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/6.
- Hofman, R.J., and W.N. Bonner. 1985. Conservation and protection of marine mammals: past, present and future. Mar. Mammal Sci. 1: 109-127.
- Hyvarinen, H., and T. Sipila. 1984. Heavy metals and high pup mortality in the Saimaa ringed seal population in eastern Finland. Mar. Poll. Bull. 15: 335-337.
- Labrador Inuit Association. 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. St. John's.
- Lander, R.H., and H. Kajimura. 1982. Status of northern fur seals, p. 319-345. In Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. IV, Small cetaceans, seals, sirenians, and otters. FAO, Rome.
- Lavigne, D.M. 1982. Marine mammal-fishery interactions: a report from a IUCN workshop, p. 312-321. In Trans. 47th N. Am. Wildl. Nat. Resour. Conf.

- Leggett, W.C., K.T. Frank, and J.E. Carscadden. 1984. Meteorological and hydrographic regulation of year-class strength in capelin (*M. villosus*). *Can. J. Fish. Aquat. Sci.* 41: 1193-1201.
- Lien, J. 1985. Newfoundland Institute for Cold Ocean Science and Dept. of Psychology, Memorial University of Newfoundland, St. John's. Letter to C.E. Tull, Royal Commission on Seals and the Sealing Industry in Canada, 23 May 1985.
- Low, L.-L., R.E. Nelson, and R.E. Narita. 1984. Trawl fisheries and net loss off Alaska. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-1/3.
- Mansfield, A.W. 1980. Impact of oil production on marine mammals. In C.R. Upton (ed.) Proceedings of the ninth environmental workshop. Arctic Institute of North America, Calgary.
- Mansfield, A.W. 1983. The effects of vessel traffic in the Arctic on marine mammals and recommendations for future research. *Can. Tech. Rep. Fish. Aquat. Sci.* 1186.
- Merrell, T.R. 1984. Fish nets and other plastic litter on Alaska beaches. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-1/5.
- Northridge, S.P. 1984. World review of interactions between marine mammals and fisheries. *FAO Fish. Pap.* 251.
- Risebrough, R.W. 1979. Pollutants in marine mammals: a literature review and recommendations for research. Final Report for Marine Mammal Commission Contract MM7AD035. Nat. Tech. Inf. Serv. Springfield, Virginia.
- Rompkey, Hon. W.R. 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. Ottawa.
- Scordino, J. 1984. Studies on fur seal entanglement, 1981-84, St. Paul Island, Alaska. Workshop on the fate and impact of marine debris, Honolulu, 29-29 November 1984. FIMD/84/WP-II/2.
- Sergeant D.E. 1973. Feeding, growth and productivity of northwest Atlantic harp seals (*P. groenlandicus*). *J. Fish. Res. Board Can.* 30: 17-29.
- Smith, T.G., and J.R. Geraci. 1975. The effect of contact and ingestion of crude oil on ringed seals of the Beaufort Sea. Beaufort Sea Project, Tech. Rep. 5. Can. Dept. Environ. Victoria.

- Smith, T.G., and M.O. Hammill. 1981. Ecology of the ringed seal, *Phoca hispida*, in its fast ice breeding habitat. *Can. J. Zool.* 59: 966-981.
- Stander, G. 1985. Director of Sea Fisheries Research Institute, Cape Town, South Africa. Letter to J.A. Gulland, Royal Commission on Seals and the Sealing Industry in Canada, 29 May 1985.
- Stewart, B.S., and P.K. Yochem. 1984. Entanglement of pinnipeds in net and line fragments and other plastic debris in the southern California Bight. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/5.
- Swartzman, G.L., and R.T. Haar. 1983. Interactions between fur seal populations and fisheries in the Bering Sea. *Fish. Bull.* 81(1): 121-132.
- Terhune, J.M., and K. Ronald. 1975. Underwater hearing sensitivity of two ringed seals (*Pusa hispida*). *Can. J. Zool.* 53: 227-231.
- Terhune, J.M., R.E.A. Stewart, and K. Ronald. 1979. Influence of vessel noise on underwater vocal activity of harp seals. *Can. J. Zool.* 57: 1337-1338.
- Wageman, R., and D.C.G. Muir. 1984. Concentrations of heavy metals and organochlorines in marine mammals of northern waters. *Can. Tech. Rep. Fish. Aquat. Sci.* 1279.
- Wallace, N. 1984. Debris entanglement in the marine environment: a review. Workshop on the fate and impact of marine debris, Honolulu, 26-29 November 1984. FIMD/84/WP-II/1.
- Warren, C.E. 1971. *Biology and water pollution control*. W.B. Saunders Co., Philadelphia.
- Wilderness Society of Newfoundland and Labrador. 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. St. John's.



PART V

**Biological
Issues**

PART V b

**Impacts of Seals
on Fisheries**



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Chapter 24

Impact on Fish Stocks and Catches

... There is no reason to believe that the harp seal has had a serious impact on fish stocks and, therefore, fish catches, and that in fact harp seals play only a small part in competition with humans for preferred fish stocks (Hughes, 1985).

Clearly, the seal population is growing... and seals have to eat. And they consume a lot of fish. They are not eating blueberries or anything that is available on land; they are eating fish (Chapman, 1985).

Introduction

The Royal Commission's responsibilities on this topic derive from Paragraph 5 (d) and (e) of its terms of reference. These sections state:

- *the interactions between seals and commercially exploited fish populations that may affect food supplies or contribute to parasite transmission;*
- *the interaction between seal populations and commercial fisheries, including, inter alia, competition between seals and fishermen for fish stocks; interference in fishing activity by seals, including damage to fishing gear and catches; and the effects and related economic costs on the quality of fish catches caused by transmission of parasites by seals. (Emphasis added.)*

The Commission's primary concern on these matters is with the effects of predation by seals on the stocks of commercially exploited species; it is assumed that "fish" in this context includes invertebrate animals such as shrimps, which are of commercial importance, and "fish" will be used in this sense in the rest of this chapter. Of secondary concern are the effects of seal predation on species which interact with commercially important species. These effects are secondary in the sense that the effects produced by the seals on commercial stocks are indirect rather than direct; this statement should

not be taken to imply that the extent, and therefore the practical significance, of these effects will *necessarily* be less than the direct effects. There is not yet sufficient scientific information, either in the form of models relating the commercial fish stocks to other animals in their environment, or as data for use in these models, to make it possible to examine the secondary effects in a quantitative manner, although it is probably possible to predict the directions in which they will operate. This chapter, therefore, will deal principally with the primary effects of seals on fish stocks and seek answers to the following questions:

- *What do seals eat?*
The food of all species of seals consists exclusively of animals, both fish and invertebrates, although different species have different principal foods. This chapter seeks to establish the proportion of food formed by each of the important food animals, how this varies by season and locality as the seals undertake their annual migrations, and how the proportions change as the seals grow and mature.
- *How much do seals eat?*
The basic question is how much food an individual seal needs to grow, maintain itself and carry out its feeding, migrating and other activities. Females need a substantial amount of extra food to support development of the young and milk production while pups are suckled; males also have increased energy requirements in the breeding season. We also need to know how the amount of food consumed varies seasonally, locally and as the animals grow. Combining this knowledge of the food requirements of individual seals with information on the size, composition and movements of the seal population as a whole provides an estimate of the total food consumption of the seal populations for which such data are available.
- *How much of the commercially important fish species do seals eat?*
A response to this question can be formulated by combining the answers to the first two questions. If, for example, a given seal population consumed an estimated 10,000 tonnes (t) of food a year, and half their food *always* consisted of herring, it could be concluded that these seals ate 5,000 t of herring a year. Unfortunately, the answer to the question is not as simple in practice. Although there is some variation in the amount that individual seals eat, this is small compared to the variability in the species composition of their food. This variability depends primarily on the kinds of food available to the seals, which may change greatly with the season and from one area to another. To obtain an estimate of the amount of any particular fish or invertebrate consumed by

a given seal population, the data need to be subdivided as finely as possible, to take account of the amount and composition of the food eaten by particular components of the seal population at particular times. Unfortunately, the existing data of this kind are both patchy in nature and, even for the most studied species, barely adequate in quantity; for other species virtually no data exist.

- *What is the effect of the removals by seals on the stocks of commercial fish?*
- *How do these effects of seal predation on commercial fish stocks further influence the commercial catches?*

These two questions interlock so closely that they almost always have to be considered together. The size and structure of a fish population (the proportion of animals of different ages and the two sexes) depends on the number of young being produced by the parents in the previous generation, and on the rate at which the fish are dying off from a variety of causes such as fishing, predation by seals and other predators (birds, sharks, etc.), disease, and old age. If the number of fish killed by seals is reduced, perhaps because of a reduction in the number of seals, the average population will not be increased by an amount equal to the number "saved"; neither will all the saved fish subsequently be taken by the fishery. They will die off gradually, and their deaths will be distributed among all the other possible causes. The effect on the commercial catch will depend, in part, on the relative timing of the fishermen's and the seals' operations. If, for example, the seals had been taking all their share in a short period just before an intense fishery operation like some salmon gill-net fisheries, the fishery might catch most of the fish saved from the seals. If, however, the seals were taking larger fish than those taken in the commercial catch, stopping the seal take would have relatively little effect on the catch, since the fishermen have already had first chance. The extent to which any effects of seal predation on commercial catches that do occur can be detected in practice will also be influenced by the amount of natural variation in the abundance of the prey species. Some fish, such as capelin, show great variation in the number of young produced from year to year so that any effects on the catch resulting from changes in the numbers eaten by seals may well be masked.

A question closely related to those above concerns the effects which the reduction of fish stocks by commercial fisheries have on the well-being and abundance of the seal populations. This is considered in Chapters 21, 22 and 23, which deal with the status of seal stocks and human effects on those

stocks. However, the necessary basic information on seal diet and on the dynamics of fish and seal populations is the same, and it is worth remembering that interactions work in both directions.

These technical and biological questions, once answered, lead into the political question which is the basic reason for the Royal Commission's interest in this subject: should seal numbers be reduced, by a cull, for example, in order to benefit the commercial fisheries? This question is examined in Chapter 29, which takes into account other factors such as the transmission of parasites, gear damage, costs of a cull, and public attitudes towards a cull; the question will not be addressed directly here. The answers produced here to the final question asked above refer primarily to the impact of the overall consumption of fish by seals on commercial catches, and can, by dividing by the estimates of the total number of seals, be expressed as the average impact per seal. The more meaningful quantity in relation to management policy, however, is the marginal impact, that is, the change in commercial catches that would result from a given small change in seal numbers. As discussed in Chapter 29, this will not necessarily be the same as the average impact, but the calculations of total average impact provide an essential stage in the process of estimating the marginal impact.

What Do Seals Eat?

Biologists who have studied seals generally agree that they are opportunistic feeders. That is, they feed mainly on whatever animals are most abundant in the particular place and time where they are living. Their food consists mainly of small- and medium-sized fish, shrimp and other pelagic crustaceans, and squid. Only the bearded seal seems to feed largely on benthic invertebrates.

Most of the available data on the feeding habits of Canadian seals are examined in detail in Northridge (1986). The following sections summarize some of the published information about the feeding habits of the various species of seals. The available data on harp, hooded, harbour, grey and northern fur seals are summarized in tables for each species.

Harp Seal

In addition to the review in Northridge (1986), Bowen (1985) and Beddington and Williams (1979b) have provided comprehensive reviews of

the information about the composition of the food of harp seals. These reviews suggest that the feeding habits at each stage in the life history of harp seals can be summarized as follows:

- Pups (whitecoats), born in early March in the Gulf of St. Lawrence and northeast of Newfoundland, are dependent on milk; they moult and become beaters at about three weeks of age.
- Beaters fast for a period of two to three weeks while they live on the fat accumulated while suckling, and generally start feeding in late April. They then migrate north along the Newfoundland coast, feeding mainly on shrimps including the commercially important *Pandalus borealis* and euphausiids, although they also take small quantities of fish.
- During the summer, beaters and immatures (one to five years of age) live mainly off the coast of west Greenland. There they feed heavily on small crustaceans and to a lesser extent on small fish, predominantly capelin. There are regional and seasonal variations; in some years arctic cod are an important part of the food of harp seals. Immatures may take a higher proportion of capelin than do beaters.
- Capelin appears to be a major food during both the northward spring migration and the southward autumn migration along the coast of Labrador, but the number of observations is extremely limited. A variety of other species of fish are eaten. Arctic cod, not to be confused with the commercially important Atlantic cod, may be particularly important in the autumn.
- In the Gulf of St. Lawrence juveniles and older seals feed mainly on capelin during the winter, but also on other pelagic fish and crustaceans, as well as arctic cod on occasions. Records indicate that herring are taken around the Magdalen Islands in the spring (Fisher and Mackenzie, 1955; Myers, 1959).

Northridge (1986) has pointed out, however, that all these conclusions are based on only about five small samples of harp seal stomach contents, and that a single sample obtained from a group of seals, all of which are feeding on a particular prey, may lead to an overestimate of a particular prey species. Table 24.1 summarizes the published data on the stomach contents of harp seals, and examination suggests that these support only the more limited conclusions that:

- Capelin is one of the major foods of harp seals throughout their range.

Table 24.1
Summary of Feeding Data for Harp Seals

Food Species	No. of Stomachs Containing Item	Minimum No. of Samples	% of Occurrences ^a
"Winter": December through June (total 1579 + "several" stomachs)			
Flatfish (all species)	30.5	4	5.5
Witch	2.0	1	-
Plaice	1.0	1	-
Cod	4.0	3	0.7
Redfish	4.0	2	0.7
Capelin	205.5	15	37.0
Herring	196.0	8	35.3
Barracudina	1.5	1	-
Skate	1.0	1	-
Decapods (indet. spp.)	64.0	7	11.5
<i>Pandalus</i> spp.	12.5 ^b	3	2.2
Euphausiids	24.5	8	4.4
Squid	2.5	2	-
Octopus	0.5	1	-
Unidentified	27.0	2	4.8
Empty	1,024.0	21	-
"Summer": July through November (total numbers of stomachs unknown)			
Arctic cod	12+	6	c
Capelin	Often recorded	5	c
Mysids	9	5	c
Euphausiids	5	2	c
Amphipods	7	3	c

Source: Compiled by Northridge (1986) from data from Dunbar (1949), Myers (1959), Fisher and Mackenzie (1955), Sergeant (1973, 1976), and Stewart and Lavigne (1980, cited in Bowen, 1981).

- a. For 555 winter samples, excluding empty stomachs.
- b. Plus "several".
- c. Unquantifiable.

- Herring is an important food when its migrations coincide with those of the harp seals, as occurs near the Magdalen Islands in the spring.
- Crustaceans, including commercial species of shrimp, are consumed by harp seals in significant quantities, both in the Gulf. of St. Lawrence and in northern waters.
- Other commercial fish, particularly flatfish, form a small, but not negligible, part of the food in the southern (winter) range.

Attempts to specify the proportion of the diet of harp seals which are made up of particular species or groups can only be tentative and have wide ranges of possible values.

Hooded Seal

Comparatively little is known about the feeding habits of the hooded seal in Canadian waters. It generally inhabits deeper water than harp seals and is believed to dive deeper. Sergeant (1979) reports that its food includes squid, redfish, Greenland halibut, capelin and arctic cod. Pups may eat small crustacea. More data are available for Greenland, and Table 24.2 summarizes some results. Of the stomachs which were not empty, the great majority (87%–100%) contained fish, and only a very small proportion contained squid, shrimp and other crustacea. Most of the fish were large commercial species such as Greenland halibut, redfish, gadids (e.g., cod), and wolffish. Capelin were found in about 4% of the stomachs.

Harbour Seal

The harbour seal is widespread, found in cool temperature waters of all northern hemisphere oceans and in the eastern Canadian Arctic. It is generally non-migratory and lives in small localized populations with probably little mixing among them. Bonner (1979) states that it feeds on "pelagic, demersal, anadromic and catadromic fishes, cephalopods and crustacea. Gadids, clupeids, pleuronectids and salmonids are fishes of commercial importance eaten by these seals."

Spalding (1964) reported on the food of harbour seals off the west coast of Canada. He found a large number of species, mainly fish, in the stomachs of the 50 harbour seals sampled. The most frequent were salmon, octopus, squid, clupeids (herring), and rockfish. (In this chapter, the term

Table 24.2
Stomach Contents of Hooded Seals Caught in Greenland Waters
1970-1978

Stomach Contents	South Greenland 1970-78		Southeast Greenland 1970-74		Northwest Greenland 1972-78	
	No.	%	No.	%	No.	%
Fish						
Greenland halibut	13	1.0	2	0.9	278	45.3
Wolffish	28	2.3	1	0.4	49	8.0
Redfish	101	8.2	24	10.2	6	1.0
Capelin	58	4.7	1	0.4	26	4.2
Gadidae	131	10.6	1	0.4	15	2.4
Other fish	15	1.2	-	-	22	3.6
Unspecified	482	39.0	1	0.4	5	0.8
Fish total	828	67.0	30	12.7	401	65.3
Squid	6	0.5	-	-	1	0.2
Crustaceans						
Decapods	14	1.1	-	-	4	0.6
Other crustaceans	2	0.2	-	-	55	9.0
Crustacean total	16	1.3	-	-	59	9.6
Stomachs with food	850	68.8	30	12.7	461	75.1
Stomachs empty	386	31.2	206	87.3	153	24.9
Total of records	1,236	100.0	236	100.0	614	100.0

Source: Kapel (1982).

"salmon" when relating to the west coast of Canada, refers to sockeye, pink, coho, chinook and chum salmon, and sometimes the steelhead trout.) About 54% of the food was fish of commercial value, including herring, salmon, eulachon, hake, whiting, flatfish, sablefish and lingcod. Salmon and herring were the most common commercial species. Salmon was found in about 23% of the seals examined, and herring in about 11%. Unfortunately, it is not clear whether these figures refer to the percentages, by weight or volume, of the various foods in the stomachs examined, or to the percentages of seals which contained each prey. The figures probably overestimate the amount of

salmon and underestimate the amount of herring, as 88% of the samples were taken between June and October, when salmon are returning to the rivers. Herring are available to the seals mainly in winter.

Boulva and McLaren (1979) reported on the stomach contents of about 600 harbour seals in eastern Canada. In the half that contained food, the most common prey were herring (24%), squid (21%) and flounder (14%), but 14 other species of fish, crabs and molluscs were also found (Table 24.3). These percentages are described as occurrences, but appear from the text to be percentages of the total number of prey items. As in the western Canadian studies, most samples were taken in summer and autumn. It is not clear what effect this timing would have on the relation between the relative occurrence of the various fish species in the samples and in the total consumption. The data of Boulva and McLaren include 201 stomach contents from the Atlantic coast which were originally reported by Fisher and Mackenzie (1955). In this sample the percentages by volume of the most frequent foods were herring (37%), winter flounder (13%), hake (8%), gaspereau and squid (each 7%).

It is evident that the harbour seal is an opportunistic feeder, varying its diet from time to time and place to place according to local abundance and availability of the species on which it feeds. In these circumstances, it is not possible to make any useful generalizations concerning the proportion of its total food which is composed of any particular prey species, but it is evident that in most areas much of its food will consist of common pelagic and demersal (bottom-dwelling) fish which are also of interest to commercial fishermen.

Grey Seal

The grey seal is common on the west coast of Europe, as well as on the east coast of Canada, and it has been studied quite extensively in Europe because of the damage it is reputed to do to the salmon fishery. The most recent review of Canadian data on the food of grey seals is by Mansfield and Beck (1977), who incorporated material used by Fisher and Mackenzie (1955). Their tabulation of the results of the examination of 446 stomachs, of which 207 contained food, is reproduced in Table 24.4. These data relate only to frequency of occurrence. The average number of species found in a single seal stomach is approximately 1.5, so that it appears that few seals would contain more than one or two prey species at one time. The data give no direct information on the quantities of the various species present in the stomachs, although the small number of species per stomach may imply a

Table 24.3
Summary of Atlantic Data on Harbour Seal Feeding

Food Species	Fisher and Mackenzie (201 stomachs)		Boulva and McLaren (279 stomachs ^a)
	No. of Stomachs	% of Volume	% of Occurrence
Smelt	7	2	3.7
Shad	2	2	0.8
Gaspereau (Alewife)	5	7	6.8
Winter flounder	37	13	-
Smooth flounder	3	trace	-
Unidentified flatfish	14	5	14.1
Cod family	13	2	-
Cod	-	-	2.1
Haddock	10	2	1.8
Pollock	-	-	1.1
Hake	28	8	6.0
Ocean pout	-	-	0.7
Walffish	-	-	0.6
Sand lance	-	-	2.9
Redfish (Rosefish)	4	1	1.9
Sea raven	-	-	0.6
Cunner	-	-	0.9
Morone	-	-	0.4
Capelin	-	-	2.9
Herring	64	37	24.2
Mackerel	-	-	3.6
Selachian egg cases	-	-	0.8
Crab	-	-	1.0
Shrimp	7	1	2.2
Limpet, Scallop & Clam	-	-	0.3
Squid	82	7	20.6
Unidentified fish meat (not herring)	42	13	-
Empty	87	-	-

Source: Fisher and Mackenzie (1955), Boulva and McLaren (1979).

a. Containing food.

Table 24.4
Food Items from 446 Grey Seal Stomachs Sampled in Atlantic Canada

Species	No. of Times Occurring	Percentage Occurrence
Fish		
* Herring, <i>Clupea harengus</i>	48	15.9
* Cod, <i>Gadus</i> spp.	35	11.6
* Flounder, Pleuronectidae	30	9.9
* Skate, Rajidae	29	9.6
* Mackerel, <i>Scomber scombrus</i>	15	5.0
* Hake, <i>Merluccius</i> spp. and <i>Urophycis</i> spp.	8	2.6
* Salmon, <i>Salmo salar</i>	5	1.7
* Smelt, <i>Osmerus mordax</i>	4	1.3
* Shad, <i>Alosa sapidissima</i>	4	1.3
* Lumpfish, Cyclopteridae	4	1.3
Sand lance, <i>Ammodytes</i> spp.	3	1.0
Skate egg case, Rajidae	3	1.0
Cunner, <i>Tautogolabrus adspersus</i>	2	0.7
* Capelin, <i>Mallotus villosus</i>	2	0.7
Sculpin, Cottidae	2	0.7
* Wolffish, <i>Anarhichas</i> spp.	2	0.7
* Salmon eggs, Salmonidae	1	0.3
* Haddock, <i>Melanogrammus aeglefinus</i>	1	0.3
* Pollock, <i>Pollachius virens</i>	1	0.3
Prickleback, Stichaeidae	1	0.3
Dogfish, Squalidae	1	0.3
Unidentified fish	43	14.2
Invertebrates		
* Squid, unidentified spp.	17	5.6
• Shrimp, unidentified spp.	8	2.6
* Rock crab, <i>Cancer</i> spp.	7	2.3
Gastropoda	4	1.3
Clam, unidentified spp.	3	1.0
Polychaeta	3	1.0
Sipunculida	2	0.7
* Lobster, <i>Homarus americanus</i>	1	0.3
Spider crab, Maiidae	1	0.3
* Mussel, Mytilidae	1	0.3
Seaweed, algae	6	2.0
Mud, clay, stones	5	1.7
Empty	239	

Source: Mansfield and Beck (1977).

• Of commercial importance.

fairly close relationship between frequency of occurrence and quantities eaten, at least for the more important prey species. Concerning the occurrence of flounders in the table, Mansfield and Beck (1977) note that this term includes at least seven species; the two most commercially important species, plaice and witch, were not found in 11 stomachs from the Magdalen Islands, and the species most frequently recorded was winter flounder, which is of minor commercial importance. The number of species consumed by grey seals is considerable, but in this sample, five species of fish (herring, cod, flounder, skate and mackerel) contribute over 50% of the occurrences. The species marked with an asterisk are those of some commercial importance, and it is evident that they constitute a very large proportion of the food of at least this sample of Canadian grey seals.

More data on the food of the grey seal are available from the eastern Atlantic. Table 24.5 summarizes the results of studies of the food of the grey seal at four localities round the British Isles (SMRU, 1985) and round Iceland (Hauksson, 1984). These data clearly illustrate two points. The first is that,

Table 24.5
Percentage Composition of Food of Grey Seals in Eastern Canada,
at Four British Localities, and at Iceland

	Eastern Canada	Donna Nook	Farne Islands	Isle of May	Orkney Islands	Iceland
Demersal ^a	49.8	63.9	65.0	82.2	18.8	66.1
Pelagic ^b	37.2	0.6	-	-	-	5.7
Sand lance	1.0	28.7	32.9	14.9	80.4	5.4
Others	13.0	6.8	2.0	2.9	0.8	22.8

Source: Canada: Mansfield and Beck (1977). United Kingdom: SMRU (1985).
Iceland: Hauksson (1984).

- a. The principal demersal species in the British Isles and Iceland are cod, flatfishes, whiting, saithe and haddock.
- b. The principal pelagic species in the British Isles and Iceland are herring and mackerel.

in many cases, a large proportion of the food of grey seals consists of commercially exploited demersal fish species; the total range is 19%–82%, but the low figure applies to an area where sand eels (sand lance) are clearly abundant, and in the other four areas the range is 64%–82%. The second point that the data illustrate is the great variability from place to place in the composition of the food. The Canadian data are also summarized in Table 24.5. While the total proportion of commercially important species (demersal and pelagic) is again very large (87%), the data include a higher proportion of pelagic species than do the data for grey seals taken in European waters (37%).

Northern Fur Seal

This seal is confined to the north Pacific Ocean and the Bering Sea. Because of its commercial value and the fact that its management was under the control of the North Pacific Fur Seal Commission, it has been studied extensively. It feeds on a wide variety of pelagic fishes and squids. Kajimura (1984) recorded 63 species in stomach samples. Like most seals, it appears to be an opportunistic feeder, and its principal prey varies greatly with time and season (Lander and Kajimura, 1982). Fur seals migrate south from their breeding grounds in the Bering Sea and appear off the B. C. coast only during the winter and spring (December–June). Spalding (1964) reported on the stomach contents of over 2,000 fur seals taken in B. C. waters. Herring was the dominant food found, making up nearly 50% of the total; of the remainder, squid was the most important (20%). Salmon accounted for less than 10%.

Perez and Bigg (1985) examined over 18,000 fur seal stomachs taken at sea throughout the species' range. Like Spalding, they found that herring was the dominant food on the B.C. coast, making up 43% by volume of stomach contents, weighted by calorific value. Squid and salmon each made up about 20% of the weighted volume; most of the salmon was found in seals taken offshore. A number of fish species of commercial importance, including pollock, Pacific cod, whiting and sablefish were also found in smaller amounts (up to 5%). Table 24.6 lists the principal species found in the stomachs of fur seals by Perez and Bigg (1985); those of importance off British Columbia are marked with an asterisk.

Table 24.6
Food Composition from Stomachs of Northern Fur Seals^a

Prey	Number of Occurrences as the Only Food Item	Percent
Pacific sand lance	517	84.5
* Pacific herring	686	69.3
Walleye pollock	401	68.7
Threespine stickleback	65	68.4
Northern anchovy	771	66.8
Capelin	708	66.7
Rockfishes	210	61.8
* Salmonids	228	50.2
Pacific whiting	296	48.9
American shad	32	47.1
* Eulachon	50	44.2
Onychoteuthid squids	164	41.1
Atka mackerel	54	39.7
Jack mackerel	27	36.5
Flounders	23	32.5
* Sablefish	40	30.8
* Market squid	83	26.3
Pacific saury	86	26.0
Myctophiform fishes	15	21.1
<i>Gonatopsis borealis</i> (squid)	121	21.1
* <i>Beryteuthis magister</i> (squid)	98	20.2

Sources: Perez and Bigg (1985, Table 2).

- a. Percentage of the total number of occurrences of each important prey species ($N > 50$) in which the food item was the only food item found in stomachs of northern fur seals.
- * Of commercial importance in B.C. waters.

Sea Lions

Two species of sea lions are found on the Canadian west coast. The population centre of the California sea lion is on the southern U.S. west coast, but about 4,500 males enter Canadian waters, mainly in fall and winter; 5,000 to 6,000 Steller sea lions inhabit Canadian territory throughout the year.

Spalding (1964) reported on the stomach contents of 393 Steller sea lions taken off the B.C. coast. Like the harbour seal, this sea lion feeds mainly inshore, and the broad range of food found in the stomachs of the two species is similar. The dominant food of Steller sea lions appears to be octopus (20%). A variety of commercial fish accounted for just over 50%, including herring (10%), salmon (6%), hake and several other species. The percentage of commercially important species eaten depends on what is available at the time and place where the sea lions are feeding. Sixteen in a sample of 29 Steller sea lions collected in Barkley Sound on the lower B.C. coast, a herring spawning area, contained herring in their stomachs. The small proportion of salmon that Spalding reported may not represent the extent to which sea lions eat salmon, since few of his samples were taken during the period of the principal salmon runs through inshore waters. Three out of a sample of four taken in July and August, when salmon were running, contained salmon.

Dr. M.A. Bigg (1985) provided data on the composition of the food of Steller sea lions along the B.C. coast during fall and winter, obtained by examination of scats at hauling-out places. Roughly 50% of the food consisted of herring, with the remainder comprising approximately equal amounts of dogfish, hake, salmon, eulachon and squid. Other species such as pollock, anchovy, skate and rockfish occurred in minor amounts. There are major variations, however, in the food consumption from place to place and time to time, depending on the movements of other prey species, particularly salmon and herring.

The combined observations of Spalding (summer) and of Bigg (winter) suggest that herring could make up about 30% of the diet of Steller sea lions.

Bigg also advised that visiting California sea lions ate essentially the same foods as Steller sea lions in winter.

Northern Elephant Seal

The numbers of northern elephant seals visiting the B.C. coast are probably too small to have any impact on commercial fish stocks. Le Boeuf (1979) states that it "feeds near shore and offshore to a depth of 100 fathoms . . . species include bottom and mid-water fishes, skates, rays, ratfish, small sharks, squid, Pacific hake."

Bearded Seal

The bearded seal is essentially an arctic species which lives in shallow water near the pack ice (Stirling and Archibald, 1979). As a result its feeding habits have no significant impact on commercial fisheries. Bearded seals eat a great variety of food in shallow water, including demersal fish and invertebrates (Davis et al., 1980).

Ringed Seal

The ringed seal is even more of an arctic species than the bearded seal, as it keeps open breathing holes in the ice during the winter and does not have to retreat southwards with the pack ice. Davis et al. (1980) reviewed data on its feeding habits and reported a great variety of both fish and invertebrates in ringed seal stomachs. Davis et al. quote Lowry et al. (1978) that "it appears that food consumed by ringed seals at any given place and time will consist of the most abundant and suitable species." Since there are no significant commercial fisheries within its area of distribution, it has no appreciable impact on catches.

The seal species which are likely to have sufficient potential impact on commercial fisheries to merit further discussion in this chapter are harp, hooded, harbour, grey and northern fur seals, and both species of sea lions.

How Much Do Seals Eat?

Although the kind of food a seal eats depends on the species of seal and on the kind of prey animals available at any particular place and time, the amount it eats in a day is much less variable. A seal, like any other animal, requires food to provide the necessary energy to maintain its bodily processes, to grow, to undertake activities such as swimming, fishing and

migrating, and in the case of females, to develop and suckle its young. The energy required, relative to size, varies little between species of seals, or indeed between seals and other mammals (Lavigne et al., 1985). Any differences probably result from differences in such factors as sexual activity, the amount of swimming the animals do, and the temperatures in which they normally live. Species such as northern fur seals and harp seals that make long migrations may spend more energy than localized species such as harbour seals. Animals living in cold water, such as bearded and ringed seals, and harp and northern fur seals at the northern end of their migrations, may need more energy to maintain their body temperatures than more southern-dwelling species such as harbour and grey seals. Young seals of all species are still growing rapidly and need more energy than older animals which only have to maintain a steady body weight. Actively breeding males (Anderson and Fedak, 1985) and female seals which are pregnant or suckling young (Fedak and Anderson, 1982) need substantial amounts of additional energy over their normal individual requirements. None of the evidence seen by the Royal Commission suggests any other differences in the amounts of food consumed by different species of seals, except as a consequence of their size differences, as discussed later in this chapter. We shall therefore pool the available evidence on all species to develop an estimate of the amount of food consumed by seals of any species.

The amount of food that individual seals eat in a day can be estimated in three ways:

- Measure the amount of food in the stomachs of wild seals when killed, and multiply this by the number of "meals" taken in a day.
- Find the amount of food required to keep captive seals healthy.
- Examine experimentally the amount of energy, measured in kilocalories (kcal), which seals and related animals require to maintain their activities, and determine the amount of food needed to provide this energy.

Each approach yields useful information, and the results of all three are reasonably consistent.

Stomach Contents and Rate of Digestion

Boulva and McLaren (1979) reported on the weight of the stomach contents of 25 harbour seals from eastern Canada. Despite great individual

variation, the average contents were about 4% of body weight in small seals and 3% in large seals. Boulva and McLaren fitted to their data the regression equation:

$$\text{food weight} = 0.089 (\text{seal weight})^{0.76}$$

Weights were in kilograms. As their studies also showed that the seals fed during the night and usually rested on shore during the day, they assumed that the average stomach contents of animals killed in the morning represented one daily meal. The above relation was apparently obtained by fitting a functional regression (Ricker, 1975) to their observed data. The fact that the value of the exponent (0.76) is the same as that commonly used to describe the relation between the basic metabolic energy requirement and body weight in many mammals seems to be coincidental, although somewhat similar values should be expected.

Sergeant (1973) records the highest percentage weight of food in the stomach of an unspecified sample of harp seals as 4.7% in both an adult and a young seal. He provides no evidence on frequency of feeding during the day. Spalding (1964) reports the maximum percentage weights of stomach contents found in harbour seals and northern fur seals as 11% and 10% respectively; in the Steller sea lion, a much larger animal, the maximum percentage found was 2%. The variability of the data and the uncertainty as to how accurately the average stomach contents represent daily food consumption make it difficult to estimate accurately the average daily food consumption in this way. Few data have been published on the variability of the stomach contents, but the root mean square of the deviation from regression of Boulva and McLaren's data is about 1.3% of body weight. The mean stomach contents are also likely to be an underestimate of daily food consumption unless the animals take all their food within a short time and are killed and examined immediately afterwards. Otherwise, food already digested or food that would have been eaten later in the daily cycle is not measured. Spalding (1964) found evidence that northern fur seals and Steller sea lions feed almost entirely at night, as do harbour seals (Boulva and McLaren, 1979). Spalding's report does not make clear, however, whether harbour seals on the west coast had similar feeding patterns.

Captive Seals

There are considerable data on the amounts of food supplied to captive seals. Boulva and McLaren (1979) collected information from a number of institutions where seals were kept in captivity, and they pointed out that

some captive seals are "obviously overfed", and that it is necessary to select institutions where the animals were given just enough food to "satisfy the needs of a moderately active seal". Using data from six facilities selected on this basis, they found feeding rates for harbour seals ranging between 2.6% and 5.5% of body weight per day, with a mean of 4.6%. They note that some seals were receiving less than the amount predicted by their regression formula, but on average they received 25% more. Spalding (1964) quotes Scheffer (1958) as recording daily diets for harbour seals of 6% of body weight. Havinga (1933) found that the average stomach contents of adult harbour seals weighing about 100 kilograms was about five kilograms; his experiments with marked food indicated that this represented the daily intake. He also found that the rate of intake of 5% of body weight a day was consistent with observations of captive animals.

Some data are also available for other species of seals. Geraci (1972) found that young harp seals fed on herring required 6%–8% of body weight per day, and Bonner (1982) quotes Geraci (1975) as stating that adult harp seals consumed 4%–7% a day. Spalding (1964) quotes Scheffer (1958) as giving the daily food intake of northern fur seals and Steller sea lions as 7% and 2% respectively. Ronald et al. (1984) quote ICES (1981) as giving the food requirements of grey seals as 3%–5% of body weight per day. California sea lions at the London Zoo consume some 5%–10% of body weight per day, but these include rapidly growing young animals (Gulland, 1986).

These results indicate that most seals in captivity can remain healthy and active on a diet of about 4%–6% of body weight a day. The data are not suitable for attempting to examine the relation between the rate of feeding and the size of the seal. It is less clear whether the seals in these experiments were maintaining normal growth or the amount of activity required of a seal in the wild. Bigg (1985) reported that female northern fur seals kept in tanks and swimming actively consumed about 6% of body weight per day. He stated that fur seals kept in tanks large enough to allow them to swim actively appear to maintain about the same level of activity as they would under natural conditions. In contrast to the above, Nightingale (pers. comm. to Bonner, 1982) found that northern fur seals kept in large tanks required 26%–27% of body weight a day to maintain normal body growth. The discrepancy with the results of other observers seems remarkable, but no evidence is available as to whether these animals appeared overfed.

Energy Requirements

Study of the energy requirements of seals as a means of estimating their food requirements is complex, but has two major potential advantages. In the first place, it should lead to a better understanding of the processes involved, and of any fundamental errors which may arise in approaching the problem. Secondly, because of the general nature of the processes, it may be possible to make use of data which have been obtained from study of other mammals. Its major disadvantage is that such studies generally require long-term and continuing detailed observations of the food consumption, excretion, activity and so on of seals kept under carefully controlled conditions.

Lavigne et al. (1982, 1985) have reviewed the work which has been done on the energy requirements of seals and the relation to the food consumed. The available data indicate that about 67%–75% of the energy in the food consumed by a seal is available to support basal metabolism, activities, growth and reproduction. The remainder is lost in faeces, urine and other waste products, and in waste heat. The data suggest that the energy required by resting seals for their basal metabolism does not depart greatly from a formula applied to mammals in general by Kleiber (1975). This is:

$$M = KW^{0.76}$$

where, if M is basal metabolism in kilocalories/day, and W is the weight of the seal in kilograms, then K , a species-specific growth constant, equals 70. Lockyer (1985a) used a similar equation with the same multiplier and an exponent of 0.7325 for grey seals. This relation means that the amount of food required increases more slowly than the weight of the seal; for instance, if the weight is doubled, the food requirement increases 1.69 times, and if the weight is quadrupled (e.g., from 50 kg to 200 kg) the food requirement increases 2.87 times.

The problem in applying this relationship to seals in natural populations is that animals in the wild require energy for purposes additional to basal metabolism; these purposes include: swimming (for feeding and migration), growth, reproduction (Anderson and Fedak, 1985; Fedak and Anderson, 1982), and temperature regulation. Thus if Kleiber's relation is used to estimate the energy requirements of wild seals, K must be given a value substantially higher than 70.

Lavigne et al. (1985) examined the results of laboratory experiments measuring the energy requirements of seals which were not under the restricted conditions leading to $K = 70$. They found that many of these obser-

vations fitted to curves for $K = 140$. Most of the animals observed were active, but were neither growing nor reproductively active.

Innes et al. (1985) reviewed a large amount of data on the energy and biomass requirements of seals and other marine and terrestrial mammals. They concluded that "rates of food consumption by marine and terrestrial mammals do not differ significantly when comparisons are made under appropriate standardized conditions." They also found that estimates of the daily energy requirements of many animals, including seals, fell "within the expected range of 1.5 to 3.0 times the basal metabolic rate predicted for mammals by Kleiber's equation": that is, $K \approx 105-210$. Lockyer (1985a, 1985b) reviewed the available data on the energy requirements of harp and grey seals (kcal/day) when provision is made for activity and reproduction. Her results may be summarized as follows:

	Grey Seal	Harp Seal
Breeding bull	19,000	11,000
Breeding cow	14,000	10,000
Pup	5,500	4,000
Mature male	12,376	
Mature female	9,464	

Lavigne et al. (1982) used the population model of Benjaminsen and Lett (1976) to calculate the average individual energy intake (without allowing for growth or reproduction) of the northwest Atlantic harp seal herd. They obtained a value of 6,050 kcal/seal/day.

Fedak and Hiby (1984) calculated the energy requirements of the U.K. grey seal herd, taking account of activity, growth and reproduction, and obtained an average figure of 5,860 kcal/seal/day. These workers used a linear function relating energy requirement per kilogram of body weight with age, rather than a Kleiber-type relationship.

These estimates of daily energy requirement and the approximate body weights of the animals have been used to calculate the corresponding values of K given in Table 24.7, together with observations by Lavigne et al. on basic metabolic rates. The table also includes the value of K used by Antonelis and Perez (1984) for female northern fur seals (converted from a value of M measured in megajoules in the original).

These values of K cover a wide range (105–375, excluding that for basal metabolism only). The differences arise not only from possible biases in some estimation techniques, but also from differences in the species, age, growth rate and reproductive condition of the animals examined. It seems likely that a representative value of K to be applied to calculations for a seal population as a whole would be in the range of 200–300.

Some researchers have also addressed the question of whether the energy requirement of a single population could change in a density-dependent manner, through such factors as effects on growth rate and age at maturity. There does not appear to be agreement at present as to whether such changes would occur, or in which direction they would operate (Brodie and Päsche, 1982; Winters, 1975). However, any effects of this kind are negligible in relation to the uncertainties still existing in the estimates of total population energy requirements.

Conversion of Energy to Food Requirements

Calculating the approximate amount of food consumed from estimates of energy requirements requires information on the energy content of the prey. Data on energy values have been tabulated by Lavigne et al. (1982, Table 3), McConnell et al. (1984, Table 6.3), and Perez and Bigg (1985, Table 3). The values in kcal/g wet weight of flesh range from 2.0 to 2.2 for oily fishes like herring, to about 0.8 to 1.0 for fish like cod; both shrimp and squid have values of about 1.2–1.3. Many fish, however, have substantial seasonal fluctuations in energy value as they go through their annual cycles. Among other factors which affect the amount of energy obtained by the seal from prey are the amount of inedible material (high in shrimps, for example) and the size of prey (seals may swallow small fish whole, but discard heads and other parts of large fish).

Assuming the weight of the seal, the energy content of the prey, and the value of K in the Kleiber equation, it is possible to calculate daily food consumption as a percentage of seal body weight. A range of results is shown in Table 24.8. The percentages, particularly for $K = 200$ and 300, are quite consistent with estimates based on direct observation.

Lockyer (1985a) reviewed direct data and energy considerations to conclude that the daily food requirement of grey seals is probably 5%–6% of body weight, but emphasized that the energy content of the food affects this value.

Table 24.7
Available Estimates of the Value of the Constant K in the Kleiber Equation

Species	Category	Approx. Mean Weight (kg)	Daily Energy Consumption (kcal)	K	Source
Harp	Population model	80	6,050	216	Lavigne et al. (1982)
Harp	Breeding bull	135	11,000	264	Lockyer (1985b)
Harp	Breeding cow	120	10,000	263	Lockyer (1985b)
Harp	Pup	35	4,000	268	Lockyer (1985b)
Grey	Population	135	5,860	141	Fedak and Hiby (1984)
Grey	Breeding bull	212	19,000	324	Lockyer (1985b)
Grey	Breeding cow	147	14,000	315	Lockyer (1985b)
Grey	Pup	50	5,500	281	Lockyer (1985b)
Grey	Mature bull	212	12,376	211	Lockyer (1985b)
Grey	Mature cow	147	9,464	213	Lockyer (1985b)
Northern fur	Mature females	35	-	375	Antonelis and Perez (1984)
General seals	Basal metabolism	-	-	70	Lavigne et al. (1982)
	Active in captivity	-	-	140	Lavigne et al. (1985)
General mammals	Daily energy requirement	-	-	105-210	Innes et al. (1985)

Table 24.8
Calculated Daily Food Consumption as Percentage of
Body Weight^a

Weight (kg)	Energy Conversion Factor (kcal/g)	K in Kleiber Equation		
		100	200	300
100	0.8	3.9	7.9	11.9
	1.4	2.3	4.5	6.8
	2.0	1.6	3.2	4.7
200	0.8	3.3	6.6	9.9
	1.4	1.9	3.8	5.7
	2.0	1.3	2.7	4.0
300	0.8	3.0	6.0	9.0
	1.4	1.7	3.4	5.1
	2.0	1.2	2.4	3.6

a. Calculated for a range of body weights, prey energy contents, and values of *K* in the Kleiber equation.

Following these results the daily rates of consumption used in estimating the total food consumption of seal populations will be 6% of body weight for the smaller seals such as harbour seals and female and juvenile northern fur seals, and (scaled down roughly in inverse proportion to the 0.25 power) 5% and 4% for the larger species. For the relatively small northern fur seals which visit Canadian waters the figure of 6% may be disproportionately low, but since, as will become apparent, no significant impact is involved, 6% will be used for all the smaller seals.

In calculating estimates of the total food consumption of seal populations, the main uncertainties lie in the size of the seal populations, the energy requirements of individual seals and the energy content of prey species. Each of these estimates is subject to error, but the extent of this error is not known, and it is impossible to give precise confidence limits. If we assume,

as a rough generalization, that the confidence limits for each of these three factors are likely to be about $\pm 25\%$ of the true value, and that the errors are independent, then a simple model would calculate the confidence limits for the estimates of total food consumption as:

$$3 \times 0.25^2 \times 100 = \pm 43\%.$$

Considering the uncertainties in the confidence limits of the individual factors, combined confidence limits of $\pm 40\%$ seem appropriate.

How Much of the Commercially Important Species Do Seals Eat?

Total Food Consumption by Species

The first stage in calculating the annual amount of each prey species consumed by each species of seal is to estimate the total food consumption of that seal population as the product of the number of animals in the population and the average food consumption per seal. These calculations, for the species of seals which are of significance in this Report, are set out in Table 24.9. Ideally, such calculations should be done with structural population models, taking into account the effect of such factors as growth and reproduction on each age group. The Commissioners do not believe, however, that sufficient information is available even for such relatively well-studied species as the harp seal and northern fur seal for this to be done effectively. To attempt to do so might only give a spurious appearance of accuracy to the results.

There is evidence for harp (Sergeant, 1973), grey (Parrish, 1979; Ling, 1969) and harbour (Venables and Venables, 1955) seals that the animals may fast for periods of several weeks during the moulting and whelping seasons. During these times energy is still being consumed, at least for basal metabolism, and the animals lose condition. Subsequently, however, an additional food intake is required to restore their reserves. No allowance is therefore made for these fasting periods in the calculations in Table 24.9.

Table 24.9
Estimated Total Annual Food Consumption of Canadian Seal Herds

Species	Present Population ^a (1000s)	Mean Wt. (kg)	Daily Consumption (%)	Total Food Consumption (1000 tonnes)
Harp	2,000	80	6	3,500
Hooded	300	350	4	1,5000
Harbour:				
East coast	13	60	6	17
West coast	45-60	55	6	54-72
Grey	70	190	5	240
Northern fur:	870	M 180	5	1,800
Total Pribilof herd		F 35	6	
Off B.C. coast	20-30 (5 months)	26	6	4.7-7.1
Steller sea lion	4.8-6.6	M 350 F 150	4 5	19-26
California sea lion	4.5	180	5	6
Off B.C. coast	(5 months)			

a. From Chapter 21 and 22.

The values used in Table 24.9 for the population size and mean weight of the northern fur seal require special mention. They make allowance for the fact that only part of the population spends only part of the year off the B.C. coast and thus has an impact on Canadian fish stocks. The adult males remain throughout the year in northern waters, but the younger animals (one to four years) and the females of all ages undertake extensive southward migrations, mostly within 130 kilometres of land (United States, 1985). It is during these migrations that they enter Canadian waters. The

younger animals appear in Hecate Strait and other inshore waters about January and remain there until about the end of May. The main herd of the older females remains farther offshore, and the animals migrate farther along the U.S. coast, many as far as California. In April the main herd is off British Columbia on its northward journey and the young animals move out of the inshore waters to join it. By June only a few late migrants are left (Spalding, 1964). Antonelis and Perez (1984) give the results of a number of counts of northern fur seals off the coasts of Washington, Oregon and California. For Washington, the state nearest to British Columbia, the average count for the months January to May, when fur seals were abundant, was 68,000 animals. Bigg (1985) believes that the number on the B.C. coast is perhaps about 20,000–30,000 animals, and this figure has been used in Table 24.9. The mean weight is the weighted mean of the values given by Antonelis and Perez (1984) for the months January to May off the Washington coast.

On the Atlantic coast, it is important when assessing the impact of consumption by seals on the fishery, to examine the local distribution of the seals and of the fishing activities. For this purpose the northwest Atlantic–Davis Strait area adjacent to the Canadian coast has been divided into six areas (Figure 24.1) based on the North Atlantic Fisheries Organization (NAFO) subdivisions.

In Table 24.10 the total food consumption by each species of seal, as given in Table 24.9, has been subdivided between these areas, on the basis of what is known of the distribution and migration of each species.

For the distribution of harp seal food consumption among these areas, the Royal Commission is indebted to Dr. W.D. Bowen. Using the following assumptions:

- there is a lactation period of 12 days during which mothers fast;
- mothers represent 25% of the adult population;
- all animals aged one year and older fast for 14 days during the annual moult;
- age groups one to five years (juveniles) comprise 55% of population;
- harp seals spend equal amounts of time north and south of the 2H–2J NAFO line;

Figure 24.1
Areas Used in Discussion of Fish Consumption by Seals

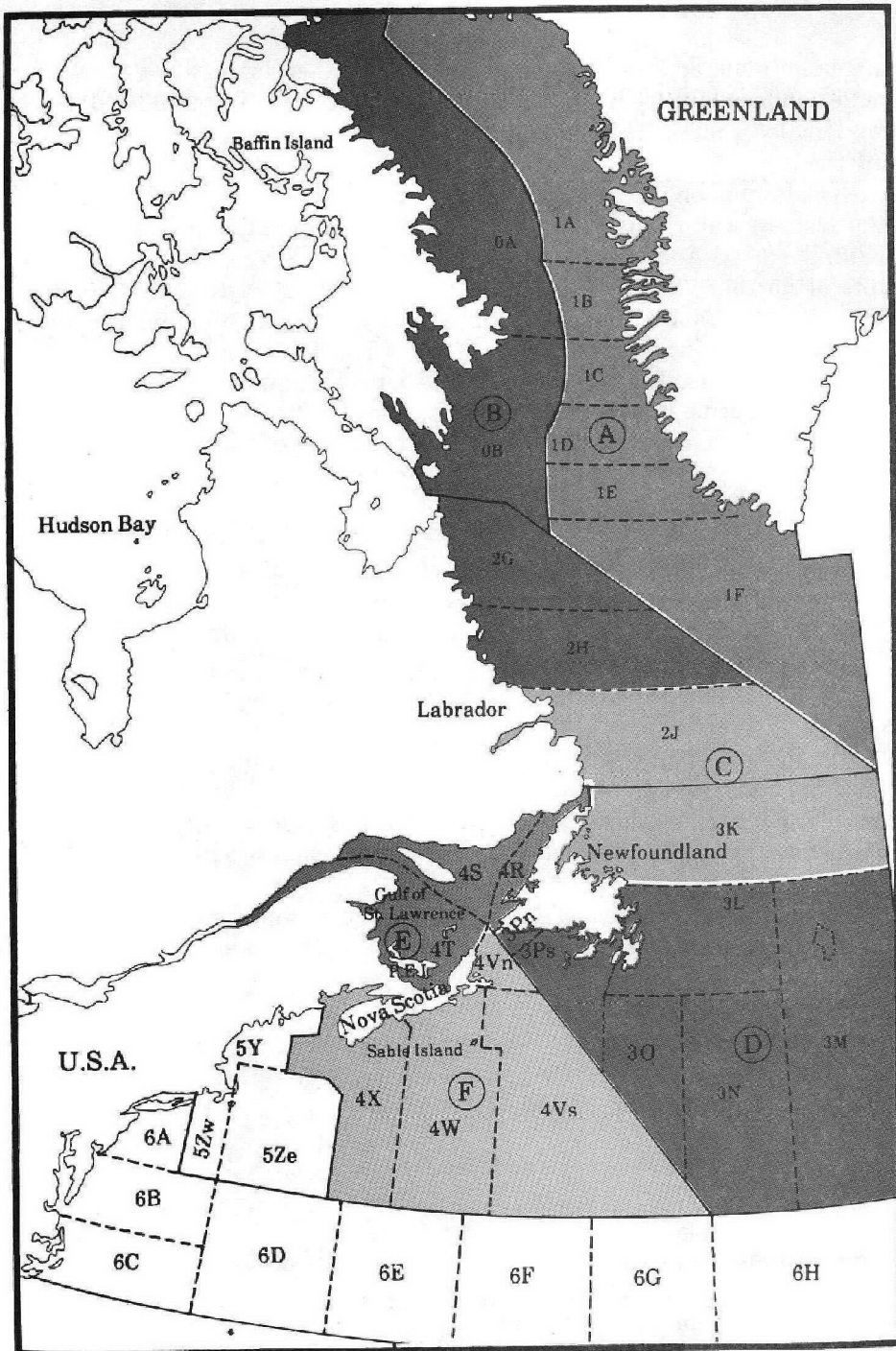


Table 24.10
Estimated Total Food Consumption by Species in the Principal
Atlantic Fishing Area

Areas	NAFO Subdivisions	Seal Consumption (1000 t)				Total
		Harp	Hooded	Grey	Harbour	
A: W Greenland	1 A - F	1,200	500	-	-	1,700
B: N Canada	0,2 G - H	1,000	500	-	-	1,500
C: S Labrador/ NE Nfld.	2 J, 3 K	800	500	-	-	1,300
D: SE Nfld.	3 L - P	250	-	24	2	276
E: Gulf	4 R - T	250	-	130	8	388
F: Scotian Shelf	4 V - X	-	-	86	7	93
Total		3,500	1,500	240	17	5,257

- about 75% of juveniles and 25% of adults summer off west Greenland;
- about 20% of juveniles remain off west Greenland in winter (see Larsen, 1985);
- one-third of adult males and females feed in the Gulf of St. Lawrence, as well as 20% of the juveniles which migrate south;
- the remainder feed at the Front;
- all animals migrate along the Labrador coast (2GH) before crossing Davis Strait or Hudson Strait and return along the Labrador coast in the fall;
- food requirements are independent of body size (not a very good assumption); and
- the caloric value of food is the same in all areas.

Bowen (1986) calculated the approximate percentage distribution of harp seals in each area to be:

Area	%
A	34.0
B	29.0
C	22.5
D	7.5
E	7.0
F	0.0

These figures are consistent with the estimate of Northridge (1986) that 62% of the food of harp seals is taken in the summer, when they are predominantly in Areas A and B, and 38% in winter when they mainly occupy Areas C to F. The distribution within the latter areas is also similar to that shown on the map published by Northridge (1986).

The allocation of hooded seals among areas is based, in the absence of better information, on the assumption that their feeding activities are equally distributed among the three northern areas, which are the only ones in which they occur in significant numbers.

For grey and harbour seals the allocations have been based on available information about the distribution of the species, taking into account the relative extent of the coastal seas within each of the southern areas. The small northern populations of harbour seals, and of grey seals in summer, have been ignored.

Table 24.11 compares the estimated total seal consumption in each of these areas with recent total and Canadian commercial catches. It is apparent that, although both harp and hooded seals feed heavily in Areas A and B, the Canadian catches in them are extremely small. Unless there is a very substantial increase in Canadian fishing effort in these areas, it does not seem likely that any change in the seal populations would have any significant effect on those Canadian catches. In Areas C to F, on the other hand, there are major Canadian fisheries, and the significance of any impact requires further examination.

Table 24.11
Comparison of Total Seal Consumption with Total and Canadian Commercial Catches

Area	Total Seal Consumption (1000 t)	Commercial Catch (1000 t)		Percentage Composition of Catch				
		Total	Canadian	Cod	Haddock	Redfish	Herring	Prawn
A	1,700	117	-	45	-	-	-	31
B	1,500	19	5	-	-	-	-	42
C	1,300	369	320	46	-	-	-	-
D	276	189	96	49	-	27	-	-
E	388	294	285	45	-	-	12	-
F	94	457	290	25	11	-	25	-
Total	5,258	1,445	996					

Note: Catches for 1981 are from NAFO (1983).

Breakdown of Food Consumed by Species

It is clear that the data available on the composition of the food of seals are not sufficient to make possible precise estimates of the amounts of individual fish species consumed. All that can generally be done is to identify groups of prey species which play a similar role in the diet of seals, as well as in relation to the commercial fisheries, and to make educated guesses at the possible range of the proportion each group makes up in the seals' food. In the following sections, these educated guesses are combined with the estimates of total food consumption to develop possible figures for the amount of each of the principal prey groups consumed. These results will later be compared with sizes of the catches and what is known of the stock sizes of the various prey species.

In a thorough analysis of the impact of seals on commercial fisheries and especially on individual fishermen or groups of fishermen, it would be important to distinguish between different stocks of the same species of fish. The extreme example is salmon, where each river or stream may have its independent spawning stock, and a seal colony located at the mouth of a salmon river might have a serious impact on the fisheries in that river, even though their consumption of salmon, as a proportion of all salmon caught along the whole coast, might be small.

Stocks of marine fish are less distinct and less finely divided, but may still be differently affected by seal predation. The east coast herring are a case in point. The total consumption of herring by harp seals is small, compared with the total herring biomass, but the 4T stock in the Gulf of St. Lawrence may possibly suffer quite intense predation in the spring, and the impact on this stock may be significant.

In practice, the data on seal feeding are seldom, if ever, good enough to attempt a detailed stock-by-stock analysis, and they will have to be examined here in terms of the fish species as a whole. However, the possible differences among stocks should be borne in mind, especially when considering the possible impact on particular groups of local fishermen.

Harp Seal

It has been generally accepted that capelin form a major component of the food of harp seals (Beddington and Williams, 1979b), and the data reviewed earlier, although very sparse, do not contradict this. Sergeant (1973) used an estimate of 25% capelin in the food of harp seals as a basis for discussion, and this still seems to be a reasonable figure for the winter food in Areas C to F in the 1970s. The data, limited though they are, do show that harp seals not infrequently eat capelin, but they eat other food as well, so that possible limits to the range might be taken as 10%–40%. On this basis, using 1.3×10^6 t as the estimate of current harp seal consumption in Areas C to F (Table 24.10), we obtain 325,000 t as a central figure and about 130,000 t–520,000 t as the likely range if capelin had continued to be as abundant as they were in the 1970s. Since that time there have been major changes, as discussed later, in the abundance of capelin in the northwest Atlantic; at one time, indeed, capelin were only about one-quarter as abundant as in 1970. A conservative estimated range of 30,000 t–130,000 t might be more appropriate to present conditions.

There is no good evidence concerning the proportion of capelin in the food of harp seals during the summer in Areas A and B, but it could well be higher than in winter. However, since these stocks are fished very lightly, if at all, by Canadian fishermen, the impact of seals on their catches in these areas will be ignored.

The year-class strength of capelin of the Labrador–Newfoundland stock (Area C), on which harp seals feed in the winter, can vary from year to year by as much as a factor of 8, and this has been shown to be largely the result of environmental factors (wind and temperature) (Leggett et al.,

1984). The opportunistic feeding behaviour of seals probably implies that, as a result, there will be substantial variations in the quantities of capelin consumed by harp seals, and that other foods will make up much of the difference. The same effect will apply to other capelin stocks, as well as to herring and shrimp.

Unlike capelin, herring overlap with harp seals in their distribution to only a limited extent (Northridge, 1986); the main coincidence is in the southern Gulf of St. Lawrence (NAFO Area 4T) in the spring. Sergeant (1973) brought together what was known of the movements of the two species to obtain an estimate of the amount of herring consumed by harp seals in this area about 1970, obtaining a figure of 21,500 t. This was calculated on the basis that the seals in this area were feeding exclusively on herring for a period of 60 days, and that during this period the proportion of seals actively feeding increased, although the number present gradually diminished. A mean feeding rate of 5 kg per day was used. If the *per capita* consumption has not changed, the estimate of current total consumption would have to be scaled up, to allow for an increase in the seal population from 1.3 to 2 million; this would give an estimate of current consumption of 33,000 t.

The Gulf herring stocks are now less abundant than they were in the 1970s. Ahrens and Nielsen (1984) have shown that between 1970 and 1985, the Area 4T herring stock declined to about one-fifth of its initial value. Thus it is likely that current consumption by seals has also dropped. Northridge (1986) ran a simulation of the 4T stock of herring, using the mean logarithm of recruitment over the period 1971–1973 as an index of stock size. Using a fairly extreme assumption, that seals accounted for three-quarters of the natural mortality (assumed $M = 0.2$), he obtained an estimate of total consumption by seals of 7,000 t. If the assumption about the size and population dynamics of the herring stock are correct, this implies that herring constituted a much smaller proportion, perhaps one-third as much, of the diet of harp seals as was assumed by Sergeant. At the present time, with the herring stock substantially reduced and the seal population increased, the proportion of herring in the seals' diet must have been further reduced, and the extrapolation to 33,000 t cannot be sustained. Since the abundance of herring has been reduced to about one-fifth, and seals are generally regarded as opportunistic feeders, it may be more realistic to regard the present consumption of herring in the Gulf as about one-fifth of that estimated by Northridge for the 1970s, or in the range of 1000 t–3,000 t. This estimate may be conservative, however, since it does not allow for the increase in the seal population in the interval.

Some additional consumption of herring takes place outside this period and outside this area, but the data do not enable any estimate to be made of these amounts. There may also be substantial differences from year to year in spring consumption of herring in the Gulf, since both species involved may vary in their local abundance in response to environmental conditions.

The situation relating to shrimp is even less clear. Decapods (unspecified) or *Pandalus* spp. are not infrequently recorded in stomachs (Table 24.1), from which it seems possible that this group of animals could make up 5%–15% of the winter consumption, or 70,000–210,000 t. It is not known how much of this is *P. borealis* or other commercial species. Northridge (1986) suggested that the total biomass of *P. borealis* in Canadian waters might amount to about 100,000 t. The possibility therefore exists that the consumption of shrimp by harp seals represents a high proportion of the stock, but the data are not good enough to confirm or reject this possibility.

Harp seals occasionally eat various species of demersal fish. In a later section, it is estimated that these species may possibly constitute about 7%–12% of their diet, but the data are scanty, and the confidence limits for these estimates are, therefore, very wide. These seals may also eat some pelagic species other than capelin and herring but only a single specimen of one such species (barracudina) is recorded in Table 24.1.

If, however, as suggested above, the amounts of herring and capelin eaten by harp seals have declined substantially since the mid-1970s as a result of the decrease in the stocks, harp seals, which have increased in numbers during the interval, must have increased their consumption of other prey species, although there are no data as to which species these may be.

Harbour Seal

Boulva and McLaren (1979) state that in eastern Canada the most frequently occurring food items found in the stomach of harbour seals were herring (24%) and flounder (14%). Fisher and Mackenzie (1955) found that herring made up 37% by volume of the stomach contents they examined, and flounders and other flatfish made up 18%. If these frequencies of occurrence actually represented proportions in the food, and the samples were representative of the total seal population, these figures would correspond to a consumption of about 4,000 t–6,300 t of herring, and 2,400 t–3,000 t of flounder.

Northridge (1986) compares the estimated consumption of herring by harbour seals in Area 4WX (mainly south of Nova Scotia) with the yield of the fishery. Taking the number of harbour seals in the area as 5,900 in 1973 (Boulva and McLaren, 1979), and applying the mean weight and rate of consumption used in Table 24.9, the total consumption becomes 7,800 t. (Northridge, using slightly different parameters, obtains 10,000 t.) It is estimated elsewhere (Chapter 21) that the Atlantic coast harbour seal population in 1985 was not far from the 1973 level. If this applies to the population in Area 4WX, and on the assumption that the diet includes 25%–37% herring, then the range of the estimate of herring consumption is about 2,000 t–2,900 t.

The data in Table 24.3 also suggest that about 30% of the food of harbour seals on the Atlantic coast consists of commercially important demersal fish such as flatfish, gadids and redfish. No data have been found for the east coast suggesting that harbour seals take salmon in the estuaries as they are returning from the sea to spawn.

On the west coast of Canada, however, the situation seems to be rather different, and harbour seals appear to feed extensively on salmon in the narrow waters of the B.C. coast and up the river estuaries. Stewart (1983), for instance, records aerial surveys as showing 1,330 harbour seals in the "Fraser River area". In Table 24.9 the total amount of food consumed in a year by west coast harbour seals is estimated at about 60,000 t. As noted in a previous section, the proportions of salmon and herring in the stomachs examined were 23% and 11%, and these would correspond to a consumption of 14,000 t and 6,600 t respectively. It is likely that these figures overestimate the amount of salmon consumed and underestimate the amount of herring. Stewart (1983) examined the combined biomass of six species of salmonids entering the Fraser River, and his figures show that almost 97% of the total biomass enters in the five months of June to October. Since the great bulk of the samples reported on by Spalding (1964) were taken in these months, it is likely that a better estimate of the proportion of salmon in the total harbour seal diet is five-twelfths of 23%, or 9.5%; this proportion corresponds to an estimated consumption of about 6,000 t of salmon.

The most uncertain figure in these calculations is, of course, the 23% salmon in the food consumed during the months when salmon are available to the harbour seal. It is not possible to attach statistical confidence limits to this figure, but a factor of 2 in either direction might be not unreasonable.

Grey Seal

Table 24.9 estimates the food consumption of grey seals on the Atlantic coast as about 240,000 t. Grey seals feed on a wide variety of fish species, but the data in Table 24.5 show consistently for Canada, Iceland and the British Isles that there is a high proportion of commercially important species in their diet. These consist of both demersal and pelagic species, but in Europe the demersal forms predominate strongly; in Canada the data include 50% demersal, 37% pelagic, 1% sand lance and 13% other non-commercial species. There will certainly be a great deal of variation in the detailed specific composition by both time and place, and it is not possible to make useful estimates of the amounts of any particular species that are consumed. Nevertheless, it seems clear that a very large proportion of the food of grey seals consists of commercially important species, probably within the limits of 60%–90%. Comparison of the results in Table 24.5 also indicates great variation in the relative amounts of demersal and pelagic species. While these comparisons are between major geographical areas, it seems likely that there will be similar variability on a smaller time-space scale within Canada.

Mansfield and Beck (1977) calculated separately the amounts of each of the principal prey species consumed in each of three areas – Gulf of St. Lawrence, Sable Island and eastern Nova Scotia – on the basis of their estimates of the numbers of grey seals in each area and the corresponding stomach-content data. It is not possible to determine the total amount of commercially important species in these weighted estimates but, re-combining the three areas, the proportions of the most important species are:

herring	23%	cod	14%
skate	19%	squid	6%
flounder	16%	mackerel	5%

For the purpose of future calculations, it will be assumed that 70% of the total commercial fish in the diet of grey seals (60%–90%) consists of demersal species, and the rest of pelagic fish in the form of herring. The effect of the variability in the proportion of total commercial species that are pelagic species, which is not being taken into account in this calculation, would be quite small compared to the variability of total commercial species within total consumption, which is being included in the calculations. The Gulf herring stocks have, however, declined substantially below their level at the time when most of the seals reported by Mansfield and Beck (1977)

were collected, and it is possible, therefore, that the proportion of herring in the grey seal diet is now lower than their data indicate.

While concern is often expressed about the consumption of salmon by grey seals, the amount is also very difficult to assess. This is because of the very localized effects of any predation which may occur when salmon are running along the coasts and into river mouths. Northridge (1986) cites evidence from the United Kingdom and the Baltic which suggests that "seal predation on salmon may have little to do with absolute seal numbers, with just a few seals accounting for most of the predation." If this is so, it is clearly impracticable to try to estimate the amount of salmon consumed using the methods employed here.

Northern Fur Seal

The amount of food consumed by fur seals on their winter and spring migration off the B.C. coast is estimated at about 5,000 t–7,000 t. Of this amount, the major components are herring, salmon and squid. The last includes a number of species, not all of which are of any commercial significance. Applying the percentages given earlier (from Perez and Bigg, 1985) provides estimates of the amounts consumed as: herring 2,100 t–3,000 t; salmon 1,000 t–1,400 t; and squid 1,000 t–1,400 t.

Spalding (1964) states "the northward migration of fur seals off the west coast of Vancouver Island coincides with the offshore movement of herring out of Barkley and Clayoquot Sounds after spawning which reaches a peak in mid-March." He shows an apparent relation over years between frequency of herring in the fur seals' stomachs and the size of the adult herring population as measured by "miles of spawn" deposited. It is very doubtful, however, if this relation, based on a total of 139 stomachs over four years, has any statistical validity.

Steller Sea Lion

The estimated total food consumption of this species, shown in Table 24.9, is 19,000 t–26,000 t. Application of the figures for food composition supplied by Bigg (1985) leads to the following estimates of the amounts of the major prey species consumed: herring, 5,500 t–8,000 t; and dogfish, hake, salmon, eulachon, and squid each about 2,700 t–3,600 t. As noted earlier, there are major variations from time to time and place to place, particularly as regards salmon and herring. The relative availability suggests, how-

ever, that herring would be more important in the winter and early spring, and salmon in the summer months. These calculations are based on the number of Steller sea lions breeding on the B.C. coast rookeries. If, as seems not impossible, the number of sea lions breeding on the large Forrester Island rookery in Alaska and feeding in Canadian waters exceeds the number of Canadian-bred sea lions feeding in U.S. waters, the above figures will tend to be an underestimate of the total food consumption by Steller sea lions in Canadian waters.

California Sea Lion

The total food consumption of California sea lions off the B.C. coast is estimated at about 6,000 t. Since this sea lion is present on the B.C. coast only in the winter, when the adult herring are making their mass migration (Hourston and Haegele, 1980), it is appropriate, as discussed in the previous section, to apply the factor of 50% to calculate the amount of herring consumed by this species; this calculation produces a figure of about 3,000 t. The other 3,000 t will presumably be made up of a variety of species, including those listed for Steller sea lions. Since, however, the time of the California sea lions' presence does not overlap with the major salmon runs, the amount of salmon consumed may be relatively small.

Summary

The foregoing sections suggest that the principal commercial fish stocks which may be subject to significant predation by each species of seal are:

On the east coast:

harp seal:

- capelin, throughout the range;
- herring, in the Gulf of St. Lawrence in the spring;
- shrimp, in the Gulf, off west Greenland, and on the northeast Newfoundland Shelf;

harbour seal:

- herring, flounder and other commercial demersal fish;

grey seal:

- commercial fish generally, possibly Atlantic salmon;

hooded seal:

deep water demersal species, e.g., redfish, but no adequate data.

On the west coast:

northern fur seal:

herring, squid, possibly salmon;

harbour seal:

salmon, herring, possibly other commercial species;

Steller sea lion:

salmon, herring, commercial fish generally;

California sea lion:

herring.

Comparison of Predation with Stocks and Catches

In this section the information available on the amounts of fish consumed by seals is compared with estimates of biomass and commercial catch for the fish species most likely to be affected by seal predation.

Capelin

Capelin consist of a number of more or less distinct stocks. The Greenland stock (Areas A and B) supports a large part of the harp seal population during the summer feeding season, but this stock is not fished by Canada. The largest of the stocks that are fished by Canada is that in the southern Labrador-northeast Newfoundland area (Area C).

Bowen (1985) and Northridge (1986) have reviewed recent data on the size of this stock. It has been subject to a significant fishery since about 1971; catches rose rapidly to a peak of about 300,000 t in 1973-1976 and fell again, in 1979, to less than 35,000 t. The average catch over 1972-1978 was about 230,000 t. The estimated biomass of capelin in the NAFO Divisions 2J and 3K, which correspond with the distribution of this stock, has fluctuated

widely, apparently largely because of environmental effects (Leggett et al., 1984). It rose to a peak of about 4 million t in 1975, then declined to about 0.5 million t in 1978; it amounted to 223,000 t in 1983, and to about 860,000 t in 1984.

For statistical Area 3LNO, which forms part of our Area D, Beddington and Williams (1979a) quote Carscadden and Miller (1979) for estimates of biomass southeast of Newfoundland as ranging between 3.7 million t in 1973 and 0.6 million t in 1978. That biomass subsequently fell to 280,000 t in 1984 (Northridge, 1986). The stocks in the Gulf of St. Lawrence (Area E) and Division 3Ps (part of Area D) are much smaller, about 4,000 t (Northridge, 1986).

Northridge (1986) estimates the current total biomass, excluding Greenland stocks, at about 1.2 million t. Using a natural mortality rate of 1.2, he calculates natural deaths as about 840,000 t annually. A substantial, but unknown, part of this mortality would be attributable to predators.

The available estimates of capelin biomass, fisheries catch and consumption by harp seals in the areas (other than A and B) used in Figure 24.1 and Table 24.10 can be summarized as follows (quantities in thousands of tonnes):

Area	Capelin Biomass	Fisheries Catch	Harp Seal Consumption	Consumption by Other Predators
C	223 - 4000 (1200)	35 - 300	20 - 80	1700 - 3800
D	(250?)	5 - 200	6 - 25	
E	2	0.4	?	
F	0	0	0	

Note: Figures in parentheses are estimates of current biomass.

The estimated consumption of capelin in Areas C and D is calculated by distributing the estimated total of 30,000 t-130,000 t in proportion to the consumption for those areas given in Table 24.10. A similar calculation for Area E (Gulf of St. Lawrence) would give a figure equal to that for Area D, which is about an order of magnitude greater than the estimated biomass.

This suggests that either food consumption in the Gulf is greatly overestimated, or that capelin form only a small proportion of the food of harp seals in this area. In these circumstances it does not seem possible to make any useful estimate of the amount of capelin eaten by harp seals in the Gulf. This observation must also add to the uncertainties about the estimates for the other areas, particularly since most of the data about the occurrence of capelin in harp seal stomachs are derived from seals taken in the Gulf.

For both biomass and catch, the ranges of values given for Areas C and D cover the variations in the estimated and reported values respectively, which have resulted from changes in abundance and fishing intensity since the early 1970s (figures in brackets are estimated current biomass). For consumption, on the other hand, the ranges given derive from the uncertainties in the proportion of the food consisting of capelin, on the assumption that the total food consumption is that estimated for the present seal population; a further $\pm 40\%$ should be imposed to allow for uncertainties in total food consumption, as discussed earlier. These results suggest, very broadly, that the amount of capelin eaten by harp seals in these areas is of the same order as the catch in the commercial fishery. However, the very wide variations from year to year in the abundance of capelin and in the intensity of the fishery must complicate the relationship between catch and consumption. While the total food consumption of harp seals is likely to have changed in fairly close proportion to their abundance, their opportunistic feeding behaviour makes it probable that they have made large changes in the composition of their food in response to the fluctuations in capelin abundance, and that they have eaten correspondingly fewer capelin when the stock has been small.

The total food consumption of the hooded seal is about half that of the harp seal. It is not possible to estimate how much of the food of hooded seals consists of capelin taken from stocks of concern to the Canadian fishery, but this amount is likely to be less than that taken by harp seals. There are several reasons for this. The more northerly distribution of the hooded seal herd means that more of these seals spend a greater proportion of their time in Areas A and B; part of the population breeds on the ice in Davis Strait, well north of the harp seals at the Front; only very small numbers of hooded seals go as far south as Areas D and E. Secondly, the hooded seals at the Front breed seaward of the harp seals and may be outside the areas where capelin are abundant. Finally, the hooded seal feeds at a greater depth and commonly takes larger fish than the harp seal, whereas the capelin is small and frequents the upper layers of the water. The observations from Greenland in Table 24.2 suggest strongly that capelin is a comparatively minor food of hooded seals.

No other species of seal seems to be of any significance as a predator on capelin.

Capelin are also subject to predation by a number of species in addition to seals. Major predators which have been identified are Atlantic cod, seabirds, Atlantic salmon and whales. Lilly et al. (1981) estimate annual consumption by Atlantic cod in Divisions 2J, 3KL and 3NO as 1.2 million t–3.3 million t. Carscadden (1983) estimates that seabirds consume 0.25 million t of capelin annually. Beddington and Williams (1979a) show estimates of the combined consumption by minke and fin whales of 0.28 million t. All these amounts must presumably be subject to large variations from year to year in response to the changes in the abundance of capelin.

All figures for consumption by other predators have been derived by the same kind of techniques as have been used to obtain estimates of consumption by harp seals. It seems that the seals are only one of a number of major predators on capelin, and that Atlantic cod are the most important. The figures given above would appear to suggest that seals may account for about 1%–5% of the total predation. However, since the estimates of amounts of capelin consumed by other predators apply to a time when capelin were more abundant than in recent years, the above comparison with current consumption by seals has probably produced an underestimation of the percentage of total predation which is due to seals.

As Northridge (1986) points out, these figures lead to an estimate of total predation which is substantially greater than the estimate of total natural deaths obtained by multiplying current stock size by natural mortality rate (M). This discrepancy may be explained, at least in part, by the substantial variation in capelin abundance, and the fact that the estimates of biomass exclude the young, pre-recruit fish. It also illustrates, however, the general level of uncertainty in attempts to quantify the relationship between fish stocks and their predators, even in such relatively well-studied cases as harp seals and capelin.

The capelin eaten have, apparently, not been measured or aged. It is possible, however, that the capelin eaten by the seals in January–June are in the main the larger capelin which would have spawned in June–July, about one to five months later than when they were taken by the seals. Whales are present, feeding on capelin, in and after May–June. The Newfoundland fishermen and the nesting seabirds on the coast typically take their capelin when they approach the coast for spawning in June–July–August. The northern cod over the NAFO Division 2J–3K area are moving to deep and moderately warm water in January–February and spawning there mainly

in March–April, though some spawning occurs in May; they are not eating much over a good deal of this period. In any case, the northern cod spawning grounds are in temperatures somewhat seaward of the capelin, which at this time occupy more coastal, colder waters and are not being preyed on significantly by these spawning northern cod.

The Newfoundland fishermen concentrate, as far as possible, on the larger female capelin which would spawn earliest and on the beaches, but they try to take them for their roe and therefore before spawning. On the east coast of Newfoundland, the capelin which have escaped the human, mammal, fish and bird predators begin spawning at or near the beaches. The larger capelin begin to spawn in the latter part of June, and the younger and smaller fish continue spawning throughout July and to some extent in August, in gradually deeper water close to shore as the season advances. Inevitably, if there is considerable selection for the larger fish, most of the capelin spawning will be the smaller young fish, which are commercially less desirable.

The seals, therefore, are the first in line to prey on the ripening capelin in the southern Labrador–northeast Newfoundland area; the other main predators take their turns later. In each year, therefore, the numbers of adult capelin may be considerably reduced by harp seals before man comes strongly into the picture. Thus, the capelin situation has some of the characteristics of a gauntlet fishery.

If the harp seals are being harvested by the fishermen, the capelin could be considered to be utilized by the seal to help provide a seal fishery for the fishermen.

As described above, the main fishery for capelin takes place as they mature, when they are generally about three years old. They are also subject to heavy predation by various predators at this time. Nothing seems to be known, however, about the extent to which seals feed on younger capelin, since there are no data on the sizes of capelin eaten by seals.

Atlantic Herring

Harp, harbour and, probably, grey seals are all predators on Atlantic herring stocks. Predation by harp seals is important in the southern Gulf of St. Lawrence, but estimates of the amount consumed cover a fairly wide range.

The discrepancies in estimates of the amount consumed by harp seals between those calculated from the believed size of the herring stocks and those calculated from the seal population have been discussed earlier. If the former estimates are more nearly correct, the consumption would have been about 7000 t in 1970, when the herring stock was about five times as large as it is at present. Consumption of herring is therefore likely to be considerably less at present. Calculated from the seal population, consumption at the same period was about 21,000 t. However, even if this estimate is correct, it seems likely that current consumption of herring would be reduced as the declining herring stock forced the seals to turn to other prey.

Predation on herring by harbour seals seems to be most important in NAFO Area 4WX (Area F) round Nova Scotia. In a previous section current consumption of herring by harbour seals in this area was estimated at 2,000t–2,900 t. This estimate can be compared with the 1983 catch (81,000 t) and the estimated biomass in the same area (335,000 t). Seal consumption does not seem to be of any great significance in this area.

Pacific Herring

Pacific herring are subject to significant predation by harbour seals, northern fur seals, Steller sea lions and California sea lions. The rounded estimates of consumption developed above are:

Harbour seals	6,500 t
Northern fur seals	2,000–3,000 t
Steller sea lions	5,500–8,000 t
California sea lions	3,000 t
Total estimated consumption	<u>17,000–20,500 t</u>

As noted earlier, the harbour seal figure seems likely to be an underestimate.

Shrimp

It is known that shrimp of various species figure largely at times in the diet of harp seals, probably particularly in the northern part of the seals' range. Northridge (1986) points out correctly that if all the consumption is of the main commercial species (*P. borealis*), a major discrepancy appears, in

that such tentative estimates as can be made of the amount of shrimp consumed appear to be much too large when compared with present estimates of the size of the shrimp stocks. Other species of shrimp, however, such as *P. montagui*, also appear in the stomach contents of harp seals (Sergeant, 1973, 1976) and this will tend to reduce the discrepancy. At present very little is known either about the feeding habits of the seals or about the distribution and abundance of the shrimp, but at the upper extreme, the impact of harp seals on the commercial shrimp fishery could be quite substantial, although it could equally well be very small. Further studies of harp seal diet at appropriate times and places should help to narrow this wide range of possibilities.

Salmon

Predation by seals on salmon attracts considerable attention from both the public and the fishing industry. This attention is probably rather out of proportion to the actual quantities of salmon removed and is stimulated both by the value of the fish and by the fact that the depredations, which take place as salmon enter narrow waters on their spawning migrations, are relatively conspicuous.

On the Atlantic coast, the grey seal seems to be the only species recorded as taking salmon, although from its behaviour elsewhere, it would be expected that the harbour seal would also feed on salmon occasionally. There are no data to indicate what proportion of grey seal food is composed of salmon, but this species does not appear to be a major component. The estimate of total food consumption by grey seals is about 240,000 t. Current commercial salmon catches are around 1,000 t–2,000 t. Thus if salmon were only 0.4%–1% of the food of the grey seals, their consumption would equal the catches. Such a low proportion is impossible to estimate with any precision from direct observations of occurrence in the diet. Northridge (1986) refers to evidence which suggests that the amount of predation on salmon by grey seals may not vary much with changes in seal abundance. Since the Atlantic salmon fishery is now much restricted and actually closed on some rivers, the effect of grey seal predation may be greater on the spawning run than on the catch.

On the Pacific coast, the various species of salmon are eaten by harbour seals, northern fur seals and Steller sea lions; consumption by California sea lions is probably relatively unimportant. The very tentative estimates of the amount taken by the various predators are:

Harbour seal:	6,000 t, mainly in the inlets and lower parts of rivers;
Northern fur seal:	1,000 t–1,400 t and possibly higher (Northridge 1986), mainly offshore but some in the inlets;
Steller sea lion:	2,700 t–3,600 t, mainly where rookeries and hauling-out places are adjacent to major salmon runs.

These estimates may be compared to an average catch, for 1973–1982, of 64,000 t for all Pacific species of salmon combined (Canada, DFO, 1984b).

Demersal Fish

Bottom-dwelling, or demersal, fish of various species form a significant part of the food of several species of seals. The proportions of the various species within this group will vary seasonally and with locality; the small size of most of the samples of seal stomach contents examined will also cause relatively large random variations in the proportions recorded. Observations of the proportion of demersal fish as a group will, therefore, be more reliable and consistent than those of the individual species. Similarly, it is the demersal fish as a group that are the target of many trawl, and some line and net, fisheries, although, again, there are local and seasonal variations. It will therefore be most useful to compare estimates of seal consumption and catches, and to try to assess possible impacts, for the demersal fish as a whole, rather than for individual species.

Harp seals feed on demersal fish to a small extent when they are in their southern range. The summarized data in Table 24.1 show that of 555 stomachs containing food, a minimum of 39 (7%) and a maximum of 66 (12%) contained demersal fish. (The high figure makes the unlikely assumption that all 27 stomachs containing "unidentified food" contained demersal fish.) Since it is not possible to convert percentage occurrences to actual proportions in the food with any accuracy, the proportion of demersal fish in the weight of food eaten by harp seals will be taken as 7%–12%. This proportion must have wide confidence limits, but the evidence suggests that it is much smaller than the proportion of capelin.

Hooded seals appear to take a much larger proportion of demersal fish than do harp seals. No data are available for Canadian waters, but the Greenland data in Table 24.2 show that a minimum of 649 and a maximum

of 1,175 stomachs contained demersal fish out of 1,341 with food; this represents a range of 48%–88%. The individual samples show ranges of 31%–90% (south Greenland), 94%–97% (southeast Greenland), and 75%–81% (northwest Greenland). In this species, it seems likely that much of the unidentified or unspecified fish was of demersal species, so that the true value is towards the upper end of the range. A range of 70%–90% will be used in future calculations.

Harbour seals on the Atlantic coast feed on a wide range of fish and invertebrates. The data in Table 24.3 show about 30% of the stomach contents consisting of commercially important demersal species, but again, the confidence limits must be wide. On the Pacific coast, the proportion of demersal fish is probably lower, on account of the greater extent to which both salmon and herring are eaten, but the amounts taken of bottom-living fish like lingcod, flatfish and hake are still significant (Spalding, 1964).

In a previous section it was stated that commercially important species, including a large proportion of demersal fish, were consistently recorded in the stomachs of grey seals in the North Atlantic, including Canadian waters. It was considered likely that the overall proportion of commercial species in the diet of grey seals was in the range of 60%–90%, and that about 70% of those were demersal species, that is, about 42%–63% of the total food. In addition, an unknown, but possibly small, proportion of the food of grey seals will consist of sand lance, which are the subject of important fisheries in some parts of the Atlantic area, although they are not fished at present in Canadian waters.

The northern fur seal, at least in Canadian waters, seems to feed largely on pelagic and mid-water species. All the types listed in Table 24.6 as important in B.C. waters fall into this category, although some, such as the rockfishes and walleye pollock, are important to commercial trawl fisheries elsewhere. Consumption of demersal fish by northern fur seals in Canadian waters can thus be ignored.

Both species of sea lion apparently feed principally on herring in B.C. waters, but the data reviewed earlier suggest that demersal species, particularly dogfish and hake, are also important. The combined consumption of these species by Steller sea lions is estimated at 5,400 t–7,200 t, about 30% of a total consumption of 19,000 t–26,000 t. The California sea lion visits the B.C. coast only during the winter, when herring are abundant; other species, including the demersal fish, may therefore form a rather smaller proportion of their food, perhaps 20%–30% out of 6,000 t, or 1,200 t–1,800 t.

Impact on Fish Stocks and Catches

These estimates of consumption of demersal fish are summarized in Table 24.12.

Table 24.12
Estimated Consumption of Demersal Fish

Species	Total Consumption (000s t)	% Demersal	Demersal Consumption (000s t)
<u>Atlantic Coast (areas C-F)</u>			
Harp seal	1300	7 - 12	90 - 155
Hooded seal	500	70 - 90	350 - 450
Harbour seal	17	30	5
Grey Seal	240	42 - 63	100 - 150
Total			<u>540 - 760</u>
<u>Pacific Coast</u>			
Harbour seal	54 - 72	20	10.8 - 14.4
Northern fur seal	5 - 7	-	-
Steller sea lion	19 - 26	30	5.4 - 7.2
California sea lion	6	20 - 30	1.2 - 1.8
Total			<u>17.4 - 23.4</u>

For comparison purposes the combined catch of hand- and longlines, Danish and Scottish seiners and otter trawlers on the Atlantic coast averaged about 630,000 t in 1981/82 (Canada, DFO, 1984a). This figure is of about the same order of magnitude as that for the consumption of demersal fish by seals, though there are important differences in the areas (the seal consumption is generally further north) and in species composition (the commercial catches will contain a higher proportion of cod).

On the Pacific coast in 1981, the combined landings of the principal species of groundfish (lingcod, Pacific ocean perch, Pacific cod and soles) amounted to about 17,000 t; this figure, again, is of about the same order of magnitude as that for the consumption by seals.

As Table 24.11 shows, Atlantic cod are the most important demersal fish to the east coast Canadian fishery, forming about 40% of the total catch. They are sometimes reputed to be a major food of harp seals, but the data do not support this view. Only four harp seals have been recorded as containing cod, and in general harp seals seem to prefer smaller prey. Grey seals feed extensively on demersal fish of rather larger sizes. Table 24.4 shows that cod form about 13% of the occurrences of commercial fish in the data of Mansfield and Beck (1977). Their weighted calculations indicate that cod constitute 14% of total food consumption, which might be equivalent to about 20% of the commercial species in the diet. Mansfield and Beck also note that grey seals feed on cod when the fish are making their inshore migration in the spring. Cod have been recorded, however, as forming up to 49% of the food from some localities in the United Kingdom, with an average of a little under 20% (SMRU, 1985).

There are no useful data on the food of hooded seals in Area C. Since this seal feeds extensively on large demersal species, cod may form a significant part of its diet although it has only been recorded in small numbers in the Greenland data (Table 24.2). A tentative estimate of cod consumption by seals could be based on the assumption that they form the same percentage of the demersal fish eaten by hooded and grey seals as they do of the commercial demersal catches, and on ignoring any consumption by harp seals. This calculation yields an estimated consumption of about 200,000 t–280,000 t. In recent years the estimated biomass of cod in Areas C to F has been over 2 million t (Northridge, 1986). The combined catches have been in the vicinity of 500,000 t, about twice the tentative estimate of the amount consumed by seals.

Redfish are a deep-water species and it is unlikely that they figure to any great extent in the food of grey or harp seals. They may be considerably more important in the food of hooded seals, and formed about 10% of the occurrences in the Greenland samples (Table 24.2). If this figure is applied to the estimated total consumption by hooded seals in Area C, it gives an estimated consumption of redfish of the order at 50,000 t. The total Canadian landings of this species in 1983 were 58,000 t (Northridge, 1986).

Flatfish of various species are recorded from time to time in the stomachs of grey and harbour seals, and occasionally in harp seals. The data are scanty, but both for Canada (Tables 24.3 and 24.4) and the United Kingdom (Table 24.5), they are consistent with the hypothesis that flatfish form 5%–10% of the food of harbour and grey seals. This leads to a tentative estimate of total consumption in Areas C to F of 12,000 t–25,000 t. Recent Canadian flatfish landings (1982) from Areas C to F have amounted to about 110,000 t (NAFO, 1984). Northridge (1986) estimates the consumption of flatfish by harbour seals in the Maritimes at about 2,000 t. Of this amount, about 1,000 t was taken in NAFO Division 4VWX, which is about equal to recent landings from the area. Canadian fishermen have recently been catching a wider range of species of flatfish, and this may tend to increase the level of competition between them and the seals.

A special case among the bottom-living fish is the sand lance. This species is the subject of specialized fisheries in some European waters, where it is locally abundant and is also, apparently, subject to heavy predation by grey seals under similar circumstances. SMRU (1985) reports it as forming between 15% and 80% of the diet of grey seals in four localities round the British Isles (Table 24.5). The sand lance, however, forms only a small percentage in data from Iceland (Table 24.5) and only 1% of the Canadian occurrences listed in Table 24.4. The Royal Commission has, however, been informed (Harwood, 1985; Stobo, 1986) that in the vicinity of Sable Island grey seals feed heavily on sand lance. It is not possible to assess what proportion of the food of Canadian grey seals as a whole consists of sand lance, although the fish may be locally important.

Other Pelagic and Mid-Water Species

The pelagic species most frequently eaten by seals in Canadian waters are capelin and herring, and these have been discussed in preceding sections. On the Atlantic coast a variety of other pelagic species are eaten in small amounts by harp and harbour seals, but grey and hooded seals eat very few pelagic fish. The principal species consumed is probably mackerel. On the Pacific coast the northern fur seal seems to feed almost exclusively on pelagic species. Its consumption of salmon and herring has already been discussed, and Table 24.6 suggests that it also eats significant amounts of sablefish. If the proportion of this latter species is similar to that of salmon or squid, the amount consumed may be of the order of 1,000 t as compared with 1982 landings of about 7,000 t (Canada, DFO, 1984a).

Squid form significant components of the diet of harbour seals on the east coast and of northern fur seals in the Pacific, but it is not possible to make any useful comment on the amounts eaten in relation to the size of the stocks or of the commercial catch.

Effects on Commercial Fish Stocks and Catches

General Principles

Previous sections have reviewed such data as are available on the amounts of commercial fish consumed by seals, and have made some comparisons with the biomass of the fish stocks and with the present levels of catch. The next and critical questions are: What effect has seal predation on the size of the commercial catches, and how will these effects change if the size of the seal population alters? Virtually no direct observations have been made which can provide guidance as to the effects to be expected, and long-continued large-scale experiments would be necessary to provide useful results. It is necessary, therefore, to have recourse to a theoretical approach founded on the basic biological principles involved.

It may be noted that the approach followed is very similar to that involved in assessing the impact of commercial fisheries on fish stocks, and especially the interactions between the impacts of two or more fisheries on the same species. The two types of study involve making similar assumptions, for example about the response of fish stocks and their predators to change in the mortality rate of the fish stocks, which may never be precisely fulfilled. Nevertheless, the fishery assessments have provided useful bases for taking policy decisions concerning the management of fisheries. The Commissioners believe that the same is true in relation to the interactions between seals and fisheries.

The problems which arise are very complex, and even in an ideal situation where it is known exactly how many fish of each sex at each age were in the stock, and how many were eaten by the seals, it would still be impossible to achieve precise results unless it was also known what the fishery took, how the fishery would respond to any change in the abundance of the fish, and how the recruitment of young fish to the stock would be affected by such changes. Knowledge of the size and structure of the commercial catch is relatively good for most of the commercial fishes, and for those which have been most studied (e.g., salmon and Atlantic cod) a consid-

erable amount is known about the size and structure of the population, although relatively little is known about the effect of stock size on recruitment to fish stocks. It is inadequate knowledge of the amount and size and age-composition of fish consumed by seals which most hampers attempts to assess the impact of seal predation on commercial fish catches.

In developing a theoretical study of the problem, the most simplistic approach would be to consider that any fish that were not eaten by seals as a result of a reduction in seal numbers would subsequently be caught by fishermen, so that the increase in commercial catch would equal the amount previously eaten by seals. Conversely, on this basis, if the amount eaten by seals increased by a certain amount, then the catch would decrease by the same amount. There are a number of reasons why this simple approach usually leads to incorrect conclusions; the changes in seal consumption and in catch will be equal only under certain special conditions.

In the first place, not all the fish which would have been eaten by seals would be caught if the seals were removed; a proportion will die from other causes, so-called "natural deaths". This well-known aspect was discussed by Dr. S.J. Holt in his submission (Holt, 1985), and as he pointed out, the actual change in catch produced by a change in consumption by seals will depend on the rates of fishing, consumption by seals and natural mortality. The higher the fishing mortality rate compared to the natural mortality rate, the larger will be the proportion of the seal consumption which would be transferred to the catch if the seals were removed.

Put simply, if a fish which might have been eaten by a seal today is not eaten, perhaps because the seal has been killed in a culling program, it will still die ultimately. It may die from natural causes, such as old age, disease or being eaten by a shark, or it may be caught by a fisherman. Assuming that it is a typical member of the population, the chance of its being caught and thus added to the yield of the fishery depends on the relative rates of mortality deriving from fishing (F) and from natural causes (M). A simple model (Appendix 24.1) shows that, if as a result of a change in the seal predation rate, the numbers of fish caught and the numbers consumed by seals change from C and H to C' and H' , the proportion of the amount of fish no longer eaten by seals ($H - H'$) which is now added to the catch ($C' - C$) is given by:

$$R = (C' - C) / (H - H') = (F/M) / (1 + F/M) ,$$

$$\text{or } R = F / (F + M) = E ,$$

where E is often referred to as the exploitation rate.

Thus R depends only on the relative magnitudes of the fishing and natural mortality rates and is not affected by their absolute value or by the rate of predation by the seals. The following table illustrates how this effect would operate:

F/M	R
0.2	0.17
0.5	0.33
1.0	0.50
2.0	0.67
5.0	0.83

These simple calculations do not allow for the fact that typically, fish are growing over the period during which they are subject to seal predation and to the fishery. If a fish is not eaten by a seal because that seal has been killed, but is subsequently caught by a fisherman, it will be older and therefore probably larger than it would have been if the seal had eaten it. These calculations will therefore underestimate the impact of the seals on the fishery in terms of weights.

This effect was considered by the International Council for the Exploration of the Sea's (ICES) ad hoc working group (ICES, 1979), and the group proposed a formulation similar to that shown above. Using our symbols and extending the ICES equation for the total life span of the fish, the equation becomes:

$$R = (F/M) / (1 + F/M - G/M)$$

where G is the instantaneous growth rate of the fish. It is obvious from this relationship that the effect of allowing for growth is to increase the value of R . If G were greater than M , then the amount added to the catch would be greater than the amount eaten by the seals.

One weakness in this model, as expressed in the equation above, is that it assumes that the fish continue indefinitely to grow at a constant instantaneous rate, whereas the growth rate of nearly all fish slows down as the fish get older. More realistic forms of this model would include other expressions for the growth of fish.

In general, G is greater than M in young fish, but decreases as the fish get older, and there is a critical age (Ricker, 1975) at which G equals M , and the biomass of a year-class would, in the absence of fishing, be at maximum. For most commercial fish, especially demersal fish, fishing starts before the critical age. If fishing is heavy so that older, slow-growing fish form only a small part of the population, the average G will be greater than M so that R will be greater than 1.0.

This model does not make it possible to examine the effects that would arise if seals ate older or younger fish than those caught in the fishery, a complication which becomes important if growth rate can vary with age. These problems can be overcome by using an age-structured population model which incorporates the growth of the fish and permits the separation of mortality due to fishing, seal predation, and other natural causes.

It is common practice in such models to use the von Bertalanffy growth curve (Beverton and Holt, 1957), which provides for a gradual decline in growth rate with age. Three models using this relationship have been developed to examine the relation between catch and the amount of fish consumed by seals. One such model is presented in Appendix 24.2, and two others in Northridge (1986). Other models using different growth functions could easily be developed, but since the shape of the growth curves would have to resemble the same natural curves, they would give similar results.

The curves in Appendix 24.2 show the results of a preliminary study of how the increase in yield to the fishery, following cessation of predation by seals, would compare with the quantity of fish removed by the seals. It is assumed that recruitment to the fish stock remains constant.

The results show that the ratio of the gain in catch to the removals by seals is affected not only by the intensity of the fishery and of the seal predation, but also by the respective ages at which the fishery and the predation begin to operate. In general terms it appears that:

- The relative gain increases as the fishing intensity increases.
- The relative gain tends to increase as predation intensity increases, particularly when fishing intensity is high.
- The relative gain is greater when the predation starts earlier than the fishery.

The examples make it clear that the gain to the fishery may be either greater or less than the quantity of fish taken by the seals. The relation depends on the relative mortality rates due to the fishery, to seal predation and to natural causes, and on the ages at which fish become susceptible to fishing and predation. In example B, where fishing mortality begins at age four and seal predation at age two, the gain becomes greater than the seal removals when the fishery is fairly intense, with an F of about 0.4 or more, and this level of intensity is typical of a number of major fisheries.

Other expressions for the growth of the fish could be used in these models, but they would all lead to similar general conclusions: particularly, that making allowance for growth increases the potential benefit to the fishermen of reducing seal predation.

Northridge (1986) has developed two other computer routines, based on rather similar models, to examine other aspects of the problem. The first model (Northridge, 1986, Appendix) is a yield isopleth model based on the Beverton and Holt (1957) yield equation. This model shows how the weight of the catch from a fixed level of recruitment to the fish stock and with a known level of predation by the seals will vary with the fishing intensity and the size of the fish at first availability to the fishery. This model can be used, for example, to examine how the fishing intensity would have to be changed to maintain the catch at the same level after a change in the rate of seal predation. Comparison of Northridge's (1986) Figure 4 with his Figure 5 shows that, for this particular model and set of parameters, which correspond to those of the Division 2J3K cod stock, when the seal predation rate is doubled, the fishing mortality rate F has to be increased from about 0.2 to over 0.5 to maintain the catch at the same level (250 units). Alternatively, if F remained the same – and this is perhaps a more likely situation – the maximum catch for $F = 0.2$ would drop from 250 to 200 units.

In his second approach Northridge (1986, Appendix) has used a population model similar to that in Appendix 24.2 to develop simulations to show how the catch and the seal consumption will change over time. These simulations can allow for random variations from year to year in the amount of recruitment, and it is possible to set this variability at levels based on actual observations of fish stocks. The simulation also allows the rate of seal predation to be changed during the run so that the possibility of detecting any resulting change in yield in the presence of variable recruitment can be examined.

In applying all these models to examine the effects of consumption by seals on the catches from stocks of fish, a number of assumptions have to be

made. These assumptions, which will be more or less justifiable in many situations, include:

- that a change in the rate of predation by seals would not change the rate of natural mortality from other causes. This assumption might break down if a significant change in fish abundance resulted from the change in the predation rate.
- that the seal predation is evenly spread over the population.
- that seal predation rate (i.e., the proportion of the fish stock taken by seals) is independent of fish density. This may be in error in either direction; if a particular fish species becomes scarce, seals might tend to move in search of more abundant species; on the other hand, if a fish stock becomes locally very dense, the seals might need a smaller proportion of it to satisfy their food requirements.
- that fish growth rate and recruitment rate are not density dependent.

In applying approaches such as these to determining the impact of seal populations on fish stocks, it is also necessary to make assumptions concerning the relation between the mortality rate due to seal predation and the number of seals in the population. At the present time it does not seem justifiable to adopt any hypothesis other than the simple one that predation rate is proportional to the number of seals. These and other factors which may affect the extent of the impact of seal predation on commercial fish catches are discussed in more detail later in this chapter.

The foregoing discussion deals with situations in which predation by seals and commercial fishing both operate over an extended period during the life of the fish, and there is generally some degree of overlap between them. A rather different kind of situation exists where both seals and fishing operations intercept migrating fish at a strategic point on their return journey, the so-called "gauntlet fisheries". Pacific salmon provide the most important example of this situation in the present context. There is little concrete evidence at present of a similar situation with regard to Atlantic salmon.

In such cases, natural mortality can probably be ignored for the duration of the fishery. The fish no longer eaten by the seals would now partly be caught in the fishery and partly escape to spawn. Thus the gain in the number caught will always be less than the original seal removals.

Growth also can probably be ignored so that the proportional gain will be the same for either the number or the weight of the catch.

A fairly simple formulation is possible if it is assumed that the seal predation and fishery operate simultaneously for a time, and that any fish which have not been caught by either constitute the escapement. It is shown in Appendix 24.3 that if N is the total run, C is the catch, H is the removal by seals, and E is the escapement, then, in the absence of seals, the new escapement E' is given by:

$$E' = NH/(C+H) EC/(C+H)$$

The new catch is then given by:

$$C' = N - E'$$

In a hypothetical example when $E = 200$, $C = 600$ and $H = 200$, then $E' = 299$ and $C' = 701$, so that the proportion of the seal take which has been added to the catch is $101/200 = 50.5\%$.

If the seal removal is made relatively small by putting $E = 2,000$, $C = 6,000$ and $H = 200$, then the relative addition to the catch becomes $107/200 = 53.4\%$. If the catch is reduced in this model to 4,000 out of the same total population, the relative addition becomes $61/200 = 30.5\%$.

In the above analysis it is assumed that the amount of fishing effort is kept constant, as seems appropriate in considering many pelagic or demersal fisheries. In some gauntlet fisheries, however, such as those for Pacific salmon, it is possible to monitor the actual escapement, and there is also excess fishing power available which, under regulation, is only employed for a restricted period. In such cases it may be possible to adjust fishing effort quickly so as to keep escapement to the desired level, and when this occurs, much, or all, of the additional fish becoming available through reduced seal predation might be added to the catch.

Size Effects

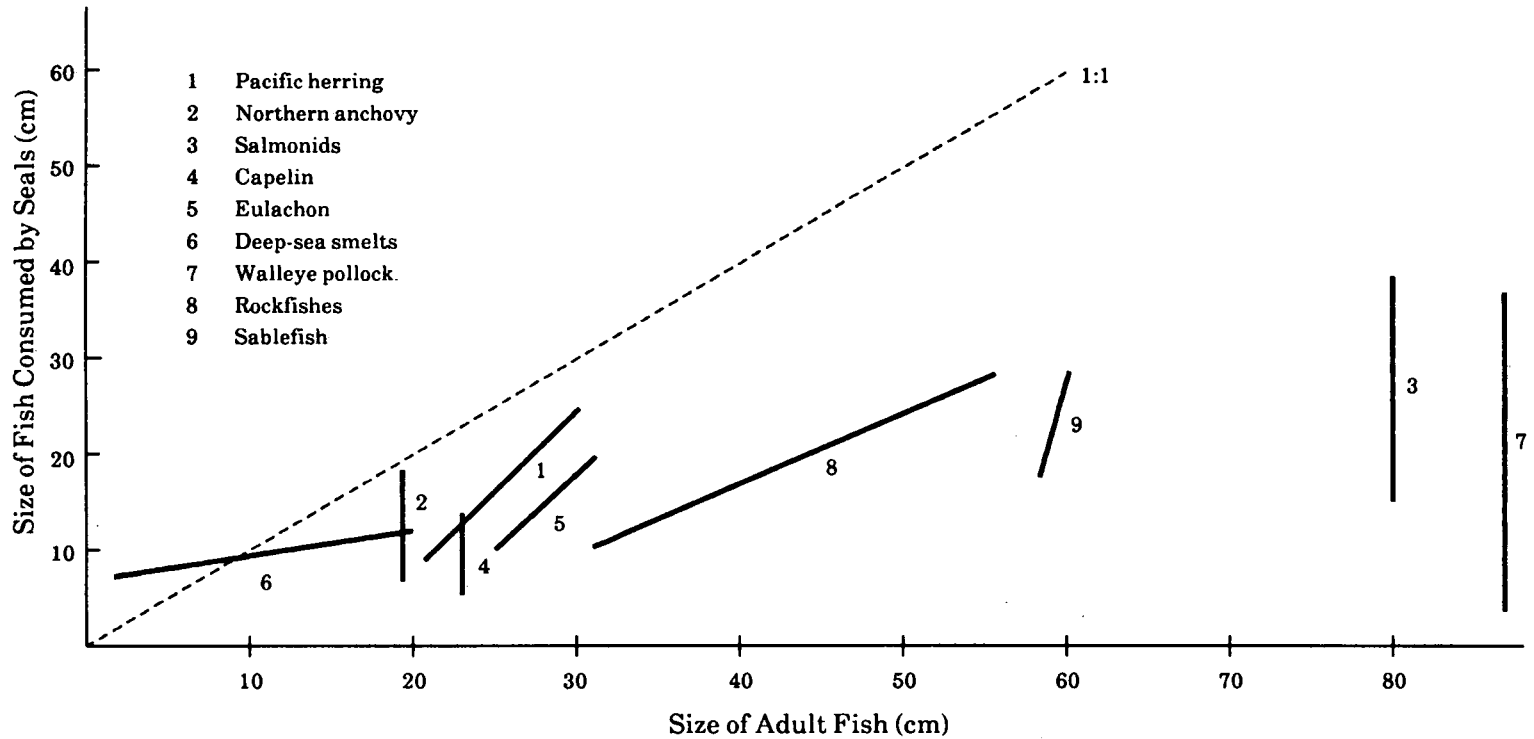
The analysis given in Appendix 24.2 assumes that the mortality rates due to fishing (F) and from predation by seals (S) are constant above a certain age, and in the first instance that both mortalities operate over the

same range of ages. More complex models show that the ratio R will vary if seals and fishermen take different sizes of fish. If seals include in their diet fish smaller than those taken by the fishery, this will tend to increase the impact on catches of a given weight consumed; this means that R will increase. The extent of the difference, if any, between the age of recruitment to the fishery and age at first consumption by seals will depend both on the sizes of fish which particular species of seals normally prefer and on the size to which each species of fish grows. In general, it is likely that the larger species of seals (e.g., grey, hooded and male fur seals, and sea lions) eat larger fish than do the smaller seals (e.g., harp, harbour and female fur seals). Spalding (1964), for example, showed that large species of fish (those with a mean adult length of 25 cm or more) formed a larger proportion of the food of sea lions than did smaller species (with a mean adult length of less than 25 cm), whereas the reverse was true of the harbour seal.

It also seems likely that, in general, any differences in age (or size) between fish eaten by seals and those caught by commercial fishermen, will tend to increase with the size to which the fish normally grows. Fish whose normal adult size is not much greater than the size first taken by seals are likely to show little difference, but fish whose adult size is much greater than that first taken by seals will probably show a substantial difference. The only extensive comparison of the "normal adult size" of a variety of fish species with the sizes eaten by seals has been published for migrating fur seals (females and young males) off the North American coast by Perez and Bigg (1985). The data in their Table 4 are summarized in Figure 24.2; the line for each species of fish joins the point of minimum size in seal stomach and minimum adult size with the point for the maximum ends of both ranges. It is evident that for these seals, the preferred food range is about 10 cm–30 cm, and that above an adult length of 15 cm–20 cm there is an increasing difference between size consumed and adult size as the latter increases. In most fisheries, the size mainly taken would correspond fairly closely to the adult size range, which implies that in the larger fish species, seal consumption would normally start at an earlier age than would the commercial catch.

The grey seal is larger than the female fur seal and appears generally to feed on larger fish when these are available, although, as has been mentioned earlier, it does take the relatively small sand lance in large quantities when that species is abundant. In some localities grey seals feed extensively on cod, which are recorded as forming about 50% of its diet at the Farne Islands and the Isle of May, off the east coast of the British Isles (SMRU, 1985).

Figure 24.2
Relationship Between Size of Adult Fish and Size Consumed by Northern Fur Seals



Source: Perez and Bigg (1984, Table 4).

Note: The line for each species joined the point representing the lower ends of both ranges with the point representing the upper ends of both ranges.

The mean weights of cod in the seal stomachs in these areas are stated as 1,050 g and 450 g respectively. These amounts are less than the average weight of cod in commercial catches, indicating that seals feed on cod younger than those taken in the fishery. Failure to allow for this in the model would lead to underestimates of the impact of predation on the fisheries.

If the larger species of commercial fish can grow fairly rapidly to sizes at which they are less vulnerable to attack by seals, this also could have a significant effect on the impact of seal predation on commercial catches. As an example, tests with a model having similar parameters to the North Sea cod stock referred to above showed that with seal predation starting at age one and the fishery at age two, the effect of a given seal consumption on the catch was nearly twice as great ($R = 1.4$) if seal predation extended only to age four, than it was ($R = 0.8$) if predation, like the fishery, took cod of all ages over the critical point. The effects are complex, however, and a specific analysis would be necessary for any case for which adequate data were available.

Application to Particular Species

The following sections apply these general principles and mathematical techniques to the principal groups of prey species. Rather than carry out a detailed presentation, describing the impact of any given change in seal consumption on fish stocks and commercial fish catches, the results have been summarized in terms of the likely ratio, R , of the change in catch to the change in amount consumed by seals. This method will take explicit account of the mortality rates due to fishing, seals and other causes, and of the growth of the fish. It is subject to the assumptions discussed earlier (e.g., that the fish consumed by the seals are, in other respects, typical members of the fish population). This procedure is probably valid (subject to the validity of these assumptions) for small changes in seal consumption, but may be less valid for large changes when second-order effects (e.g., compensatory changes in other causes of mortality) may become significant. The model assumes, however, that the mortality rate due to natural causes other than seal predation (M in Appendix 24.2) remains unchanged if seal predation is reduced. In other words, the fish not now eaten by seals are shared between the fishery and the other causes of mortality in the same ratio as before the seal stock was reduced. This means that the number of fish dying from these causes will increase. This, in turn, might require an increase in the numbers of other competing predators.

It may be noted that the presentations in this chapter concern the total impact of the stock of a given species of seal on fish catches; that is, the theoretical increase that would occur in fish catches if all the seals of that species were to disappear or to give up eating commercial species of fish. This hypothesis has some convenience for the purposes of presentation, but it has no practical significance. Further, large changes in consumption, fish stocks and fish catches would theoretically be involved, and several of the assumptions involved in the calculation of the ratio R may well break down. Chapter 29 on population control examines the more realistic question of what would happen to fish catches if there was a small or moderate change in seal consumption, or if a potentially expanding population were held stable. As used there, assumptions used in calculating R are more likely to be satisfied. In other words, the figures of total impact presented here should be treated with some caution, but the figures for the effect on the impact of the smaller population changes used in the population-control chapter are likely to be more reliable.

Capelin

Pauly (1980) gives estimates of the natural mortality rate (M) and the von Bertalanffy growth exponent (K) for capelin in the Labrador area as 1.3 and 0.48 respectively. Northridge (1986) suggests that total allowable catches (TACs) of capelin have been calculated as 10% of initial biomass, and with $M = 1.3$, the implicit value of F is 0.19. Recent catches have been small, however, and the current value of F is much less than this. In an earlier section it was stated that seal predation is likely to be between 1% and 5% of total predation; ignoring natural mortality from causes other than predation, this implies that the rate of seal predation mortality (S) is in the range of 0.01 to 0.06 and that, correspondingly, the non-seal mortality rate (M') is in the range 1.3–1.2. These values of K , M' , F and S can be used in the formula developed in Appendix 24.2 to obtain an estimate of R . It is also necessary to give values to T_r , the age at which the fish are first taken in the fishery, and T_s , the age at which they are first subject to seal predation. Some results are given in the table on the next page.

A central value of 0.10 will be used in the following calculations which corresponds approximately to $F = 0.1$ or about half the value believed to be required to yield present TACs. Under the present low intensity of the capelin fishery, however, this may still lead to an overestimate of the impact of seal predation on current catches.

Impact on Fish Stocks and Catches

T_r	T_s	F	0.05	0.10	0.19
		M	1.20	1.20	1.20
		S	0.04	0.04	0.04
2	1		0.06	0.11	0.19
2	2		0.05	0.10	0.17
3	2		0.04	0.09	0.16
3	3		0.05	0.09	0.15

Atlantic Herring

The principal seal predator on some east coast herring stocks is the harp seal, although herring are also eaten by harbour seals and grey seals. The main predation by harp seals is in the southern Gulf of St. Lawrence, and the same model can be used to examine what effect the removal of a given quantity of Atlantic herring by seals in this area would have on the commercial catch. Following Northridge (1986) for the value of the parameters, we have both seals and the fishery beginning to take herring at age two, the fishing mortality rate (F) of 0.3, and the von Bertalanffy exponent (K) of 0.616. The value of the total natural mortality rate (M) for herring varies from stock to stock over a range of about 0.2–0.4 (Pauly, 1980). The proportion (R) of the change in seal predation which will appear in the catch then depends on how much of total natural mortality is the result of predation by seals. The following table shows R for S forming different proportions of the total mortality, S being the mortality rate due to seal predation:

S/M	$M = 0.2$	$M = 0.4$
0.05	0.75	0.55
0.25	0.83	0.63
0.5	0.94	0.77

It appears that in the case of the Atlantic herring, a change in the amount consumed by seals is likely to produce a slightly smaller change in the amount of the catch. A value of 0.7 will be used for R in subsequent calculations.

The consumption of herring by harbour seals takes place mainly in a different area (4WX) and on a different stock from that by harp seals. It was estimated in a previous section at about 2,000 t –2,900 t against a biomass of 335,000 t and a catch of 81,000 t. The ratio of catch to biomass suggests that the value for F for this stock is not unlike that for area 4T, and in this case it is again likely that any change in seal consumption will cause a slightly smaller change in the catch. Since, however, seal consumption seems very small here compared to the catch, the effect of, for example, a 25% increase or decrease in the seal stock would have much less visible effect on catches in 4WX than a similar change in area 4T.

Pacific Herring

Since 1972, the pre-season biomass of herring on the British Columbia coast has averaged about 900,000 t, and the average catch has been about 50,000 t (Haist et al., 1985). Pauly (1980) gives values of K and M for the Pacific herring in B.C. waters of 0.48 and 0.50 respectively. The estimates of biomass and catch suggest that F is about 0.075. Since the seal consumption seems likely to be about half this, S can be taken as about 0.04, and the natural mortality rate from other causes as 0.46. These values can be used in the Appendix 24.2 model. The result shows that the change in catch is 18% of the change in seal consumption. This figure is almost totally insensitive to the rate of consumption by seals; it increases slowly with the rate of fishing mortality and reaches about 40% if F is 0.20, which seems an improbably high value. The model is also not very sensitive over a reasonable range of ages at which seals and the fishery begin to take fish; in the above calculations these ages were taken as two years and three years respectively. Reduction in the natural mortality rate, excluding seals, tends to increase the value of R , but only slowly.

The above estimate is based on the assumption that the fishing pressure would remain constant if seal predation changed. However the Pacific herring fishery in Canada has been managed in recent years with the aim of maintaining a fairly constant spawning stock. If this policy were continued, it would allow an increase in fishing pressure if seal predation were reduced, and consequently the catch would increase by a proportion greater than that calculated on the assumptions of the Appendix 24.2 model; that is, R would move towards 1.0.

Salmon

Much of the seal predation on the various salmon stocks takes place at about the same time as the fishery, and in this case the model described in Appendix 24.3 can be applied. The ratio between the catch and the desired escapement can vary greatly among different salmon stocks, depending on the species, on environmental factors and, particularly, on the size of the spawning run relative to the optimum level. The optimum escapement can range between a small fraction of, and several times the amount of, the acceptable catch. Using the above catch and seal-consumption figures with escapement/catch ratios of 0.2, 1.0 and 2.5 (which do not fully cover the range of possible values), the corresponding proportions of consumption transferred to catch are 38%, 70% and 84%. Thus, while reduction in seal consumption should, on this model, lead to an increase in catch, the amount of the increase will be less than, and possibly less than half of, the amount of the reduction. We have already noted, however, that where it is possible to adjust the fishing effort in these highly regulated fisheries to keep the spawning escapement at the desired level, virtually all the saving on seal predation will be transferred to the catch.

Demersal Fish

There is considerable variety in the growth and mortality rates of demersal fish, not only among species but also among stocks within species such as cod. It is not possible, therefore, to carry out more than indicative calculations of appropriate values for this group.

In making these calculations, a value of 0.2 has been used both for total natural mortality rate (M) and for the growth exponent (K). Results tabulated by Pauly (1980) suggest that these values are central to the commonly reported range for both gadid fish (e.g., cod) and flatfish. Other factors to be taken into account are the ages at which the fish enter the fishery (T_r) and at which they become subject to predation by seals (T_s), the amount that seal predation contributes to total natural mortality, and the fishing mortality rate.

The following table summarizes the values of R for a number of combinations of these parameters:

Impact on Fish Stocks and Catches

		<i>S/M</i>	0.25	0.75	0.25	0.75	0.25	0.75
		<i>S</i>	0.05	0.15	0.05	0.15	0.05	0.15
		<i>M'</i>	0.15	0.05	0.15	0.05	0.15	0.05
		<i>F</i>	0.10	0.10	0.20	0.20	0.30	0.30
<i>T_r</i>	<i>T_s</i>							
2	1		0.89	1.76	1.32	2.20	1.57	2.35
2	2		0.76	1.40	1.11	1.78	1.29	1.85
4	2		0.76	1.46	1.10	1.79	1.29	1.89
4	4		0.60	1.08	0.86	1.30	0.98	1.35
6	4		0.59	1.08	0.84	1.31	0.97	1.38
6	6		0.52	0.88	0.73	1.09	0.84	1.13

The value of S/M of 0.75 is probably much higher than will occur in nature, but it is included here to illustrate the effect that increasing the proportion of seal predation in total mortality has on the value of R ; that is, on the impact on the fishery.

The range of R is generally from 0.5 to 2.0, but it is between 0.5 and 1.5 for $S/M = 0.25$. It increases both with S and with F . It decreases with an increase in the age at which predation by seals begins, though it is insensitive to changes in the age at recruitment. It is also higher when seals start preying on fish younger than the age of recruitment to the fishery than it is when seal predation and the fishery commence at the same age. A value for R of 1.0 will be used for demersal fish in subsequent calculations, but an error of about $\pm 30\%$ seems possible.

Factors Modifying the Impact

Methods of estimating the amount of commercial fish eaten by seals and the effect that this consumption will have on catches have been developed above. There are a number of points which could modify the simple approach used so far, and which would lead to changes in the estimates if more detailed analysis based on more comprehensive data were possible.

Local Distribution of Stocks

Nearly all the preceding comparisons are based on estimates of stock, catch and consumption over large regions. In smaller areas where seals are concentrated, the fish they take may constitute a much larger proportion of the stock and, possibly, of commercial catches. This could occur in the vicinity of seal rookeries, or perhaps where seals are concentrated to feed on an abundant food supply, for example in estuaries where salmon are running. Such effects are likely to be of more importance in the case of resident seal species, such as harbour and grey seals and sea lions, than for the more migratory species, like harp and northern fur seals. There appears, however, to be little or no evidence concerning the significance of such local effects. If the areas of high seal concentration are also areas of above-average importance to the fishermen – which is quite possible – then the overall impact of seals on the fisheries will be increased. On the other hand, it is also possible that fishermen and seals may hunt in different areas, and in this case the impact will be reduced. The importance of the impact will also depend to a large extent on the degree of mixing which takes place in the fish stocks. If the stocks consisted of a series of small, more or less discrete populations, the local effects would be much more important than if there was a large degree of mixing among the fish.

Migratory fish stocks may also be exposed to predation by seals to different degrees during different stages of their movement cycle.

Destruction Additional to Consumption

Seals may sometimes kill fish in addition to those they consume, or, in the case of larger fish, take a bite from them without eating them fully. The ICES (1981) ad hoc working group noted that "grey seals are believed to kill more fish than they eat". This seems to occur most conspicuously when seals take fish from fishing gear, such as salmon gill nets; the question is also discussed in Chapter 25. If the seals eat only part of the fish they kill, the estimates of consumption will be underestimates of the total numbers killed, and therefore of the effect on the stock. The Commissioners believe that this effect is small compared to other uncertainties in the estimates.

Selection of Prey

In the simple equations fish eaten by seals are treated as similar in all other respects, to the rest of the fish population. In particular, they are

assumed, if not eaten by seals, to be just as likely to be caught as any other fish. The effects of differences between the fishery and seal predation in the age distribution of the fish they take or in the geographical area of their operations have already been discussed. There could, however, be other differences between the fish taken by seals and either the population as a whole or the commercial catch. In particular, fish eaten by seals might be sick or otherwise abnormal animals which, if not so eaten, would die soon from other causes, and would therefore in any case, be unlikely to be caught. There is no direct evidence on this matter (see IUCN, 1982). The effect certainly exists with some large land predators, particularly those that run down their prey, so that the impact of, say, wolves on a deer population is much less than would be expected on the simple hypothesis. Where the size of the predator is similar to, or smaller than, that of the prey, as with wolves and deer, it certainly would be sensible of the predator to pick out the weaker individuals among the target population. For most seals, however, the weight of the prey may be one or two orders of magnitude less, and thus the incentive to pick out sickly individuals might be small. There are exceptions: an adult salmon is not so small compared to a harbour seal, or even a grey seal, and these animals seem adept at finding salmon at a disadvantage as when they are caught in a gill net or trap. (See Chapter 25.) In general, though, there is no evidence that seals eat a significant proportion of sick or vulnerable animals, and the Commissioners believe that any such tendency is not so widespread as to invalidate the preceding conclusions about the proportion of the fish eaten by seals which would, if not so eaten, be caught by fishermen.

Second-Order Effects

Another aspect that should be considered concerns the less direct, or second-order, effects on commercial fisheries from the consumption by seals of fish other than commercial species. These effects can, in principle, be significant or negligible, and can be positive or negative. In general it can be expected that increased predation by seals on a fish species which is not itself the target of commercial fishing will be beneficial to commercial fisheries if the prey species is a predator on, or a competitor with, commercial species, but will be harmful if the prey of the seals is also a significant food source for commercial fish. This statement is complicated by the fact that fish will change their trophic position as they grow from larvae to big fish, but it may be used as a guide to the second-order effects.

A possible example of a positive effect may be provided by the grey seal off Scotland. In some areas a major element in its diet is ling (SMRU,

1985), which itself is of minor commercial value, but is a significant predator on other species, including more valuable commercial species such as haddock and whiting. Thus increased consumption by seals could mean fewer ling, but more haddock and whiting. This may be so, although if it is, it might be argued that the best decision, in terms of fishery management, would be to encourage greater fishing effort for ling, and thus benefit directly from increased catches of ling, as well as from increased catches of other species.

Species of fish which are eaten both by seals and by commercially important fish may or may not themselves be exploited commercially. The non-commercial species eaten by seals appear to be mainly small fish and invertebrates, many of which are also food for cod and other commercial species. It is clearly impossible to put any reliable numbers on these second-order effects, but it seems reasonable to suppose that they will generally tend to increase the negative impact of seals as estimated from the direct effects.

Second-order effects involving commercially important species at two different levels of the food chain may also be important, but they will be even more difficult to assess. Seal predation will tend to reduce the availability of both prey species to the fishery, but if the result of a reduction in seals were to be an increased catch of the lower-level species, there might be no benefit at the higher level. The ultimate impact would depend on how the fisheries for the two species responded to the changed conditions and, to an important extent, on the relative values of the two species of fish. In general, there is probably a tendency for the higher-level, larger species of fish to be more valuable than the lower-level species.

The second-order effect of this kind which seems particularly likely to be significant is that arising from the predation of cod on capelin, which are the most important forage fish in the Newfoundland area. Figures quoted in an earlier section give estimates of total capelin mortality due to predation of several million t as compared with a maximum commercial catch of about 300,000 t. Cod account for a large proportion, perhaps two-thirds, of this predation. A change in the amount of capelin consumed by seals would probably lead to some degree of compensatory change in the amount consumed by cod. It is impossible to assess how effectively cod would be able to adjust to a change in the amount of capelin available. If the capelin decreased, the cod might be able to make up the deficiency from other kinds of prey; if the capelin increased, the cod might not be able to increase their rate of food consumption accordingly, or they might compensate by eating less of other species. The fact remains, however, that any

capelin no longer eaten by seals must ultimately be accounted for by some other source of mortality. Kohler (1964) found, in experiments, that cod fed on herring converted their food into body weight with an efficiency of about 25%, allowing for maintenance. This suggests that if, as an example, half of the capelin no longer eaten by seals were eaten by cod, the additional weight of cod produced might be about one-eighth of the weight of capelin not consumed by seals. Some proportion of this additional production of cod would be taken by the fishery. If this proportion was similar to the proportion which the fishery takes of the additional fish made available by reduction in seal predation (i.e., equal to R), the benefit to be gained by the fishing industry through this channel would seem not insignificant compared to that obtained directly through the fishing for capelin.

Another example of these second-order effects is provided by the sand lance, which is an important part of the food of grey seals near Sable Island and is also eaten extensively by larger commercial fish. Leim and Scott (1966) state that over half of the food of haddock in this area consists of sand lance.

Compensatory Effects

A final point that might reduce the expected impact of seals on fish stocks arises from possible density-dependent or similar effects in the prey population that might occur as a result of changes in seal consumption (e.g., compensating changes in the mortality rates from other causes, changes in recruitment, or growth). Similar effects have been suggested in order to modify the estimated impacts of heavy fishing, and these effects have been examined by many of those studying the dynamics of fish stocks, from the major study of Beverton and Holt (1957) onwards. These investigators have concluded that taking account of density-dependent effects on growth or natural mortality will slightly reduce the estimated extent of the effects of changes in the amount of fishing from the estimates obtained from simple models. Taking account of density-dependent recruitment effects will increase the magnitude of the estimated effects. Similar arguments can be applied to predictions of the impact of seal predation; that is, taking account of compensatory effects on growth and mortality (other than that due to seals or humans) will reduce the extent of any impact, while density-dependent recruitment will increase the estimated impact of seals on fish catches.

In any case, if, following a change in seal predation, fishing effort is modified in an attempt to maintain the fish stock at about the same target level, these density-dependent effects will be very small.

Other Impacts on Fish Stocks

So far the discussion has focused on the changes in fish stocks and catches from them, as a result of changes in the number of seals, on the assumption that other things were equal. Other things are not equal, however, and fish stocks off Canada have undergone changes as a result of fishing pressure or of natural factors other than seals that exceed any changes likely to be caused by changes in seal numbers. Similar changes may well occur in the future.

Environmental factors can cause great year-to-year changes in the numbers of young fish reaching a fishable size, the result, it is believed, of events during the first few weeks or months of life (Hjort, 1914; Cushing, 1973). These factors have been important in determining the variations in, for example, some capelin stocks (see above). Short-term changes of this kind could have the effect of masking changes in the level of catch caused by variation in the abundance of seals. These effects have been discussed earlier, particularly in relation to effects on Atlantic cod. Longer-term changes, of decades or more, can also be significant, and may sometimes be related to observable changes in climate. Thus the rise and fall of the cod stocks off west Greenland in the 1920s can be clearly associated with the warming of the water and the more recent cooling (Cushing, 1982). This temperature change may also have affected the distribution, and perhaps the abundance, of hooded seals. (See Chapter 21.)

The dominant impact on Canadian fish stocks during the past half-century has been human exploitation. By 1975, the stocks of many of the more valuable fish on both coasts had been seriously reduced from their pristine abundance by large catches made by Canadian and, especially in the Atlantic, by foreign fishermen. Since the 1930s, Canada, in association with other countries concerned, has taken part in a number of international agreements aimed at controlling the situation. These agreements include the International Commission for the Northwest Atlantic Fisheries (ICNAF) for all fisheries on the Atlantic, and a number of more specialized agreements on the Pacific, including bilateral agreements with the United States over halibut and over salmon originating in the Fraser River. These arrangements have achieved some successes in managing the stocks, although the successes have been far from complete, especially on the east coast. There, the need to reach agreement among a large number of countries with diverse economic interests often meant that the measures adopted were too weak and were applied too late.

Canada only acquired the ability to apply fully effective measures with the extension of its jurisdiction over fisheries in 1977. Since then considerable progress has been made in rehabilitating some of the most seriously depleted stocks, including many of the Atlantic cod stocks, but many stocks are still below their most productive, or most economically rewarding, levels. In biological terms, the impact of fishing on many stocks is too high, and in economic terms the capacity of the fishing industry, both afloat and ashore, is too large. A complete solution of these problems would involve large social and economic disruptions, at least in the short term, and thus is far from easy. The problems of the fishing industry on both coasts have been examined by a number of other inquiries (Canada, Task Force, 1983; Canada, Commission on Pacific Fisheries, 1982), whose reports provide full details and reference to the relevant literature.

Some spokesmen for groups opposed to sealing, while not denying that seals eat fish, have stressed that seals should not be the scapegoats for the depletion of fish stocks caused by excess human exploitation (Holt and Lavigne, 1982). It is undoubtedly true that in most recent years, fishermen would have benefited more from successful measures to control and reverse the effect of overfishing than from controlling seals. This does not alter the conclusion, however, that control of seals could bring benefits, and that these benefits would become relatively more significant as the efforts to manage the fishery became more successful.

These considerations do not influence the quantitative estimates of the effects of seals on fish stocks and fish catches. The estimates developed in this Report apply mostly to current conditions of fish stock abundance and fishing mortality, and if these do not change, and if environmental factors affecting year-class strength also stay the same, the validity of the estimates will not change either. If there are changes, the adjustments will generally be minor. For example, if climatic factors cause a decline in the fish stocks, then both catches and consumption by seals are likely to decline. The impact of seals on catches, in terms of tonnes of fish, will also decline, but will remain much the same as a percentage of the catch, except to the extent that either seals or fishermen change their predation rates, for example, by switching attention to relatively more abundant species.

Discussion

To this point discussion has been concerned with the feeding of seals and their relation to fish stocks in a somewhat descriptive manner. It now

turns to address more directly the basic question within the mandate of the Royal Commission: Is there any reason to consider controlling the abundance of seals because of their competition with fishermen for fish? This question can be addressed in three stages.

- Is there any impact of seal predation, that is, do seals affect the size of fish stocks, and through them the size of fishermen's catches?
- How large, in terms of weight and value, is the reduction in catch caused by the seals?
- How much would this impact change as a result of a change in seal abundance?

Is There an Impact?

The Commissioners believe that there can be no serious doubt that seals have an impact on fish stocks. Most of the evidence presented and submissions made to the Royal Commission on this subject accepted this point, though there were considerable differences about the magnitude and the social and economic implications of the impact. The report of a working party set up by the International Union for the Conservation of Nature and Natural Resources (IUCN), with support from the People's Trust for Endangered Species, and the International Fund for Animal Welfare concluded:

The first [question] is whether the concern of the IUCN and other bodies about the seriousness of the conflict, actual and potential [impact of fisheries on marine mammals as well as vice versa], between marine mammals and fisheries is justified. By and large, the answer is yes, despite the frequent lack of conclusive evidence (IUCN, 1982).

In the first place, there can be no doubt that seals feed mainly on fish, and that a substantial, though variable, amount of that food consists of fish species that are taken by the commercial fisheries.

Secondly, we have been able, in this chapter, to consider estimates of the total quantities of food eaten by the principal seal populations. These estimates have been based on scientific evidence drawn from a variety of sources. While there are a number of points still subject to debate in the

underlying data, these uncertainties are relatively small. When they are taken into account, the Commissioners believe that the estimates of total food consumption for most of the major seal herds are likely to be correct within the range $\pm 40\%$.

The estimates of the amounts of particular fish species consumed are considerably less accurate than those of total consumption, because of the small size of the samples and the substantial seasonal and geographical variability. If, however, the consumption by one species is underestimated, that of another species must be overestimated by a similar amount in order to maintain the more precisely known total consumption.

Consequently, the estimates of amounts consumed of groups of similar species, taken together, are likely to be considerably more reliable than estimates for individual species. In our analysis we have therefore grouped together species, such as the commercially exploited demersal fish, which are harvested in a similar manner and to a similar extent by the fishery.

Although the effect of seal predation on commercial fish stocks and catches is difficult to demonstrate directly, many of the estimates of fish consumption by seals are of the same orders of magnitude as the takes of related commercial fisheries; and the ability of commercial fisheries to reduce the size of fish stocks to their own ultimate disadvantage has been only too widely demonstrated. It would seem to follow that the effects on the fish stocks would be similar whether a given quantity of fish is removed by fishermen or by seals, although seals, being opportunistic feeders, may have less tendency than the fisheries to push preferred species to low levels of abundance.

Nevertheless, although the evidence that seals can have an effect on the abundance of fish stocks and the size of catches seems overwhelming, the Royal Commissioners are not aware of any instance in which a known and measured change in the abundance of seals has had a measurable effect on fish catches. In this connection Dr. S.J. Holt stated in his brief (Holt, 1985):

It can be said that it emerges that there is no single case in the world where scientific evidence, dispassionately evaluated, supports the view that commercial fish catches will increase if seals are "controlled" by "culling".

If this statement is interpreted to mean that no clear-cut cause-and-effect relationship between seal numbers and fisheries' catches has been demonstrated, it is largely true. Almost the only clear demonstration in the scientific literature of the effect of a change in the abundance of any marine mammal on a fishery concerns the impact of sea otters on abalone (Johnson, 1982; Wild and Ames, 1974). Here the circumstances for demonstrating the impact were exceptionally favourable; sea otters have abalone as one of their favourite foods, they are capable of imposing a serious impact, and there was a substantial increase in sea otter populations as they recovered from near extinction as a result of severe overexploitation in the 19th century.

In other cases where fishermen or others have expressed concern about the impact on their catches of increasing numbers of seals or other marine mammals, it has not been possible to make a clear scientific demonstration of a neat one-to-one relation between a change in marine mammal numbers and a change in fish stocks or fish catches. There are good reasons for this: the data base for both seals and fish is often poor; the expected extent of the impact is uncertain; and the change may be small relative to the other sources of variation in the system.

Northridge (1986) used his simulation model to examine the last point, and to test whether quite large changes in the rate of seal predation on cod would produce changes in the catch that would be noticeable when allowance was made for random variation in year-class strength from year to year. He used parameter values based on what is known of cod in the Labrador area, biomass and catch values similar to those discussed above, and a seal consumption of about 150,000 t. The results suggest that increasing seal predation by a factor of about 3 (from $S = 0.06$ to $S = 0.2$) would produce a decrease in the catch of about 29%, which seems to be about half the amount of the increase in the hypothetical consumption by seals (Northridge, 1986, Figures 14(a), 14 (b)). Northridge suggests that this change in the catch would be detectable by statistical tests in about 10 years, but such a detection could, in practice, still fall short of a convincing scientific demonstration, since other factors influencing the situation, such as climatic changes or modifications to fishing pattern, could well have occurred.

In another simulation using the same cod stock parameters (Northridge, 1986, Figures 13(a), 13 (b)), a halving of the seal consumption caused an increase in catch of 9%, and it does not appear that the change would be detectable by statistical analysis over the 50 years during which the changed conditions were run in the simulation.

In summary, there are many factors that can complicate the simple theory that the fewer fish that seals eat, the more there will be for fishermen to catch, but none of those considered here seem sufficient, either alone or in combination, to modify the conclusion that seals do have some impact on several Canadian fisheries. Further, nothing the Royal Commission has heard or read suggests that there are any serious doubts within the scientific community that such impacts do exist. The doubts that exist concern the question of how big, or how small, the impacts are in any particular case. This question is addressed next.

How Large Is the Impact?

The preceding sections have discussed the difficulties in estimating the extent of the impact, and it is clear that any figures obtained will be at best very approximate. At the same time, the degree of uncertainty should not be exaggerated. The estimates of total food consumption by the major herds are probably correct to within about $\pm 40\%$. The percentage that any given fish species makes up of the total diet of the seals is subject to major uncertainty, but the sum of the consumptions of the individual species must be equal to the total consumption which is relatively better known. By grouping together species with a similar position in the fishery, it may be possible, therefore, to reduce this uncertainty to a level which makes the resulting estimates of some practical value; they may show, for example, whether the impact is likely to be serious enough to merit further consideration.

Thus, if the loss to fishermen caused by seal predation can be expressed, even very approximately, as so many dollars per tonne of the main categories of food consumed by the seals, many of the problems which arise from trying to calculate losses for the commercially important fish species individually can be avoided. The following sections attempt to develop this approach for the Atlantic region.

The first step is to estimate the amounts of each of the main types of fish which are consumed by the seals. In a previous section it has been pointed out that the Canadian industry takes only a very small amount of fish in the waters inhabited by hooded and harp seals in summer in Davis Strait and off Greenland and the northeastern Canadian archipelago. These waters constitute Areas A and B in Figure 24.1 and they will be ignored in calculating the approximate impact of seals on the Atlantic coast fishery.

We have also discussed the likely amounts of the principal groups of commercial fish taken by each species of seal in the rest of the Canadian waters on this coast (Areas C to F). Table 24.13 summarizes the estimated total consumption by each species of seal in Areas C to F and the amounts which are believed to be composed of each group of fish species. The estimates for capelin, herring and demersal fish have been discussed in detail earlier. Grey seals probably eat some salmon, but the amount is likely to be small, and no estimate can be inserted in the table. Harp seals are believed to eat substantial amounts of shrimp, but much of this is probably taken in Areas A and B; there are no data on which to base any estimate of the amount of shrimp consumed in the other areas, but it is probably less than the amount of capelin taken. It was also noted earlier that only harp and harbour seals feed significantly on other pelagic fish; no good estimate of the proportion is available, but it is assumed here to be fairly small. (See Tables 24.1 and 24.3.)

The next step is to ascribe a financial value to the loss caused by the consumption of commercial fish as determined in the preceding paragraph. This process has two components: assessing the reduction in catch caused by the seal consumption and placing a monetary value on that reduction.

The problem of determining the value of the ratios (R) of the change in catch to the amount consumed by seals was discussed in a previous section. The values which were estimated for the principal species groups were:

capelin	0.1
herring	0.7
demersal	1.0

The effect of using other values for the population parameters, including the relative ages of first capture by seals and by the fishery, and the intensity of seal predation, has been examined earlier for several species. The results suggest that other combinations of likely values for the parameters commonly produce estimates of R within a range of $\pm 30\%$ of the central value used, and this range will be used in the next stage of the calculations.

By multiplying these values of R by typical prices for the various fish classes, a "value factor" for each class is obtained which can be used to convert amounts consumed to losses to the industry. This is done in the following table, in which the average prices are rounded from values derived from the official statistics for 1981 and 1982 (Canada, DFO, 1984a). The value factor represents the loss to the catching side of the industry for each tonne of the various types of fish consumed by seals.

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Table 24.13
Indicative Calculations of Loss in Catch to Canadian East Coast Fisheries as a Result of Seal Predation

	Harp Seal	Hooded Seal	Harbour Seal	Grey Seal
Total Consumption (1000 t)	3,500	1,500	17	240
Consumption in Areas C-F (1000 t)	1,300	500	17	240
Consumption of Commercial Species (1000 t)				
Capelin	30-130	-	-	-
Herring	1-3	-	2-3	43-65 (18-27%)
Demersal	90-155 (7-12%)	350-450 (70-90%)	5 (30%)	100-150 (42-63%)
Salmon	-	-	-	?
Shrimp	?	-	-	-
Other Pelagic	?	-	1-3 (5-20%)	-
Total	121-288	350-450	8-11	143-215
Value (\$1,000,000)	Value Factor (\$/t)			
Capelin	14-26	0.4-3.4	-	-
Herring	125-225	0.1-0.7	-	0.3-0.7
Demersal	250-460	22.5-71	87-207	1.2-2.3
Salmon	?	-	-	-
Shrimp	?	?	-	-
Other Pelagic	125-225	?	-	0.1-0.7
Total Value	23-75	87-207	1.6-3.7	30-84

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	Capelin	Other Pelagic	Demersal	Atlantic Herring	Atlantic Salmon
<i>R</i>	0.07-0.13	0.5-0.9	0.7-1.3	0.5-0.9	0.7-1.3
Price (\$/t)	200	250	350	250	6,000
Value Factor (\$/t)	14-26	125-225	250-460	125-225	4,200-7,800

These values are subject to uncertainties of different kinds. The uncertainties in the values of *R* have been discussed above. The prices used can only be indicative, since the true prices vary with time and with the species and sizes of fish within the broad categories of other pelagic and demersal fish.

The results of these calculations for the Canadian Atlantic fisheries are set out in Table 24.13. This table does not include provision for any impact on the fishery from seal predation on Atlantic salmon, shrimp or sand lance, since the data available for these species are inadequate. Grey seals, and possibly harbour seals, are known to eat some Atlantic salmon. The large size and very high value (about 15 times that of cod) of these fish must make any impact of seal predation relatively large in proportion to the number of fish taken, but there are no data on which to base even an approximate estimate of the number consumed. Crustaceans, including a proportion of shrimp, are eaten quite extensively by harp seals in both their summer and their winter feeding grounds, but it is not possible to relate the amounts consumed to individual species, still less to stock size or catch levels. As was shown above, attempts to do so only reveal apparent discrepancies in the data. Sand lance are reputed to be an important food for grey seals around Sable Island, but there are no data on which to develop an estimate of the amount consumed. There is currently no significant fishery for sand lance in the western Atlantic.

The ranges given in Table 24.13 for the estimates of loss are based on the ranges of values adopted for the value of *R* for each category of fish, and for the percentage of each category of fish in the diet of each species of seal. It should be realized that the lowest estimates of the loss due to any species of seal would be correct only if the correct values of *R* for all fish categories were those given at the lower end of the range, and if the correct values of all the percentages of the diet for all fish categories were also equal to the lower end of the range. Similarly, the highest estimate of total loss would be correct only if the true values of all *R*s and all percentages in the diet were those given as the high end of the range. If some true values are nearer the

upper end of the ranges and others nearer the lower end, then the true losses would be at some intermediate point in the range given. If some of the true values of R or of percentages in diet are outside the ranges used in the table, the losses could be above or below the range given, but this would occur only if, for example, some value or values were below the range, and all the others were at or near the bottom end.

The estimates of loss given in Table 24.13 are based on the assumption that the single values used for the total consumption by each seal population are all correct. In an earlier section it was suggested that these estimates might be subject to a probable error of $\pm 40\%$. These error ranges could therefore be superimposed on the estimated losses attributable to each species of seal. It must be emphasized again that these extreme values would be applicable only if, in the lower case, the true values of all the R s and all the percentages in the diet were at the bottom end of the ranges given, and the total consumption estimates were 40% too high; or, in the upper case, all true values were at the top of the ranges and the total consumption estimates were all 40% too low. Readers will exercise their own judgment as to whether such combinations of errors are likely.

The estimates of loss due to each species of seal listed in Table 24.13 have not been combined to provide an estimate of the total loss attributable to all species of seals on the Atlantic coast. There are two reasons for this. First, for the purpose of practical applications, it will be necessary to consider each species of seal separately in determining the appropriate management policy. Secondly, there are great differences among the species in relation to the nature of the principal uncertainties which affect the values of the estimates, and these differences, combined with the great differences among species in the size of the estimated losses, will tend to make any process of combination rather meaningless.

Probably the greatest problems in assessing the accuracy of these estimates apply to the hooded and harp seals. The greatest uncertainty with the hooded seal lies in the extent to which it preys on fish stocks which are subject to exploitation by the Canadian fishery. In Table 24.13 it has been assumed that two-thirds of the food of the northwest Atlantic hooded seal stock are taken in Areas A and B, where these seals do not compete with the Canadian fishery; it has been further assumed that the 70%–90% of the diet in Areas C to F, which consist of demersal fish, is taken from stocks which are exploited by Canadians. Very little is known of the location of the main feeding areas of hooded seals in Areas C to F, and, in particular, of their relation to the principal fishing grounds. It is not impossible, therefore, that there is less overlap, and therefore less impact, than has been assumed in

the table. Furthermore, the figure for the proportion of commercial demersal fish in the diet is based on Greenland data, and no useful data are yet available for Canadian waters. There is little room for the true figure to be higher than the value of 70%–90% which has been used, but a lower figure is not impossible. There seems no doubt, however, that the hooded seal does feed predominantly on medium to large demersal fish, and that a substantial proportion of these fish are likely to be commercially important. The implications of the data in Tables 24.10, 24.11 and 24.13 are that in the absence of hooded seals, demersal catches in Area C would approximately double. This is dependent, however, on the assumptions that about one-third of the food of hooded seals is taken in Area C and that most of the demersal fish component taken there is from stocks subject to Canadian fisheries. These assumptions may well be true, but the resulting very large estimate of the impact should be regarded with reservation until much more data are available.

The difficulty with the harp seal arises principally from the fact that the estimated total food consumption is so great that even small errors in the proportion of its food taken from commercially important stocks can produce quite large changes in the absolute estimates of total impact. The uncertainty in the proportion of the food taken in areas of importance to Canadian fisheries is considerably less than that for the hooded seal; there is some uncertainty about the proportions of the total food taken in Areas A and B and in Areas C to F, but the relative values used (about 60%, 40%) are unlikely to be seriously in error. The greater uncertainty lies in the proportion of the food which is taken from commercially exploited stocks. In Table 24.13 the estimated consumption of commercial species by harp seals is 9%–22% of total consumption, and this does not include any allowance for the consumption of commercially important shrimp. On purely mathematical grounds therefore, it would be possible for the commercial fish consumption to be underestimated by a factor of 3 or 4. There seems no doubt that capelin is an important food of harp seals in this area, but just how important is not clear. The significance of errors relating to capelin will, however, be reduced by the relatively lower value of this fish, which leads to a lower monetary impact. The great fluctuations, both in the size of the capelin fishery and in the size of the stock, add a further element of uncertainty to the appropriate value of R for these stocks. Demersal fish, and possibly pelagic fish other than capelin, form only a small proportion of the diet of harp seals, but the very fact of the smallness of the proportion makes it extremely difficult to estimate. The values used in the calculations may, therefore, be subject to relatively wide probable errors. The high value factor for these species, combined with the large total consumption by harp seals, can cause relatively small uncertainties in diet percentages to produce

large uncertainties in the resulting estimate of the size of the impact. The relative stability of the demersal fish stocks and the operations of the fishery suggest that the value of R for these species is subject to less uncertainty than that for capelin. The same applies to pelagic commercial fish.

Grey and harbour seals feed almost entirely within the area of Canadian fishing operations; the uncertainties in the estimates of loss due to these species therefore arise mainly from the estimates of total food consumption, the proportions of the principal fish types in the diet, and the values of R . The ranges of estimates of loss given in Table 24.13 can therefore be viewed with more confidence than those given for harp and hooded seals.

No allowance has been needed in the estimates of loss for the fact that in some fisheries the catch is headed and/or gutted before landing; this is because the values per tonne used are adjusted to live (round) weight landed values. Use of prices prevailing at other levels in the marketing chain (e.g., wholesale, retail or export) would, of course, lead to higher estimates of the loss. No allowance has been made for elasticity in fish prices, but this seems to be appropriate. Fish prices are largely determined by the world market, and any variation in supply resulting from a change in the level of predation by seals might not have any significant effect.

Similar calculations could be made for the Pacific coast fisheries. They have not been attempted here for two reasons. One is that the data base is even more uncertain than that pertaining to the Atlantic coast. The other is that the impact on the fisheries is likely to be much less, since the estimated total food consumption is smaller by nearly two orders of magnitude.

Effect of Changing Seal Numbers

If consideration is to be given to reducing the numbers of seals in order to diminish the losses to the fishing industry, it is necessary to have some basis for assessing what effect a given change in numbers of seals will have on the amount of the losses. A number of factors are involved in this question.

- The total amount of food consumed will be proportional to the number of seals unless individual food consumption changes as the population size alters.

- The composition of the food may change with the number of seals.
- The ratio of loss of catch to seal consumption, R , may change with the amount consumed.

The question of changes in individual consumption in response to changes in population size is discussed briefly elsewhere in this chapter. Scientists do not fully agree about the direction in which such changes would operate, and it is likely that they would also be small compared to the direct effect of a change in the number of seals on overall consumption. Thus, total consumption will change in the same direction as changes in seal numbers, but perhaps not exactly in the same proportion.

It is possible that if the number of seals were reduced, they would be able to take a greater proportion of their food from preferred species. If these preferred species were also commercially important, the change in the impact on the fishery would be proportionately less than the change in the seal population. An opposite effect might occur if the number of seals increased, but such possibilities are only speculative at this stage.

The influence of a change in the seal population on the ratio of loss of catch to consumption can be examined by modelling techniques such as those in Northridge (1986) and Appendix 24.2. These or similar techniques could be used to examine any specific proposal. In general, it appears that the changes in the ratio are not likely to be great.

In the initial stages of developing policy relating to control of seal numbers for the benefit of the fishery, it seems reasonable to assume that the reduction in the loss attributable to seal predation on commercial fish would be roughly proportional to the reduction in the seal population.

Adjustments of Fishing Patterns

The foregoing discussions have dealt with one question: By how much will fish catches change, all other circumstances being equal, if the consumption by seals changes by a given amount? In particular, it was assumed that fishing mortality was held constant. Consideration should also be given to the degree to which changes in seal consumption might be followed by changes in fishing mortality.

The Royal Commission did not attempt to make a detailed review of Canadian fish stocks, although some information is given by Northridge (1986). It is clear, however, that the dominant factor in determining the abundance of the major commercial species on both coasts has been fishing. Further, some of these stocks (e.g., cod on the east coast, herring on both coasts) have been depleted in the past below their optimum level either by Canadian fishermen alone, or by the joint efforts of Canadian and foreign fishermen. This is true regardless of what precise definition of "optimum" is used.

This situation is now changing, especially since the introduction of the 200-mile limit. Canadian fisheries are, in principle, being managed, and the catches in most major commercial fisheries are subject to controls such as quotas. The basis of these controls varies from stock to stock; it includes objectives such as maintaining some target escapement (especially for salmon), exerting a fishing mortality equal to $F_{0.1}$ (mainly demersal stocks), or ensuring that the spawning stock does not fall below some prescribed level. In all cases, the nature and effectiveness of the controls depend on the biological situation, in which predation by seals must be a component.

If seal predation is reduced, it should be possible, at least in theory, to increase the fishing pressure while continuing to achieve the objectives for which the fishery is being managed. Since the fishery would now, in a sense, be replacing the predation previously exercised by the seals, the new regime should be able to provide a greater increase in yield than that indicated by the simple model in which fishing pressure is kept constant. If the seals and the fishery are taking fish of precisely the same range of ages, then the increase in catch should be exactly the same as the reduction in seal predation. Since, however, the age ranges are often very different, the increase in catch and the reduction in predation will not be the same. Modelling techniques such as those in Northridge (1986) could be used to examine possible effects in such cases.

Before any adjustment could be made to fishing pressure to maximize a gain in yield resulting from a reduction in seal predation, it would be necessary to have a much more detailed understanding of exactly what effects seal predation is producing than would be possible at present. Basically, two approaches are possible. The first is the continuation and extension of present studies of the population dynamics of commercial fish stocks with the aim of measuring any changes in population parameters, especially year-class sizes and mortality rates, which can be correlated with changes in seal abundance. The second is to undertake much more extensive and detailed studies of seal biology, particularly as it relates to seal distribution

and feeding, so as to place studies of the kind which have been outlined in this Report on a much sounder basis. The most critical questions are: Where and when do seals feed? What kinds of animals do they eat? What is the size and age composition of their food as compared with the population composition of the prey species? In addition, more needs to be known about the overall amounts of food that seals require, although present knowledge of this point, as it relates to most seals, is considerably better than knowledge of the composition of the food, and where and when it is taken. The problems involved are so complex, however, and the present level of knowledge so deficient that it will be necessary to undertake a major continuing research program for some time along all these lines before a sound basis for the joint management of seal and fish populations can be established.

Summary

1. The species of seal which may have significant impacts on commercial fish stocks are harp, hooded, harbour, grey and northern fur seals, and Steller and California sea lions. The northern elephant seal occurs in negligible numbers in Canadian waters, and the ranges of the ringed seal and bearded seal do not overlap substantially with commercial fisheries.
2. The food of all the seals making significant impact consists mainly of fish and sometimes of significant amounts of squid and shrimps. Seals are opportunistic feeders, and the composition of their food varies greatly, not only among species, but also with time and place. Because of this and because of the small amount of material which has been examined, even for relatively well-studied species like the harp seal and the northern fur seal, it is only possible to determine in very general terms what proportion of the food is made up of the various prey species.
3. All the species of seals listed above include a substantial amount of commercial fish or invertebrates in their food. The most important species are:

harp seal:	capelin, herring, shrimp
hooded seal:	deep-water demersal fish
harbour seal (east coast):	herring, flounder and other commercial demersal fish

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harbour seal (west coast):	salmon, herring, possibly other commercial species
grey seal:	commercial demersal fish, possibly salmon
northern fur seal:	herring, squid, salmon
Steller sea lion:	herring, salmon, commercial fish generally
California sea lion:	herring.

4. Examination of information on the stomach contents and rate of digestion of seals, their food requirements in captivity and their energy requirements suggests an average food requirement for wild seals of about 6% of body weight per day for the smaller species, grading down to 4% for the largest. These figures are used in subsequent calculations. The actual requirement of an individual seal is, however, affected by its rate of growth, level of activity and reproductive condition, as well as the energy content of its food.
5. Combining the estimates of the sizes of the various seal populations with those of the food requirements of individual seals provides estimates of total food consumption which are given in Table 24.9. These estimates should be regarded as, at best, correct within $\pm 40\%$.
6. Harp and hooded seals consume much larger amounts of fish than any of the other species examined, but their impact on Canadian fisheries is not proportionally as great. Harp seals in summer and hooded seals during most of the year feed largely in Davis Strait and off Greenland and the northeastern Canadian archipelago, where little Canadian fishing takes place. Hooded seals, when further south, also feed in deep water which may to some extent be outside the range of the fishery. Harp seals are thought to feed largely on capelin, and to some extent on shrimp and small demersal and pelagic fish, but non-commercial species may form a substantial proportion of their diet. Hooded seals feed to a large extent on medium to large demersal fish, some of which are of commercial interest. In the following discussion consumption by hooded and harp seals in the northern regions (Areas A and B in Figure 24.1) is ignored.
7. It is possible to attempt any quantification of the impact by seals only for the following stocks:

Capelin. The best estimate of the present amount consumed by harp seals in the southern area is within a probable range of 30,000t–130,000 t, but considerably more may have been eaten in earlier years when capelin were more abundant. No other seals take significant amounts of capelin. Comparison with the stock size and catches is complicated by wide fluctuations in both, due to effects of heavy fishing and of environmental factors. Biomass has varied between 0.5 and over 4 million t. Catches since 1973 have ranged between 30,000 t and 350,000 t, and are currently somewhere about the lower end of this range.

Other major predators on capelin are birds, cetaceans and particularly cod; at a rough, but possibly low, estimate harp seals may account for about 1%–5% of the total predation. Calculations suggest that any change in seal consumption of capelin would produce a change of the order of one-fifth of that amount in the commercial catch in periods of moderately high fishing effort, assuming that recruitment to the capelin stock did not vary. If fishing intensity on capelin is low, as it is at present, the impact will be correspondingly less.

Atlantic herring. Harp seals feed on herring, particularly in the southern Gulf of St. Lawrence (Area 4T) in the spring. Estimates of the amount consumed in the 1970s, using different methods, and with reference to different periods, are 7,000 t and 21,000 t, but at the present low level of the herring stock, consumption seems likely to be currently much less. The recent TACs here have averaged about 16,000 t so that seal predation seems to take about the same order of magnitude as the catch.

Harbour seals appear to take about 2,000 t–2,900 t of herring off the Nova Scotia coast (Area 4WX). This amount is relatively small compared to an estimated biomass of 335,000 t and a recent catch of 81,000 t.

Application of the population model suggests that a change in seal consumption of Atlantic herring will produce a slightly smaller change in the catches.

Pacific herring. All species of seals on the Pacific coast consume herring; their estimated combined consumption is about 16,000 t–20,000 t. This amount can be compared with a recent biomass of about 900,000 t and an average catch of 50,000 t. Thus consumption by seals is of the order of half the present catch. The model indicates that a

change in consumption would change the catch by only about one-fifth of the amount involved, but if the present policy of regulating the fishery to try to maintain a constant spawning stock could be successfully maintained, this ratio would move up towards 1.0.

Shrimp. Crustaceans, including shrimp, are eaten quite extensively by harp seals, particularly in the north, but it is not possible to give useful estimates of the amount consumed. Some estimates suggest that consumption could be large compared with stock size and catches.

Salmon. Atlantic salmon are eaten to some extent by grey seals, but it is not possible to assess the effect on the stock or on the catch.

Pacific salmon of all species are eaten by harbour seals, northern fur seals and Steller sea lions. The amount consumed is likely to be in the range 10,000 t–11,000 t. This amount may be compared with a recent average commercial catch of 64,000 t. Since there is often direct competition between the seals and the fishery as the fish return to spawn, a reduction in seal consumption might lead to an equivalent increase in catch if effort in this closely regulated fishery could be adjusted to keep escapement at about a constant level.

Demersal fish. These bottom-living fish, which are the target of trawl and some line and net fisheries, are best considered as a group. On the Atlantic coast they are an important component in the diets of hooded and grey seals, and are eaten to a lesser extent by harbour and, possibly, harp seals. On the Pacific coast they are relatively minor components of the food of harbour seals and sea lions. The total amounts consumed are estimated to be: Atlantic coast, 540,000 t–760,000 t; Pacific coast, 18,000 t–23,000 t. On both coasts these amounts are fairly similar to the commercial catches of these species. The reduction in commercial catch caused by seal predation on demersal fish is calculated to be about equal to the amount taken by seals.

Squid. Squid are eaten frequently by harbour seals on the east coast and by northern fur seals on the west coast, but it is not possible to evaluate the importance of this predation.

8. Very approximate calculations indicate that the reduction in the landed value of the Canadian Atlantic fisheries because of predation by the existing seal herds is very large and probably significant when compared with the value of recent Canadian commercial catches in

the area. The loss on the Pacific coast is very much smaller, perhaps by as much as two orders of magnitude, and also, very much less than the value of the catch. These figures are subject to a number of constraints which have been discussed in this chapter. Moreover, they do not allow for indirect effects which would arise if seals are eating significant amounts of species which are prey of, or predators on, commercial species. As an example, it is possible that the benefit to be gained by the fishing industry from increased production of cod as a result of reduced predation by seals on capelin could be significant. It is also possible, if less likely, that there are indirect effects in the opposite direction due to seals feeding on carnivorous fish like hake which also prey on commercially valuable species.

Conclusions

1. Seals consume large quantities of commercial fish in Canadian waters and, consequently, cause a reduction in the catches of fishermen. On the Atlantic coast, roughly five million tonnes of a wide variety of fish and some crustaceans and molluscs are consumed, mainly by harp and hooded seals. Rather less than half of this amount is taken on or near commercial fishing grounds off southern Labrador, Newfoundland, the Maritimes and Quebec. On the Pacific coast, only about 90,000 tonnes are consumed. Although some of this, on both coasts, consists of non-commercial species, the consumption of commercial species is considerable. This must have some impact on catches, though the catch will not be reduced by exactly the amount of the consumption of that species by seals. For some lightly exploited stocks the reductions, if any, may be much less than the seal consumption, but for heavily exploited species the reduction may be similar to or exceed the amount consumed.
2. The value of the difference between the actual catch and that which could hypothetically be taken in the absence of predation by seals can be estimated only approximately, primarily due to a serious lack of information regarding the nature and amount of food taken by seals. There is, however, also a need for much greater understanding of the inter-specific and density-dependent effects in the marine ecosystem.

3. On the Atlantic coast the value of this unavailable catch is undoubtedly very great; it is clearly significant in comparison with the total value of the current commercial catch. Less information is available regarding the potential losses on the Pacific coast, but they appear to be very much smaller, not only in absolute terms but also in comparison with the commercial catch.

Appendices

Appendix 24.1. Calculation of Relation between Change in Catch and Change in Seal Predation in a Simple Model

Given a fish stock (N) subject to constant instantaneous rates of natural mortality (excluding seal predation), fishing mortality and seal predation of M , F and S respectively, then by the time the entire stock is dead and if $F/M = a$ and $S/M = b$:

$$\text{Catch} = C = NF/(M + aM + bM) = aN/(1 + a + b)$$

$$\text{Seal consumption} = H = NS(M + aM + bM) = bN/(1 + a + b).$$

If the seal predation rate is changed by a factor k :

$$\text{Catch} = C' = NF/(M + aM + bkM) = aN/(1 + a + bk)$$

$$\text{Seal consumption} = H' = NS/(M + aM + bkM) = bkN/(1 + a + bk).$$

The ratio of change of catch ($C' - C$) to change in seal consumption ($H - H'$) is then given by:

$$R = \frac{C' - C}{H - H'} = \frac{a/(1 + a + bk) - a/(1 + a + b)}{b/(1 + a + b) - bk/(1 + a + bk)}$$

which simplifies to:

$$R = a/(1 + a) = (F/M)/(1 + F/M).$$

Appendix 24.2. Calculation of Change in Yield per Recruit Following Elimination of Removal of Fish by Seals

Using the previous notation, we can write for year t to $t + 1$:

$$\text{Seal removals} = H_t = N_t S_t W_t [1 - \exp(-M - F_t - S_t)] / (S_t + F_t + M),$$

$$\text{Catch} = C_t = H_t F_t / S_t.$$

$$\text{Next year's initial stock} = N_{t+1} = N_t \exp(-M - F_t - S_t).$$

Total removals and catch are then given by:

$$H' = \sum_0^{\infty} H_t \quad \text{and} \quad C' = \sum_0^{\infty} C_t.$$

In the absence of a take by seals $S_t = 0$ for all t and the total catch is then C'' . The ratio of the increase of yield to the amount previously taken by seals is then given by:

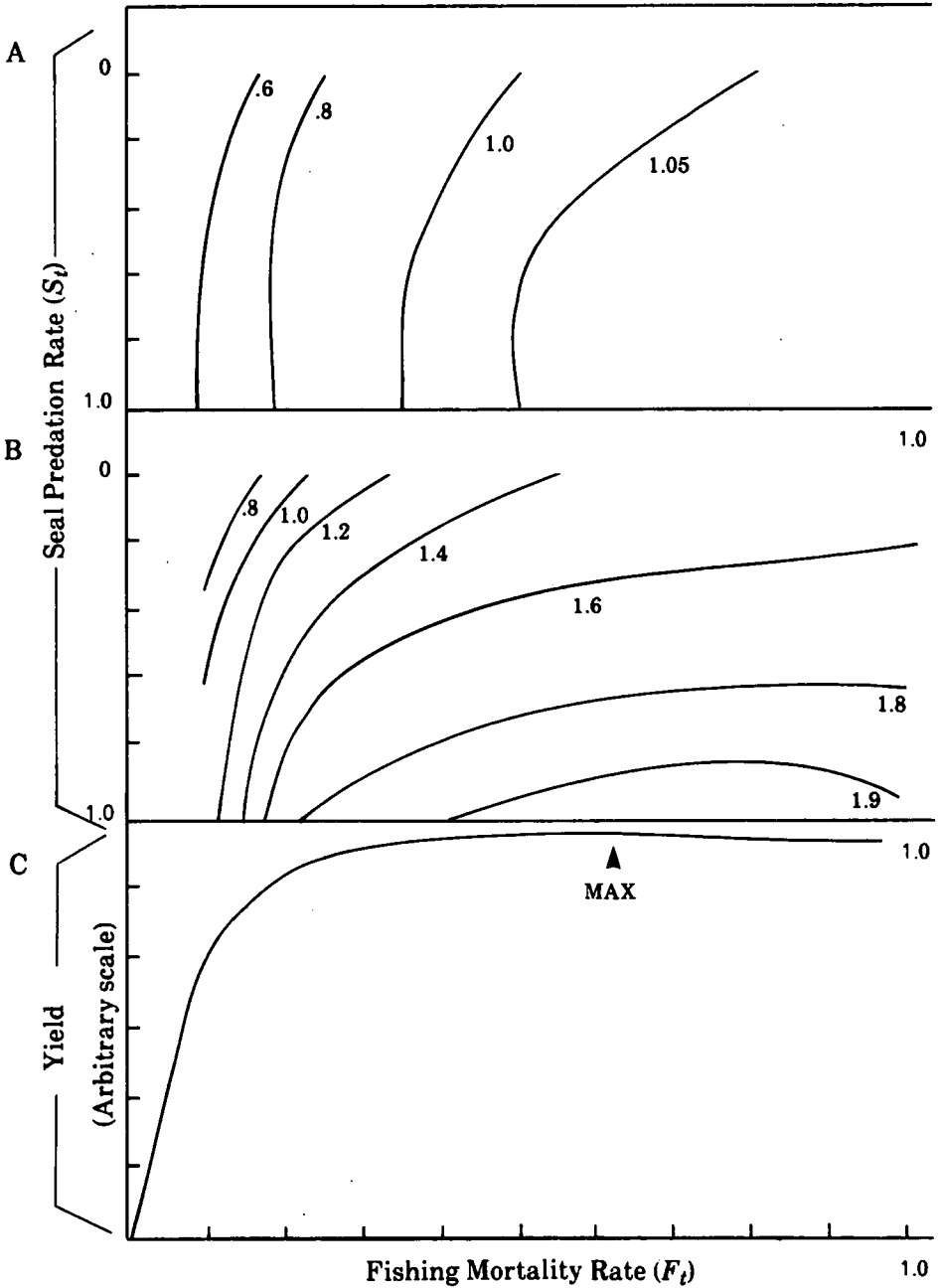
$$R = (C'' - C') / H'.$$

In applications where the initial ratio H'/C is known or assumed, S_t could be adjusted for a given series of F_t to produce the desired value. The application can be extended to determine the increase in catch produced by any defined reduction in the level of seal removals.

A computer program has been written to carry out these calculations with F_t and S_t set at constant values over defined ranges of fish age, and with W_t determined at the mid-point of each year, using the von Bertalanffy growth curve and isometric growth. To demonstrate the properties of the model it has been run for a range of values of S_t and F_t with $M = 0.2$; $K = 0.2$; $t = 0$; $W_{\infty} = 1$.

Figure 24.3 shows the isopleths for R for values of F_t and S_t between 0 and 1.0; for run A both fishing mortality and seal predation were taken as beginning at age 4; for run B fishing mortality began at age 4, but seal predation at age 2. Run C shows the value of the yield in the absence of seals for values of F_t between 0 and 1.0.

Figure 24.3
Yield Isopleths for R (A and B) and Yield in the
Absence of Seals (C)



Appendix 24.3. Calculation of Change in Yield in a Gauntlet Fishery Following Elimination of Removal of Fish by Seals

Ignoring natural mortality and growth over the relatively short period involved, if the number of fish entering the fishery is N , then the catch (C), removal by seals (H), and escapement (E) are given by:

$$\begin{aligned} E &= N \exp(-F - S) \\ H &= NS[1 - \exp(-F - S)] / (F + S) \\ C &= NF[1 - \exp(-F - S)] / (F + S) \end{aligned}$$

where F and S are the instantaneous fishing and seal predation mortality rates, taking the duration of the fishery as unit time.

$$\text{It follows that: } E = N \exp[-F(C + H)/C]$$

$$\text{From which } F = C \ln(N/E) / (C + H).$$

In the absence of seal removals, escapement (E') is given by:

$$E' = N \exp[-C \ln(N/E) / (C + H)]$$

which simplifies to:

$$E' = NH/(C + H) EC/(C + H).$$

The new catch is given by $C' = N - E'$.

The proportion of seal consumption which has been added to the catch is then given by:

$$R = [EC/(C + H) NH/(C + H) - E] / H.$$

References

- Ahrens, M., and G. Nielsen. 1984. An assessment of the 4T herring stock. CAFSAC Res. Doc. 84/64.
- Anderson, S.S., and M.A. Fedak. 1985. Grey seal males: energetic and behavioural links between size and success. *Anim. Behav.* 33: 829-838.
- Antonelis, G.A., and M.A. Perez. 1984. Estimated annual food consumption by northern fur seals in the California current. *CalCOFI Rep.* 25: 135-145.

- Beddington, J.R., and H.A. Williams. 1979a. The capelin *Mallotus villosus* (Müller). International workshop on biology and management of northwest Atlantic harp seals. University of Guelph, 3-6 December 1979, 3: 480-507.
- Beddington, J.R., and H.A. Williams. 1979b. Harp seal feeding. International workshop on biology and management of northwest Atlantic harp seals. University of Guelph, 3-6 December 1979, 3: 472-479.
- Benjaminsen, T., and P.F. Lett. 1976. A stochastic model for the management of the northern Atlantic harp seal *P. groenlandicus* population. ICNAF Res. Doc. 76/XI/130.
- Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., Ser. 2, 29.
- Bigg, M.A. 1985. Pacific Biological Station, Nanaimo, B.C. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Bonner, W.N. 1979. Harbour (common) seal, p. 58-62. In Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians. FAO, Rome.
- Bonner, W.N. 1982. Seals and man: a study of interactions. University of Washington Press, Seattle. Wash.
- Boulva, J., and I.A. McLaren. 1979. Biology of the harbour seal, *Phoca vitulina* in eastern Canada. Bull. Fish. Res. Board Can. 200.
- Bowen, D.B. 1981. Harp seals and their foods - how do they interact? NAFO SCR Doc. 81/XI/154.
- Bowen, D.B. 1985. Harp seal feeding and interaction with commercial fisheries in the northwest Atlantic, p. 135-152. In J.R. Beddington, R.J.H. Beverton and D.M. Lavigne (ed.). Interactions between marine mammals and fisheries. George Allen and Unwin, London.
- Bowen, W.D. 1986. Bedford Institute of Oceanography, Dartmouth, N.S. Letter to J.A. Gulland, Royal Commission on Seals and the Sealing Industry in Canada, 5 February 1986.
- Brodie, J.F., and A.J. Päsche. 1982. Density-dependent condition and energetics of marine mammal populations in multispecies fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 59: 35-38.

Impact on Fish Stocks and Catches

- Canada. Commission on Pacific Fisheries Policy. 1982. Turning the tide: a new policy for Canada's Pacific fisheries. Ottawa.
- Canada. Dept. of Fisheries and Oceans (DFO). 1984a. Canadian fisheries, annual statistical review, 1982. Vol. 15. Economic Analysis Division, Economic and Commercial Analysis Directorate, Ottawa.
- Canada. Dept. of Fisheries and Oceans (DFO). 1984b. 1984 commercial fishing guide: proposed fishing plans and stock expectations. Dept. of Fisheries and Oceans, Vancouver.
- Canada. Task Force on Atlantic Fisheries. 1983. Navigating troubled waters: a new policy for the Atlantic fisheries. Ottawa.
- Carscadden, J.E. 1983. Capelin as a forage species. NAFO SCR Doc. 83/IX/72.
- Carscadden, J.E., and D.S. Miller. 1979. Biological aspects of capelin and a sequential capelin abundance model for the division 3NLO stock. ICNAF Res. Doc. 79/33 (Rev.), Ser. No. 5359.
- Chapman, B. 1985. Testimony before the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of Fisheries Association of Newfoundland and Labrador Limited. St. John's, 23 May 1985. Vol. 3, p. 534-559.
- Cushing, D.M. 1973. The dependence of recruitment on parent stock. J. Fish. Res. Board Can. 30: 1965-1976.
- Cushing, D.M. 1982. Climate and fisheries. Academic Press, London.
- Davis, R.A., K.J. Finley, and W.J. Richardson. 1980. The present status and future management of arctic marine mammals in Canada. Science Advisory Board of the Northwest Territories, Yellowknife.
- Dunbar, M.J. 1949. The Pinnipedia of the Arctic and Subarctic. Bull. Fish. Res. Board Can. 85.
- Fedak, M.A., and S.S. Anderson. 1982. The energetics of lactation: accurate measurements from a large wild mammal, the grey seal (*Halichoerus grypus*). J. Zool. Lond. 198: 473-479.
- Fedak, M.A., and A.R. Hiby. 1984. Energy requirements of seals, p. 135-147. In Interactions between grey seals and U.K. fisheries. Natural Environment Research Council, Cambridge.
- Fisher, H.D., and B.A. Mackenzie. 1955. Food habits of seals in the Maritimes. Atlantic Biol. Stn. Note 133. Prog. Rep. Atlantic Coast Stations. Fish. Res. Board Can. 61: 5-9.
-

Impact on Fish Stocks and Catches

- Geraci, J.R. 1972. Experimental thiamine deficiency in captive harp seals (*P. groenlandica*) induced by eating herring and smelt. *Can. J. Zool.* 50: 179–195.
- Geraci, J.R. 1975. Pinniped nutrition. *Rapp. P. -v. Réun. Cons. int. Explor. Mer* 169: 312–323.
- Gulland, F.M.D. 1986. London Zoo, London, U.K. Personal communication with J.A. Gulland, Royal Commission on Seals and the Sealing Industry in Canada.
- Haist, V., M. Stocker, and J.F. Schweigert. 1985. Stock assessments for British Columbia herring in 1984 and forecasts of the potential catch in 1985. *Can. Tech. Rep. Fish. Aquat. Sci.* 1365.
- Harwood, J. 1985. Sea Mammal Research Unit, Cambridge, U.K. Personal communication with J.A. Gulland, Royal Commission on Seals and the Sealing Industry in Canada.
- Hauksson, E. 1984. Food of common seal and grey seal at Iceland. *Hafrannsóknir* 30.
- Havinga, B. 1933. Der Seehund (*P. vitulina*) in den Hollandischen Gewässern. *Ned. Dierkd. Ver. Tijdschr.* 3: 79–111.
- Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe, viewed in the light of biological research. *Rapp. Cons. Explor. Mer* 20: 1–228.
- Holt, S.J. 1985. The status of stocks. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of the International Fund for Animal Welfare, Rye, E. Sussex, U.K.
- Holt, S.J., and D.M. Lavigne. 1982. Seals slaughtered – science abused. *New Scientist*, 93(1296): 636–639.
- Hourston, A.S., and C.W. Haegele. 1980. Herring on Canada's Pacific coast. *Can. Spec. Publ. Fish. Aquat. Sci.* 48.
- Hughes, T.I. 1985. Testimony before the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of Committee on Seals and the Sealing. Toronto, 30 January 1985. Vol. 3, p. 75–125.
- Innes, S., D.M. Lavigne, W.M. Earle, and K.M. Kovacs. 1985. Feeding rates of seals and whales. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of the International Fund for Animal Welfare, Rockwood, Ont.
- International Council for the Exploration of the Sea (ICES). 1979. Ad hoc working group on interaction between grey seal populations and fish species. *ICES CM* 1979/N:5.

Impact on Fish Stocks and Catches

- International Council for the Exploration of the Sea (ICES). 1981. Interaction between grey seal populations and fish species. ICES Coop. Res. Rep. 101.
- International Union for the Conservation of Nature and Natural Resources (IUCN). 1982. Report of the IUCN workshop on marine mammal/fishery interactions, La Jolla, California, 30 March – 2 April, 1981. Gland, Switzerland.
- Johnson, A.M. 1982. The sea otter (*Enhydra lutris*), p. 525–531. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. IV, Small cetaceans, seals, sirenians and otters. FAO, Rome.
- Kajimura, H. 1984. Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the eastern north Pacific Ocean and eastern Bering Sea. NOAA Tech. Rep. NMFS SSRF-779.
- Kapel, F.O. 1982. Studies on the hooded seal (*Cystophora cristata*) in Greenland, 1970–1980. NAFO Sci. Coun. Studies 3: 67–75.
- Kleiber, M. 1975. The fire of life. 2nd. ed. rev. John Wiley, New York.
- Kohler, A.C. 1964. Variations in the growth of Atlantic cod (*Gadus morhua* L.). J. Fish. Res. Board Can. 21: 57–100.
- Lander, R.H., and H. Kajimura. 1982. Status of northern fur seals, p. 319–345. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. IV, Small cetaceans, seals, sirenians and otters. FAO, Rome.
- Larsen, F. 1985. Report on harp seal recoveries in Greenland, 1981–84. NAFO SCR Doc. 85/1/13.
- Lavigne, D.M., W. Barchard, S. Innes, and N.A. Øritsland. 1982. Pinniped bioenergetics, p. 191–235. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. IV, Small cetaceans, seals, sirenians and otters. FAO, Rome.
- Lavigne, D.M., S. Innes, G.A.J. Worthy, K.M. Kovacs, O.J. Schmitz, and J.P. Hickie. 1985. Metabolic rates of marine mammals. Brief to the Royal Commission on Seals and the Sealing Industry in Canada, Rockwood, Ont.
- Le Boeuf, B.J. 1979. Northern elephant seal, p. 110–114. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians. FAO, Rome.
-

Impact on Fish Stocks and Catches

- Leggett, W.C., K.T. Frank, and J.E. Carscadden. 1984. Meteorological and hydrographic regulation of year-class strength in capelin (*Mallotus villosus*). *Can. J. Fish. Aquat. Sci.* 41: 1193-1201.
- Leim, A.H., and W.B. Scott. 1966. Fishes of the Atlantic coast of Canada. *Bull. Fish. Res. Board Canada* 155.
- Lilly, G.R., R. Wells, and J.E. Carscadden. 1981. Estimates of the possible consumption of capelin by the cod stocks in divisions 2J + 3KL and 3NO. NAFO SCR Doc. 81/8, Ser. No. 272.
- Ling, J.L. 1969. A review of ecological factors affecting the ecological cycle in island populations of seals. *Pac. Sci.* 23: 399-413.
- Lockyer, C. 1985a. A theoretical approach to calculating food requirements of the Scottish grey seal, (*Halichoerus grypus*). Sea Mammal Research Unit, Cambridge, U.K.
- Lockyer, C. 1985b. Sea Mammal Research Unit, Cambridge, U.K. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.
- Lowry, L.F., K.J. Frost, and J.J. Burns. 1978. Food of ringed seals and bowhead whales near Point Barrow, Alaska. *Can. Field-Nat.* 92: 67-70.
- Mansfield, A.W., and B. Beck. 1977. The grey seal in eastern Canada. *Can. Fish. Mar. Serv., Tech. Rep.* 704.
- McConnell, B.J., J.H. Prime, A.R. Hiby, and J. Harwood. 1984. Grey seal diet, p. 148-186. *In* Interactions between grey seals and U.K. fisheries. Natural Environment Research Council, Cambridge, U.K.
- Myers, B.J. 1959. The stomach contents of harp seals (*Phoca groenlandica*) from the Magdalen Islands, Quebec. *Can. J. Zool.* 37: 378.
- North Atlantic Fisheries Organization (NAFO). 1983. Fishery statistics for 1981. *Statistical Bulletin* 31.
- North Atlantic Fisheries Organization (NAFO). 1984. Fishery statistics for 1982. *Statistical Bulletin* 32.
- Northridge, S.P. 1985. Marine Resources Assessment Group, Imperial College of Science and Technology, London, U.K. Personal communication with K.R. Allen, Royal Commission on Seals and the Sealing Industry in Canada.

Impact on Fish Stocks and Catches

- Northridge, S.P. 1986. Impact of fish stocks. Technical Report 2, Royal Commission on Seals and the Sealing Industry in Canada. Deposited with DFO Headquarters Library, Ottawa.
- Parrish, B.B. 1979. Notes on the scientific basis of the fisheries' case. App. 5, p. 157-163. *In* J. Listerkaye. Seal cull, the grey seal controversy. Penguin Books, Harmondsworth, U.K.
- Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. int. Explor. Mer* 39 (2): 175-192.
- Perez, M.A., and M.A. Bigg. 1985. Food habits of northern fur seals (*Callorhinus ursinus*) off western North America. National Marine Mammal Laboratory, National Marine Fisheries Service, Seattle.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* 191.
- Ronald, K., K.M. Keiver, F.W.H. Beamish, and R. Frank. 1984. Energy requirements for maintenance, and faecal and urinary losses of the grey seal (*H. grypus*). *Can. J. Zool.* 62: 1001-1005.
- Scheffer, V.B. 1958. The food of the Alaska fur seal. *Trans. 15th N. Am. Wildl. Nat. Resour. Conf.*, p. 410-421.
- Sea Mammal Research Unit (SMRU). 1985. Impact of grey and common seals on North Sea resources. SMRU, Cambridge.
- Sergeant, D.E. 1973. Feeding, growth and productivity of northwest Atlantic harp seals (*P. groenlandicus*). *J. Fish. Res. Board Can.* 30: 17-29.
- Sergeant, D.E. 1976. The relationship between harp seals and fish populations. ICNAF Res. Doc. 76/X/125, Ser. 4011.
- Sergeant, D.E. 1979. Hooded seal, p. 86-89. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians. FAO, Rome.
- Spalding, D.J. 1964. Fur seal, sea lion and harbour seal on the British Columbia coast. *Bull. Fish. Res. Board Can.* 146.
-

Impact on Fish Stocks and Catches

- Stewart, G.C. 1983. The effects of harbour seal predation on six commercially harvested salmonid species in the Fraser River estuary: a simulated management study. Manuscript report.
- Stewart, R.E.A., and D.M. Lavigne. 1980. Neonatal growth of northwest Atlantic harp seals, *Pagophilus groenlandicus*. *J. Mammal.* 61: 670-680.
- Stirling, I., and R. Archibald. 1979. Bearded seal, p. 83-85. *In* Food and Agriculture Organization of the United Nations, Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. *Mammals in the seas. Vol. II, Pinniped species summaries and report on sirenians.* FAO, Rome.
- Stobo, W. 1986. Bedford Institute of Oceanography, Dartmouth, N.S. Personal communication with C.E. Tull, Royal Commission on Seals and the Sealing Industry in Canada.
- United States. 1985. Environmental impact statement on the Interim Convention on the Conservation of North Pacific Fur Seals. Department of State and Department of Commerce, Washington, D.C.
- Venables, V.M., and L.S.V. Venables. 1955. Observations on a breeding colony of the seal, *Phoca vitulina*, in Shetland. *Proc. Zool. Soc. Lond.* 125: 521-532.
- Wild, P.A., and J.A. Ames. 1974. A report on the sea otter (*Enhydra lutris*) in California. *Cal. Fish and Game Mar. Res. Tech. Rep.* 20: 1-93.
- Winters, G.H. 1975. Review of the capelin ecology and estimation of surplus yield from predator dynamics. ICNAF Res. Doc. 75/2, Ser. No. 3430.