KJELL ISAKSEN, VIDAR BAKKEN AND ØYSTEIN WIIG

POTENTIAL EFFECTS ON SEABIRDS AND MARINE MAMMALS OF PETROLEUM ACTIVITY IN THE NORTHERN BARENTS SEA

NORSK POLARINSTITUTT
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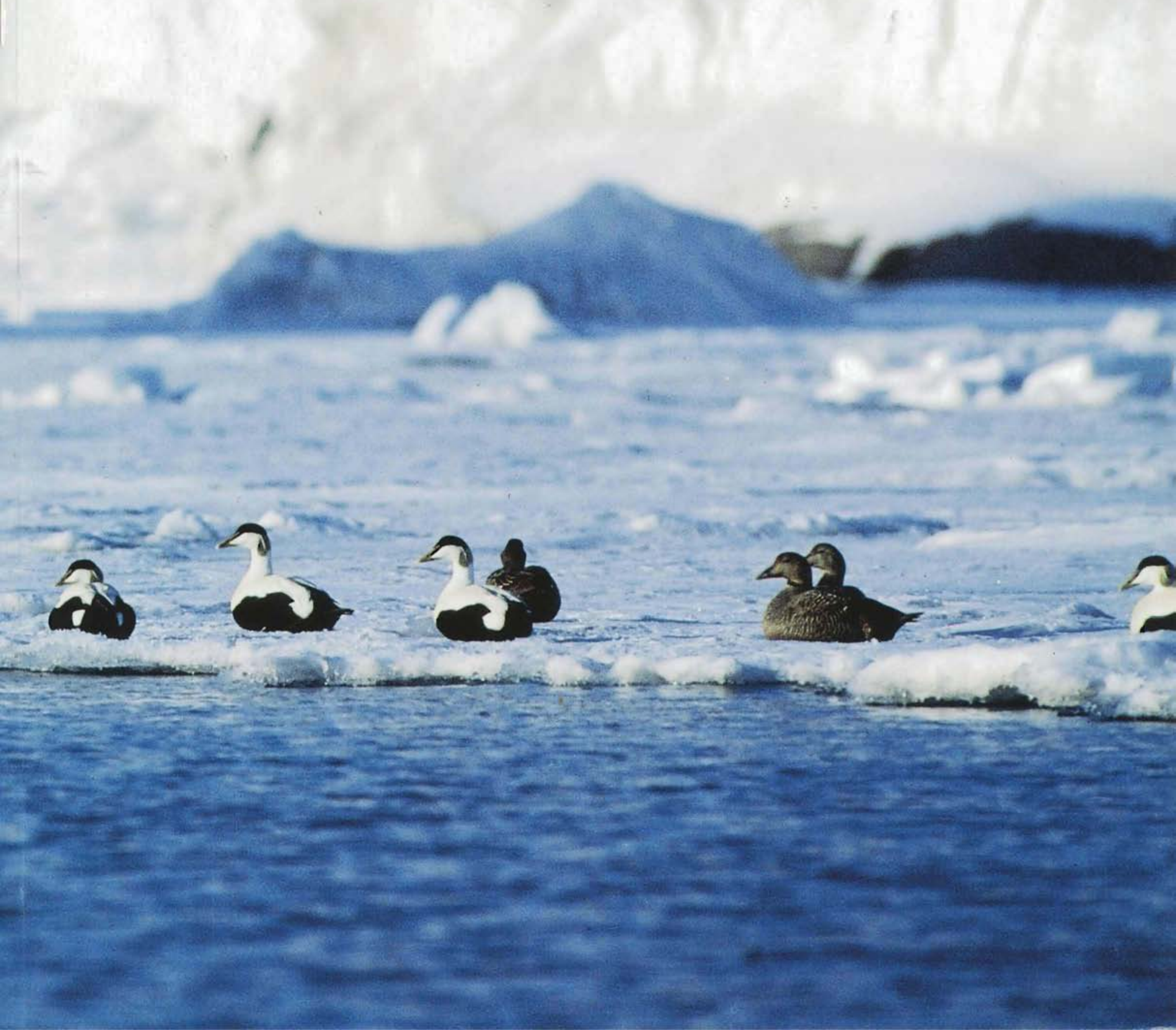

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1. INTRODUCTION

1.1 BACKGROUND

The northern part of the Barents Sea (north of 74°30'N) is the last large sea area with Norwegian sovereignty that has not been developed or assessed with respect to petroleum exploration. According to the Act of 22 March 1985, relating to petroleum activity (The Norwegian Petroleum Directorate 1985), the Norwegian Government, represented by the Ministry of Oil and Energy, is obliged to conduct an assessment of the potential effects of this activity on the environment and other values before opening the area for exploration. Such an assessment was completed for the southern part of the Barents Sea in 1988 (see Griffiths *et al.* 1987 for the work on marine mammals, Anker-Nilssen *et al.* 1988 for seabirds, and Børresen *et al.* 1988 for summary and conclusions), after which this area was opened for exploratory drilling with some restrictions on area and time period.

The responsibility for planning and carrying out the environmental impact assessments of petroleum exploration lies with the Working Group on Environmental Impact Assessments of Petroleum Activities on the Norwegian Continental Shelf (AKUP), an independent inter-governmental group under the Ministry of Oil and Energy. In addition, a separate steering committee for the projects in the northern Barents Sea has been established.

This report is the final result of work which began in 1989 to assess the potential effects of petroleum activity in the northern Barents Sea on seabirds and marine mammals. The main responsibility for coordinating and carrying out this work has lain with the Norwegian Polar Institute (NP). However, several other institutions have been involved at different stages. Some of the seabirds at sea data from the winter period which is used in this assessment has been supplied by the Norwegian Institute for Nature Research (NINA), which has also conducted a project describing the predictability of the occurrence of guillemots at sea in the Barents Sea. NINA is also responsible for the development of the computerised simulation model (SIMPACT) used in the assessment. The Institute of Marine Research (HI) has, in cooperation with Norwegian Institute of Fisheries and Aquaculture, prepared the distributional data on several marine mammal species. Finally, the Oceanographic Company of Norway A/S (OCEANOR) and the Norwegian Meteorological Institute (DNMI) have produced the oil drift statistics used in the assessment model. The assessment work has been financed by the Ministry of Oil and Energy. However, a major part of the basis data on seabirds and marine mammals has been collected during field work carried out and financed by other institutions, in particular HI and NP.

This report is an assessment of the potential impacts on seabirds and marine mammals of petroleum activity in parts of the Northern Barents Sea. The borders for this area have been set to 5°E in the west, 35°E in the east, 73°N in the south and 81°N in the north. The basis data and some initial assessments used in this assessment have been presented by Fjeld & Bakken (1993) and Isaksen & Bakken (1995a) for seabirds, and by Jødestøl & Ugland (1993), Jødestøl *et al.* (1994) and Isaksen & Wiig (1995) for marine mammals. The methods and the scheme for the assessment largely follow those outlined by Anker-Nilssen (1987) for assessments of the impacts of petroleum activity on seabirds. The same methods were used in the seabird part of the impact assessment of petroleum activity in the southern Barents Sea (Anker-Nilssen *et al.* 1988), as well as in later assessments for other areas on the Norwegian shelf (*e.g.* Lorentsen *et al.* 1993, Strann *et al.* 1993).

Only the effects of acute oil spills from the exploration area are assessed here. Petroleum activity in the area entails increased ship traffic outside this area and consequently increased risk of oil pollution also in more southern areas along the Norwegian coast. Of special concern here are accidents involving tankers carrying large quantities of oil to refineries on the mainland. The magnitude and the potential for harmful effects of such accidents was clearly demonstrated by the *Exxon Valdez* accident in Alaska in 1989 (see Piatt *et al.* 1990; Anker-Nilssen 1991; Loughlin 1994a). In addition to acute oil spills, petroleum activity and increased ship traffic will contribute to a more chronic oil pollution with the occurrence of small and frequent spills and operational discharges. The impact of low-level chronic oil pollution on seabirds and marine mammals is largely unknown, but may have important effects in the long run. Drilling operations result in the spreading of drill cuttings and discharge of large quantities of chemicals that are used in several stages of the drilling operation. At least the long-term effects of these chemicals on seabirds and marine mammals are largely unknown. Potential effects of drill cuttings and chemicals are not assessed here.

1.2 PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF THE NORTHERN BARENTS SEA

The northern part of the Barents Sea, as defined in this assessment, is relatively shallow with large areas less than 300 m deep (see Fig. 1). In the west there is a sharp shelf break towards the deeper Greenland Sea. There are several deeper trenches in the Barents Sea, Bjørnøyrenna, which reaches a maximum depth of 500 m, being the most important. Warm water is transported from the south up along the western coast of Spitsbergen and into Bjørnøyrenna and Storfjordrenna by Atlantic currents. Here these water masses meet cold water transported towards the south and west with Arctic currents. The contact zone between the two water masses is termed the 'Polar Front' and is characterised by high biological productivity during parts of the year.

Drift ice covers large areas of the northern Barents Sea. Biological productivity is particularly high along the melting ice edge in spring and early summer. There is large variation in the extent of the drift ice both within and between years, and this has important implications for the distribution of primary production as well as of seabirds and marine mammals. Further details on the physical and biological characteristics of the Barents Sea are given by Vinje (1985), Loeng (1991), Sakshaug *et al.* (1994a, b) and references therein.

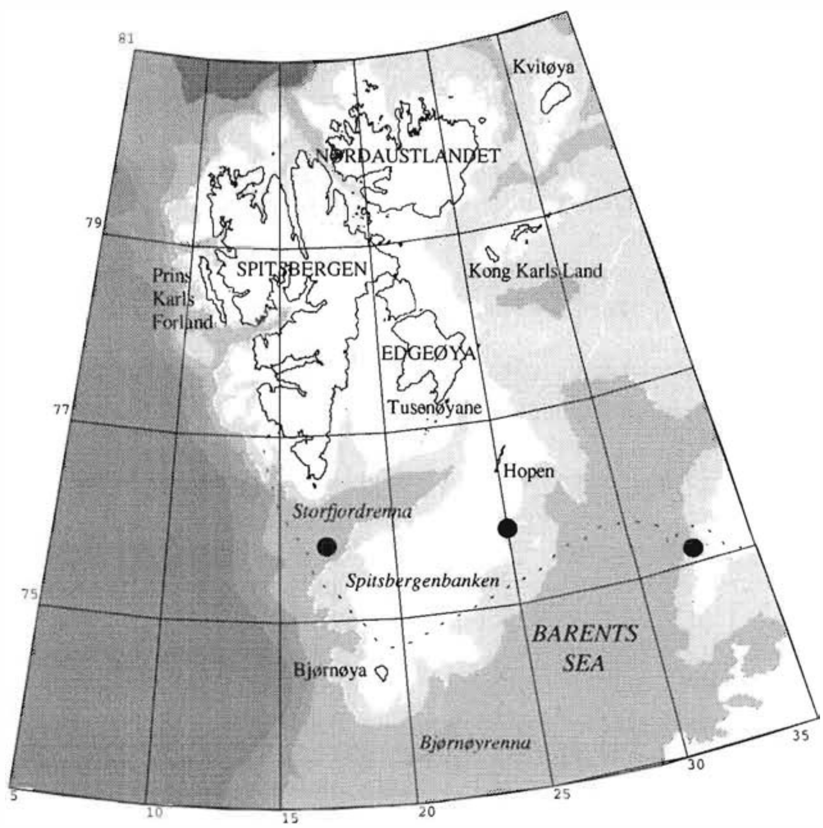


Fig. 1. Map showing the area covered by this assessment. The maximum extension of the drift ice in July is indicated by the hatched line. A rough, simplified sketch of the sea depth in the area is given in the depth categories 0–100 m (white), 100–200 m (light shading), 200–500 m (medium shading) and > 500 m (darker shadings). The three alternative drilling positions (see section 1.10) are indicated by solid black circles.

1.3 THE VALUE OF SEABIRDS AND MARINE MAMMALS

The conservation of biological diversity has been receiving increasing public and governmental attention and concern, especially since 1992 when the *Convention on Biological Diversity* was established (see Miljøverndep. 1993). A central part of the 'new' thinking on biological diversity is that each species represents a unique value independent of human economy, and that viable populations of all species should be preserved. International conventions oblige Norway to preserve several species of seabirds and marine mammals, and also some of the key habitats of these species. The most important conventions in this context are the *Convention on the Conservation of Migratory Species of Wild Animals* (the Bonn Convention), the *Convention on Wetlands of International Importance Especially as Waterfowl Habitat* (the Ramsar Convention), the *Convention on the Conservation of European Wildlife and Natural Habitats* (the Bern Convention), and the *Agreement on the Conservation of Polar Bears*.

Together with humans, seabirds and marine mammals are top predators in the food chains of the Barents Sea. As such they are important indicators of the state of the Barents Sea environment. The reproductive success of the different species in the area to a large degree reflects the availability of their preferred food organisms. The stocks of some of these organisms, especially fishes, are heavily affected by human exploitation; reduced reproductive success of seabirds and marine mammals may be a warning signal that the prey stocks are being depleted. In the same way, seabirds and marine mammals are important indicators of the levels of radioactivity and toxic contaminants in their environment; levels that may turn out to be harmful also for humans if active measures are not taken.

Seabirds transport large amounts of nutrients (mainly as excrements) from the sea to the areas around their breeding colonies. They are therefore important links between the highly productive marine ecosystem and the relatively low productive terrestrial ecosystem in the Barents Sea area. The fertilised areas are among the most luxuriantly vegetated on Svalbard and are important grazing areas for the Svalbard reindeer *Rangifer tarandus platyrhynchus*, an endemic subspecies.

Human exploitation of seabirds and marine mammals in the Barents Sea today is largely restricted to catching of Harp Seals (in the south-eastern parts) and Minke Whales. The economic value of this catching is relatively small, but it comprises an important complementary occupation in some coastal settlements in Norway.

Tourism in Svalbard has increased rapidly during the last decade, becoming one of the most promising alternative industries to coal mining. Svalbard is especially attractive and exotic to tourists because of its pristine nature and rich wildlife. The same qualities are highly valued by many people having no experience of Svalbard other than from television programmes and magazine articles. Viable populations of the naturally occurring seabird and marine mammal species are very important parts in the picture of an intact ecosystem largely unaffected by human activity. The ambition of the Norwegian authorities to make the Svalbard area one of the best managed wilderness areas in the world (Miljøverndep. 1995) is also relevant in this respect.

Protection of seabirds and marine mammals has been one of the most important motivations for establishing protected areas in Svalbard. For instance, Kong Karls Land was protected mainly due to the importance of this area as a denning area for polar bears, and the bird sanctuaries along the western coast of Spitsbergen were protected because of their importance for breeding geese and eiders. New protected areas are being planned today, for instance at Bjørnøya, and importance for seabirds and marine mammals is still among the most important criteria for establishing protected areas (see Theisen 1997, Theisen & Brude 1998).

1.4 GENERAL BIOLOGY OF SEABIRDS

The group of birds here termed 'seabirds' consists of species from seven different families, some of which are not normally considered as seabirds proper (divers; fulmars and shearwaters; swans, geese and ducks; sandpipers and allies; skuas; gulls and terns; and auks; see Appendix 1). The reproductive and behavioural biology of these species differ highly. Roughly, geese, ducks, sandpipers, skuas, gulls and terns have relatively high reproductive potential. They start breeding at an age of from one to three years (up to eight years in skuas and gulls) and lay several eggs in a single clutch (Cramp & Simmons 1977, 1983). On the other hand, fulmars and auks have very low reproductive potential; they start breeding from 6 to 12 years and from 2 to more than 10 years of age respectively, and they lay only a single egg each year (an exception is the black guillemot, which lays two eggs) (Cramp & Simmons 1977; Hudson 1985; Harris *et al.* 1994). The survival of adults is normally very high; fulmars and auks generally have an annual survival of about 90–98% after their first breeding season (Dunnet & Ollason 1978; Hudson 1985; Harris & Wanless 1995). As a result, recovery from a major loss of adults in a population of these species may be very slow (Samuels & Lanfear 1982; Heinemann 1993).

Most seabirds find all their food at sea and spend the major part of their lives offshore. However, the time spent flying, diving or swimming on the surface of the sea differs highly between the species. Fulmars, skuas and gulls spend much time flying and, compared to some other species, are relatively seldom in direct contact with water. In contrast, auks and ducks spend much time resting on and diving from the sea surface, and spend little time flying. These behavioural differences have important consequences for the species' vulnerability to oil spills, the species spending much time on the water tending to be those most vulnerable.

Generally, seabirds spend the non-breeding season in areas distant from their breeding sites. In addition to being important to seabirds in the breeding season, the Barents Sea is also important for seabirds as a wintering area and as a area used during migration to and from breeding areas (see Isaksen 1995a). Large numbers of seabirds breed in the Russian Arctic, especially on Zemlja Franca Iosifa, Novaja Zemlja, the Kola peninsula and in the White Sea (Norderhaug *et al.* 1977; Golovkin 1984). A large proportion of these birds winter in the Barents Sea or are transients here on migration. Immature and non-breeding birds from Russian areas may also spend the summer out in the Barents Sea. Oil spills in the Norwegian part of the Barents Sea may therefore influence not only breeding populations from Svalbard and North Norway but also populations breeding in Russia (see Barrett 1979).

1.5 SEABIRDS AND OIL

The effects of oil pollution on seabirds have been reviewed by a number of authors (*e.g.* Holmes & Cronshaw 1977; Folkestad 1983; Clark 1984; Leighton *et al.* 1985; Piatt *et al.* 1991; Leighton 1993; Jenssen 1994; Nisbet 1994). Severe mortality in a number of oil-spill incidents has shown that seabirds are among the species most heavily affected by oil spills. For instance, 45,000 oiled seabirds (mainly auks and eiders) were found along the coast of Skagerrak in 1980/1981. The actual number of birds which died due to the spill was probably several times higher. The oil probably stemmed from the flushing of oil tanks or discharge of oil-containing ballast water from the Greek oil tanker *Stylis* (Anker-Nilssen & Røstad 1982). The grounding of the oil tanker *Exxon Valdez* in Prince William Sound, Alaska, in March 1989 resulted in spillage of a large quantity of oil in an area with high numbers of seabirds. Estimates of the total number of seabirds killed by the spill range from a minimum of 100,000 to 500,000 individuals, mostly auks (Piatt *et al.* 1990; Fry 1993; Piatt 1995).

Seabirds rely on a water resistant plumage for thermoregulation. When a seabird comes in contact with oil on the water, the oil adheres to its feathers and causes a reduction of the water-repellent properties of the plumage (Jenssen 1994). Water penetrates into the plumage and replaces the insulating layer of air causing an increase in heat loss to the bird. Consequently the bird must use more energy on heat production to maintain a stable body temperature. The heat loss of a heavily oiled bird may exceed the bird's heat production capacity, and as a result the bird may freeze to death. Heat loss is greatest while the bird is swimming. Oiled seabirds therefore often seek to land to minimise heat loss. Most species must, however, spend quite a lot of time in the water to attain food, which in turn increases heat loss and energy requirements. Diving species, which must find all their food in the sea, are most susceptible. Due to the surface-volume ratio, the relative heat loss of a small bird will be larger than that of a large bird. This results in the small and diving little auk being more susceptible to this direct effect of oiling on thermoregulation than a large goose feeding on land (Jenssen 1994). Oiled birds also become heavier and loose buoyancy. This may result in inhibition of feeding activities at sea or in drowning. The oil contamination of flight feathers may in addition impair flight ability (Holmes & Cronshaw 1977; Leighton *et al.* 1985).

Oiled breeding birds may transfer oil to their eggs and young during brooding and warming. Small amounts of oil on eggs has been found to cause a major reduction in hatchability, especially early in the incubation period (King & Lefever 1979; Albers 1980; Lewis & Malecki 1984; Leighton 1993; Oakley & Kuletz 1993). Surviving hatchlings may be malformed (Hoffman & Albers 1984). It has been observed that gulls use nesting material which is contaminated with oil up to several years after a spill (Maccarone & Brzorad 1994). This may result in transference of oil both to the plumage of brooding birds and to eggs and young.

Adult seabirds may ingest oil during preening of oiled feathers, by eating oil-contaminated food and by drinking oil-contaminated water. Ingestion of oil is generally stressful for birds and induces a physiological response (Leighton 1993). The physiological effects are increased in birds stressed simultaneously by other means, such as cold weather or food shortage (Holmes & Cronshaw 1977). Crude oils and their distilled products differ significantly in composition and toxicity depending on origin. The generality of toxicological effects found during single studies is therefore questionable (Leighton 1993). The major source of toxicity in oil seems to be polycyclic aromatic hydrocarbons (PAHs), which may be present in oil in different quantities (Miller *et al.* 1982; Leighton 1993). Oil is degraded by natural weathering processes (Payne *et al.* 1991), but it is not clear how this influences the oil's toxicity to seabirds (see Leighton *et al.* 1985; Leighton 1993; Stubblefield *et al.* 1995a, b).

Inhibition of egg laying, reduced hatchability of eggs, reduced growth rates and survival of young, reduced immune defence, and anemia are among the effects which have been found when relatively small, sub-lethal doses of oil have been experimentally fed to adult seabirds (Ainley *et al.* 1981; Rocke *et al.* 1984; Trivelpiece *et al.* 1984; Fry & Lowenstine 1985; Butler *et al.* 1988; Leighton 1993).

Nestlings may ingest oil when fed contaminated food and when preening plumage contaminated by contact with oiled parents or nesting materials. Ingestion of oil by young has been found to impair growth and osmoregulation and may have important effects for the long-term survival of the young (Miller *et al.* 1978; Peakall *et al.* 1980; Leighton *et al.* 1985; but see also Prichard *et al.* 1997).

In addition to the direct, often clearly visible effects of oil spills, there are several other more indirect or subtle ways through which oil pollution may affect seabirds. There is, however, no clear distinction between these and the more direct effects outlined above.

In a study of wedge-tailed shearwaters *Puffinus pacificus*, Fry *et al.* (1986) found that external application of a minor quantity of weathered crude oil on the breast feathers of adults one month prior to egg laying resulted in reduced breeding success both in the actual and the following breeding season (after which the study was terminated). Abandonment and reduced incubation attentiveness seemed to be the direct causes of the reduced breeding success observed in the first year. In the second year, the number of birds returning to the colony to breed was reduced, and disruption of pair bonds between breeding birds may have contributed to the low reproductive success (Fry *et al.* 1986).

After the *Braer* accident in January 1993 in Shetland, no immediate negative effects on breeding success were found on kittiwakes breeding nearby. The breeding birds suffered, however, from anemia (probably as a result of ingestion of oil), and there was a high incidence of non-breeding, nest-site change and disruption of breeding pairs in the study colony (Walton *et al.* 1997).

Delayed breeding and reduced reproductive success persisted for at least three years in some common guillemot colonies affected by the *Exxon Valdez* spill. This was suggested to be the combined result of a high proportion of young, inexperienced breeders and the disruption of social breeding behaviour in the colonies after a major oil-spill related mortality of older, experienced breeders (Fry 1993; Nysewander *et al.* 1993; but see Wiens 1996).

Reproductive success in seabird colonies is often highest when the density of breeding birds is high. This, at least partly, as a result of reduced rates of predation on eggs and chicks (Birkhead & Harris 1985). Direct mortality and/or sublethal effects of oiling may cause the absence during breeding season of a significant proportion of the birds normally breeding in a colony. Besides disrupting pair bonds, this leaves the remaining breeding pairs more susceptible to predation. Lightly oiled parents may also use more time than normal to meet their own requirements (preening and foraging), leaving eggs and chicks unattended and susceptible to predation (Eppley 1992).

Oil spills most often entail intensive clean-up operations, especially if the spilled oil reaches land. The increased activity by aircrafts, boats inshore and personnel on land may have negative impacts on birds in the area (see Hunt 1987; Dahlgren & Korschgen 1992). Disturbance may scare away breeding birds, leaving eggs and chicks vulnerable to the cold and to predators (Burger 1981; Åhlund & Götmark 1989); the birds' foraging opportunities and energy balance may also be influenced (Mosbech & Glahder 1991; Burger 1997). Shy species such as geese are probably the most vulnerable.

Oil spills may reduce the availability of food for seabirds by causing significant direct mortality of the seabirds' food organisms or by altering the migrations or behaviour of the food organisms (see *e.g.* Pearson *et al.* 1984) (see Hassel *et al.* 1997 for an assessment of the effects of oil spills on plankton and fish in the northern Barents Sea). In addition, hydrocarbons from a spill may be accumulated in food organisms or be retained in bottom sediments causing more long-term, low-level poisoning of seabirds (*e.g.* Patten 1993; but see also Boehm *et al.* 1996).

Little is known about whether seabirds avoid areas contaminated by oil or not. During a single incident involving a small slick, a few guillemots were seen diving and gulls were seen rising and flying away when they swam into the oil. The behaviour of the guillemots, observed to be swimming in apparently random directions under water, may act to enhance oiling as they may encounter a dense layer of oil when surfacing to breathe (Bourne 1968). There are also reports of long-tailed ducks landing in patches of oil on the water, where the sea is less heavy (Bourne 1968). Mallards *Anas platyrhynchos* held in pens with oil-covered water hesitated longer before entering the water than mallards in pens with clean water, indicating that birds try to avoid entering oiled water if they have access to clean water (Custer & Albers 1980). Results from experimental oil spills at sea suggest that fulmars deliberately avoided settling on a polluted sea surface (Lorentsen & Anker-Nilssen 1993; Lorentsen 1995). These experiments were, however, conducted during good weather and light conditions and it is unknown if the fulmars (or other species) would behave similarly under poorer conditions (Lorentsen & Anker-Nilssen 1993; Lorentsen 1995).

There is no consistent relationship between the volume of an oil spill and the impact on seabirds. The density and species of seabirds in the affected area, stage in breeding cycle, distance to shore, weather conditions and other factors are more important than spill volume alone (Clark 1984; Burger 1993). For instance, two or three small spills covering a few hundred or thousand square metres in total killed an estimated number of 10,000–20,000 seabirds (mostly Brünnich's guillemots) off the coast of Finnmark, North Norway, in March 1979 (Barrett 1979). Breeding aggregations of auks at colonies, swimming migration out from breeding colonies of young guillemots accompanied by one of the parents, and large moulting concentrations of eiders are examples of settings where oil spills would have large impacts.

There has been some debate on how important mortality from oil pollution is for long-term dynamics of seabird populations (*e.g.* Dunnet 1982; Clark 1984; Leighton *et al.* 1985; Evans & Nettleship 1985; Piatt *et al.* 1991). An important point is whether mortality from oil comes in addition to or may replace natural mortality (Hunt 1987; Piatt *et al.* 1991). This depends to some degree on the nature of the mechanisms regulating seabird populations. If these mechanisms operate in a density dependent manner, mortality from oil may substitute some of the natural mortality (Piatt *et al.* 1991). The knowledge on how seabird populations are regulated is relatively limited. Some of the main mortality factors other than oil seem, however, at least for auks, to be largely density independent. Examples of this are mass mortality (wrecks) after long periods of unfavourable weather (Hudson 1985), food shortage imposed by large scale variations in fish stocks which only to a small extent is regulated by predation from seabirds (Vader *et al.* 1990; Anker-Nilssen & Barrett 1991), and drowning in fishing nets (Strann *et al.* 1991). About 40–60% of the seabirds killed by oil spills have been found to belong to the breeding part of the population, whereas the majority of birds dying from natural causes are juveniles and immatures (Piatt *et al.* 1991). As previously mentioned, the mortality of adults has much more important consequences for the population of most seabird species than the mortality of chicks and subadults. Density dependent factors seem to be more important in determining recruitment rates to populations (see Birkhead & Furness 1985).

In conclusion, oil pollution may have important long-term effects on seabird populations. In some cases oil spills seem to have driven local breeding populations almost to extinction (see Piatt *et al.* 1991). Major oil-spill related mortality may be especially detrimental for populations that are significantly reduced in size or for populations negatively affected by other commercial and industrial activities (drowning in fishing nets, food deficiency due to human over-harvesting of the seabirds' food resources, or long-range transported pollution).

1.6 GENERAL BIOLOGY OF MARINE MAMMALS

In this report representatives from seven different families of 'marine mammals' are included: walrus, true seals, bears, right whales, rorqual whales, dolphins, and narwhal and white whale (see Appendix 2). Most of the species are characterised by a slow reproductive rate. Seals are sexually mature when two–seven years old and the females may give birth to one young each year (Ridgway & Harrison 1981). Walruses reach sexual maturity when five years old or later. Females may give birth to one calf at intervals of two years or more (Born *et al.* 1995). Most whales probably start breeding when at least five–ten years old and have litter sizes of one single calf. Normal calving intervals are between one and three years, dependent on species (Ridgway & Harrison 1985, 1989). Female polar bears reach sexual maturity at an age of about four years. They normally have two cubs which follow the mother for over two years. Most females normally have litters with intervals of three years (Larsen 1986).

Pelagic crustaceans and shoaling fish such as herring and capelin are the main food of most whales and seals. The walrus and the bearded seal feed mainly on benthic invertebrates such as molluscs and crustaceans, but especially the bearded seal may also eat quite a lot of fish. Ringed seals are the most important source of food for the polar bear, but other species of seals are also taken.

Seasonal migrations and high mobility are a prominent feature of the biology of several species. Harp seals spend the summer in the northern Barents Sea and migrate south and east to the White Sea area in autumn. Here they breed and moult in large aggregations and then return to the northern parts of the Barents Sea in spring and summer. Most minke whales, and probably also fin whales, migrate from more southern Atlantic waters into the Barents Sea in spring; they migrate south again in autumn.

The sea ice is an important habitat for several species of marine mammals, especially walrus, ringed seal, bearded seal, polar bear, bowhead whale and white whale. These species occur both along the ice edge and in areas with leads within the ice. Walruses, ringed seals, bearded seals and bowhead whales are able to sustain open breathing holes in the ice and may therefore also live in areas with continuous ice. The extent of the sea ice varies largely both with seasons and from year to year, and the distribution of the species with high affinity for ice-filled waters may vary accordingly. This variation is a main environmental feature in the northern Barents Sea which makes it difficult to predict the impacts of an oil spill.

1.7 MARINE MAMMALS AND OIL

The available information on the effects of oil on marine mammals has been reviewed by Engelhardt (1985), Griffiths *et al.* (1987), Geraci & St. Aubin (1990) and Haebler (1994); see also Jødestøl & Ugland (1993) and Jødestøl *et al.* (1994). An extensive summary of the effects following the *Exxon Valdez* accident is given in Loughlin (1994a). Relatively little is known about the effects of oil on marine mammals as compared to seabirds. This reflects the difficulty in studying these large mammals both in the wild and under controlled conditions, and that the overall effects of oil for most species seem to be smaller than for seabirds. Seals and whales dying due to oil pollution at sea will usually sink, and carcasses on beaches are often washed off by the tide and also sink (Frost *et al.* 1994a; Dahlheim & Matkin 1994). It may therefore be difficult to prove oil-related mortality of marine mammals even in cases where such mortality is real and significant. Monitoring of marine mammals is seldom good enough to detect anything else than large differences between pre- and post-spill population levels.

No mass mortality of marine mammals has been observed after oil-spill accidents. An exception is otters (Baker *et al.* 1981; Geraci & Williams 1990; Garrott *et al.* 1993). Otters *Lutra lutra* do not occur in the northern Barents Sea, but they are found along the coast of North Norway, an area which is not included in this assessment. Observations in connection with the *Exxon Valdez* accident in Alaska suggest that about 300 harbour seals died as a result of the spill (Frost *et al.* 1994a). The *Exxon Valdez* spill may also have caused the death of 14 killer whales *Orcinus orca* which disappeared from a pod in the affected area shortly after the spill, although no direct evidence for this was found (Dahlheim & Matkin 1994).

1.7.1 Walrus and seals

While no studies on the effects of oil spills on walrus are available, information both from experimental work and studies from oil-spill situations exists for seals. Most studies are, however, from situations with relatively high temperatures and do not resemble arctic conditions with ice, as will be met in the northern Barents Sea.

Seals have a thick insulating layer of blubber and do not rely on feathers or pelage for thermoregulation as do seabirds and some other marine mammals. Geraci & Smith (1976) exposed ringed seals to oil for one day and did not find any subsequent effect of oiling on deep body temperature. They concluded that oiling had no effect on the seals' thermoregulation. Griffiths *et al.* (1987) argued, however, that long-term exposure to oil can cause skin inflammations and increased blood supply to the skin. This will lead to increased heat loss and energetic costs for the seal. Because Geraci & Smith (1976) only exposed the seals to oil for a relatively short period, kept the seals in relatively warm water and did not measure metabolic rate, Griffiths *et al.* (1987) recommended further study on the topic. Pups oiled before they have accumulated a thick layer of blubber are probably most vulnerable (Geraci & Smith 1976; Engelhardt 1985). Especially in the cold arctic environments this effect may result in impaired physical condition for both adults and pups, which in turn will influence survival and reproduction.

Fouling, especially with heavy oils, may interfere with the seals' locomotion and normal activity. Pups have been observed drowning because heavy oiling impaired their ability to swim (Davis & Anderson 1976; St. Aubin 1990a). The normal function and movement of eyelids, nostrils and vibrissae may also be restrained by oiling (Engelhardt 1985; St. Aubin 1990a). Eyes and mucous membranes are sensitive to hydrocarbon exposure, especially the volatile aromatic components. Eye damage and irritation have been observed in oiled seals (Geraci & Smith 1976; Lowry *et al.* 1994; Spraker *et al.* 1994). The visible inflammations seemed to be healed quickly when experimentally exposed seals were moved to clean water after 24 hours of exposure (Geraci & Smith 1976). Griffiths *et al.* (1987) were, however, concerned about the more permanent damages to the seals' eyes, especially after long-term exposure.

All examined species of seals have been able to metabolise and excrete ingested petroleum hydrocarbons (Addison *et al.* 1986; St. Aubin 1990a). Geraci & Smith (1976) found that seals which ingested small quantities of oil (daily doses of 5 ml for 5 days) or single doses of up to 75 ml did not seem to suffer from any serious damages. However, oil-dosed pups showed signs of being stressed, probably due to pain in the gut (see Griffiths *et al.* 1987). At high doses, the seals' ability to detoxify and excrete hydrocarbons may cease to function (Engelhardt *et al.* 1977). This was probably the reason for the observed accumulation of polycyclic aromatic hydrocarbons in blubber and milk in harbour seals affected by the *Exxon Valdez* oil spill (Frost *et al.* 1994b). Accumulation in blubber may result in chronic exposure at later dates and high exposure during mobilisation of fat stores in situations of energetic constraints, such as breeding or moulting (St. Aubin 1990a; Frost *et al.* 1994b). Hydrocarbons may be transferred from female seals to their pups with the milk. Pups may also ingest oil when sucking nipples of externally oiled mothers (Engelhardt 1985; Frost *et al.* 1994b; Lowry *et al.* 1994). This may be serious because pups have significantly lower levels than adults of some of the detoxifying enzymes (Addison *et al.* 1986).

There are reports that at least grey seals (*Halichoerus grypus*) and harbour seals can swallow oil in fatal quantities. Autopsies on stranded dead seals of these species have revealed oil metabolites and damaged tissue in a number of organs. The most serious damage was to the microvilli of the small intestine, but damage to the liver, kidney and lungs was also indicated (see Griffiths *et al.* 1987).

There are conflicting evidence as to whether or not seals avoid oiled areas (St. Aubin 1990a). During the *Exxon Valdez* oil spill, harbour seals continued to use traditional haul-out sites that were heavily oiled and seals were observed swimming in oil-covered water (Lowry *et al.* 1994). Behavioural changes, including decreased flight distance, lethargy, disorientation and increased tendency to haul out, were observed in seals in this area. These changes in behaviour were probably due to the observed lesions in the midbrain of oiled seals caused by inhalation of short-chained aromatic hydrocarbons. If severe, these neuronal lesions may seriously affect the seals' ability to perform crucial activities such as thermoregulation, swimming and feeding (Lowry *et al.* 1994; Spraker *et al.* 1994). The strong discomfort, loss of coordination and subsequent death of three ringed seals in a laboratory oil-immersion study (Geraci & Smith 1976) may probably also be ascribed to inhalation and intoxication from lighter hydrocarbon components, possibly in combination with stress (Griffiths *et al.* 1987; St. Aubin 1990a).

Although no specific studies exist on walrus and oil, much of what has been found for seals probably also applies for walrus. Due to their thick insulating skin, thick layer of blubber and large body size, they are probably less prone to the possible effects of external oiling on thermoregulation (Griffiths *et al.* 1987). As harbour seals did during the *Exxon Valdez* oil spill, walruses would probably continue to use their traditional haul-out sites if these were contaminated by oil. The walruses using the haul-out sites would then be exposed to oil for a long period of time. The deleterious effects of inhaling aromatic hydrocarbons then become of special concern, although most of these components may evaporate relatively quickly.

A major oil spill may cause reduced availability or contamination of the food organisms of the marine mammals. Walruses and bearded seals may be especially susceptible because their staple food comprises benthic invertebrates which are known to be vulnerable to oil pollution and to accumulate hydrocarbons in their tissue (Neff 1990; Born *et al.* 1995).

In an oil-spill situation, both walruses and harbour seals are prone to disturbance during clean-up activities at their traditional haul-out sites. Walruses may be especially vulnerable. Aeroplanes flying over walrus haul-out sites have been reported to cause panic among the walruses and up to hundred individuals being killed in the resulting stampede (Born *et al.* 1995). Seals and walruses may also be vulnerable to other sources of disturbance as a result of clean-up operations or increased activity during normal petroleum-related operations (see Born *et al.* 1995; Richardson *et al.* 1995).

In summary, the most serious effects of oiling on seals seem to be neuronal damage due to inhalation of aromatic hydrocarbons and irritation and damage to eyes. The occurrence of inflammations and lesions in skin resulting from oiling, and the importance of this for thermoregulation, is unresolved, but it is potentially important particularly for seals living in cold arctic waters. The effects of long-term exposure to oil are largely unknown. Animals stressed by other means, such as parasites or food shortage, will probably be more prone to negative effects from oiling than unstressed animals.

1.7.2 Polar bear

There are no reports of incidents of conflict between oil spills and polar bears. The existing information on the effects of oil spills on polar bears are from an experimental study of captive bears (Øritsland *et al.* 1981; Hurst & Øritsland 1982). Three bears swam in oil-covered water for 15, 30 and 53 minutes respectively. The animals absorbed great quantities of oil in their pelts and gradually ingested a lot of oil while trying to lick themselves clean. The oil accumulated in the pelt resulted in reduced insulation, skin irritation and a severe loss of hair. The ingestion of oil resulted in vomiting, dehydration, lowered blood volume, inflammation of the digestive system, and kidney and brain damage. Two of the animals died, the third would under natural conditions also have died. Based on this experiment, Griffiths *et al.* (1987) conclude that even a single, brief oiling will, under natural conditions, kill a great number of the affected polar bears. Because of their reliance on insulating fur for thermoregulation and their grooming of oiled fur, the polar bears are probably more likely to die if oiled than any of the other marine mammal species treated here.

Polar bears live in close contact with the sea. They tend to stay on the ice edge, along leads or in drift ice; they often enter the water and migrate over vast areas. It is not known whether or not polar bears will actively avoid getting in contact with oil under natural conditions (St. Aubin 1990b; Stirling 1990). In the event of an oil spill which affects ice-filled waters, it is accordingly possible that a relatively great number of polar bears may be fouled by oil. Polar bears may also be oiled and ingest oil when preying or scavenging on oiled seals and seabirds (St. Aubin 1990b; Stirling 1990).

Polar bears may be affected by disturbance from increased, oil-related human activity, especially during intense clean-up operations after an accidental oil spill. Denning females that are pregnant or have small cubs are probably most vulnerable (cf. Swenson *et al.* 1997), but it is unclear to what degree female polar bears in dens are vulnerable to disturbances (Blix & Lentfer 1992; Amstrup 1993; Linnell *et al.* 1996).

1.7.3 Cetaceans

There is relatively little information on the effects of oil on whales and dolphins (cetaceans), and oil has not been confirmed to cause mortality in cetaceans. There are several reports of dead cetaceans in areas affected by oil spills, but these animals seem in most cases to have died from natural causes (Geraci 1990). The *Exxon Valdez* accident may have been responsible for the death of 14 killer whales, but no firm conclusion could be drawn (Dahlheim & Matkin 1994; Matkin *et al.* 1994).

Experiments with bottlenose dolphins *Tursiops truncatus* showed that at least this species is able to detect oil on the water surface and avoid surfacing in oiled areas in the experimental setting. It has also been reported that grey whales *Eschrichtius robustus* seemed to spend less time at the surface and blow less frequently in oiled areas than in unoiled areas (see Geraci 1990). Cetaceans have, however, on a number of occasions been observed surfacing, feeding, and seemingly behaving normal in oil-covered areas (Harvey & Dahlheim 1994; Loughlin 1994b; Matkin *et al.* 1994; Lorentsen 1995; see also Griffiths *et al. 1987*; Geraci 1990). Harvey & Dahlheim (1994) did not find any differences in swimming speed in Dall's porpoise *Phocoenoides dalli* between areas with different amounts of oil on the surface.

Cetaceans rely on a thick layer of blubber for thermoregulation, and their skin has been shown to be fairly resistant to hydrocarbon exposure (Geraci 1990). Thermoregulatory effects of oiling on cetaceans is, therefore, unlikely to occur.

Hydrocarbons may be ingested during feeding activities and have been found to accumulate in cetaceans, especially in the blubber. Cetaceans do, however, seem to be able to metabolise hydrocarbons, and it has been questioned whether they may ingest large enough quantities to produce acute, fatal effects (Geraci 1990).

Oil fouling of baleen plates may reduce filtering efficiency and thereby interfere with feeding in baleen whales. Experiments have shown that baleen plates fouled by oil have decreased filtration efficiency, but that they seem to be quickly rinsed in clean water. The results suggest that fouling with heavy oil may interfere with feeding efficiency for at least several days; repeated contamination will extend the effect (Geraci 1990). Bowhead whales may be especially vulnerable to this kind of fouling as they often skim feed in surface waters (Lowry 1993).

Inhalation of hydrocarbons, especially volatile aromatic components in the early phases of an oil spill, is an important potential threat also for cetaceans, but there is no data on such effects in this group (Geraci 1990). Brain damage in harbour seals affected by the *Exxon Valdez* oil spill was probably caused by inhalation of toxic hydrocarbons. These damages probably explain behavioural changes observed in seals after the spill (Spraker *et al.* 1994). From the *Exxon Valdez* oil-spill area, Harvey & Dahlheim (1994) reported observations of an oiled, apparently stressed, Dall's porpoise that was approached within 20 m before it dived. Furthermore, a group of grey whales in an oiled area were seen swimming continually on the surface for 10 minutes and appeared lethargic (fumes from the oil could here be detected by the observer in the aeroplane at 100–200 m elevation). Although possibly normal, the behaviour of these animals may indicate damage similar to that found in harbour seals.

Of the species considered here, cetaceans probably are those least vulnerable to oil pollution.

1.8 OIL SPILLS AT SEA

1.8.1 Sources of oil pollution

Accidental oil spills in the marine environment occur from offshore production installations, from vessels and from land-based activity. Globally only a small proportion of the total spill volume (about 2%) is due to offshore production (Clark 1989). However, in Norwegian waters the offshore activity is high and a large proportion of the total spill volume stems from this source (30–70% annually) (Moe *et al.* 1993; SFT 1995). The spill situation from offshore activity is characterised by many small and a few larger spills. The largest spills are normally those of greatest concern. However, small spills contribute to the more chronic oil pollution at sea, which may be even more important than the larger accidental spills in terms of long-term population effects, at least for seabirds. There is no consistent relationship between spill volume and the resulting seabird mortality for spills above some lower level. Density and distribution of seabirds in the area, weather conditions and distance to the shore have greater bearing on the resulting mortality than spill volume alone (Burger 1993).

There have been some attempts to estimate the probability of uncontrolled blow-outs of oil from offshore activity. In connection with the opening of the southern Barents Sea for exploratory drilling, the probability of a blow-out involving several thousand tons of oil was estimated at 1 per 1,800 wells (OED 1989). There is great uncertainty connected with this estimate. The historical data that the estimate is based on are from the Gulf of Mexico where the environmental conditions are quite different from those on the Norwegian shelf. It is not known how the harsh environmental conditions in arctic areas such as the Barents Sea influence on the probability of an uncontrolled blow-out. Not included in this estimate are the far more frequent smaller spills from offshore installations. The present statistics on the probability of oil spills are insufficient for use in environmental impact assessments, and a more qualitative approach should be taken when assessing the effects of oil spills.

The traffic of ships in the northern Barents Sea is relatively low compared to more southern Norwegian areas. It is associated mainly with fisheries, transportation of cargo to and from Svalbard and tourism. Petroleum activity in the area will necessarily entail an increase in ship traffic, and consequently also an increase in the risk of oil pollution from this source. The consequences of increased shipping activity in the area are not analysed specifically in this assessment.

1.8.2 Oil spills in arctic ice-filled waters

The northern Barents Sea is a high-arctic area where drifting sea ice may be found at all times of the year. Previous areas within Norwegian sovereignty that have been assessed with respect to petroleum activity and its effect on wildlife have been more southern, temperate areas. One exception is the southern Barents Sea where sea ice may be found more irregularly (see Anker-Nilssen *et al.* 1988; Børresen *et al.* 1988). Sea ice and the harsh environmental conditions in the northern Barents Sea pose new challenges in safeguarding petroleum activity and also modify the processes by which wildlife is threatened by oil spills. Only the second issue is treated here.

Oil spilled in the northern Barents Sea has a high probability of contacting sea ice (see Skognes *et al.* 1995). The properties and fate of oil in ice-filled waters have been described in varying depth by several authors (*e.g.* Clark & MacLeod 1977; Clark & Finley 1982; Mackay 1985; Payne *et al.* 1991; Sakshaug *et al.* 1994a). Only a few points of major interest in relation to seabirds and marine mammals are briefly reviewed here.

Wind and currents may herd oil up against the ice edge, and the slick may attain greater thickness here than at the open sea (Ayers *et al.* 1974; Mackay 1985). The drift ice will partly function as a barrier for the oil, but some oil will float into leads in the ice where it will concentrate. The oil may also coat the lower surface of the ice. Under-ice spills will coat the underside of the ice drifting by and may thus contaminate large areas of ice (Mackay 1985). Due to the movement of the ice, with leads opening and closing, the oil may penetrate quite a distance into the ice, especially in open drift ice. Oil may be encapsulated in freezing ice, moved with the ice and be released after months in areas far from the first place of contact (Clark & Finley 1982). Oil encapsulated in ice may also migrate up brine channels and appear in meltwater pools on the top of the ice (Payne *et al.* 1991).

The low temperatures and entrapment of oil in ice will retard the volatilisation of hydrocarbons and prolong the acute toxicity of spilled oil. Also other degrading processes will be slowed, resulting in the oil being kept 'fresh' and fluid for a longer time (Mackay 1985; Payne *et al.* 1991; Engelhardt 1994). Combined with the movement of oil with ice described above, this may lead t• oil spills in arctic conditions and the effects on wildlife persisting longer and being spread over larger areas (by ice) than would be the case in temperate areas. For instance, both the oil's potential for interfering with plumage of seabirds and fur of polar bears, and the toxic effects of inhalation of volatile hydrocarbons, will be prolonged.

Concentration of oil in the ice-edge zone and in leads in the ice conflicts with the importance of these areas for many species of seabirds and marine mammals; both oil and wildlife are concentrated in areas of open water close to the ice (Neff 1990). In the northern Barents Sea, the ivory gull, Brünnich's guillemot, black guillemot, little auk, walrus, ringed seal, bearded seal, polar bear, bowhead whale and white whale are the species most closely associated with areas with sea ice (see Isaksen & Wiig 1995; Mehlum & Isaksen 1995). Their affinity for these areas, where both floating oil and petroleum vapours may be found in high concentrations, makes them susceptible to detrimental effects from external fouling (thermoregulatory and mechanical effects), inhalation of toxic compounds and ingestion of hydrocarbons.

The very low temperatures of both air and water in the northern Barents Sea make the extra demands on heat production posed by oiling very hard to meet; this is valid for all seabirds, polar bears and, possibly, heavily oiled seals (Griffiths *et al.* 1987; Jenssen 1994). Birds and mammals swimming in leads may be exposed to higher concentrations of toxic gases than at open sea due to the shielding effects of the ice floes which reduce the exchange of air close to the water surface. On the other hand, it is possible that very low temperatures may reduce evaporation so much as to prevent petroleum gases from reaching acute toxic concentrations. Especially if released under the ice, the oil may concentrate in breathing holes. The mammals using these (particularly ringed seals) will be contaminated each time they come up to breathe and when reentering the water (Engelhardt 1985, 1994). The bowhead whale, being a skim-feeder of surface waters in leads and along the ice edge, may ingest considerable quantities of oil and may also entrap thick-floating oil in its baleen plates in sufficient quantities to reduce feeding efficiency.

In the northern Barents Sea response activities after an oil spill will, dependent to a varying degree on season, be hampered by cold, darkness, fog, ice and distance from logistic support. It will be more difficult to survey the spill area both from boat and aeroplane, and the capabilities of remote-sensing techniques will also be reduced. Oil entrapped in and under ice will be difficult to follow and nearly impossible to recover with present recovery systems. The effectiveness of dispersants and bioremediation will also be reduced due to the low temperatures and lack of nutrients (Mackay 1985; Engelhardt 1994; Siron *et al.* 1995).

1.9 PLANNED PETROLEUM ACTIVITY

As of January 1998 there are no concrete plans for petroleum activity in the northern Barents Sea. The present Norwegian Government has stated that petroleum activity is not to be started in environmentally sensitive areas, which presumably includes the northern Barents Sea.

The AKUP-financed projects in the northern Barents Sea started in 1991. At that time the aim was to produce an environmental impact assessment (EIA) of the opening of the northern Barents Sea for exploratory drilling. As it became clear that the political motivation for opening the area was low, the Ministry of Industry and Energy (now the Ministry of Oil and Energy) decided that no EIA was to be made at this stage. The AKUP-financed projects should rather be concluded by summarising the present knowledge and presenting (a preliminary) analysis of the potential effects of petroleum activity in the area. The work completed at this stage will form the basis for a possible future EIA.

1.10 AREA OF ANALYSIS

In the final stage of the projects, the Ministry decided that the analysis should be made for the area between 5°E, 35°E, 73°N and 81°N (see Fig. 1). Three alternative drilling positions were defined for the analysis: two on Spitsbergenbanken between Bjørnøya and the rest of the Svalbard archipelago (75°50'N 17°00'E and 75°50'N 25°00'E) and one on Sentralbanken further east (75°10'N 32°30'E) (see Fig. 1). The scenario used is a spill of 200 tons of oil per hour lasting 10 days. The drift of the oil has been modelled for the following 30 days (or until the oil reached land) for 600 spills from each spill point (Johansen *et al.* 1997). The actual area of risk (defined as the area with 5% or higher probability of being reached by oil in the spill scenario used) stretches outside this area, especially towards east and west. The shortest period for drift to land (including Bjørnøya and Hopen) registered in the model in summer is approximately 3, 3 and 12 days from the western, middle and eastern spill points, respectively (Johansen *et al.* 1997).

2. MATERIAL AND METHODS

2.1 DATA ON SEABIRDS AND MARINE MAMMALS

The basis in this assessment is distributional data on seabirds and marine mammals collected mainly during the last 10–15 years. These data have earlier been presented by Isaksen & Bakken (1995a) and Isaksen & Wiig (1995) (see also Jødestøl & Ugland 1993 and Jødestøl *et al.* 1994). No specific exploration area (or area of risk) was given at the time of print of these reports. The borders of the presented maps were therefore somewhat different from those used in this analysis. Only a brief description of the data is given here together with an evaluation of the data.

2.1.1 Seabirds

The data on the distribution, size and development of the breeding seabird populations in Svalbard (see Isaksen & Bakken 1995b) are from the database at NP on seabird colonies in the Barents Sea. This database currently holds information about more than 500 colonies in Svalbard and includes probably all major seabird colonies in the area. Recent counts or estimates of the number of breeding pairs are not available for many colonies. This is especially true for species which are difficult to survey, such as fulmar, black guillemot and little auk (see, however, supplementary work on little auks in Isaksen 1995b and Isaksen & Bakken 1995c). The database is far from complete for species with a more dispersed breeding pattern, such as glaucous gull and black guillemot. However, the present data are relatively good for most typical colonial breeding species (notably barnacle goose, common eider, kittiwake, common guillemot and Brünnich's guillemot). These are also among the most vulnerable and important species with respect to oil spills. The population size of brent geese in Svalbard is not well known. They breed in remote areas and are very shy and vulnerable to disturbance in the breeding season, which make them difficult to census. Large parts of the known breeding population are concentrated in one relatively small area. The relative distribution in the area of risk, which is most important in this assessment, is therefore known.

Moulting common and king eiders have been counted by NP during helicopter censuses covering large parts of the coast of Svalbard (Isaksen & Bakken 1995d). The data on king eiders are also supplemented with observations from other sources. Large parts of the coastline have only been censused once. The main concentrations, which are located in shallow coastal areas, are, however, probably relatively stable from year to year. Geese generally moult while raising their young in areas relatively close to the breeding colonies. The locality and size of these colonies are mainly well known (see above).

The distribution of seabirds at sea has been mapped by the Norwegian Institute for Nature Research (NINA), NP and Tromsø Museum during ship line transects in the Barents Sea (Isaksen 1995a). The cruises have covered areas both in the open sea and along the ice edge (especially in spring) and to a lesser degree areas which are ice-covered. The coverage for the area differs between seasons. The data for the summer season (June–August) is clearly the best and is considered to be fairly good. This is also the most important season for the assessment area with respect to the effects of oil spills on seabirds. The least satisfactory data are from the autumn season (September–October). Generally, the data from the most eastern areas (east of 30°E) are scanty, even for the summer period.

One major problem with this kind of mapping is that the distribution of seabirds at sea is not static from year to year (see Fauchald & Erikstad 1995; Fauchald *et al.* 1996). The distribution of the seabirds is probably strongly influenced by the distribution of their prey organisms (see *e.g.* Erikstad *et al.* 1990). The populations of these organisms, *e.g.* the capelin *Mallotus villosus*, may show large variations both in stock size and distribution between years (Røttingen 1990).

Another important determinant for the distribution of seabirds in the Barents Sea is the extent of the sea ice. This varies considerably, not only during the year, but also from year to year (Vinje 1985; Skognes *et al.* 1995). Very high numbers of seabirds may be found along the ice edge, especially in spring (Mehlum & Isaksen 1995). Some species show high affinity for ice-filled waters in offshore areas (mainly ivory gull, black guillemot, Brünnich's guillemot and, to a lesser degree, little auk), whereas others do not (*e.g.* fulmar and common guillemot). Areas with closed ice attract few seabirds, but high numbers, mainly Brünnich's guillemots, may be found in leads and polynyas in large distances from the ice edge.

Because of the variation in sea-ice conditions and prey distribution in the Barents Sea, the distribution of seabirds found in one year may not necessarily be valid for other years. This is clearly a major problem in the present effort to assess the potential effects of oil spills on seabirds in this area.

2.1.2 Marine mammals

The population status of the marine mammal species in the northern Barents Sea has been dealt with by Jødestøl & Ugland (1993), Jødestøl *et al.* (1994), and Lydersen & Wiig (1995). Most species of marine mammals live solitarily or in small groups dispersed over large sea areas for most of the year. They are highly mobile and several species have regular migrations within the Barents Sea or to other areas. Several aspects of their biology (including diving and dispersed living) make them difficult to census, and the knowledge on the population size, trends and quantitative distribution is relatively poor for some species (*e.g.* bearded seal, ringed seal and white whale). The knowledge of other species is far better due to specific studies using satellite telemetry, helicopter censuses or extensive ship surveys (walrus, polar bear and minke whale).

The present knowledge on the geographical distribution at different times of the year is presented by Wiig & Isaksen (1995) and Øien & Hartvedt (1995). The knowledge is poor for many species, especially regarding seasons other than the summer. For some species and seasons, the authors have judged the knowledge to be too poor to allow for any distribution maps to be made. The distributional data used in this assessment for seabirds are real observational data. This was judged not to be a feasible approach for marine mammals, mainly because of a low number of observations. The distribution maps for this group are therefore expert assessments based on results from systematic sighting surveys and/or incidental observations, not maps of unmodified observational data.

Many species live more or less exclusively in ice-filled waters (ringed seal, bearded seal, polar bear, and to some extent also walrus and white whale), while other species seem to prefer open waters (most other species of whales except bowhead whales). As noted for seabirds, the extent of the sea ice and the distribution of prey varies largely and the distribution of the marine mammals may vary accordingly. Combined with the poor knowledge on the relative distribution, this results in the production of very broad, tentative distribution maps for several species. As for seabirds, this clearly influences on the precision of the assessment.

2.2 VEC-ANALYSIS

The Valued Ecosystem Component (VEC) analysis is a method to identify (1) key or especially valued components in the ecosystem (*e.g.* species, species groups, specific habitats, ecological processes), (2) which part of a planned activity that may affect these VECs, and (3) how the VECs may be affected by the activity. The analysis is based on the Adaptive Environmental Assessment and Management methods (Holling 1978), and is fully explained by Hansson *et al.* (1990) and Thomassen *et al.* (1995).

A VEC-analysis should be worked out by a broad group of experts early in the assessment process. The results from the analysis should give important priorities for further studies that have to be done before the assessment can be finished. Such an approach has been followed in some of the recent seabird assessments for other areas on the Norwegian shelf (Lorentsen *et al.* 1993; Strann *et al.* 1993). No initial VEC-analysis was performed for the northern Barents Sea area. However, information needs and priorities were discussed at a seminar in May 1989. Later, Fjeld & Bakken (1993) evaluated the knowledge on seabirds in the northern Barents Sea in relation to petroleum exploration; they also proposed priorities for additional field work. Studies were conducted on all topics suggested by Fjeld & Bakken (1993) in the field seasons 1993 and 1994 (see Isaksen 1994 and Isaksen & Bakken 1995a for results of this work).

VEC-analysis for test drilling and the production phase in the northern Barents Sea were conducted at two seminars in 1995 (in Trondheim in February and in Stavanger in December, respectively; see Thomassen *et al.* 1995, 1996). The aim of these seminars, which were held at the closing stage of most of the assessment projects, was to determine if there still were important gaps in the assessment work that had to be filled before a final assessment could be accomplished. The need for development of new methods for analysing the effects of oil spills on resources in ice-filled waters was emphasised at the seminar in Trondheim (see Thomassen *et al.* 1995). It was also recommended that the mapping of the main breeding colonies of little auks along the western coast of Spitsbergen should be completed. This has not been done. Some work in northwest Spitsbergen was done by field parties organised by the Governor of Svalbard in the field season 1995. These data have not been analysed and included here.

2.3 CONSERVATION VALUE AND VULNERABILITY ASSESSMENT

An evaluation of the conservation value of the seabird populations in the northern Barents Sea was conducted by Fjeld & Bakken (1993; see Table 1). The evaluation was based on a method described by Anker-Nilssen (1987). The breeding population in the northern Barents Sea (*i.e.* on Svalbard) was compared with the total population in Norway (including Svalbard) and in the North Atlantic. The lower limit for populations of national conservation value has been defined as 20%, 10% and 5% of the national population for species with good, moderate and low recovery ability at the population level, respectively. Similarly, the lower limits for populations of international conservation value have been defined as 10%, 5% and 2.5% of the North Atlantic population (Anker-Nilssen 1987).

A similar evaluation of the conservation value of marine mammals in the northern Barents Sea has been conducted by Jødestøl & Ugland (1993), Jødestøl *et al.* (1994) and Lydersen & Wiig (1995) (see Table 2). In this evaluation the international conservation value was determined by comparing the population in the northern Barents Sea with the total world population (see the original references for more details on the evaluations).

The vulnerability of the seabird populations in the northern Barents Sea to oil spills has been assessed by Fjeld & Bakken (1993) (and later supplemented by Isaksen & Bakken 1995) according to a method developed by Anker-Nilssen (1987). The same method, slightly modified, has been used to assess the vulnerability of marine mammals in the same area to oil. The work on marine mammals is presented in detail in Appendix 3 (see also Table 2 for results). The results from the seabird assessment are presented in Appendix 4 (see also Table 1).

All species of seabirds and marine mammals having significant populations in the northern Barents Sea (see Appendix 1 and 2) have been evaluated in the vulnerability assessment, but only populations found to be vulnerable to oil (defined as populations in vulnerability category 2 or 3 in spring and summer, and vulnerability category 3 in autumn and winter) have been included in the impact analysis.

Table 1. Conservation value and vulnerability to oil of seabirds in the northern Barents Sea. The populations of these species in the area are either of special national conservation value (N), international conservation value (I) or none of these (–). Vulnerability to oil is ranked on a scale from 1 (low vulnerability) to 3 (high vulnerability) in each season (Sp = spring, Su = summer, Mo = moulting male eiders, Au = autumn and Wi = winter). Seasons in which the actual species is not present in the area are indicated by '–'.

Species	Conserv. value	Vulnerability to oil				
		Sp	Su	Mo	Au	Wi
Red-throated diver	N	2	3	–	2	–
Great northern diver	N	2	2	–	2	–
Fulmar	I	3	3	–	3	3
Pink-footed goose	I	2	3	–	3	–
Barnacle goose	I	2	3	–	3	–
Brent goose	I	3	3	–	3	–
Common eider	I	3	3	3	3	2
King eider	I	3	3	3	3	–
Long-tailed duck	–	3	3	–	3	–
Grey phalarope	N	1	1	–	1	–
Arctic skua	–	1	2	–	1	–
Great skua	N	2	1	–	2	–
Sabine's gull	N	–	2	–	–	–
Glaucous gull	N	3	2	–	3	2
Great black-backed gull	–	2	2	–	2	2
Kittiwake	I	3	3	–	3	3
Ivory gull	I	2	1	–	2	3
Arctic tern	N	2	3	–	2	–
Common guillemot	I	3	3	–	3	3
Brünnich's guillemot	I	3	3	–	3	3
Razorbill	–	3	2	–	3	–
Black guillemot	I	3	3	–	3	3
Little auk	I	3	3	–	3	3
Puffin	–	3	3	–	3	3

Sources: Fjeld & Bakken 1993, Isaksen & Bakken 1995a.

Table 2. Conservation value and vulnerability to oil of marine mammals in the northern Barents Sea. The populations of these species in the area are either of special national conservation value (N), international conservation value (I) or none of these (–). Vulnerability to oil is ranked on a scale from 1 (low vulnerability) to 3 (high vulnerability).

Species	Conservation value	Vulnerability to oil[4]
Walrus	N[2]	3
Harbour seal	(I)[3]	3
Ringed seal	N[1]	1
Harp seal	I[1]	1 (Feb.–May) 2 (June–Jan.)
Bearded seal	I[3]	2 (April–July) 1 (Aug.–March)
Polar bear	I[3]	3
Bowhead whale	I[3]	2
Minke whale	I[2]	1
Fin whale	N[3]	1
Humpback whale	I[3]	1
White-beaked dolphin	N[3]	1
White whale	I[3]	3

[1]Jødestøl & Ugland 1993
[2]Jødestøl *et al.* 1994
[3]Lydersen & Wiig 1995
[4]This volume (Appendix 3)

2.4 OIL-DRIFT STATISTICS

In an oil spill situation at sea the oil will drift from the spill site. The direction, speed and spreading of the drifting oil depend mainly on the weather conditions, weaves and ocean currents. The statistical probability of oil reaching different areas around the spill site can be obtained by modelling a large number of oil spills on a computer with random input data from historical databases on wind, currents and other parameters in the area. For the present exploration area, a specific type of oil-drift model called SLIKMAP has been used to calculate oil-drift statistics (Johansen *et al.* 1997; see also Skognes *et al.* 1995). This model follows a large number of spills from a given spill position for a period of 30 days (or until the oil reaches land). The statistics from the model give probabilities for grid cells of 25x25 km around the spill site being contaminated by oil in each of four seasons (January–March, April–June, July–September and October–December). The scenario for the oil-drift statistics used in this analysis is a spill of 200 tons of oil per hour over 10 days. The drift of the oil has been modelled for 600 spills from each spill point. See Johansen *et al.* (1997) for a more detailed description of the oil-drift statistics and Anker-Nilssen (1987) for a discussion of the use of such statistics in seabird assessments.

2.5 IMPACT ASSESSMENT MODEL

The impact assessment model used here is based on methods developed for the seabird part of the EIA of opening of the southern Barents Sea for exploratory drilling (Anker-Nilssen 1987; Anker-Nilssen *et al.* 1988). This model has later been developed further and incorporated into a GIS-based analysis tool called SIMPACT. The Norwegian Institute for Nature Research has been responsible for developing the model (Anker-Nilssen *et al.* 1992; Anker-Nilssen & Kvenild 1993, 1996). The model has been used in the seabird part of the EIA of petroleum exploration in the Norwegian part of the Skagerrak (Lorentsen *et al.* 1993) and in the corresponding EIA for coastal seals and seabirds on the shelf outside Central Norway (Røv 1993; Strann *et al.* 1993).

The main point in the model is to combine data on the distribution of resources vulnerable to oil (in our case seabirds and marine mammals) and oil-drift statistics from the potential drilling area. The analysis is based on a grid with 25x25 km resolution. The borders of the grid are the same as the area of analysis. Each grid cell has three values attached to it:

- r the proportion of the resource (*e.g.* no. of breeding pairs of a seabird species) in the grid cell as compared to the whole area ($\Sigma r = 1$) (see section 2.1);
- p probability of the grid cell being reached by oil ($0 \le p \le 1$) (see section 2.4); and
- v the vulnerability index for the actual resource ($0 \le v \le 1$) (see section 2.3).

The product of the three values in each grid cell ($k = r \times p \times v$; $0 \le k \le 1$) is summed for all grid cells in the analysis area ($K = \sum k$; $0 \le k \le 1$). The resulting consequence index (K) is the main product in the analysis. This analysis is made for all species and seasons. For simplicity, the consequence indices are categorised into four consequence categories: (0) insignificant, (1) small, (2) medium, and (3) large consequences. The border values for this categorisation are determined by the user after an overall evaluation. The same border values are used to categorise the colouring of the conflict squares (grid cells) on the maps.

Within-year and year-to-year variation in the sea-ice coverage is a major problem in the analysis. This is especially true for species known to be associated with ice-edge areas. A separate module (called SIMICE) in the analysis tool has been developed to deal with this problem specifically. In a separate ice-edge analysis, records (observations) of an ice-edge associated species is 'moved' to the closest grid cells along the median ice edge of the actual season. Only records made in or close to ice-covered areas are included in this analysis. An overlap analysis, as described above, is then performed for the modified resource distribution.

It is important to emphasise that the model is used only as a tool to compare and scale the level of potential impacts between different seasons, spill sites and species. The model does *not* give a quantitative result in terms of the number of individuals lost or the time needed for population recovery. (K represents the proportion of the resource lost within the whole area of analysis if the vulnerability index is identical to the proportion of the resource in a grid cell lost if the cell is reached by oil. This is not the case in this analysis).

The consequence index and the map only represent a 'mean incidence' and do not show the variation between the individual spills that have been modelled (*i.e.* variation in the oil-drift statistics). Consequence indices may only be compared between species in the same species group (for which the same vulnerability assessment model have been used). The consequence index for a seabird species in this analyses should therefore not be compared to that of a marine mammal species.

See Anker-Nilssen *et al.* (1992) and Anker-Nilssen & Kvenild (1996) for further details on the impact assessment model.

3. RESULTS

3.1 IMPACTS ON SEABIRDS

Separate impact analyses have been made for all species (seasonal populations) found to be vulnerable to oil spills (cf. section 2.3) except those for which the data on geographical distribution is too weak to allow meaningful analyses to be made (see section 2.1.1). Analyses have been made for the following resource distributions: (1) breeding colonies of all species in summer, (2) the distribution of moulting eiders and the swimming migration of guillemots in late summer, (3) the distribution of seabirds in ice-free areas at sea in all four seasons, (4) the distribution of seabirds in ice-filled areas in winter and spring, and (5) modified ice-edge distributions (see section 2.5) of Brünnich's guillemot in winter and Brünnich's guillemot and little auk in spring.

The consequence indices from the analyses are presented in Appendix 5. In the analyses for breeding colonies and moulting populations, the effects were judged to be large if consequence indices were larger than 0.1. In the other analyses the corresponding value was judged to be 0.2. The borders between the other consequence categories were set at 1/3 and 2/3 of these values (see Table 3). The reason for the two different sets of border values are differences in the resource data. A large proportion of the breeding colonies and the concentrations of moulting eiders in Svalbard have been adequately mapped and represented in the analyses. The distribution of seabirds at sea and in ice-filled waters, on the other hand, have been far less well mapped, especially in autumn and winter. There are large areas that have not been covered during the cruises and only small or moderate proportions of the birds present in the area are probably represented in the analysis.

Table 3. Classification of consequence categories for seabirds. The numbers are consequence indices from the analysis tool SIMPACT.

Consequence categories	Breeding and moulting pop.	Pop. at sea and in ice-filled waters
Large (3)	>0.100	>0.200
Moderate (2)	0.067–0.100	0.133–0.200
Small (1)	0.033–0.067	0.067–0.133
Insignificant (0)	<0.033	<0.067

3.1.1 Summer

The breeding birds are connected to the breeding colonies in summer. Some species, such as geese and (female) eiders, stay close to the breeding site throughout most of the summer. For these species an analysis of how the breeding areas may be affected will be representative of how the species will be affected. Other species (*e.g.* fulmar, kittiwake and Brünnich's guillemot) spend much of their time searching for food at sea distant from the breeding colonies, and their distribution at sea must also be included in the analysis. There is also a proportion of subadults and other non-breeding birds that may stay close to the colonies or dispersed at sea.

Breeding colonies

The analysis shows that barnacle goose and brent goose are the species potentially most heavily affected at the breeding colonies. An oil spill might have large consequences for these species. A spill from the western spill point will have the largest consequences for the barnacle goose (Appendix 7, fig. 1). This is due to the concentrations of colonies in the bird sanctuaries along the western coast of Spitsbergen. For the brent goose, a spill from the middle spill point will have the largest consequences. This spill point is situated close to Tusenøyane, south of Edgeøya, which is the main breeding area for brent geese in Svalbard (Appendix 7, fig. 2).

An oil spill may also have large consequences for the breeding populations of great northern diver, common eider, king eider, great black-backed gull, common guillemot, Brünnich's guillemot and razorbill. Oil from the western and middle spill points may reach Bjørnøya which is the only known breeding area for great northern diver in the Barents Sea. A major proportion of the common eiders in Svalbard breeds along the western coast of Spitsbergen, making this species especially exposed for a spill from the western spill point (Appendix 7, fig. 3). The great black-backed gull breeds in small numbers at Bjørnøya and along the western coast of Spitsbergen, and it would be most heavily affected by a spill from the western spill point. A spill from the western or the middle spill point may have large consequences for both common and Brünnich's guillemots. Oil from both these spill points may reach Bjørnøya, the main breeding area for common guillemots in Svalbard (Appendix 7, fig. 4). The large Brünnich's guillemot colonies at Bjørnøya and on the southeastern coast of Spitsbergen are especially exposed to spills from the western spill point. Spills from the middle spill point may in addition reach the colonies at southern Edgeøya and Hopen (Appendix 7, fig. 5).

A spill from the eastern spill point yields the smallest consequences for all species in this part of the analysis. This result is as expected because this point is positioned considerably more distant from the breeding colonies than the western and middle spill points. The mean consequence index (all analysed species included) is 0.004 for spills from the eastern point, whereas the corresponding values for the western and middle spill points are 0.093 and 0.065, respectively.

Moulting eiders and guillemots

Male eiders gather in flocks in shallow areas along the coast to moult in late summer. A spill from the western spill point may have large consequences for both common and king eiders moulting along the western coast of Spitsbergen. For king eiders, the consequences may be large also in a spill from the middle spill point (Appendix 7, fig. 6). The analysis shows insignificant effects on moulting eiders of a spill from the eastern spill point.

Common and Brünnich's guillemot chicks leave the breeding colonies before they are able to fly. They are then accompanied by the male parent in a swimming migration from the breeding colonies to foraging areas at sea. As the males moult at this time, both the chicks and the parents are unable to fly for a period of about 45–50 days. A separate analysis using the distribution of guillemot parents with chicks (and Brünnich's guillemot vulnerability index) has been made. The results indicate that the consequences will be large of a spill from the middle spill point (Appendix 7, fig. 7) and small and insignificant for the western and eastern spill points, respectively. The consequences in the eastern part of the analysis area may be higher as these areas may be important feeding areas. The timing of a spill will be of large significance because the birds leave the colonies synchronously, most leaving within a week.

Seabirds at sea

The analysis of the potential impacts on seabirds at sea predicts large consequences for little auk, Brünnich's guillemot and fulmar. The little auk is most heavily affected by a spill from the western spill point. This is due to concentrations at sea off southern Spitsbergen (Appendix 7, fig. 8). The Brünnich's guillemot is most heavily affected by a spill from the middle spill point. A spill from this point will affect both important foraging areas in Storfjorden and Storfjordrenna as well as areas around the main breeding colonies (as described above) (Appendix 7, fig. 9). The results indicate that a spill from the western and middle spill points would have large consequences for the fulmar.

3.1.2 Autumn

After the breeding season, some species stay in coastal waters (geese and eiders) whereas others disperse at sea. Many species also begin migrating towards wintering areas in more southern areas.

Seabirds at sea

The results show that a spill in autumn may have large consequences for several species. The largest consequence index in the analysis occurred for Brünnich's guillemot in a spill from the eastern spill point (Appendix 7, fig. 10), but a spill from the middle spill point also resulted in large consequences for this species. The reason for the high consequence level predicted in the analysis is the high concentration of Brünnich's guillemots that have been found in the Spitsbergenbanken area. These birds are probably mostly breeding birds and juveniles from the surrounding colonies (see above for a separate analysis of the swimming migration from breeding colonies in late summer and early autumn). Later in autumn and winter the distribution is probably more dispersed in the Barents Sea, and many of the juveniles migrate to areas off southwest Greenland.

Large consequences are also predicted for fulmar, glaucous gull, kittiwake, common guillemot, little auk and puffin. For all species, the calculated consequences are larger for spills from the eastern and middle spill points than for a spill from the western point.

3.1.3 Winter

Only a few species winter in the northern Barents Sea in significant numbers. Most species leave the area altogether, wintering in more southern areas, whereas a varying proportion of other species winter in the area around Svalbard. Several species occur in significant numbers in areas with sea ice, mainly in connection with leads in the ice. Ivory gull, Brünnich's guillemot and black guillemot are the most important in this respect. The leads may freeze in periods with low temperatures, forcing individuals of species requiring open water to fly out to the ice edge. In such situations high concentrations of birds may occur along the ice edge.

Seabirds in areas with sea ice

The basis data are very weak, but a tentative analysis has been made for Brünnich's guillemot in ice-filled areas and for an aggregated distribution of this species along a mean ice-edge. The results from the analysis for ice-filled waters indicate large consequences for a spill from the eastern and middle spill points. In the ice-edge analysis, large consequences are indicated for a spill from the eastern spill point only.

Seabirds at sea

The resource data are insufficient for a meaningful analysis to be made for seabirds in ice-free areas. The data are mainly from the southeastern part of the analysis area, and the model only predicts effects of a spill from the eastern spill point.

3.1.4 Spring

Several seabird species return to their breeding colonies in early spring (April). A large proportion of the breeding population may be present in the colonies for more than a month before the eggs are laid.

There is high biological production along the ice edge in spring. This attracts several seabird species, especially Brünnich's guillemot and little auk, which may be found in high concentrations in ice-edge areas. High aggregations along the ice edge may also occur because leads in the pack ice close due to strong winds or low temperatures, forcing birds relying on open water to fly out to the ice edge or to open sea.

Seabirds at sea

The results from the analysis show that a spill from the western spill point may have large consequences for Brünnich's guillemot (Appendix 7, fig. 11), little auk and puffin. The modelled consequences for these species are small or insignificant for a spill from the two eastern spill points. A spill from the eastern spill point may have medium to large consequences for kittiwake (Appendix 7, fig. 12).

Seabirds in areas with sea ice

A spill from the middle spill point may have large consequences for Brünnich's and black guillemots in ice-filled waters, whereas a spill from the western spill point may have large consequences for little auk. Consequences predicted by the analysis for other species are medium (fulmar and glaucous gull) or small (kittiwake and ivory gull).

When the distributions of Brünnich's guillemot and little auk are aggregated along a mean ice edge, the predicted consequences are generally increased compared to the analysis for ice-filled areas outlined above. This is especially true for spills from the two eastern spill points for Brünnich's guillemot. However, the relative differences between the three spill points remain the same.

3.2 IMPACTS ON MARINE MAMMALS

Impact analyses have been made for all species (seasonal populations) found to be vulnerable to oil spills (cf. section 2.3 and Appendix 3) except those for which the data on geographical distribution is too weak to allow meaningful analyses to be made (bowhead whale and partly walrus). Separate analyses have been made for female and male polar bears and walruses because the geographical distribution and calculated vulnerability to oil spills of the males and females differ. The consequences for polar bears are expected to be most serious if reproductive females are affected. Concentrations of such females are found in and around important denning areas in autumn and spring when they enter and emerge from their dens. A separate analysis is therefore made for conflicts with important denning areas in these seasons.

The consequence indices from the analyses are presented in Appendix 6. The effects were judged to be large if consequence indices were larger than 0.1. The borders between the other consequence categories were set at 1/3 and 2/3 of this value (Table 4).

Table 4. Classification of consequence categories for marine mammals. The numbers are consequence indices from the analysis tool SIMPACT.

Consequence categories	Consequence index (K).
Large (3)	>0.100
Moderate (2)	0.067–0.100
Small (1)	0.033–0.067
Insignificant (0)	<0.033

3.2.1 Summer

In summer, polar bears have followed the drift ice towards north in the Barents Sea and some are also found in coastal areas in Svalbard. The results from the analysis indicate that an oil spill from the middle spill point may have large consequences for both sexes. The consequences for a spill from the western and eastern spill points are small and medium, respectively.

The population of harbour seals in Svalbard is confined to Prins Karls Forland west of Spitsbergen. In summer these seals moult and then spend more time hauled out on land than at other times of the year. They may therefore be more exposed to soiling by stranded oil. Prins Karls Forland is reached by oil from the western spill point only, and the predicted consequences for harbour seals are large. Harp seals have a wider distribution in the analysis area and the consequences are medium for spills from all three spill points (Appendix 8, fig. 1). For bearded seals, the calculated consequences are small for spills from all spill points.

Knowledge on the distribution of walrus in summer is relatively good. The females are found in the northeast, whereas the males occur in more southern and western areas. A large part of the walrus males in the Svalbard area may aggregate at the haul-out sites at Tusenøyane. As a worst-case scenario, the analysis has been made for a walrus distribution where most individuals have been aggregated in this area. The results show that a spill from the middle spill point may have large consequences (Appendix 8, fig. 2). Spills from the two other spill points may have insignificant effects.

White whales may in summer be found both along the ice edge and in coastal waters of Svalbard. The calculated consequence indices show that a spill from the middle spill point may have large consequences for white whales (Appendix 8, fig. 3), whereas spills from the two other spill points may have small or small to medium consequences.

In summary, spills from the middle spill point will have the largest consequences for walrus, polar bear and white whale, whereas the consequences for harbour seals are largest for spills from the western spill point. The calculated consequence indices are highest for walrus with harbour seal second.

3.2.2 Autumn

In autumn, polar bear females congregate in the denning areas. The consequences indicated by the analysis of effects on these areas are, however, relatively small. Spills from the two easternmost spill points may have large consequences for both female and male polar bears. A spill from the western spill point may have medium consequences.

In autumn, some of the harbour seals may have migrated south from Prins Karls Forland towards Bjørnøya. The calculated consequences are large for spills from the two westernmost spill points (Appendix 8, fig. 4), whereas a spill from the eastern spill point may have medium consequences.

Harp seals have an eastern distribution in the analysis area at this time of the year and a spill from the two easternmost spill points may have medium consequences. As in summer, walrus males are highly exposed to spills from the middle spill point, and the calculated consequences are large. White whales are probably found both along the ice edge and in coastal waters. The calculated consequences are large for the two easternmost spill points for this species (Appendix 8, fig. 5).

In general, the analysis indicates that the consequences of an oil spill in autumn are largest for the harbour seal and somewhat smaller for polar bear, walrus and white whale.

3.2.3 Winter

The knowledge on the distribution of the vulnerable populations in winter is poor. Denning polar bear females will not be affected by a spill before they leave the dens in spring. Other polar bears are mainly distributed along the ice edge and close to leads in the interior parts of the ice-filled areas. The analysis indicates large consequences for a spill from the eastern spill point for both sexes (Appendix 8, fig. 6). The modelled consequences for the two other spill points are smaller;

large to medium for the middle spill point and medium to small for the western spill point.

In winter harbour seals probably have a distribution similar to that in autumn. The analysis shows that a spill particularly from the western spill point, but also a spill from the middle spill point, may have large consequences. The calculated effects for a spill from the eastern spill point are small for harbour seals.

Little is known about the distribution of walruses in winter. They occur in areas covered by sea ice, distant from the ice edge, where there presumably must be open leads. It is assumed that walruses occur in areas with open water between Tusenøyane, Hopen and Bjørnøya, but it has not been possible to quantify this. Therefore, no analysis have been made for walruses in winter.

Knowledge of the distribution of white whales in winter is also poor. It is assumed that they are distributed along the ice edge in the Barents Sea. The results from the analysis indicate large consequences for a spill from the eastern spill point and medium consequences for spills from the two westernmost spill points.

Again, the analysis indicates that the harbour seal is the species most heavily affected, at least by a spill from the western spill point.

3.2.4 Spring

Oil spills from the eastern and middle spill points may reach Hopen, which is an important denning area for polar bears. The calculated consequence indices are, however, small. The consequences for polar bears of both sexes are large to medium for spills from all three spill points, with the largest consequences for a spill from the western spill point for females (Appendix 8, fig. 7).

In spring harbour seals are mainly restricted to areas close to Prins Karls Forland. The calculated consequences for a spill from the western spill point are the highest in the entire analysis (Appendix 8, fig. 8). The consequences indicated for the two easternmost spill points are small and insignificant.

Due to lack of knowledge on the distribution of walrus in spring, the potential effects on this species have not been analysed. Bearded seals are found throughout the area, probably with a high density of breeding females with pups along the ice edge in spring. The consequences indicated by the analysis are small. White whales are assumed to occur along the ice edge and in coastal areas, particularly in the fjords in western Spitsbergen. The calculated consequences are large for a spill from the western spill point and medium for spills from the two easternmost points.

4. DISCUSSION

4.1 GENERAL

At several stages in this analysis there are methodological problems, uncertainties in parameter values used and insufficient basis data. These problems will to a varying extent influence on the results from the analysis. The scientific basis for the results is in several cases weak.

It must be stressed that the analysis is not intended to give exact, quantitative results in terms of number of dead individuals or recovery time for the affected populations. The model only ranks between individual drilling/spill positions and affected populations, thus highlighting the spill positions and species (and combinations of these) for which the potential conflicts are highest. Compared to a quantitative analysis of time required for population restitution, this qualitative approach relaxes the great demands for good basis data and knowledge of the biological processes involved in an oil spill situation. The input data for this analysis still have to be fair for the results to be meaningful.

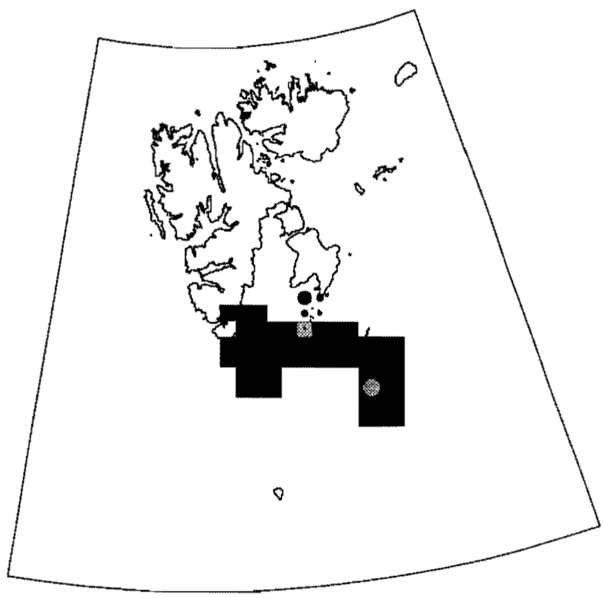
In this analysis, the largest uncertainties are in most cases connected with the distributional data for individual species. There are also uncertainties in the values ascribed to the different parameters in the vulnerability analyses. The vulnerability models are only approximations and may in some cases produce unintended results. The least uncertainty is probably connected with the oil-drift statistics. Given the volume and duration of the spills modelled, these statistics probably give a reasonably good prediction of the probability of oil reaching the different areas around the spill sites. Exceptions are fjords and coastal areas where the oil-drift models either stop or produce unreliable results. The oil-drift statistics are compiled from a large number of modelled spills. It is important to be aware that an actual spill may follow quite a different trajectory than the 'mean' predicted by the oil-drift statistics (compare the single scenario shown in Fig. 2 and the overall result in Appendix 7, fig. 2).

The uncertainties at several levels in the analysis imply that the results should be viewed as indications of possible consequences only.

The SIMPACT model sums all records of the actual resource within the 25x25 km grid cells. In some cases it would be more correct to take the average of the resource records within the grid cells. This is the case for the distributional data of seabirds at sea and in ice-filled waters.

The seasons have been defined somewhat differently for the oil-drift statistics and the distributional data for seabirds and marine mammals. For instance, the autumn season has been defined as September–October for seabirds whereas the corresponding season for oil drift is October–December. For most species/seasons, this lack of seasonal accordance is not thought to have had major influence on the results compared to the more important uncertainties outlined above.

Most areas of southern and western Svalbard are included in one of several protected areas. These are South-Spitsbergen National Park, Forlandet National Park, Southeast-Svalbard Nature Reserve and 15 bird sanctuaries along the western coast of Spitsbergen. The protected areas include the coastline as well as marine areas out to four nautical miles from land. An oil spill from one of the three defined spill sites is very likely to affect one or more of the protected areas.



insignificant small moderate large

Scenario index: 0 025

Fig. 2. Analysis map showing the modelled drift of a single oil spill from the middle spill point in summer. The overlap with the known breeding distribution of brent geese (black dots) is shown with the calculated consequence index for this single scenario.

Reserves and national parks are protected to keep the areas, and wildlife inhabiting them, unaffected by human activity. From this point of view, oil spills affecting protected areas must be considered as more serious than other spills. For seabirds, the bird sanctuaries along the western coast of Spitsbergen (common eider and geese), Southeast-Svalbard Nature Reserve (brent geese and Brünnich's guillemot), and South-Spitsbergen National Park (Brünnich's guillemot and little auk) are of particular importance. In addition, the planned nature reserve at Bjørnøya is very important, especially for great northern diver and common guillemot, but also for Brünnich's guillemot, kittiwake and several other species. For marine mammals, Forlandet National Park (harbour seal), Southeast-Svalbard Nature Reserve (walrus and polar bear) and Kong Karls Land Nature Reserve (polar bear) are particularly important.

4.2 DIRECT IMPACTS ON SEABIRDS

The quality of the basis data on seabird distribution is of crucial importance for the results of the analysis. For several seasonal populations these data are incomplete and the validity of the results from the analysis may be questioned. This is particularly the case for seabirds at sea in winter and autumn, and to a lesser degree also in spring and summer.

Only parts of the total analysis area have been covered during ship-based surveys of seabirds at sea and in ice-filled waters. In some cases the surveys have been concentrated in certain parts of the analysis area (*e.g.* the south-eastern part), leaving other parts unsurveyed or with poor coverage. The analysis may then show higher consequences for spills close to the area with best coverage than would have been the case if the whole analysis area had been equally well surveyed.

The distribution of seabirds at sea may vary between years, probably largely in accordance with variations in relative distribution of prey. At least some seabird species have been found to be patchily distributed at sea, reflecting the patchy distribution of prey (*e.g.* Erikstad *et al.* 1990; Fauchald & Erikstad 1995). Patterns of seabird distribution found in one year may therefore not be representative for other years, as has been found for guillemots (*Uria* spp.) in the Barents Sea in winter (Fauchald & Erikstad 1995). This may be an important source of error in our analysis, influencing the generality of the results. The basis data on seabird distributions at sea used has been collected during the period 1986–1994, but several parts of the analysis area have only been visited once or a few times in one season, especially in winter and autumn (see Isaksen 1995a).

The distribution of seabirds is probably much more stable in the breeding season than in non-breeding seasons. In the period during which the birds start to attend the breeding colonies in spring until they leave the colonies in autumn, the movements of the breeding birds are restricted to a certain foraging range from the colonies. The distribution of the breeding colonies in Svalbard is fairly well known, at least for eiders, geese, guillemots and kittiwake, and the number of breeding pairs in the colonies is in most cases relatively stable from year to year. The main areas for moulting eiders and geese are probably also known and stable from year to year. Other areas where high densities of some seabird species may be predicted are along the polar front and along ice edges (Hunt 1990, 1991; Mehlum & Isaksen 1995; Mehlum *et al.* 1998).

Fauchald *et al.* (1996) have argued that a generalised model of the distribution of seabirds, incorporating environmental variables, may give more reliable results in oil/seabird assessments than survey data alone. Their model of the distribution of guillemots (*Uria* spp.) in the Barents Sea in winter, based on the same seabird data as has been used in our analysis, predicts highest densities of guillemots in areas close to the polar front. High densities are, however, predicted in most parts of the Central Barents Sea (the model was limited to areas south of 75°N) (Fauchald *et al.* 1996).

The main results from the analysis are summarised in Table 5. In some cases, the results are in disagreement with our intuitive expectations. This might be due to biases or insufficiencies in the distributional data used, or other more subtle factors in the analysis. Suggested adjustments of the results from the analysis are indicated in Table 5. These adjustments are based on knowledge on the distribution, biology and population status of the populations involved. The reasoning behind the adjustments is outlined below. In some cases, it has not been possible to incorporate all knowledge into the analysis (especially on distribution), or important factors do not seem to have been given enough weight. Particularly for species/seasons with poor data basis on distribution, emphasis should be placed on these adjustments.

4.2.1 Suggested adjustments of results

Glaucous gull: This species is found scattered throughout the analysis area in autumn. A limited spill at this time of the year will probably not have large consequences for the population.

Common guillemot: A large majority of the breeding population of this species in the Norwegian part of the Barents Sea is concentrated at a single breeding site, Bjørnøya. The populations both at Bjørnøya and along the Norwegian coast have declined seriously during the last decades. The species is among the most vulnerable to oil spills, and the calculated consequence indices is judged to be too low.

Brünnich's guillemot: This species is one of the most important species in the area in winter. A spill from the western spill point in winter will probably have larger consequences than indicated by the consequence index. The reason for this is that distributional data for the western part of the analysis area is lacking in winter.

Razorbill: The majority of the relatively few razorbills breeding in the analysis area is concentrated to Bjørnøya. The probability of oil from the middle spill point reaching Bjørnøya in summer is high, and the calculated consequence index seems to low.

Little auk: The main part of the little auk population in Svalbard breeds along the western coast of Spitsbergen. A significant part of these birds may still be present in the area in early autumn. The calculated consequence index for the western spill point in autumn therefore seems too low. The calculated index for the eastern spill point is, on the other hand, too high.

Puffin: A large proportion of the puffins breeding in Svalbard are found along the western coast of Spitsbergen. The chicks leave the nests very late, and it is expected that a large number of puffins may still be found in areas outside the western coast in autumn. There is no distributional data from this area in autumn. A spill from the western spill point, with oil drifting up along the western coast of Spitsbergen, will therefore have considerably higher consequences than calculated.

All species in winter: The data on distribution at sea in winter is mainly from the middle and eastern parts of the (southern) analysis area. The consequences of spills from the western spill point indicated in the analysis are consequently too low, whereas consequences indicated for spills from the middle and eastern spill points may be too high.

Breeding colonies and eastern spill point: Several of the species in the analysis are concentrated at or have main breeding colonies at Bjørnøya. The oil spill statistics show that the areas close to Bjørnøya may be reached by oil from the eastern spill point, although the probability is low. The 25x25 km grid cells containing Bjørnøya and its breeding colonies is for some reason not affected, but the neighbouring cells are. Since all seabirds use the marine areas around the island, they will be affected if the areas around the island are contaminated. The calculated consequence indices are therefore too low.

4.3 INDIRECT IMPACTS ON SEABIRDS

Indirect impacts of an oil spill covers most effects other than direct mortality of soiled birds. These effects have been described in general in section 1.5. Here, only a few points of special relevance to the Northern Barents Sea will be mentioned.

An oil spill reaching land will contaminate the shoreline close to breeding colonies. If not removed by clean-up operations, the oil may be present at the beach for several years and may cause impacts in more than one breeding season. Clean-up operations are often large operations involving a large number of personnel and traffic from boats and helicopters. This activity may disturb breeding, moulting and feeding seabirds. Breeding and moulting geese seem to be particularly sensitive to such disturbance. A worst case scenario is an oil slick reaching the main breeding area of brent geese at Tusenøyane in the breeding season. Disturbance from clean-up operations will cause these shy birds to leave eggs and young less-guarded or unattended. The result may be loss of a large part of that year's eggs or chicks due to predation and cold. When disturbed, geese often seek safety by entering water. This habit makes them more vulnerable to being soiled by oil along the beaches, and a large proportion of the adult birds in the affected area will probably be soiled.

Table 5. Summary of results from the impact analysis for seabirds. The numbers are consequence indices converted to the consequence categories large (3), medium (2), small (1) and insignificant (0). Seasons are winter (1), spring (2), summer (3) and autumn (4). In addition, the results from the analysis for breeding colonies in summer (B) are shown. For summer and autumn, only the distribution in ice-free areas at sea have been analysed. For winter, only results from the analysis in ice-filled waters have been included. For spring, analyses have been made both for ice-free and ice-filled waters. The indicated results from spring are a synthesis of the results from the two analyses. The consequences for moulting eiders are given under season 3. See text for further comments.

Spill point	Western					Middle					Eastern				
Season	1	2	3	4	B	1	2	3	4	B	1	2	3	4	B
Great northern diver	–	★	★	–	2	–	★	★	–	3	–	★	★	–	0↑
Fulmar	★	1	3	1	1	★	1	3	3	1	★	1	0	3	0↑
Barnacle goose	–	★	★	★	3	–	★	★	★	0	–	★	★	★	0
Brent goose	–	★	★	★	0	–	★	★	★	3	–	★	★	★	0
Common eider	–	★	3	★	3	–	★	0	★	1	–	★	0	★	0
King eider	–	★	3	★	3	–	★	3	★	0	–	★	0	★	0
Arctic skua	–	–	0	–	★	–	–	1	–	★	–	–	0	–	★
Sabine's gull	–	–	★	★	0	–	–	★	★	0	–	–	★	★	0
Glaucous gull	–	1	2	1	1	–	1	1	3↓	1	–	1	0	3↓	0↑
Great bl.-backed gull	–	★	★	–	3	–	★	★	–	0↑	–	★	★	–	0↑
Kittiwake	★	0	1	1	1	★	1	2	3	2	★	2	0	3	0↑
Ivory gull	★	1	–	–	–	★	1	–	–	–	★	0	–	–	–
Common guillemot	★	0↑	1↑	0↑	3	★	1↑	1↑	0↑	3	★	1	0↑	3	0↑
Brünnich's guillemot	0↑	3	3	0↑	3	2	3	3	3	3	3	3	1	3	0↑
Razorbill	–	★	★	★	3	–	★	★	★	1↑	–	★	★	★	0↑
Black guillemot	★	1	1	★	1	★	3	2	★	1	★	1	0	★	0
Little auk	★	3	3	1↑	1↑	★	2	2	3	1↑	★	1	0	3↓	0
Puffin	★	3	1↑	0↑	1	★	0	1	0	0	★	0	0	3	0

★ no analysis has been made due to insufficient data on the resource distribution.

– the species is either not present in the area in the actual season or it has been evaluated as 'not vulnerable' to oil spills at this time of the year.

↑ the results from the analysis are judged to be too low. This is based on an evaluation incorporating knowledge on shortcomings in the resource data and other factors (see main text).

↓ the results from the analysis are judged to be too high. This is based on an evaluation incorporating knowledge on shortcomings in the resource data and other factors (see main text).

Brünnich's and common guillemots are particularly vulnerable to an oil spill during the swimming migration out from their breeding colonies at the end of the breeding season. Both the chicks and the accompanying male parents are flightless during a period after they have left the colonies. A spill affecting a large number of these males may have a larger effect on the population than if half the same number of both males and females were affected. The same may be true for moulting male eiders, but the effects are expected to be more important for guillemots because they are monogamous and form multi-year pair bonds. Reproduction in the following years may be reduced due to disruption of pair bonds and an increased incident of non-breeding among the remaining birds.

See section 1.5 for a more detailed description of indirect (and direct) effects of oil spills on seabirds.

4.4 DIRECT IMPACTS ON MARINE MAMMALS

The distributional data used for most species in this analysis is very broad. This is in part due to the lack of knowledge and in part due to the strong preference several species have for ice-covered waters. The large variations in the extent of the sea ice in the Barents Sea makes it difficult to predict the geographical distribution of these species (see section 2.1.2).

This broadness in the distributional data for most species clearly influences the expected precision in the analysis. For instance, it is probable, but not known for certain, that the density of polar bears is higher along the ice edge than in the interior of the sea-ice areas also at other times of the year than in spring. If this is the case, the calculated consequences are too low. The concentrations along the ice edge in spring may also be more important than what has been quantified in the analysis.

The analysis for polar bear denning areas showed relatively low consequences because some of the main denning areas are positioned north of the areas affected by oil from the three spill sites. Hopen, the most southerly of the denning areas, as well as some denning areas in Storfjorden, has relatively high probability of being reached by oil from the two easternmost spill points both in autumn and spring. Oil in leads around the denning areas will affect females entering dens in autumn or leaving dens with small young in spring. Reproductive females are the most 'valuable' part of the population, and the loss of even a moderate number of these may have important consequences for the population.

The main results from the analysis are summarised in Table 6. As with seabirds, the results are in some cases in disagreement with our intuitive expectations. This might be due to biases or insufficiencies in the distributional data used, or other more subtle factors in the analysis. Suggested adjustments of the results from the analysis are indicated in Table 6. These adjustments are based on knowledge on the distribution, biology and population status of the populations involved. The reasoning behind the adjustments are outlined below. Particularly for species/seasons with poor data basis on distribution, emphasis should be placed on these adjustments.

4.4.1 Suggested adjustments of results

Polar bear: In spring, high densities of polar bears may be found along the ice edge, and they are therefore very prone to being soiled by oil. In summer, most bears follow the ice edge towards north, but many individuals may also stay on land in the Storfjord-area and on Kong Karls Land. The association with ice-edge and coastal habitats increases the risk of the bears coming in contact with spilt oil. These factors do not seem to have been sufficiently quantified in the analysis, and some of the calculated consequence indices are too low.

White whale: In summer, white whales are concentrated in coastal areas in Svalbard (high densities are known from the western coast of Spitsbergen) and along the ice edge. The calculated consequences of a spill from the western spill point seem too low.

4.5 INDIRECT IMPACTS ON MARINE MAMMALS

Marine mammals may be affected in other ways than by direct oiling in the first stages of the spill. If traditional haul-out sites of harbour seals or walruses are soiled by oil, the animals may be exposed to oil for an extended period of time, probably several years. It is expected that this has larger consequences than a single brief oiling at sea. Kong Karls Land and Tusenøyane are particularly important in this respect because they are the most important haul-out sites of harbour seals and walruses in Svalbard, respectively. Experience from the *Exxon Valdez* accident in Alaska indicate that harbour seals will continue to use their traditional haul-out sites even if these are heavily oiled (Lowry *et al.* 1994).

Walruses and bearded seals feed on benthic invertebrates that may accumulate hydrocarbons from a spill in their tissues. These two species (and possibly also other marine mammals) may be affected indirectly by reduced availability of food or by ingestion of hydrocarbons accumulated in prey. Walruses may be particularly affected if their shallow feeding areas around Tusenøyane are contaminated.

As is the case for seabirds, marine mammals may also be negatively affected by disturbance during clean-up operations. Again, this may be most important for walruses and harbour seals at

Table 6. Summary of results from the impact analysis for marine mammals. The numbers are consequence indices converted to the consequence categories large (3), medium (2), small (1) and insignificant (0). Seasons are winter (1), spring (2), summer (3) and autumn (4).

Spill point	Western				Middle				Eastern			
Season (quarter)	1	2	3	4	1	2	3	4	1	2	3	4
Walrus females	★	★	★	★	★	★	★	★	★	★	★	★
Walrus males	★	★	0	0	★	★	**3**	**3**	★	★	0	0
Harbour seal	**3**	**3**	**3**	**3**	**3**	1	0	**3**	1	0	0	2
Harp seal	–	–	2	0	–	–	2	2	–	–	2	2
Bearded seal	–	1	1	–	–	1	1	–	–	1	1	–
Polar bear females	2	**3**	1↑	2	**3**	**3**	**3**	**3**	**3**	2↑	2	**3**
Polar bear males	2	**3**	1↑	2	**3**	2↑	**3**	**3**	**3**	2↑	2	**3**
Bowhead whale	★	★	★	★	★	★	★	★	★	★	★	★
White whale	2	**3**	1↑	2	2	2	**3**	**3**	**3**	2	1	**3**

★ no analysis has been made due to insufficient data on the resource distribution.

– the species is either not present in the area in the actual season or it has been evaluated as 'not vulnerable' to oil spills at this time of the year.

↑ the results from the analysis are judged to be too low. This is based on an evaluation incorporating knowledge on shortcomings in the resource data and other factors (see main text).

↓ the results from the analysis are judged to be too high. This is based on an evaluation incorporating knowledge on shortcomings in the resource data and other factors (see main text).

haul-out sites, but may also be important for polar bears in denning areas.

A more detailed, general description of indirect (and direct) effects of oil spills on marine mammals is found in section 1.7.

5. SUMMARY AND CONCLUSIONS

There has been no drilling for petroleum (oil and gas) in the Norwegian part of the northern Barents Sea. The southern part (south of Bjørnøya; 74°30'N) was opened for exploratory drilling by Norwegian authorities in 1989. According to Norwegian law, an extensive environmental impact analysis (EIA) has to be carried out before a new area can be opened for exploration. The work with an EIA for the northern Barents Sea, covering effects on different resources and interests such as marine invertebrates, fish, seabirds, marine mammals, fisheries and tourism, started in 1989.

At present a political majority does probably not exist in the Norwegian parliament (Stortinget) for opening the northern Barents Sea for petroleum activity. The government (as of February 1998) has stated that petroleum activity is not to be started in environmentally sensitive areas, which probably includes the northern Barents Sea. During the last stages of the work with the assessment for the northern Barents Sea, the aim has been to give a summary of the knowledge of the effects of oil spills in such arctic areas, and, by performing a preliminary analysis, pointing out possible effects for resources in the northern Barents Sea. The assessment is therefore not a final EIA, but it will form the basis for a possible future EIA. An extensive summary of the assessment, with possible effects on the different resources and interests outlined, is found in Aaserød & Loeng (1997).

The present report is the final report for the seabird and marine mammal part of the assessment. A review of the effects of oiling on seabirds and marine mammals, based on published information from previous oil-spill incidents, is given in the first part of the report. The other main part of the report is an analysis of potential effects of oil spills on seabirds and marine mammals in the northern Barents Sea. The Norwegian Polar Institute has had the main responsibility for carrying out the assessment, but several other institutions have participated by supplying data on oil-drift statistics, distribution of seabirds and marine mammals, and by developing analysis methods.

Methods: For this assessment, three alternative drill or spill points were defined, all between Bjørnøya and the more northern islands of the Svalbard archipelago. These are the western (75°50'N 17°00'E), middle (75°50'N 25°00'E) and eastern (75°10'N 32°30'E) spill points. The analysis area for spills from these sites was defined as the area between 73°N and 81°N, and between 5°E and 35°E. The analysis model used, SIMPACT, divides this area into 25x25 km squares (grid cells) and combines, for each grid cell, three factors: (1) the proportion of the resource (*e.g.* breeding pairs of a seabird species) within the grid cell, (2) the probability of the cell being reached by oil from the spill site in question, and (3) a vulnerability index of the actual resource (population), describing how vulnerable that population is compared to other populations within the same resource group (seabirds or marine mammals). The result from the analysis for one population, one season and one spill site is a consequence index. This index is converted to one of four consequence categories: insignificant, small, medium or large consequences. It must be emphasised that the model is used only as a tool to compare and scale the level of potential impact between different seasons, spill sites and species. The model does *not* give a quantitative result in terms of the number of individuals lost or the time needed for population recovery.

Seabirds: A spill from the western spill point generally has the highest consequences on the breeding colonies. This is especially the case for concentrations of breeding barnacle geese and common eiders, as well as moulting common and king eiders along the western coast of Spitsbergen. A spill from the middle spill point will have largest consequences for breeding brent geese, which are concentrated in Tusenøyane. Spills from both the two westernmost spill sites may reach Bjørnøya in summer and may have large consequences for both common and Brünnich's guillemots. In autumn, guillemots are again among the species most heavily affected, at this time particularly from the two easternmost spill sites. The results of the analysis for the winter period indicate that Brünnich's guillemots may be heavily affected in the eastern areas. In spring, the analysis show large consequences for Brünnich's guillemots and little auks of a spill from all three spill points and the western spill point only, respectively. Internationally important seabird populations may be heavily affected in most combinations of spill sites and seasons, but the consequences will probably be largest in spring and summer for the two westernmost spill sites.

Marine mammals: The results from the analysis show that a spill from the western spill point in summer may have large consequences for harbour seals. This species is concentrated at Kong Karls Land in western Svalbard. A spill from the middle spill point may have large consequences for polar bears, walruses and white whales. In autumn, the picture is similar, but a spill from the middle spill point may now also have large consequences for harbour seals, and a spill from the eastern spill point may have large consequences for polar bears and white whales. In winter, a spill from the western spill point may have large consequences for harbour seals, whereas a spill from the middle spill point in addition may have large consequences for polar bears. A spill from the eastern spill point at this time may have large consequences for polar bear and white whale. In spring, the analysis indicate large consequences for harbour seals and white whales of a spill from the western spill point, whereas the consequences for polar bears may be large for a spill from the two westernmost spill sites, and probably also for the eastern spill site. The analysis indicates large consequences for one or more species in most combinations of spill sites and seasons. The consequences may be largest for the two westernmost spill sites, especially for harbour seals.

The distributional data used for both seabirds and marine mammals in this analysis are in several cases either insufficient or very broad approximations. The reason for this is both lack of knowledge/data and large temporal variation in the distribution, especially of sea-ice associated species. This may have influenced the validity of the results from the analysis. The consequences predicted should therefore only be viewed as indications of potential effects of an oil spill.

6. REFERENCES

Aaserød, M. I. & Loeng, H. (eds.) 1997: *Oljeleting i det nordlige Barentshavet. Sammenfatning av mulige virkninger for miljø, naturressurser og samfunn.* Olje- og energidepartementet, Oslo. 121 pp. (In Norwegian).

Addison, R. F., Brodie, P. F., Edwards, A. & Sadler, M. C. 1986: Mixed function oxidase activity in the harbour seal (*Phoca vitulina*) from Sable Is., N.S. *Comp. Biochem. Physiol. 85C*, 121–124.

Ainley, D. G., Grau, C. R., Roudybush, T. E., Morrell, S. H. & Utts, J. M. 1981: Petroleum ingestion reduces reproduction in Cassin's Auklets. *Mar. Pollut. Bull. 12*, 314–317.

Albers, P. H. 1980: Transfer of crude oil from contaminated water to bird eggs. *Environm. Res. 22*, 307-314.

Amstrup, S. C. 1993: Human disturbances of denning polar bears in Alaska. *Arctic 46*, 246–250.

Anker-Nilssen, T. 1987: Metoder til konsekvens-analyser olje/sjøfugl. *Viltrapport 44*, Direktoratet for naturforvaltning. 114 pp. (In Norwegian).

Anker-Nilssen, T. 1991: Skader på sjøfugl i Alaska etter oljeutslippet fra *Exxon Valdez* i mars 1989. *NINA Oppdragsmelding 89*. 38 pp. (In Norwegian with English abstract).

Anker-Nilssen, T. & Barrett, R. T. 1991: Status of seabirds in northern Norway. *Brit. Birds 84*, 329-341.

Anker-Nilssen, T. & Kvenild, L. 1993: SIMPACT versjon 2.0. Oppdatering september 1993. Norsk institutt for naturforskning, Trondheim. 7 pp. (In Norwegian).

Anker-Nilssen, T. & Kvenild, L. 1996: SIMPACT versjon 3.0b. Brukerveiledning med oppdatering av modellbeskrivelse. Norsk institutt for natur-forskning, Trondheim. 25 pp. (In Norwegian).

Anker-Nilssen, T. & Røstad, O. W. 1982: Olje-katastrofen i Skagerrak ved årsskiftet 80/81 – omfang og undersøkelser. *Vår Fuglefauna 5*, 82-90. (In Norwegian with English summary).

Anker-Nilssen, T., Bakken, V. & Strann, K.-B. 1988: Konsekvensanalyse olje/sjøfugl ved petroleums-virksomhet i Barentshavet sør for 74°30'N. *Viltrapport 46*, Direktoratet for naturforvaltning. 98 pp. + app. (In Norwegian).

Anker-Nilssen, T., Johansen, Ø. & Kvenild, L. 1992: *SIMPACT*. Et analysesystem for konsekvens-utredninger av petroleumsvirksomhet. Modell-beskrivelse og brukerveiledning. *NINA Oppdrags-melding 162*. 38 pp. (In Norwegian).

Ayers, R. C., Jr., Jahns, H. O. & Glaeser, J. L. 1974: Oil spills in the Arctic Ocean: extent of spreading and possibility of large-scale thermal effects. *Science 186*, 843–845.

Baker, J. R., Jones, A. M., Jones, T. P. & Watson, H. C. 1981: Otter *Lutra lutra* L. mortality and marine oil pollution. *Biol. Conserv. 20*, 311–321.

Barrett, R. T. 1979: Small oil spill kills 10–20 000 seabirds in North Norway. *Mar. Pollut. Bull. 10*, 253–255.

Birkhead, T. R. & Furness, R. W. 1985: Regulation of seabird populations. *Symp. Br. Ecol. Soc. 25*, 145-167.

Birkhead, T. R. & Harris, M. P. 1985: Ecological adaptations for breeding in the Atlantic Alcidae. Pp. 205–231 in D. N. Nettleship & T. R. Birkhead (eds.): *The Atlantic Alcidae*. Academic Press, London.

Blix, A. S. & Lentfer, J. W. 1992: Noise and vibration levels in artificial polar bear dens as related to selected petroleum-exploration and developmental activities. *Arctic 45*, 20–24.

Boehm, P. D., Mankiewicz, P. J., Hartung, R., Neff, J. M., Page, D. S., Gilfillian, E. S., O'Reilly, J. E. & Parker, K. R. 1996: Characterization of mussel beds with residual oil and the risk to foraging wildlife 4 years after the *Exxon Valdez* oil spill. *Environ. Toxicol. Chem. 15*, 1289–1303.

Born, E. W., Gjertz, I. & Reeves, R. R. 1995: Population assessment of Atlantic walrus (*Odobenus rosmarus rosmarus* L.). *Norsk Polarinst. Medd. 138*. 100 pp.

Bourne, W. R. P. 1968: Observation of an encounter between birds and floating oil. *Nature 219*, 632.

Burger, A. E. 1993: Estimating the mortality of sea-birds following oil spills: Effects of spill volume. *Mar. Pollut. Bull. 26*, 140–143.

Burger, J. 1981: Effects of human disturbance on colonial species, particularly gulls. *Colonial Waterbirds 4*, 28–36.

Burger, J. 1997: Effects of oiling on feeding behaviour of Sanderlings and Semipalmated Plovers in New Jersey. *Condor 99*, 290–298.

Butler, R. G., Harfenist, A., Leighton, F. A. & Peakall, D. B. 1988: Impact of sublethal oil and emulsion exposure on the reproductive success of Leach's storm-petrels: short and long-term effects. *J. Appl. Ecol. 25*, 125–143.

Børresen, J. A., Christie, H. & Aaserød, M. I. 1988: *Opening of the Barents Sea South, Troms II, Troms III and the southern part of Finnmark West* *for Petroleum Activities. Environmental Impact Statement.* ●lje- og Energidepartementet, ●slo. 90 pp. (In Norwegian with English summary).

Clark, R. B. 1984: Impact of oil pollution on seabirds. *Environm. Pollut. (Ser. A) 33*, 1–22.

Clark, R. B. 1989: *Marine pollution.* 2nd ed. ●xford Univ. Press. 220 pp.

Clark, R. C., Jr. & Finley, J. S. 1982: ●ccurrence and impact of petroleum on arctic environments. Pp. 295–341 in Rey, L. (ed.): *The Arctic Ocean: the hydrographic environment and the fate of pollutants.* Macmillan Press, London and Basingstoke.

Clark, R. C., Jr. & MacLeod, W. D., Jr. 1977: Inputs, transport mechanisms, and observed concentrations of petroleum in the marine environment. Pp. 91–223 in Malins, D. C. (ed.): *Effects of petroleum on arctic and subarctic marine environments and organisms. Vol. I, Nature and fate of petroleum.* Academic Press, New York.

Cramp, S. & Simmons, K. E. L. (eds.) 1977: *The birds of the Western Palearctic, vol. I.* ●xford Univ. Press.

Cramp, S. & Simmons, K. E. L. (eds.) 1983: *The birds of the Western Palearctic, vol. III.* ●xford Univ. Press.

Custer, T. W. & Albers, P. H. 1980: Response of captive, breeding mallards to oiled water. *J. Wildl. Manage. 44*, 915–918.

Dahlgren, R. B. & Korschgen, C. E. 1992: Human disturbances of waterfowl: an annotated bibliography. *U.S. Fish and Wildl. Serv. Resource Publ. 188.* 62 pp.

Dahlheim, M. E. & Matkin, C. ●. 1994: Assessment of injuries to Prince William Sound killer whales. Pp. 163–171 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Davis, J. E. & Anderson, S. S. 1976: Effects of oil pollution on breeding grey seals. *Mar. Pollut. Bull. 7*, 115–118.

Dunnet, G. M. 1982: ●il pollution and seabird populations. *Phil. Trans. R. Soc. Lond. B 297*, 413–427.

Dunnet, G. M. & ●llason, J. C. 1978: The estimation of survival rate in the fulmar, *Fulmarus glacialis. J. Anim. Ecol. 47*, 507–520.

Engelhardt, F. R. 1985: Effects of petroleum on marine mammals. Pp. 217–243 in Engelhardt, F. R. (ed.): *Petroleum effects in the arctic environment.* Elsevier Appl. Science Publ., London and New York.

Engelhardt, F. R. 1994: Limitations and innovations in the control of environmental impacts from petroleum industry activities in the Arctic. *Mar. Pollut. Bull. 29*, 334–341.

Engelhardt, F. R., Geraci, J. R. & Smith, T. G. 1977: Uptake and clearance of petroleum hydrocarbons in the ringed seal, *Phoca hispida. J. Fish. Res. Board Can. 34*, 1143–1147.

Eppley, Z. A. 1992: Assessing indirect effects of oil in the presence of natural variation: the problem of reproductive failure in South Polar Skua during the *Bahia Paraiso* oil spill. *Mar. Pollut. Bull. 25*, 9–12.

Erikstad, K. E., Moum, T. & Vader, W. 1990: Correlations between pelagic distribution of Common and Brünnich's Guillemots and their prey in the Barents Sea. *Polar Res. 8*, 77–87.

Evans, P. G. H. & Nettleship, D. N. 1985: Conservation of the Atlantic Alcidae. Pp. 427–488 in D. N. Nettleship & T. R. Birkhead (eds.): *The Atlantic Alcidae.* Academic Press, London.

Fauchald, P. & Erikstad, K. E. 1995: The predictability of the spatial distribution of guillemots (*Uria* spp.) in the Barents Sea. Pp. 105–122 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Fauchald, P., Erikstad, K. E. & Skarsfjord, H. 1996: Physical and biological environmental properties as predictors of the broad scale spatial distribution of pelagic seabirds. *NINA•NIKU project report 6.* 20 pp.

Fjeld, P. E. & Bakken, V. 1993: Sårbarhets- og verneverdianalyse for sjøfugl i forbindelse med leteboring etter olje/gass i Barentshavet Nord. Forslag til supplerende undersøkelser. *Norsk Polarinst. Medd. 123.* 67 pp. (In Norwegian with English summary).

Folkestad, A. ●. 1983: *Sjøfugl og oljesøl.* Tapir forlag, Trondheim. 70 pp. (In Norwegian).

Frost, K. J., Lowry, L. F., Sinclair, E. H., Ver Hoef, J. & McAllister, D. C. 1994a: Impacts on distribution, abundance, and productivity of harbor seals. Pp. 97–118 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Frost, K. J., Manen, C.-A. & Wade, T. L. 1994b: Petroleum hydrocarbons in tissues of harbor seals from Prince William Sound and the Gulf of Alaska. Pp. 331–358 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Fry, D. M. 1993: How do you fix the loss of half a million birds? Pp. 30–33 in: *Abstract book.* Exxon Valdez *oil spill symposium, Anchorage, Alaska, February 2–5, 1993. Exxon Valdez* ●il Spill Trustee Council.

Fry, D. M. & Lowenstine, L. J. 1985: Pathology of common murres and Cassin's auklets exposed to oil. *Arch. Environ. Contam. Toxicol. 14*, 725–737.

Fry, D. M., Swenson, J., Addiego, L. A., Grau, C. R. & Kang, A. 1986: Reduced reproduction of Wedge-tailed Shearwaters exposed to weathered Santa Barbara crude oil. *Arch. Environ. Contam. Toxicol. 15*, 453–463.

Garrott, R. A., Eberhardt, L. L. & Burn, D. M. 1993: Mortality of sea otters in Prince William Sound following the *Exxon Valdez* oil spill. *Mar. Mam. Sci. 9*, 343–359.

Geraci, J. R. 1990: Physiologic and toxic effects on cetaceans. Pp. 167–197 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks.* Academic Press, San Diego.

Geraci, J. R. & Smith, T. G. 1976: Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. *J. Fish. Res. Board Can. 33*, 1976–1984.

Geraci, J. R. & St. Aubin, D. J. (eds.) 1990: *Sea mammals and oil: confronting the risks.* Academic Press, San Diego. 282 pp.

Geraci, J. R. & Williams, T. D. 1990: Physiologic and toxic effects on sea otters. Pp. 211–221 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks.* Academic Press, San Diego.

Golovkin, A. N. 1984: Seabirds nesting in the USSR: the status and protection of populations. Pp. 473–486 in Croxall, J. P., Evans, P. G. H. & Schreiber, R. W. (eds.): *Status and conservation of the World's seabirds.* ICBP Technical Publ. No. 2.

Griffiths, D. J., Øritsland, N. A. & Øritsland, T. 1987: Marine mammals and petroleum activities in Norwegian waters: A review of the literature on the effects of petroleum on marine mammals and recommendations for further research. *Fisken og havet ser. B no. 1 1987.* 179 pp. (In English with Norwegian summary).

Haebler, R. 1994: Biological effects: marine mammals and sea turtles. Pp. 238–252 in Burger, J. (ed.): *Before and after an oil spill: The Arthur Kill.* Rutgers Univ. Press, New Brunswick, New Jersey.

Hansson, R., Prestrud, P. & Øritsland, N. A. 1990: Assessment system for the environment and industrial activities in Svalbard. *Norsk Polarinst. Rap. 68.* 267 pp.

Harris, M. P. & Wanless, S. 1995: Survival and non-breeding of adult Common Guillemots *Uria aalge. Ibis 137*, 192–197.

Harris, M. P., Halley, D. J. & Swann, R. L. 1994: Age of first breeding in Common Murres. *Auk* 111, 207–209.

Harvey, J. T. & Dahlheim, M. E. 1994: Cetaceans in oil. Pp. 257–264 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Hassel, A., Loeng, H., Klungsøyr, J. & Fossum, P. 1997: Konsekvenser av et oljesøl på marine organismer i det nordlige Barentshavet. *Fisken og Havet no. 18-1997.* 70 pp. (In Norwegian).

Heinemann, D. 1993: How long to recovery for murre populations, and will some colonies fail to make the comeback? Pp. 139–141 in: *Abstract book.* Exxon Valdez *oil spill symposium, Anchorage, Alaska, February 2–5, 1993. Exxon Valdez* Oil Spill Trustee Council.

Hoffman, D. J. & Albers, P. H. 1984: Evaluation of potential embryotoxicity and teratogenicity of 42 herbicides, insecticides, and petroleum contaminants to mallard eggs. *Arch. Environ. Contam. Toxicol. 13*, 15–27.

Holling, C. S. 1978: *Adaptive environmental assessment and management.* John Wiley & Sons, New York.

Holmes, W. N. & Cronshaw, J. 1977: Biological effects of petroleum on marine birds. Pp. 359–398 in Malins, D. C. (ed.): *Effects of petroleum on arctic and subarctic marine environments and organisms. Vol. II, Biological effects.* Academic Press, New York.

Hudson, P. J. 1985: Population parameters for the Atlantic Alcidae. Pp. 233–261 in Nettleship, D. N. & Birkhead, T. R. (eds.): *The Atlantic Alcidae.* Academic Press, London.

Hunt, G. L., Jr. 1987: Offshore oil development and seabirds: the present status of knowledge and long-term research needs. Pp. 539–586 in Boesch, D. F. & Rabalais, N. N. (eds): *Long-term environmental effects of offshore oil and gas development.* Elsevier Applied Science, London & New York.

Hunt, G. L., Jr. 1990: The pelagic distribution of marine birds in a heterogeneous environment. *Polar Res. 8*, 43–54.

Hunt, G. L., Jr. 1991: Occurrence of polar seabirds at sea in relation to prey concentrations and oceanographic factors. *Polar Res. 10*, 553–559.

Hurst, R. J. & Øritsland, N. A. 1982: Polar bear thermoregulation: effect of oil on the insulating properties of fur. *J. Therm. Biol. 7*, 201–208.

Isaksen, K. (ed.) 1994: Isbjørn, sjøpattedyr og sjøfugl knyttet til områder i det nordlige Barentshav. Report for 1993, AKUP-project No. 73. Norsk Polarinst. 42 pp. (In Norwegian).

Isaksen, K. 1995a: Distribution of seabirds at sea in the northern Barents Sea. Pp. 67–104 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Isaksen, K. 1995b: The breeding population of Little Auk (*Alle alle*) in colonies in Hornsund and northwestern Spitsbergen. Pp. 49–57 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Isaksen, K. & Bakken, V. (eds.) 1995a: Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.* 134 pp.

Isaksen, K. & Bakken, V. 1995b: Breeding populations of seabirds in Svalbard. Pp. 11–35 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Isaksen, K. & Bakken, V. 1995c: Estimation of breeding density of Little Auks (*Alle alle*). Pp. 37–48 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Isaksen, K. & Bakken, V. 1995d: Important moulting areas for seabirds in Svalbard. Pp. 59–66 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Isaksen, K. & Wiig, Ø. (eds.) 1995: Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.* 59 pp.

Jenssen, B. M. 1994: Review article: Effects of oil pollution, chemically treated oil, and cleaning on the thermal balance of birds. *Environm. Pollut. 86*, 207–215.

Johansen, Ø., Skognes, K., Melsom, A., Ulstad, C. & Sætra, Ø. 1997: SLIKMAP-beregninger for isfylte farvann. *OCEANOR Report no. OCN R-97005* (Oceanographic Company of Norway AS, Trondheim). 22 pp. + app. (In Norwegian).

Jødestøl, K. A. & Ugland, K. I. 1993: Sårbarhetsanalyse for ringsel og grønlandsel i Barentshavet nord. *Det Norske Veritas Industry AS, Rap. Nr. 93-3740.* 59 pp. (In Norwegian with English summary).

Jødestøl, K. A., Sørgård, E., Bitner-Gregersen, E. & Ugland, K. I. 1994: Sea mammal population risk assessment. *Det Norske Veritas Industry AS, Rep. No. 94–3622.* 100 pp.

King, K. A. & Lefever, C. A. 1979: Effects of oil transferred from incubating gulls to their eggs. *Mar. Pollut. Bull. 10*, 319–321.

Larsen, T. 1986: Population biology of the polar bear (*Ursus maritimus*) in the Svalbard area. *Norsk Polarinst. Skr. 184.* 55 pp.

Leighton, F. A. 1993: The toxicity of petroleum oils to birds. *Environ. Rev. 1*, 92–103.

Leighton, F. A., Butler, R. G. & Peakall, D. B. 1985: Oil and arctic marine birds: an assessment of risk. Pp. 183–215 in Engelhardt, F. R. (ed.): *Petroleum effects in the arctic environment.* Elsevier Appl. Science Publ., London and New York.

Lewis, S. J. & Malecki, R. A. 1984: Effects of egg oiling on larid productivity and population dynamics. *Auk 101*, 584–592.

Linnell, J. D. C., Swenson, J., Barnes, B., & Andersen, R. 1996: Hvor sårbare er bjørner for forstyrrelser i hiperioden? En litteraturoversikt. En utredning foretatt i forbindelse med Forsvarets planer om etablering av Regionfelt Østlandet, del 2. *NINA Oppdragsmelding 413.* 19 pp. (In Norwegian with English abstract).

Loeng, H. 1991: Features of the physical oceanographic conditions of the Barents Sea. *Polar Res. 10*, 5–18.

Lorentsen, S.-H. 1995: Observasjoner av sjøfugl i forbindelse med eksperimentelt oljeutslipp Frigg-feltet august 1995. *NINA Oppdragsmelding 372.* 11 pp. (In Norwegian with English abstract).

Lorentsen, S.-H. & Anker-Nilssen, T. 1993: Behaviour and oil vulnerability of fulmars *Fulmarus glacialis* during an oil spill experiment in the Norwegian Sea. *Mar. Pollut. Bull. 26*, 144–146.

Lorentsen, S.-H., Anker-Nilssen, T., Kroglund, R. T. & Østnes, J. E. 1993: Konsekvensanalyse olje/sjøfugl for petroleumsvirksomhet i norsk del av Skagerrak. *NINA Forskningsrapport 39.* 84 pp. (In Norwegian with English abstract).

Loughlin, T. R. (ed.) 1994a: *Marine mammals and the* Exxon Valdez. Academic Press, San Diego. 395 pp.

Loughlin, T. R. 1994b: Tissue hydrocarbon levels and the number of cetaceans found dead after the spill. Pp. 359–370 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Lowry, L. F. 1993: Foods and feeding ecology. Pp. 201–238 in Burns, J. J., Montague, J. J. & Cowles, C. J. (ed.): *The bowhead whale.* Society for Marine Mammalogy (Spec. Publ. No. 2), Lawrence, Kansas.

Lowry, L. F., Frost, K. J. & Pitcher, K. W. 1994: Observations of oiling of harbor seals in Prince William Sound. Pp. 209–225 in Loughlin, T. R.

(ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Lydersen, C. & Wiig, Ø. 1995: Conservation value assessment of selected marine mammals in the northern Barents Sea. Pp. 7–23 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

Maccarone, A. D. & Brzorad, J. N. 1994: Gull and waterfowl populations in the Arthur Kill. Pp. 201–214 in Burger, J. (ed.): *Before and after an oil spill: The Arthur Kill.* Rutgers Univ. Press, New Brunswick, New Jersey.

Mackay, D. 1985: The physical and chemical fate of spilled oil. Pp. 37–61 in Engelhardt, F. R. (ed.): *Petroleum effects in the arctic environment.* Elsevier Appl. Science Publ., London and New York.

Matkin, C. O., Ellis, G. M., Dahlheim, M. E. & Zeh, J. 1994: Status of killer whales in Prince William Sound, 1985–1992. Pp. 141–162 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

Mehlum, F. & Isaksen, K. 1995: The effects of sea ice on the distribution of seabirds in the northern Barents Sea. Pp. 123–133 in Isaksen, K. & Bakken, V. (eds.): Seabird populations in the northern Barents Sea – source data for the impact assessment of the effects of oil drilling activity. *Norsk Polarinst. Medd. 135.*

Mehlum, F., Nordlund, N. & Isaksen, K. 1998: The importance of the "Polar Front" as a foraging habitat for guillemots *Uria* spp. breeding at Bjørnøya, Barents Sea. *J. Marine Syst. 14,* 27–43.

Miljøverndep. 1993: *St.meld. nr. 13 (1992–93). Om FN-konferansen om miljø og utvikling i Rio de Janeiro.* Miljøverndepartementet (Ministry of the Environment), Oslo. 162 pp. (In Norwegian).

Miljøverndep. 1995: *St.meld. nr. 22 (1994–95). Om miljøvern på Svalbard.* Miljøverndepartementet (Ministry of the Environment), Oslo. 91 pp. (In Norwegian).

Miller, D. S., Peakall, D. B., & Kinter, W. B. 1978: Ingestion of crude oil: sublethal effects in herring gull chicks. *Science 199,* 315–317.

Miller, D. S., Hallett, D. J. & Peakall, D. B. 1982: Which components of crude oil are toxic to young seabirds. *Environ. Toxicol. Chem. 1,* 39–44.

Moe, K. A., Lystad, E., Nesse, S. & Selvik, J. R. 1993: Skadevirkninger av akutte oljesøl. Marint miljø. *SFT* (Norwegian Pollution Control Authority) *Rap. no. 93:31.* 114 pp. + app. (In Norwegian).

Mosbech, A. & Glahder, C. 1991: Assessment of the impact of helicopter disturbance on moulting Pink-footed Geese *Anser brachyrhynchus* and Barnacle Geese *Branta leucopsis* in Jameson Land, Greenland. *Ardea 79,* 233–238.

Neff, J. M. 1990: Composition and fate of petroleum and spill-treating agents in the marine environment. Pp. 1–33 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks.* Academic Press, San Diego.

Nisbet, I. C. T. 1994: Effects of pollution on marine birds. Pp. 8–25 in Nettleship, D. N., Burger, J. & Gochfeld, M. (eds.): *Seabirds on islands: threats, case studies and action plans.* BirdLife International, Cambridge, UK.

Norderhaug, M., Brun, E. & Møllen, G. U. 1977: Barentshavets sjøfuglressurser. *Norsk Polarinst. Medd. 104.* 119 pp. (In Norwegian with English and Russian summaries).

Nysewander, D. R., Dippel, C., Byrd, G. V. & Knudtson, E. P. 1993: Effects of the *T/V Exxon Valdez* oil spill on murres: a perspective from observations at breeding colonies. Pp. 135–138 in: *Abstract book.* Exxon Valdez *oil spill symposium, Anchorage, Alaska, February 2–5, 1993. Exxon Valdez* Oil Spill Trustee Council.

Oakley, K. L. & Kuletz, K. J. 1993: Effects of the *Exxon Valdez* oil spill on pigeon guillemots (*Cepphus columba*) in Prince William Sound, Alaska. Pp. 144–146 in: *Abstract book.* Exxon Valdez *oil spill symposium, Anchorage, Alaska, February 2–5, 1993. Exxon Valdez* Oil Spill Trustee Council.

OED 1989: *St.meld. nr. 40 (1988–89). Åpning av Barentshavet Syd for letevirksomhet.* Olje- og energidepartementet (Ministry of Oil and Energy), Oslo. 143 pp. (In Norwegian).

Patten, S. M., Jr. 1993: Acute and sublethal effects of the *Exxon Valdez* oil spill on Harlequins and other seaducks. Pp. 151–154 in: *Abstract book.* Exxon Valdez *oil spill symposium, Anchorage, Alaska, February 2–5, 1993. Exxon Valdez* Oil Spill Trustee Council.

Payne, J. R., McNabb, G. D., Jr. & Clayton, J. R., Jr. 1991: Oil-weathering behaviour in Arctic environments. *Polar Res. 10,* 631–662.

Peakall, D. B., Hallett, D., Miller, D. S., Butler, R. G. & Kinter, W. B. 1980: Effects of ingested crude oil on black guillemots: a combined field and laboratory study. *Ambio 9,* 28–30.

Pearson, W. H., Woodruff, D. L. & Sugarman, P. C. 1984: The burrowing behavior of sand lance, *Ammodytes hexapterus*: effects of oil-contaminated sediment. *Mar. Environ. Res. 11,* 17–32.

Piatt, J. 1995. Water over the bridge. *Am. Sci. 83*: 396–398.

Piatt, J. F., Lensink, C. J., Butler, W., Kendziorek, M. & Nysewander, D. R. 1990: Immediate impact of the 'Exxon Valdez' oil spill on marine birds. *Auk 107*, 387–397.

Piatt, J. F., Carter, H. R. & Nettleship, D. N. 1991: Effects of oil pollution on marine bird populations. Pp. 125–141 in White, J. (ed.): *The effects of oil on wildlife: Research, rehabilitation, and general concerns*. Proc. Oil Symposium Herndon, Virginia, October 16–18, 1990. Sheridan Press, Hanover, Pennsylvania.

Prichard, A. K., Roby, D. D., Bowyer, R. T. & Duffy, L. K. 1997: Pigeon guillemots as a sentinel species: a dose-response experiment with weathered oil in the field. *Chemosphere 35*, 1531–1548.

Richardson, W. J., Greene, C. R., Jr., Malme, C. I. & Thomson, D. H. 1995: *Marine mammals and noise*. Academic Press, San Diego. 576 pp.

Ridgway, S. H. & Harrison, R. J. (eds.) 1981: *Handbook of marine mammals. Volume 2. Seals*. Academic Press, London. 359 pp.

Ridgway, S. H. & Harrison, R. (eds.) 1985: *Handbook of marine mammals. Volume 3. The sirenians and baleen whales*. Academic Press, London. 362 pp.

Ridgway, S. H. & Harrison, R. (eds.) 1989: *Handbook of marine mammals. Volume 4. River dolphins and the larger toothed whales*. Academic Press, London. 442 pp.

Rocke, T. E., Yuill, T. M. & Hinsdill, R. D. 1984: Oil and related toxicant effects on mallard immune defences. *Environm. Res. 33*, 343–352.

Røttingen, I. 1990: A review of variability in the distribution and abundance of Norwegian spring spawning herring and Barents Sea capelin. *Polar Res. 8*, 33–42.

Røv, N. 1993: Konsekvenser for kystsel av petroleumsvirksomhet i Midt-Norge. *NINA Oppdragsmelding 185*. 21 pp. (In Norwegian with English abstract).

Sakshaug, E., Bjørge, A., Gulliksen, B., Loeng, H. & Mehlum, F. 1994a: *Økosystem Barentshavet*. Universitetsforlaget, Oslo. 304 pp. (In Norwegian).

Sakshaug, E., Bjørge, A., Gulliksen, B., Loeng, H. & Mehlum, F. 1994b: Structure, biomass distribution, and energetics of the pelagic ecosystem in the Barents Sea: A synopsis. *Polar Biol. 14*, 405-411.

Samuels, W. B. & Lanfear, K. J. 1982: Simulations of seabird damage and recovery from oilspills in the Northern Gulf of Alaska. *J. Environm. Managem. 15*, 169–182.

SFT 1995: *Forurensning i Norge 1995*. Statens forurensningstilsyn (Norwegian Pollution Control Authority), Oslo. 58 pp. (In Norwegian).

Siron, R., Pelletier, É. & Brochu, C. 1995: Environmental factors influencing the biodegradation of petroleum hydrocarbons in cold seawater. *Arch. Environ. Contam. Toxicol. 28*, 406–416.

Skognes, K., Johansen, Ø., Tønnessen, H. & Høvik, O. 1995: Statistiske oljedriftberegninger Barentshavet Nord. *OCEANOR Report no. OCN R-95037* (Oceanographic Company of Norway AS, Trondheim). 69 pp. (In Norwegian).

Spraker, T. R., Lowry, L. F. & Frost, K. J. 1994: Gross necropsy and histopathological lesions found in harbor seals. Pp. 281–306 in Loughlin, T. R. (ed.): *Marine mammals and the* Exxon Valdez. Academic Press, San Diego.

St. Aubin, D. J. 1990a: Physiologic and toxic effects on pinnipeds. Pp. 103–127 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks*. Academic Press, San Diego.

St. Aubin, D. J. 1990b: Physiologic and toxic effects on polar bears. Pp. 235–239 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks*. Academic Press, San Diego.

Stirling, I. 1990: Polar bears and oil: ecological perspectives. Pp. 223–234 in Geraci, J. R. & St. Aubin, D. J. (eds.): *Sea mammals and oil: confronting the risks*. Academic Press, San Diego.

Strann, K.-B., Vader, W. & Barrett, R. 1991: Auk mortality in fishing nets in north Norway. *Seabird 13*, 22–29.

Strann, K.-B., Bustnes, J. O., Kroglund, R. T. & Østnes. J. E. 1993: Konsekvensanalyse olje/sjøfugl for petroleumsvirksomhet på Midt-norsk sokkel og Vøringplatået. *NINA Forskningsrapport 42*. 129 pp. (In Norwegian with English abstract).

Stubblefield, W. A., Hancock, G. A., Ford, W. H. & Ringer, R. K. 1995a: Acute and subchronic toxicity of naturally weathered *Exxon Valdez* crude oil in mallards and ferrets. *Environ. Toxicol. Chem. 14*, 1941–1950.

Stubblefield, W. A., Hancock, G. A., Prince, H. H. & Ringer, R. K. 1995b: Effects of naturally weathered *Exxon Valdez* crude oil on mallard reproduction. *Environ. Toxicol. Chem. 14*, 1951-1960.

Swenson, J. E., Sandegren, F., Brunberg, S. & Wabakken, P. 1997: Winter den abandonment by brown bears *Ursus arctos*: causes and consequences. *Wildl. Biol. 3*, 35–38.

Theisen, F. (eds.) 1997: Dokumentasjon og vurdering av verneverdier på Bjørnøya. *Norsk Polarinst. Medd. 143*. 96 pp. + 4 app. (In Norwegian).

Theisen, F. & Brude, O. W. (eds.) 1998: Evaluering av områdevern på Svalbard: representativitet og behov for ytterligere vern. *Norsk Polarinst. Medd. 153*. (In Norwegian) (In press).

Thomassen, J., Andresen, K. H. & Moe, K. A. 1995: Petroleumsvirksomhet i Barentshavet nord – letevirksomhet. Arbeidsdokument fra AKUP/AEAM-seminar i Trondheim 22. og 23. februar 1995. *NINA Oppdragsmelding 355.* 154 pp. (In Norwegian with English abstract).

Thomassen, J., Andresen, K. H. & Moe, K. A. 1996: Petroleumsvirksomhet i isfylte farvann – utbyggings- og driftsfase. Målfokusering for eventuell konsekvensutredning. Arbeidsdokument fra AKUP/AEAM-seminar i Stavanger 4.–6. desember 1995. *NINA Oppdragsmelding 410.* 159 pp. (In Norwegian with English abstract).

Trivelpiece, W. Z., Butler, R. G., Miller, D. S. & Peakall, D. B. 1984: Reduced survival of chicks of oil-dosed adult Leach's Storm-Petrels. *Condor 86,* 81–82.

Vader, W., Barrett, R. T., Erikstad, K. E. & Strann, K.-B. 1990: Differential responses of Common and Thick-billed Murres *Uria* spp. to a crash in the Capelin stock in the southern Barents Sea. *Stud. Avian Biol. 14,* 175–180.

Vinje, T. 1985: Drift, composition, morphology and distribution of the sea ice fields in the Barents Sea. *Norsk Polarinst. Skr. 179C.* 26 pp.

Walton, P., Turner, C. M. R., Austin, G., Burns, M. D. & Monaghan, P. 1997: Sub-lethal effects of an oil pollution incident on breeding kittiwakes *Rissa tridactyla. Mar. Ecol. Prog. Ser. 155,* 261–268.

Wiens, J. A. 1996: Oil, seabirds, and science. The effects of the *Exxon Valdez* oil spill. *BioSci. 46,* 587–597.

Wiig, Ø. & Isaksen, K. 1995: Seasonal distribution of Harbour Seals, Bearded Seals, White Whales and Polar Bears in the Barents Sea. Pp. 47–58 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

Øien, N. & Hartvedt, S. 1995: Distribution of a selection of marine mammal species in the northern part of the Barents Sea. Pp. 33–45 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

Øritsland, N. A., Engelhardt, F. R., Juck, F. A., Hurst, R. J. & Watts, P. D. 1981: *Effects of crude oil on polar bears.* Environmental Studies No. 24, Northern Affairs Program. Dept. of Indian and Northern Affairs, Ottawa, Canada. 268 pp.

Åhlund, M. & Götmark, F. 1989: Gull predation on eider ducklings *Somateria mollissima*: effects of human disturbance. *Biol. Conserv. 48,* 115–127.

APPENDIX 1. SYSTEMATIC LIST OF SEABIRDS

Systematic list of seabird species treated in this report.

	ENGLISH	NORWEGIAN	SCIENTIFIC
ORDER	**DIVERS**	**LOMMER**	**GAVIIFORMES**
FAMILY	DIVERS	LOMFAMILIEN	GAVIIDAE
	Red-throated diver	Smålom	*Gavia stellata*
	Great northern diver	Islom	*Gavia immer*
ORDER	**TUBENOSES**	**STORMFUGLER**	**PROCELLARIIFORMES**
FAMILY	FULMARS AND SHEARWATERS	STORMFUGLFAMILIEN	PROCELLARIIDAE
	Fulmar	Havhest	*Fulmarus glacialis*
ORDER	**WILDFOWL**	**ANDEFUGLER**	**ANSERIFORMES**
FAMILY	SWANS, GEESE & DUCKS	ANDEFAMILIEN	ANATIDAE
	Pink-footed goose	Kortnebbgås	*Anser brachyrhynchus*
	Barnacle goose	Hvitkinngås	*Branta leucopsis*
	Brent goose	Ringgås	*Branta bernicla*
	Common eider	Ærfugl	*Somateria mollissima*
	King eider	Praktærfugl	*Somateria spectabilis*
	Long-tailed duck	Havelle	*Clangula hyemalis*
ORDER	**WADERS, GULLS, AUKS AND ALLIES**	**VADE-, MÅKE- OG ALKEFUGLER**	**CHARADRIIFORMES**
FAMILY	SANDPIPERS AND ALLIES	SNIPEFAMILIEN	SCOLOPACIDAE
	Grey phalarope	Polarsvømmesnipe	*Phalaropus fulicarius*
FAMILY	SKUAS	JOFAMILEN	STERCORARIIDAE
	Great skua	Storjo	*Catharacta skua*
	Arctic skua	Tyvjo	*Stercorarius parasiticus*
FAMILY	GULLS AND TERNS	MÅKEFAMILIEN	LARIDAE
	Sabine's gull	Sabinemåke	*Larus sabini*
	Glaucous gull	Polarmåke	*Larus hyperboreus*
	Great black-backed gull	Svartbak	*Larus marinus*
	Kittiwake	Krykkje	*Rissa tridactyla*
	Ivory gull	Ismåke	*Pagophila eburnea*
	Arctic tern	Rødnebbterne	*Sterna paradisaea*
FAMILY	AUKS	ALKEFAMILIEN	ALCIDAE
	Common guillemot	Lomvi	*Uria aalge*
	Brünnich's guillemot	Polarlomvi	*Uria lomvia*
	Razorbill	Alke	*Alca torda*
	Black guillemot	Teist	*Cepphus grylle*
	Little auk	Alkekonge	*Alle alle*
	Puffin	Lunde	*Fratercula arctica*

APPENDIX 2. SYSTEMATIC LIST OF MARINE MAMMALS

Systematic list of marine mammal species treated in this report.

	ENGLISH	NORWEGIAN	SCIENTIFIC
ORDER	**CARNIVORES**	**ROVDYR**	**CARNIVORA**
FAMILY	WALRUS	HVALROSSFAMILIEN	ODOBENIDAE
	Walrus	Hvalross	*Odobenus rosmarus*
FAMILY	TRUE SEALS	SELFAMILIEN	PHOCIDAE
	Harbour seal	Steinkobbe	*Phoca vitulina*
	Ringed seal	Ringsel	*Phoca hispida*
	Harp seal	Grønlandsel	*Phoca groenlandica*
	Bearded seal	Storkobbe	*Erignathus barbatus*
FAMILY	BEARS	BJØRNEFAMILIEN	URSIDAE
	Polar bear	Isbjørn	*Ursus maritimus*
ORDER	**WHALES AND DOLPHINS**	**HVALER**	**CETACEA**
FAMILY	RIGHT WHALES	RETTHVALFAMILIEN	BALAENIDAE
	Bowhead whale	Grønlandshval	*Balaena mysticetus*
FAMILY	RORQUAL WHALES	FINNHVALFAMILIEN	BALAENOPTERIDAE
	Minke whale	Vågehval	*Balaenoptera acutorostrata*
	Fin whale	Finnhval	*Balaenoptera physalus*
	Humpback whale	Knølhval	*Megaptera novaeangliae*
FAMILY	DOLPHINS	DELFINFAMILIEN	DELPHINIDAE
	White-beaked dolphin	Kvitnos	*Lagenorhynchus albirostris*
FAMILY	NARWHAL AND WHITE WHALE	NARHVALFAMILIEN	MONODONTIDAE
	White whale	Hvithval	*Delphinapterus leucas*

APPENDIX 3. EVALUATION OF MARINE MAMMAL VULNERABILITY TO OIL

1. INTRODUCTION

Jødestøl & Ugland (1993; se also Jødestøl *et al.* 1994) developed a vulnerability model for marine mammals in the Barents Sea. The model is based on classification of vulnerability for oil pollution at an individual basis coupled to a population model for each species. The vulnerability of the population was classified according to the modelled recovery time for the population after an impact had occurred. Such an approach is theoretically correct. It might, however, give a false impression of the level of accuracy of the analysis because the models that are used and the population parameters that are put into them are very uncertain (Anker-Nilssen 1987; Røv 1993). In the present analysis we have used another approach which is similar to the method described by Anker-Nilssen (1987). This method has been used in several earlier assessments of oil/seabirds in Norwegian areas (Anker-Nilssen *et al.* 1988; Lorentsen *et al.* 1993; Strann *et al.* 1993).

The model described by Anker-Nilssen (1987) is a semiquantitative model for analyses of vulnerability based on realistic and documented considerations. The aim is to identify those populations or stocks that are most vulnerable to spilled oil and which must be focused in the assessment analysis. We realise that this method can also be criticised for simplicity. We feel, however, that the outcome of the analysis gives a reasonable result.

The method has not before been applied fully to marine mammals (but see Røv 1993). It was therefore necessary to redefine the vulnerability criteria for marine mammals compared to those used for seabirds. In this process we have used the work of Anker-Nilssen (1987), Jødestøl & Ugland (1993) and Jødestøl *et al.* (1994) as background.

2. VULNERABILITY MODEL

The vulnerability for oil pollution of marine mammals in an area can be said to be dependent of four factors: the animals must be in the area, they must be oiled, the oil must have an impact on the individual, and the impact must lead to a decreased probability of survival and/or decreased reproduction. The following factors have been used:

A. Representation (Time in the area)
B. Exposure (Probability of contact with oil when in the area)
C. Oil injury (Probability of impact if in contact)
D. Impact (Level of impact on survival and reproduction)

These factors are regarded as equal in the analysis because the animals are not vulnerable if the value for one of them is zero.

Each factor is dependent on several subfactors which are called vulnerability criteria. Oil vulnerability for each population is evaluated in relation to each of these criteria. For each factor the criteria are related to either individual or population level. When there are several criteria within each factor, the criteria must be weighted in relation to each other.

Based on this, an index is calculated for individual vulnerability (*IV*) and for population vulnerability (*PV*) for oil pollution. The principle of the method is discussed in some more detail by Anker-Nilssen (1987).

2.1 Vulnerability criteria

We totally use 17 vulnerability criteria. Nine of these are related to the vulnerability of individuals whereas eight are related to the population level. The individual in this context is defined as the 'average individual'. The population is defined as a predefined part (based on sex, season, etc.) of a natural population (breeding unit) that might cover larger areas in the influence area.

A short description of the criteria is given together with a description of how the vulnerability for oil pollution in relation to each criterion is evaluated on a scale from 1 to 3.

Ta – Time in the area (Short/Moderate/Long)
The relative timeframe an individual of the selected population stays in the influence area. Those that are not in the area will not be affected.

Au – Area use (Small/Moderate/Large)
The relative size of the area an individual uses per unit time. An animal that moves around quickly has a higher probability of being fouled.

Be – Behaviour
(Little/Moderately/Strongly exposed)
Individual behaviour (*e.g.* diving and swimming patterns) that will increase the probability of oiling. An animal that swims much of the time at the surface has a higher probability of being fouled than one that spends much of the time at deep water.

Ee – Edge effect (Small/Moderate/Large)
Individual affinity to ice edge or shore line. Some species spend much time along edges in the ice (*e.g.* polar bears) and shores (*e.g.* walruses) where oil will accumulate and increase the probability of the animal being fouled.

Av – Avoidance (Strong/Moderate/Small)
Individual tendency to actively avoid oil and thereby decrease the probability of being fouled.

Tv – Toxic vulnerability (Small/Moderate/High)
Individual vulnerability for toxic effects of oil. This factor relates to internal effects of ingested oil and inhalation of vapour.

Sc – Surface contact (Small/Moderate/High)
Individual vulnerability from external contact with oil. *Sc* includes effects on insulation, movement ability, increased bloodstream to the skin due to inflammation, irritation of eyes and fouling of baleen, etc. The distinction from Toxic vulnerability in some cases might be unclear.

Co – Condition (Low/Moderate/High)
Individual physical condition in relation to species and season. An animal in bad condition will have higher probability of suffering.

Ra – Recovery ability (Good/Moderate/Small)
Individual ability to recover after oil contamination related to the biology and behaviour of the species in question.

Ex – Exposure (Small/Moderate/Large)
Population level of exposure for oil pollution in relation to the animals' distribution in the area. In case of species that tend to live far into the ice, in protected fjords or on the ice, a smaller part of the population will be fouled.

Ps – Population size (Large/Moderate/Small)
Relative population size (interspecific). Large populations will have a larger resilience than smaller populations.

Ag – Aggregation (Small/Moderate/Large)
Tendency to aggregation and flocks will increase the possibility of fouling of a high number of individuals in a spill situation.

Re – Reproducing part of population
(Small/Moderate/Large)
In polygynous or promiscuous species, the loss of adult reproducing females is much more serious for the population than the loss of males or young. In some species, adult females have been treated as a subpopulation to take this into account.

Rp – Reproductive potential
(Large/Moderate/Small)
A species or population with high reproductive potential will recover faster from a depletion than a population with small reproductive potential.

Pt – Population trend
(Increasing/Stable/Decreasing)
A decreasing population that in addition is struck by oil pollution will usually suffer more than a population that is increasing.

Vf – Vulnerable fraction (Small/Moderate/Large)
Fraction of the total natural population that is exposed to contamination in the area. The effect on a natural population that only has a small part of its individuals within the affected area will be less than the effect on a population that is only distributed within the area.

Im – Potential immigration
(Large/Moderate/Small)
Probability of immigration if the population is depleted by contamination. High probability of immigration will increase the recovery rate of the affected population.

2.2 Calculation of indices

The grouping of vulnerability criteria on individual and population level in relation to vulnerability factors is shown in Table 1. There is only one criterion under factor 'Representation' (*Ta*). Under the factor 'Exposure' there are four criteria at the individual level (*Au*, *Be*, *Ee* and *Av*). We have given the edge effect (*Ee*) and avoidance behaviour (*Av*) double weight in relation to area use (*Au*) and behaviour (*Be*). There is only one criterion (*Ex*) under 'Exposure' at the population level. For the vulnerability factor 'Oil injury' there are two criteria at the individual level (*Tv* and *Sc*). They are given equal

Table 1. Grouping of vulnerability criteria (see text) on individual and population level in relation to vulnerability factors. Relative value of each criterion within each factor is shown in parentheses.

Vulnerability factor	Vulnerability criteria	
	Individual level	Population level
A. Representation	*Ta*	
B. Exposure	*Au*(1), *Be*(1), *Ee*(2), *Av*(2)	*Ex*
C. Oil injury	*Tv*(1), *Sc*(1)	*Ps*(1), *Ag*(2)
D. Impact	*Co*(1), *Ra*(1)	*Re*(2), *Rp*(4), *Pt*(2), *Vf*(4), *Im*(1)

Equation 1. $$IV = Ta \times \left(\frac{Au + Be + 2Ee + 2Av}{6}\right) \times \left(\frac{Tv + Sc}{2}\right) \times \left(\frac{Co + Ra}{2}\right)$$

Equation 2. $$PV = IV \times Ex \times \left(\frac{Ps + 2Ag}{3}\right) \times \left(\frac{2Re + 4Rp + 2Pt + 4Vf + Im}{13}\right)$$

weight. At the population level there are also two criteria (*Ps* and *Ag*). The tendency for making aggregations is here given double weight. For the 'Impact' factor there are two criteria at the individual level which have been given equal weight (*Co* and *Ra*). At the population level there are five criteria (*Re*, *Rp*, *Pt*, *Vf*, and *Im*). We have given the potential for immigration low weight, reproducing part of population and population trend are given a medium weight, and reproductive potential of the population and vulnerable fraction of total population are given high weight.

On this background, individual vulnerability (*IV*) and population vulnerability (*PV*) can be calculated as in Equations 1 and 2.

In order to convert the *PV* value to a linear scale between 0 and 1 it is necessary to calculate the cumulative probability distribution for all possible values of *PV*. From this distribution, the probability that a random set of criterion values would give a *PV* value smaller or equal to the actual estimated value for a population can be found. This probability value is the final vulnerability index for the population (PV_{ind}). This value is not an absolute value for the vulnerability of the population, but a relative index which can be used to compare the vulnerability of different populations. Since all evaluations in the analyses have been made on a three fold scale (1, 2, 3), it seems reasonable to also give the final population vulnerability on the same scale: 1 = Low, 2 = Moderate, 3 = High vulnerability. The results are shown in Table 2. See Anker-Nilssen (1987) for further details on the methods used.

3. EVALUATED MARINE MAMMAL POPULATIONS

A total of 12 marine mammal species have been evaluated in this assessment. These are walrus, harbour seal, ringed seal, harp seal, bearded seal, polar bear, bowhead whale, minke whale, fin whale, humpback whale, white-beaked dolphin and white whale. Knowledge of the distribution, population size and population parameters of these species in the Barents Sea is scarce. The results of the assessment must be seen in the light of this. Different parts of the population of a species that is distributed within the assessment area might have different vulnerability to the activity. Several species are therefore subdivided into populations based on season or sex. General descriptions of biology and distribution of the species are given in recent assessment reports

Table 2. The population vulnerability for oil pollution in the three fold scale.

Vulnerability	PV_{ind}	PV
1 Low	0.000–0.333	1–56
2 Moderate	0.334–0.666	57–134
3 High	0.667–1.0	135–2187

(Jødestøl & Ugland 1993; Jødestøl *et al.* 1994; Lydersen & Wiig 1995; Wiig 1995a; Wiig & Isaksen 1995; Øien & Hartvedt 1995) and elsewhere (*e.g.* Christensen *et al.* 1992).

The geographical borders for the oil vulnerability assessment are approximately 5°E in west, 35°E in east, 73°N in south and 81°N in north (the same as for the impact assessment; see section 1.10 and Fig. 1 in the main part of this report).

Polar bear
Polar bears in the Barents Sea probably originate from two more or less separate populations which breed in Svalbard and Zemlja Franca Iosifa/Novaja Zemlja, respectively (see Wiig 1995b). It has not been possible to separate the two populations in the present treatment. Survival of juvenile polar bears is assumed to be low and the loss of juveniles will not be very serious for the population compared to the effect of loss of adult reproductive individuals. We therefore only include adults in this analysis. As the polar bear is a polygynous or promiscuous species with a few dominant males impregnating the females, the loss of females is much more serious for the whole population than the loss of males. We have therefore treated adult males and adult females separately.

Walrus
Walruses in the Svalbard area are sexually segregated most of the year (Gjertz & Wiig 1995). The males are mostly found in the southeastern and northwestern areas while the females with calves are found in the far northeast and at Zemlja Franca Iosifa. In walruses, as in polar bears, it is a few dominant males that impregnate the reproductive females. The loss of males is therefore less serious for the total population than the loss of females. Males and females are treated separately in the analysis.

Ringed seal
Ringed seals breed in spring and have their pups in breeding lairs at the landfast ice (Smith & Lydersen 1991). It is believed that breeding activity may also occur out in the drifting pack ice of the Barents Sea, but this has not been confirmed. The pups are born with white foetal fur and are vulnerable to oil pollution during the first weeks of their lives. In summer and autumn the seals spread out from their breeding areas and probably return again when the fjords and bays freeze up in winter. The physical condition of ringed seals starts to decrease at the onset of breeding in March and continues to decrease until after the moult in July (Ryg *et al.* 1990). We have therefore treated the spring and summer populations of ringed seals separate from the rest of the year.

Harbour seal
The harbour seals in Svalbard are concentrated at the western coast of Prins Karls Forland (Prestrud & Gjertz 1990). They seem to stay in the area for most of the year. Some seals have been tracked to Bjørnøya during winter. Harbour seals breed in summer and moult in August. The pups shed the foetal fur before they are born and go into the water soon after. We do not know if there are any changes in condition of the seals through the year but assume the pattern is similar to that of ringed seals. We therefore separate harbour seals into one population from June to August and one from September to May.

Harp seal
The harp seals in the Barents Sea are mostly from the population that breed in large aggregations at the ice in the White Sea in February/March. The pups are born with white lanugo which is shed after a nursing period of about two weeks. After breeding, the adults moult in large aggregations on the ice in the southeastern part of the Barents Sea in March/April. The seals eat little during breeding and moulting and their condition is low at the end of this season (Nilssen 1995). In summer and autumn the seals migrate north in the Barents Sea where they feed intensively and are in good condition. They return to the southeastern part of the Barents Sea in winter before breeding. The spring population is treated differently from the population the rest of the year.

Bearded seal
The biology of bearded seals in the Barents Sea is poorly known. The breeding time is in spring and the seals moult in summer. The pups are born on ice floes and are able to go into the water soon after birth. We assume that bearded seals are in poorer condition during breeding and moulting than during the rest of the year, as with ringed seals. We treat the species as two populations in the analysis.

White whale

White whales are highly gregarious and are normally found in pods consisting of a mixture of different age and sex groups or in all male groups. There is a general seasonal movement of herds coming into coastal waters and river estuaries during summer, and to off-shore pack-ice areas and polynyas in winter. During the summer stay in shallow waters, white whales undergo an apparently unique process in whales, they shed their epidermis in a moult-like manner. The shallow waters are thus very important habitats for white whales. The distribution pattern of white whales used in the assessment is based on Gjertz & Wiig (1994). There is not sufficient knowledge to warrant a subdivision of the population. We therefore treat the species as one population in the analysis.

White-beaked dolphin

According to Øien & Hartvedt (1995) the observations of *Lagenorhynchus* spp. in the Barents Sea are primarily thought to be *L. albirostris*, the white-beaked dolphin, and are treated as such here. The observations made in the Barents Sea occurred between May and September. We treat the species as one population. The white-beaked dolphins may occur in large aggregations.

Bowhead whale

Knowledge of the bowhead whale in the Barents Sea is scarce. The part of the Spitsbergen stock that was centred in the Greenland Sea must be considered as almost extinct. Only a few observations have been made in the last 20 years and most of them in the area of Zemlja Franca Iosifa (Christensen *et al.* 1992). The number of bowhead whales in the area may be in the tens and observations of calves may indicate a slow re-establishment of the population. The bowhead whales spend most of their time in the pack-ice area. With so few individuals and poor knowledge of distribution, a distribution map would be misleading. However, bowhead whales can probably be found all over the influence area. The species is treated as one population.

Minke whale

Minke whales are found in the influence area from March to August. The knowledge about the minke whales in the Barents Sea indicates that there is no reason to subdivide the population for this analysis.

Fin whale

Little is known about the distribution of fin whales in the influence area. Most of the observations of the species have been made during summer. Whether or not the whales stay in the Barents Sea during winter is disputed (Christensen *et al.* 1992). We only have information on their distribution in July and the analysis is restricted to that information. The number of fin whales in the area is estimated at about 300. This probably is a part of the North Norway stock which totally counts about 1,000 individuals. We treat the species as one population.

Humpback wale

The distribution of humpback whales in the Barents Sea seems to vary with the abundance and distribution of shoaling fish, especially capelin. Humpback whales can probably be found in the Barents Sea at all times of the year. At least a part of the population migrates out of the area for a period in winter and spring. Surveys have only been performed in summer, and little is known about the distribution in other seasons. There seems to have been a shift in the distribution of humpbacks in the Barents Sea after the capelin stock was reduced in 1986 (Christensen *et al.* 1992). The number of whales in the area is about 200 which is about 20% the total Norwegian and Barents Sea population.

4. EVALUATION OF VULNERABILITY CRITERIA

This evaluation is mainly based on descriptions on general biology from the references mentioned above and on recent reviews on the effects of oil on marine mammals by Griffiths *et al.* (1987), Geraci & St. Aubin (1990) and Loughlin (1994).

Ta – *Time in the area (Short/Moderate/Long)*
Polar bears, walruses, ringed seals, bearded seals, harbour seals, white whales and bowhead whales stay in the area throughout the year. Harp seals are within the analysis area for a short time in February–May and a moderate time in June–January. The length of time the white-beaked dolphins stay in the area is uncertain and is classified as moderate. Minke whales are found in the area from March to August which is classified as moderate. Fin whales probably stay in the area for a moderate time. Humpback whales may stay in the area for longer periods.

Au – *Area use (Small/Moderate/Large)*
Polar bears cover moderate areas per unit time. Walruses and harbour seals usually cover small areas per unit time. Ringed seals cover small areas during spring and moderate areas during the rest of the year. Harp seals cover moderate areas during spring and large areas during rest of the year. Bearded seals cover small areas during breeding and moderate areas in the rest of the year. Bowhead and fin whales are considered to cover moderate areas. White whales, white-beaked dolphins, minke whales and humpback whales are considered to cover large areas.

Be – *Behaviour (Little/Moderately/Strongly exposed)*
The affiliation of polar bears to open water between ice floes make them strongly exposed to oil pollution. We also believe they would scavenge oiled seals. Walruses spend most of the time in water diving and are moderately exposed. Ringed seals spend the spring in the fast ice which normally not will be exposed to oil pollution, but the seals will be moderately exposed the rest of the year. Harbour seals will be strongly exposed because they spend much of their time resting in the water surface in shallow waters. Harp seals migrate by swimming on their backs at the surface and will be strongly exposed. Bearded seals will be moderately exposed. White whales and white-beaked dolphins migrate by swimming in the water surface and will be strongly exposed. Bowhead whales feed by skimming the water surface and will be strongly exposed. Minke whales, fin whales, and humpback whales spend much time under water and will be moderately exposed.

Ee – *Edge effect (Small/Moderate/Large)*
Polar bears seem to concentrate along ice edges during most of the year. During summer many bears stay along the shores in ice-free areas. Walruses tend to haul out on the shore in large herds. Ringed seals do not show particular affinity to ice edges or shore lines. Harbour seals haul out on the shore. Harp seals have some affinity to ice edges. Bearded seals show some affinity to ice edges, especially during the breeding season. White whales are believed to show large affiliation to the ice edge. White-beaked dolphins are not believed to show any preference for ice edges. Bowhead whales are often found in leads in the drifting ice and show large affiliation to ice edges. Minke whales, fin whales and humpback whales are not believed to show any preference for ice edges.

Av – *Avoidance (Strong/Moderate/Small)*
All marine mammals are believed to be able to detect oil on the surface, but there are no indications that they tend to avoid the oil.

Tv – *Toxic vulnerability (Small/Moderate/High)*
Oiled polar bears will clean their fur by licking and are highly vulnerable to toxic effects of oil. Walruses and bearded seals which feed on bottom molluscs may ingest oil components through their food. Seal pups can ingest oil if they are suckled by an oiled mother. All the seal species are vulnerable to effects of inhalation of petroleum vapours, particularly during the early phase of a spill. White whales and bowhead whales trapped in leads with oil may also suffer from vapours. All other whales are believed to be little vulnerable to toxic effects of oil.

Sc – *Surface contact (Small/Moderate/High)*
Polar bears are highly vulnerable to the decreased insulation of oiled fur. During spring ringed seals with pups are believed to be moderately vulnerable to loss of insulation due to oil in lanugo. The effects of oil contact on the seal skin is disputed and it is not known whether or not irritation of the skin will increase the heat loss and interfere with thermoregulation. This could be an important effect particularly during moult. All seals are therefore classified as moderately vulnerable to surface contact with oil. Toothed whales are not believed to be vulnerable to surface contact with oil, except for white whales during moulting. Bowhead whales are assumed to be moderately vulnerable to oil in the baleen, which might decrease their feeding efficiency, while the other whales are assumed to be less vulnerable.

Co – *Condition (High /Moderately/Low)*
The condition of polar bears varies with season and reproductive status (for females), and the spring is their most important feeding season. In the analyses we have not subdivided bears into seasonal populations. Females are regarded to have a moderate condition due to their effort to take care of the young, while males are classified as having a high condition. We believe that the condition of walruses is generally high during the year. The condition of ringed seals starts to decrease at the onset of breeding in March and

continues to decrease until after the moult in July. Ringed seals are classified as having a moderate condition during spring and summer and a high condition during the rest of the year. It is assumed that harbour seals and bearded seals follow a similar pattern with a moderate condition in the breeding and moulting seasons and a high condition during the rest of the year. Harp seals are known to follow the same pattern. All the whales are considered to have a moderate condition during the time they stay in the assessment area.

Ra – *Recovery ability (Good/Moderate/Small)*

Polar bears are considered to have low ability for recovering after oil pollution. Seals are regarded as having a moderate ability for recovering during breeding and moulting and a good ability for recovering through the rest of the year. Walruses and whales are considered to have good ability for recovering.

Ex – *Exposure level (Small/Moderate/Large)*

The part of the polar bear population that is exposed will vary throughout the year. On average, a moderate part is assumed to be exposed. A large part of the male walruses are exposed, whereas the females are found in the far northeast and is classified as having a moderate exposure level. Ringed seals are little exposed during breeding and moderately exposed through the rest of the year. The harbour seal population is very exposed. Harp seals are little exposed during breeding and moulting and moderately exposed through the rest of the year. Bearded seals and white whales are moderately exposed. Only smaller parts of the populations of the other species might be exposed.

Ps – *Population size (Large/Moderate/Small)*

Harbour seals, bowhead whales, fin whales and humpback whales are considered to have small population sizes. Polar bears and walruses are considered to have moderate population sizes. The other species are considered to have large population sizes.

Ag – *Aggregation (Small/Moderate/Large)*

Polar bears, bearded seals and the baleen whales are considered as not forming aggregations. Ringed seals have moderate aggregations in breeding and moulting areas in spring but are more dispersed during other parts of the year. Harp seals are highly aggregated during breeding and moderately aggregated during the rest of the year. Walruses, harbour seals, white whales and white-beaked dolphins may form large aggregations.

Re – *Reproducing part of population (Small/Moderate/Large)*

Polar bear females may be seen as comprising a large part of the reproducing population while males make up a small part. The same is the situation for walruses. For the other species the classification is moderate for this criterion.

Rp – *Reproductive potential (Large/Moderate/Small)*

Polar bears, walruses, white whales and the baleen whales, except for the minke whale, have a multiyear reproductive interval and are considered to have a small reproductive potential. The other species in the analysis are considered to have a moderate reproductive potential.

Pt – *Population trend (Increasing/Stable/Decreasing)*

The population trend of most populations in the analysis is poorly known and is classified as stable (2). We have some information indicating that the polar bear population is stable. The population of walrus, and maybe also the bowhead whale population, is probably increasing very slowly. Taking into consideration the time that has lapsed since they were protected and the small increase that has been observed, we classify the populations of walrus and bowhead whale here as decreasing for conservative purposes.

Vf – *Vulnerable fraction (Small/Moderate/Large)*

Polar bears have a large vulnerable fraction of their natural population within the area. Walruses have a medium fraction of females and a large fraction of males within the area, and harbour seals have a large fraction in the area. Harp seals have a small vulnerable fraction of the population in winter and spring and a moderate fraction during the rest of the year. The white whale, bowhead whale and humpback whale have larger parts of their natural populations within the area. The populations of white-beaked dolphins and fin whales in the analysis area are regarded to be moderate fractions of the natural populations they represent, while only a small part of the minke whale population is regarded as in the analysis area.

Im – *Potential immigration (Large/Moderate/Small)*

The potential for immigration from other areas is considered to be small for walruses, harbour seals and bowhead whales, large for ringed seals and bearded seals, and moderate for the other populations.

5. VULNERABLE POPULATIONS

The aim of the vulnerability analysis is to identify the relative vulnerability of the species for use in an impact assessment. The indices are relative measures of vulnerability which can be used to compare populations and they do not show how large parts of the populations which might be injured.

The results of the evaluations are summarised in Table 3 and Fig. 1. Based on the analysis, polar bears, walruses, harbour seals and white whales are the most vulnerable species in the assessment area with population vulnerability indices larger than 135. These species are classified in vulnerability class 3. Females are the most vulnerable part of the polar bear population. The male walruses have a higher vulnerability than females because they are more exposed. The breeding and moulting season for harbour seals is the part of the year when they are most vulnerable to oil pollution.

Harp seals have a medium vulnerability in summer and autumn. Bearded seals have medium vulnerability in spring and summer. Bowhead whales are also in vulnerability class 2. Their individual vulnerability (*IV*) is just as high as that of white whales but their assumed scattered distribution make it less probable that they will be subject to oil pollution.

Other populations are classified in vulnerability class 1.

Jødestøl & Ugland (1993) and Jødestøl *et al.* (1994) made population risk assessment studies of ringed seals, harp seals, walruses and minke whales on the basis of hypothetical oil spill scenarios. Individual oil vulnerability was specified for different age groups and seasons for the populations. Jødestøl and co-workers combined this with oil spill scenarios to arrive at a perturbation factor based on effects on survival and reproduction. The population impact and vulnerability classification were based on recovery time for the population estimated from population dynamics models. We agree that this approach is theoretically correct, but we have questioned the reliability of such models in this context because the values that are put into the model for the population parameters are very uncertain. Jødestøl and co-workers found that walruses in general have a high vulnerability for oil spills, that ringed seals and harp seals had a medium to low vulnerability, and that minke whales probably will be little affected by a spill.

The present work differs from the works referred above in that we have analysed the relative vulnerability between populations only, and the coupling with oil-drift scenarios will be done at a later stage. It seems, however, that our results are in accordance with the results found by Jødestøl & Ugland (1993) and Jødestøl *et al.* (1994).

6. REFERENCES

Anker-Nilssen, T. 1987: Metoder til konsekvens-analyser olje/sjøfugl. *Viltrapport 44*, Direktoratet for naturforvaltning. 114 pp. (In Norwegian).

Anker-Nilssen, T., Bakken, V. & Strann, K.-B. 1988: Konsekvensanalyse olje/sjøfugl ved petroleums-virksomhet i Barentshavet sør for 74°30'N. *Viltrapport 46*, Direktoratet for naturforvaltning. 98 pp. + app. (In Norwegian).

Christensen, I., Haug, T. & Øien, N. 1992: Seasonal distribution, exploitation and present abundance of stocks of large baleen whales (Mysticeti) and sperm whales (*Physeter macrocephalus*) in Norwegian and adjacent waters. *ICES. J. mar. Sci. 49*, 341–355.

Geraci, J. R. & St. Aubin, D. J. (eds.) 1990: *Sea mammals and oil: confronting the risks.* Academic Press, San Diego. 282 pp.

Gjertz, I. & Wiig, Ø. 1994: Distribution and catch of white whales (*Delphinapterus leucas*) at Svalbard. *Meddr Grønland, Biosci. 39*, 93–97.

Gjertz, I. & Wiig, Ø. 1995: The number of walruses (*Odobenus rosmarus*) in Svalbard in summer. *Polar Biol. 15*, 527–530.

Griffiths, D. J., Øritsland, N. A. & Øritsland, T. 1987: Marine mammals and petroleum activities in Norwegian waters: A review of the literature on the effects of petroleum on marine mammals and recommendations for further research. *Fisken og havet ser. B no. 1 1987.* 179 pp. (In English with Norwegian summary).

Table 3. Results of evaluation of marine mammal vulnerability to oil.

Population	*Ta*	*Au*	*Be*	*Ee*	*Av*	*Tv*	*Sc*	*Co*	*Ra*	*Ex*	*Ps*	*Ag*	*Re*	*Rp*	*Pt*	*Vf*	*Im*	IV_{ind}	PV_{ind}	*PV*
Polar bear females	3	2	3	3	3	3	3	2	3	2	2	1	3	3	2	3	2	64	471	3
Polar bear males	3	2	3	3	3	3	3	1	3	2	2	1	1	3	2	3	2	51	293	3
Walrus females	3	1	2	3	3	2	2	1	1	2	2	3	3	3	3	2	3	15	215	3
Walrus males	3	1	2	3	3	2	2	1	1	3	2	3	1	3	3	3	3	15	286	3
Ringed seals March–June	3	1	1	1	3	2	2	2	2	1	1	2	2	2	2	1	1	20	54	1
Ringed seals July–Feb.	3	2	2	1	3	2	2	1	1	1	1	1	2	2	2	1	1	12	19	1
Harbour seals June–Aug.	3	1	3	3	3	2	2	2	2	3	3	3	2	2	2	3	3	32	687	3
Harbour seals Sept.–May	3	1	3	3	3	2	2	1	1	3	3	3	2	2	2	3	3	16	343	3
Harp seals Feb.–May	1	2	3	2	3	2	2	2	2	1	1	3	2	2	2	1	2	10	37	1
Harp seals June–Jan.	2	3	3	2	3	2	2	1	1	2	1	2	2	2	2	2	2	16	98	2
Bearded seals April–July	3	1	2	2	3	2	2	2	2	2	1	1	2	2	2	1	1	26	84	2
Bearded seals Aug.–March	3	2	2	1	3	2	2	1	1	2	1	1	2	2	2	1	1	12	38	1
White whales	3	3	3	3	3	2	2	2	1	2	1	3	2	3	2	3	2	27	310	3
White-beaked dolphins	2	3	3	1	3	1	1	2	1	1	1	3	2	2	2	2	2	7	33	1
Bowhead whales	3	2	3	3	3	2	2	2	1	1	3	1	2	3	3	3	3	26	114	2
Minke whales	2	3	2	1	3	1	1	2	1	1	1	1	2	2	2	1	2	6	11	1
Fin whales	2	2	2	1	3	1	1	2	1	1	3	1	2	3	2	2	2	6	23	1
Humpback whales	3	3	2	1	3	1	1	2	1	1	3	1	2	3	2	3	2	11	46	1

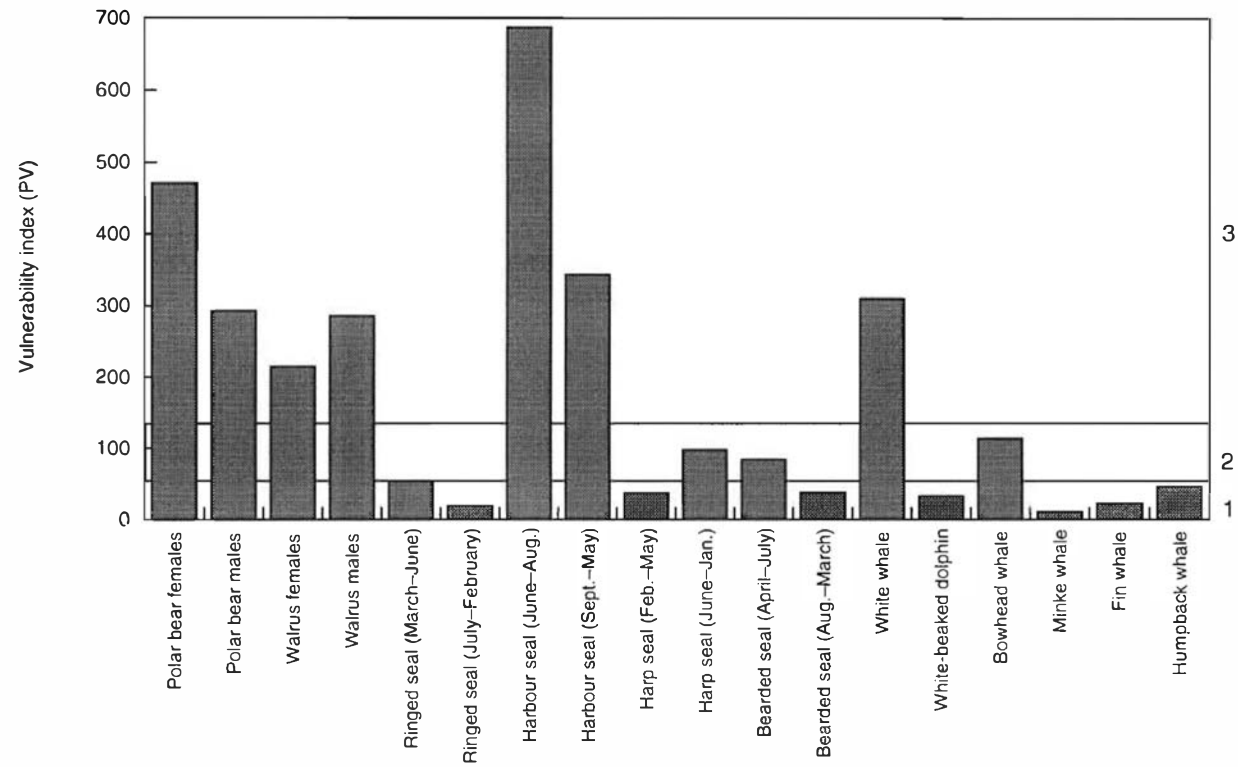


Fig. 1. Results of evaluation of marine mammal vulnerability to oil.

Jødestøl, K. A. & Ugland, K. I. 1993: Sårbarhetsanalyse for ringsel og grønlandsel i Barentshavet nord. *Det Norske Veritas Industry AS, Rap. Nr. 93-3740.* 59 pp. (In Norwegian with English summary).

Jødestøl, K. A., Sørgård, E., Bitner-Gregersen, E. & Ugland, K. I. 1994: Sea mammal population risk assessment. *Det Norske Veritas Industry AS, Rep. No. 94–3622.* 100 pp.

Lorentsen, S.-H., Anker-Nilssen, T., Kroglund, R. T. & Østnes, J. E. 1993: Konsekvensanalyse olje/sjøfugl for petroleumsvirksomhet i norsk del av Skagerrak. *NINA Forskningsrapport 39.* 84 pp. (In Norwegian with English abstract).

Loughlin, T. R. (ed.) 1994: *Marine mammals and the* Exxon Valdez. Academic Press, San Diego. 395 pp.

Lydersen, C. & Wiig, Ø. 1995: Conservation value assessment of selected marine mammals in the northern Barents Sea. Pp. 7–23 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

Nilssen, K. T. 1995: Seasonal distribution, condition and feeding habits of Barents Sea harp seals (*Phoca groenlandica*). Pp. 241–254 in Blix, A. S., Walløe, L. and Ulltang, Ø. (eds.): *Whales, seals, fish and man.* Elsevier Science B.V., Amsterdam.

Prestrud, P. & Gjertz, I. 1990: The most northerly harbour seal, *Phoca vitulina*, at Prins Karls Forland, Svalbard. *Mar. Mammal Sci. 6*, 215–220.

Ryg, M., Smith, T. G. & Øritsland, N. A. 1990: Seasonal changes in body mass and body composition of ringed seals (*Phoca hispida*) on Svalbard. *Can. J. Zool. 68*, 470–475.

Røv, N. 1993: Konsekvenser for kystsel av petroleumsvirksomhet i Midt-Norge. *NINA Oppdragsmelding 185.* 21 pp. (In Norwegian with English abstract).

Smith, T. G. & Lydersen, C. 1991: Availability of suitable landfast ice and predation as factors limiting ringed seal populations, *Phoca hispida*, at Svalbard. *Polar Res. 10*, 585–594.

Strann, K.-B., Bustnes, J. O., Kroglund, R. T. & Østnes. J. E. 1993: Konsekvensanalyse olje/sjøfugl for petroleumsvirksomhet på Midt-norsk sokkel og Vøringplatået. *NINA Forskningsrapport 42.* 129 pp. (In Norwegian with English abstract).

Wiig, Ø. 1995a: Survey of polar bears (*Ursus maritimus*) along the spring ice edge in the Barents Sea. Pp. 25–32 in Isaksen, K. & Wiig, Ø.

(eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

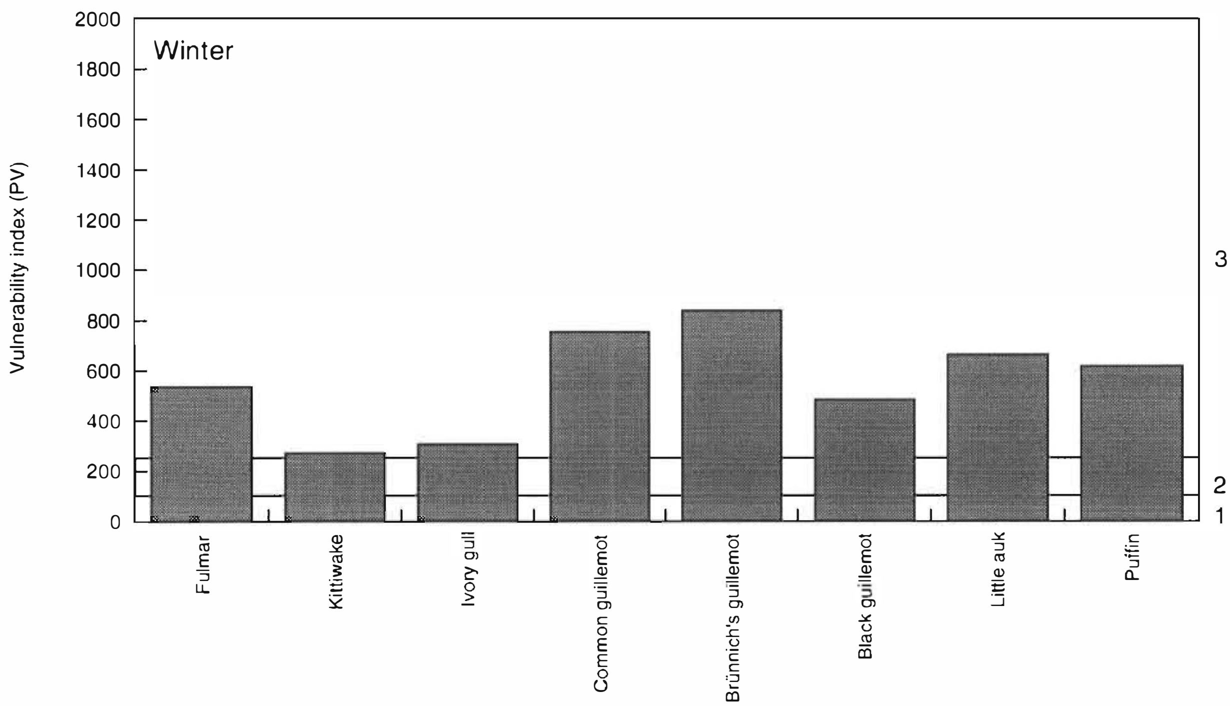
Wiig, Ø. 1995b: Distribution of polar bears (*Ursus maritimus*) in the Svalbard area. *J. Zool.*, London *237*, 515–529.

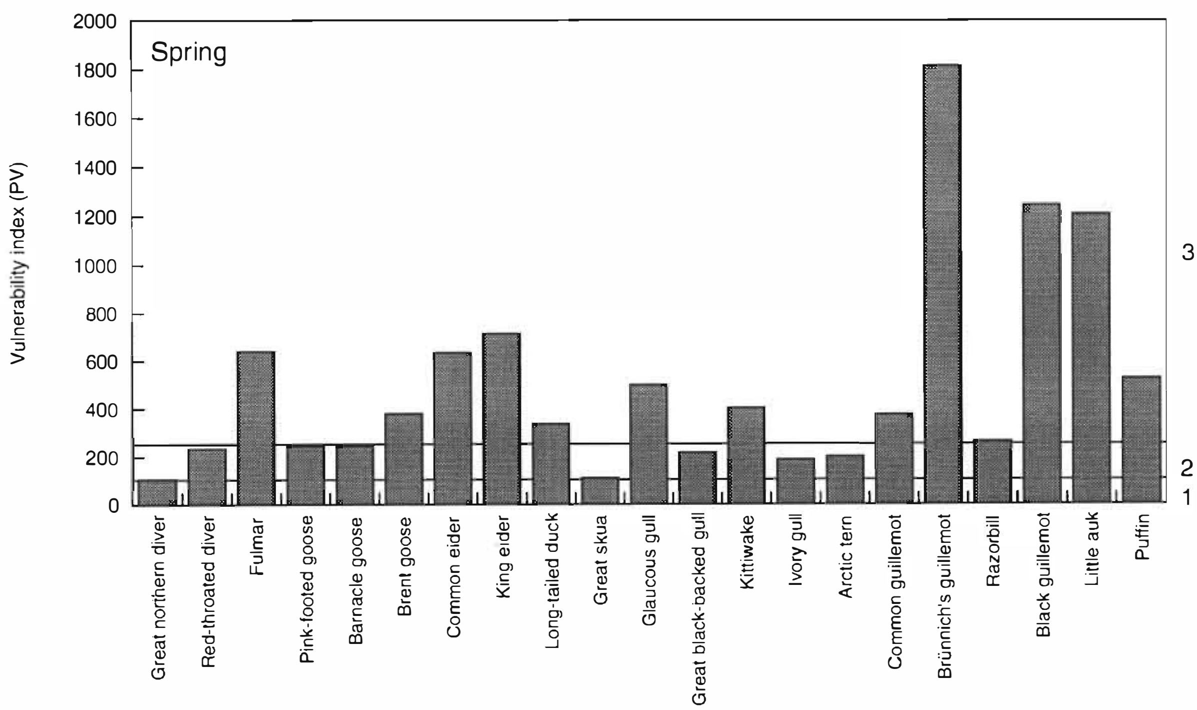
Wiig, Ø. & Isaksen, K. 1995: Seasonal distribution of Harbour Seals, Bearded Seals, White Whales and Polar Bears in the Barents Sea. Pp. 47–58 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

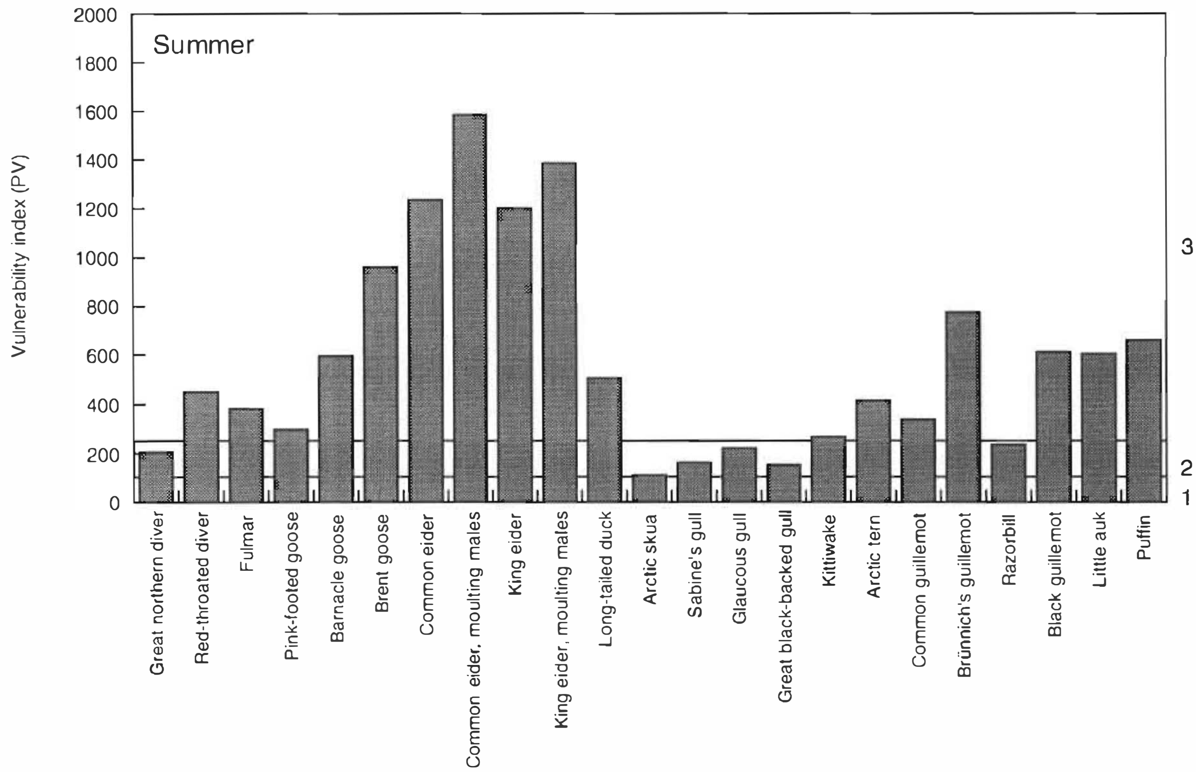
Øien, N. & Hartvedt, S. 1995: Distribution of a selection of marine mammal species in the northern part of the Barents Sea. Pp. 33–45 in Isaksen, K. & Wiig, Ø. (eds.): Conservation value assessment and distribution of selected marine mammals in the northern Barents Sea. *Norsk Polarinst. Medd. 136.*

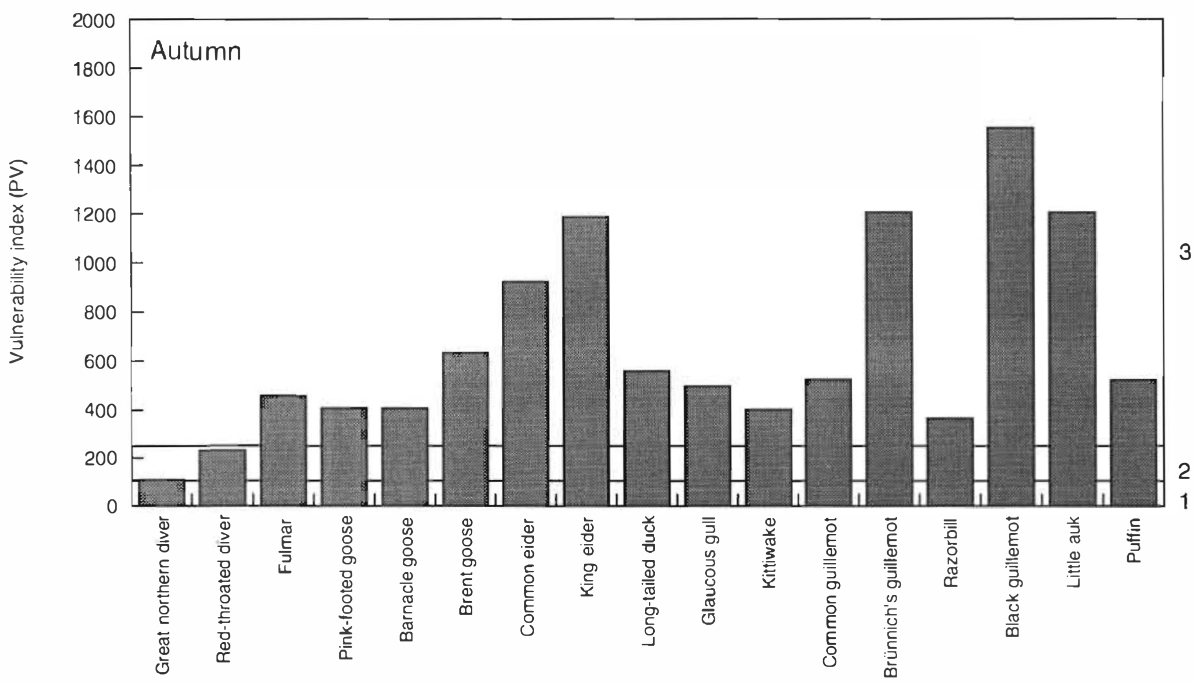
APPENDIX 4. RESULTS FROM THE OIL-VULNERABILITY ASSESSMENT FOR SEABIRDS

Results from the analysis of the vulnerability to oil of the seabird populations in the northern Barents Sea in the winter, spring, summer and autumn seasons (after Fjeld & Bakken [1993] and Isaksen & Bakken [1995]). The assessment model defines populations with vulnerability indices (*PV*) lower than 100 as of low vulnerability to oil spills (vulnerability category 1), whereas populations with *PV* between 100 and 250, and higher than 250 are defined as of moderate (vulnerability category 2) and high vulnerability (vulnerability category 3), respectively. All species listed in Appendix 1 have been evaluated in the assessment, but only populations found to be vulnerable (defined as populations in vulnerability category 2 or 3 in spring and summer, and vulnerability category 3 in autumn and winter) are shown in the figures below.



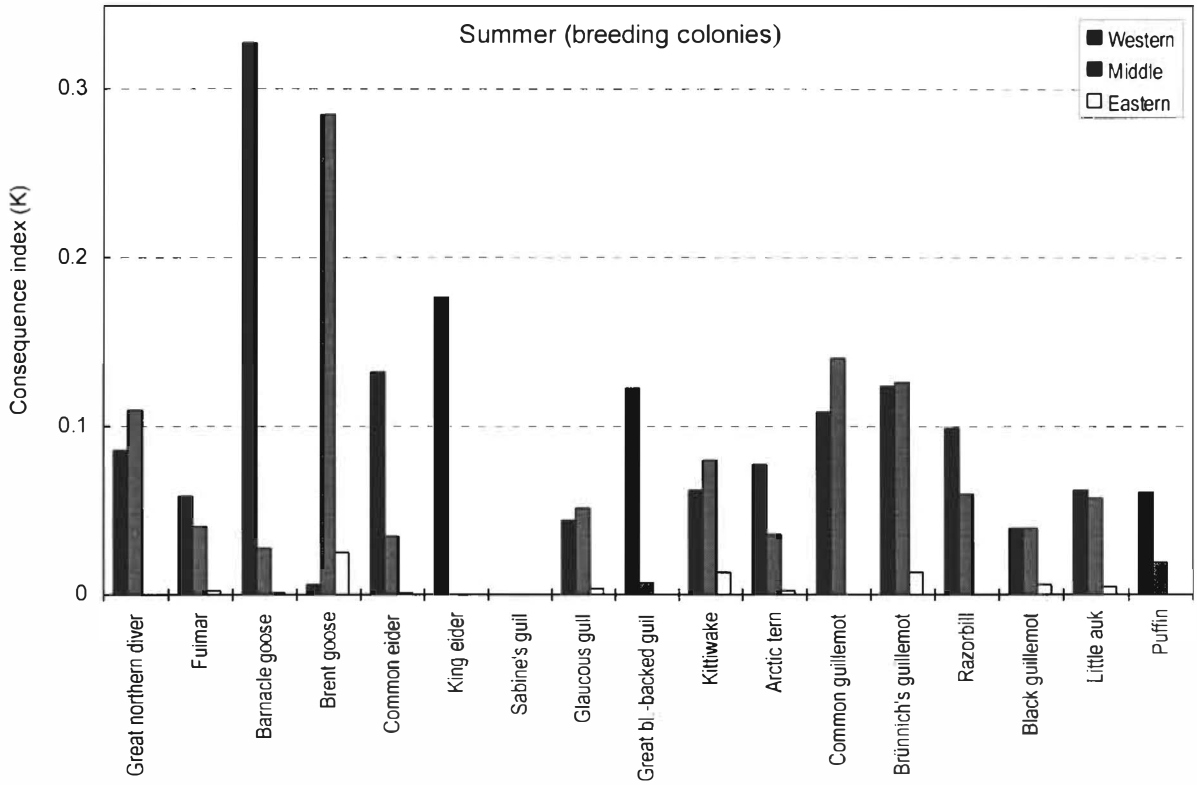


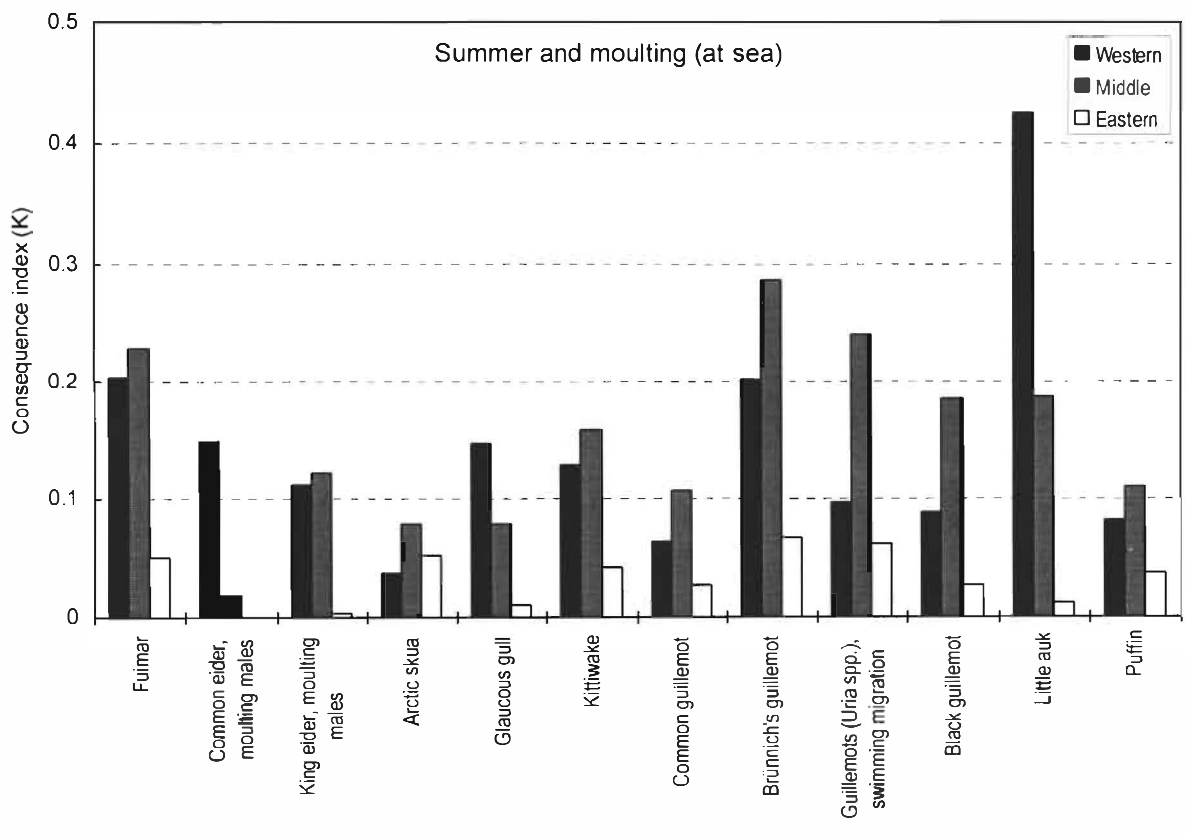

Summer
Vulnerability index (PV)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3
2
1
Great northern diver
Red-throated diver
Fulmar
Pink-footed goose
Barnacle goose
Brent goose
Common eider
Common eider, moulting males
King eider
King eider, moulting males
Long-tailed duck
Arctic skua
Sabine's gull
Glaucous gull
Great black-backed gull
Kittiwake
Arctic tern
Common guillemot
Brünnich's guillemot
Razorbill
Black guillemot
Little auk
Puffin

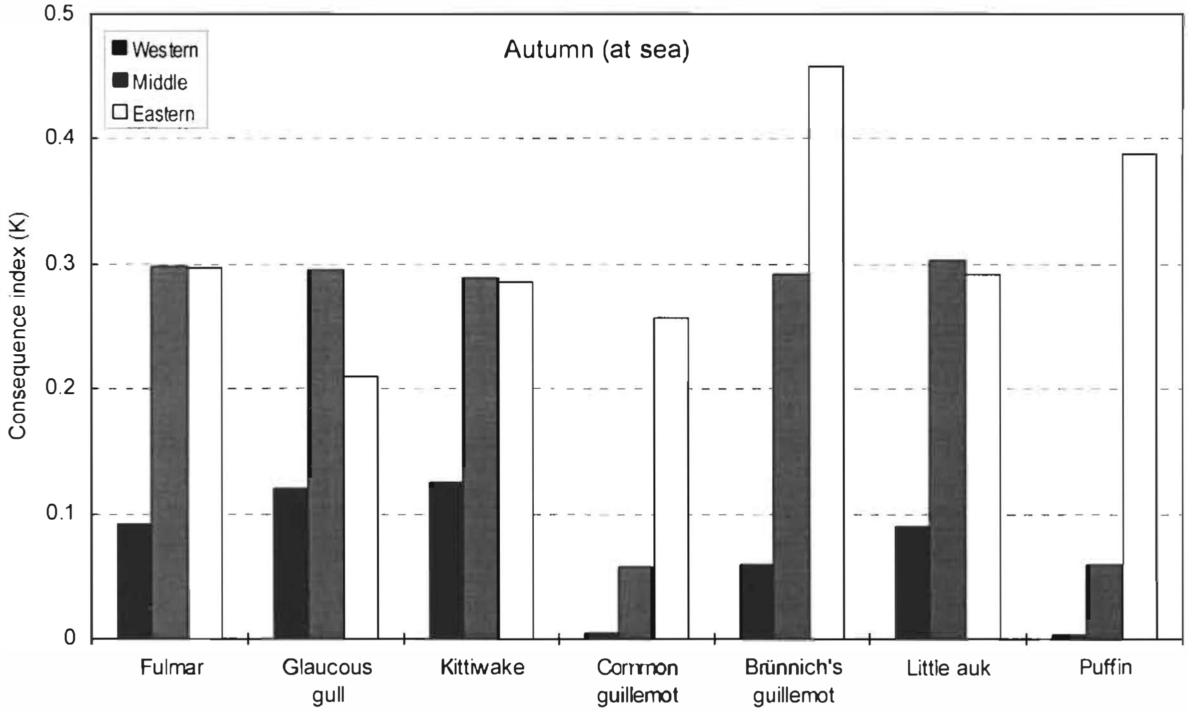

Autumn
Vulnerability index (PV)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3
2
1
Great northern diver
Red-throated diver
Fulmar
Pink-footed goose
Barnacle goose
Brent goose
Common eider
King eider
Long-tailed duck
Glaucous gull
Kittiwake
Common guillemot
Brünnich's guillemot
Razorbill
Black guillemot
Little auk
Puffin

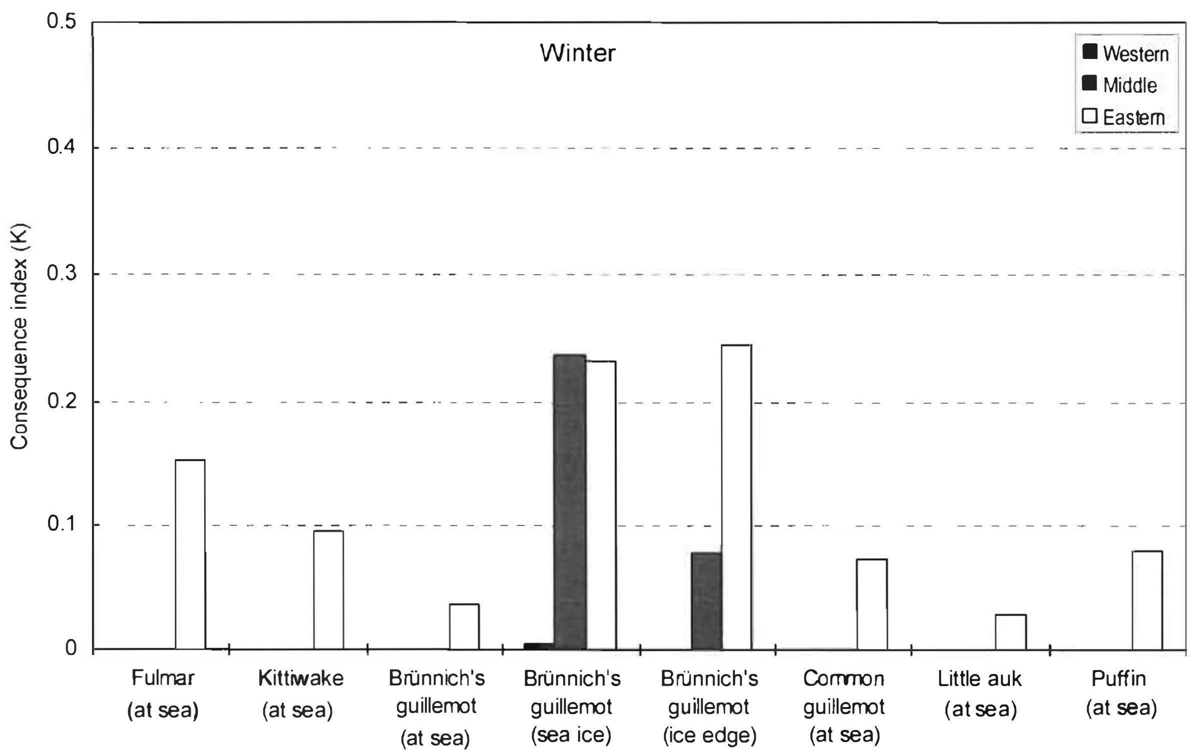
APPENDIX 5. RESULTS FROM THE IMPACT ASSESSMENT FOR SEABIRDS

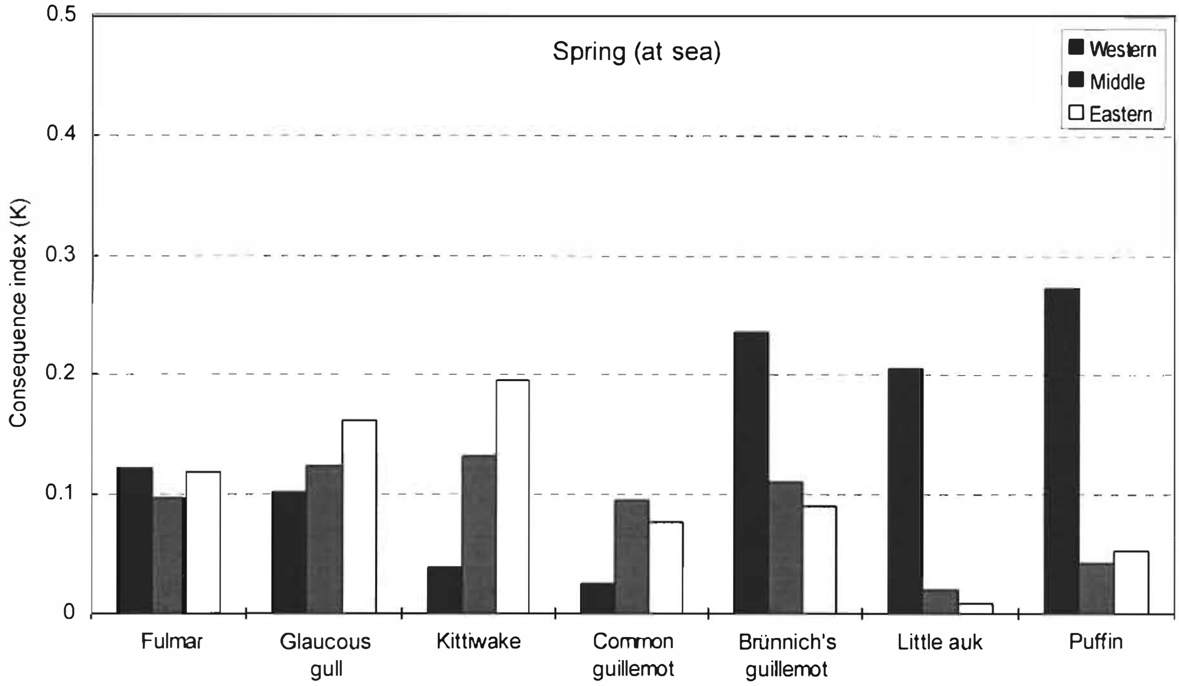
Results (calculated consequence indices, K) from the impact analysis for seabirds. The consequence index for a species of a spill from one of the three spill points is shown separately for each season.

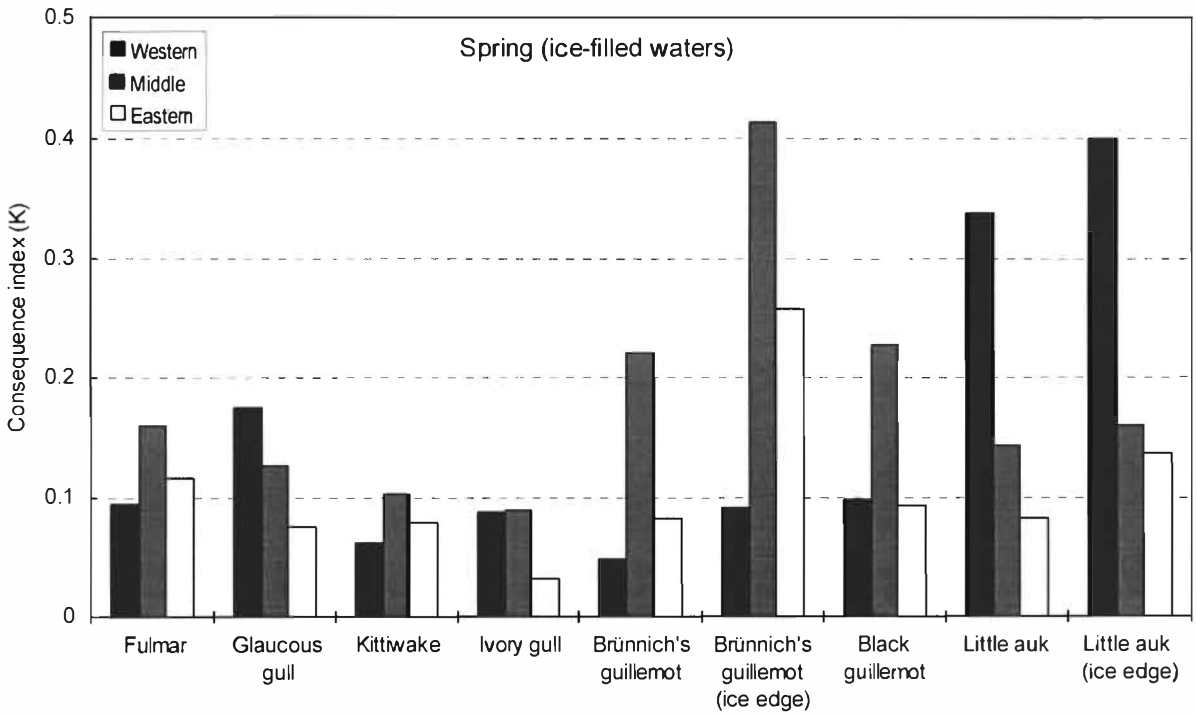





Autumn (at sea)
Western
Middle
Eastern
Consequence index (K)
0.5
0.4
0.3
0.2
0.1
0
Fulmar
Glaucous gull
Kittiwake
Common guillemot
Brünnich's guillemot
Little auk
Puffin

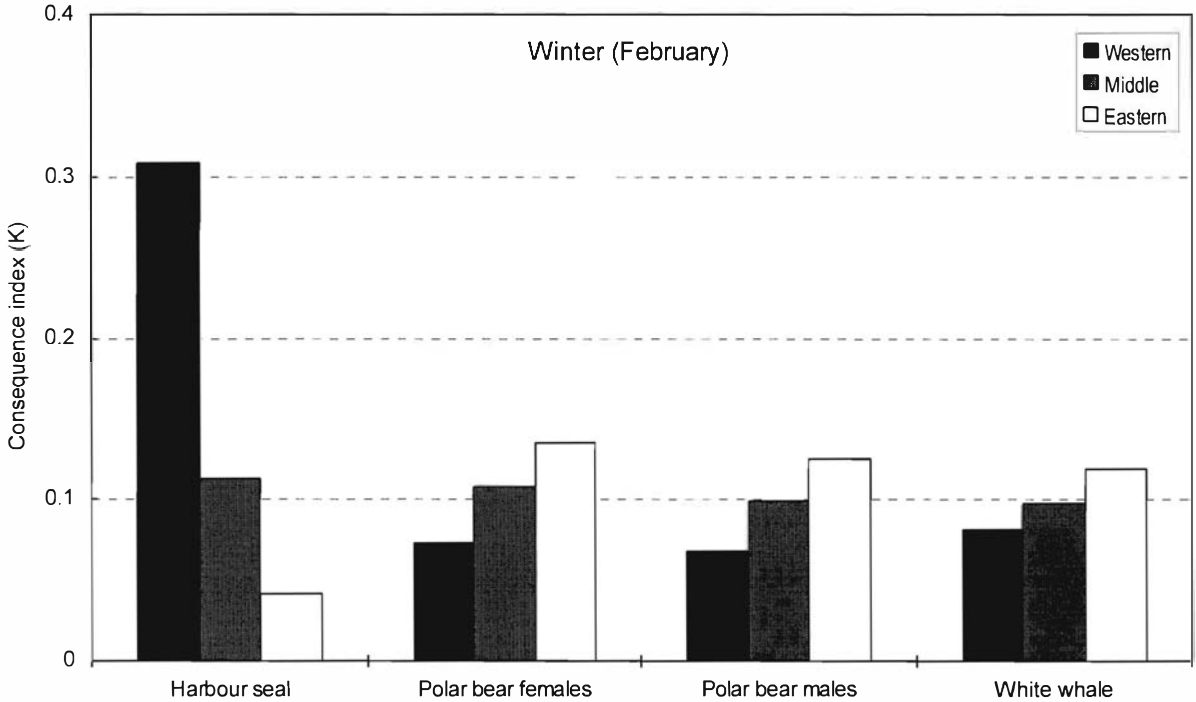

Winter
Western
Middle
Eastern
Consequence index (K)
0.5
0.4
0.3
0.2
0.1
0
Fulmar (at sea)
Kittiwake (at sea)
Brünnich's guillemot (at sea)
Brünnich's guillemot (sea ice)
Brünnich's guillemot (ice edge)
Common guillemot (at sea)
Little auk (at sea)
Puffin (at sea)

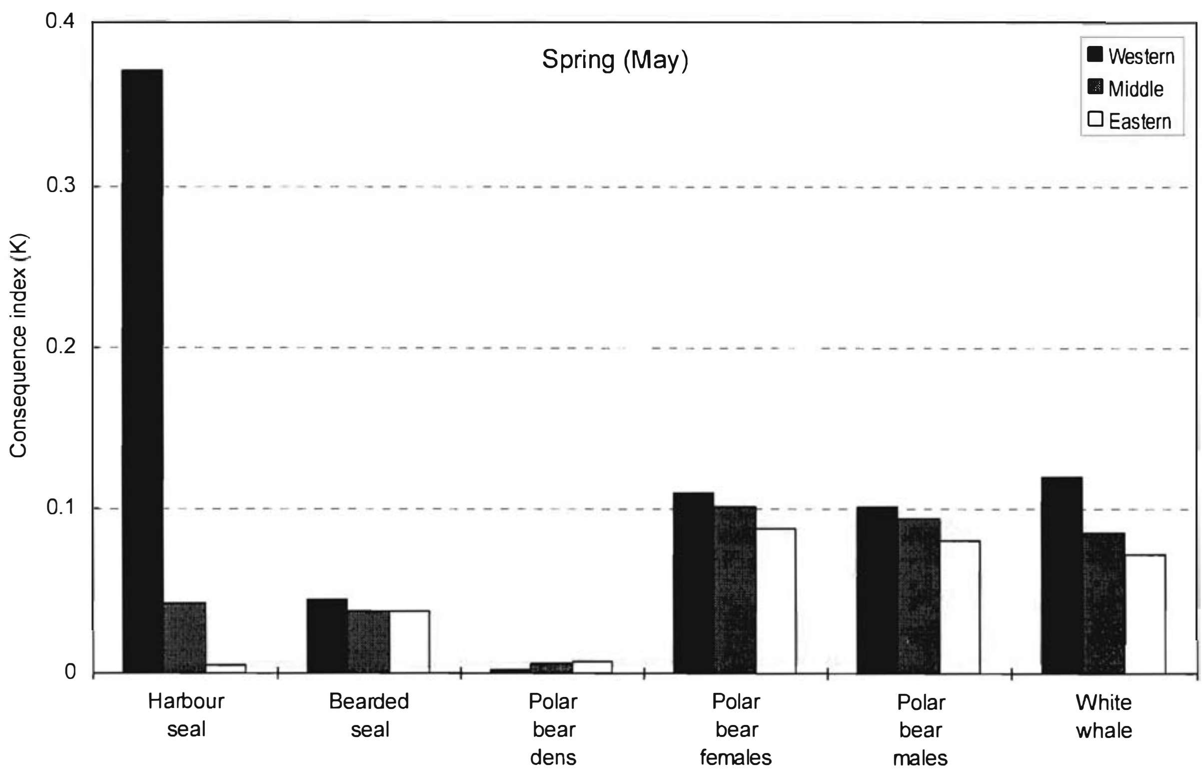

Spring (at sea)
Western
Middle
Eastern
Consequence index (K)
0.5
0.4
0.3
0.2
0.1
0
Fulmar
Glaucous gull
Kittiwake
Common guillemot
Brünnich's guillemot
Little auk
Puffin

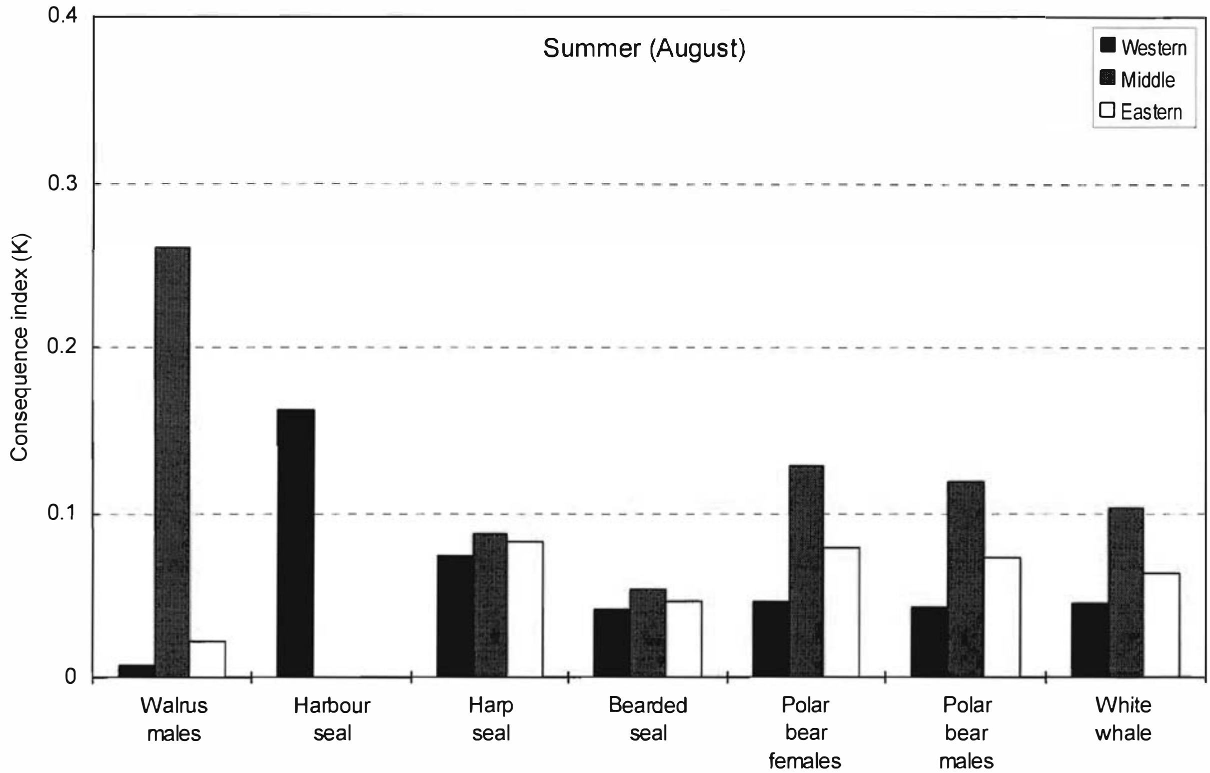

Spring (ice-filled waters)
Western
Middle
Eastern
Consequence index (K)
0.5
0.4
0.3
0.2
0.1
0
Fulmar
Glaucous gull
Kittiwake
Ivory gull
Brünnich's guillemot
Brünnich's guillemot (ice edge)
Black guillemot
Little auk
Little auk (ice edge)

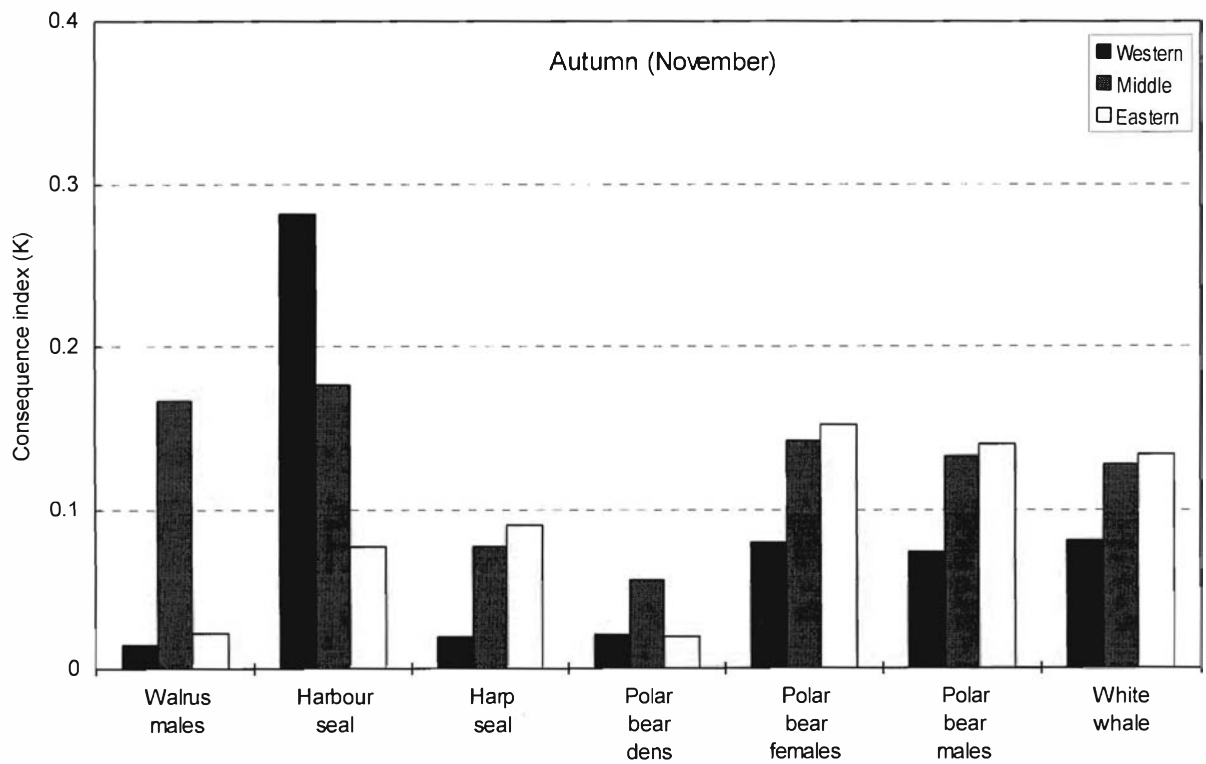
APPENDIX 6. RESULTS FROM THE IMPACT ASSESSMENT FOR MARINE MAMMALS

Results (calculated consequence indices, K) from the impact analysis for marine mammals. The consequence index for a species of a spill from one of the three spill points is shown separately for each season.



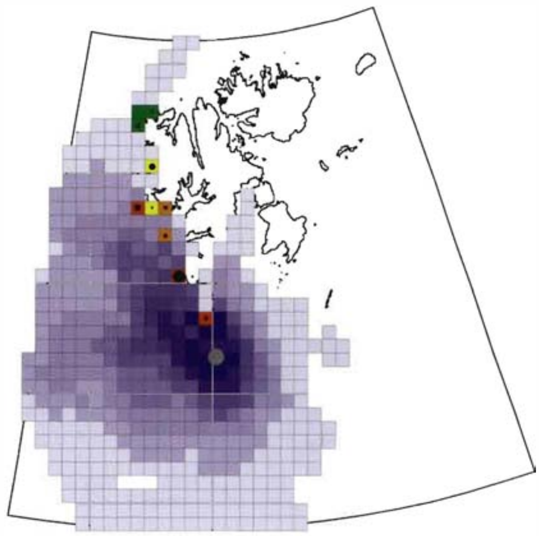



Summer (August)
Western
Middle
Eastern
Consequence index (K)
0.4
0.3
0.2
0.1
0
Walrus males
Harbour seal
Harp seal
Bearded seal
Polar bear females
Polar bear males
White whale


Autumn (November)
Western
Middle
Eastern
Consequence index (K)
0.4
0.3
0.2
0.1
0
Walrus males
Harbour seal
Harp seal
Polar bear dens
Polar bear females
Polar bear males
White whale

APPENDIX 7. ANALYSIS MAPS FOR SEABIRDS

Maps showing the effects indicated by the SIMPACT model of an oil spill for selected combinations of species, season and spill site.



insignificant small medium large

Fig. 1. Barnacle goose, breeding colonies. Western spillpoint. Summer. Consequence index: 0.327

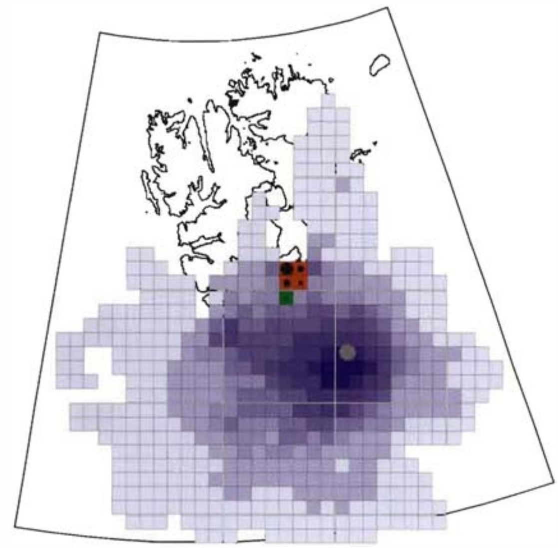


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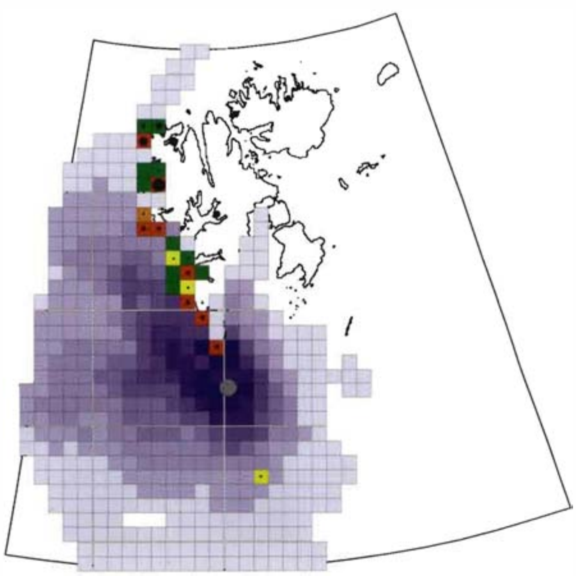
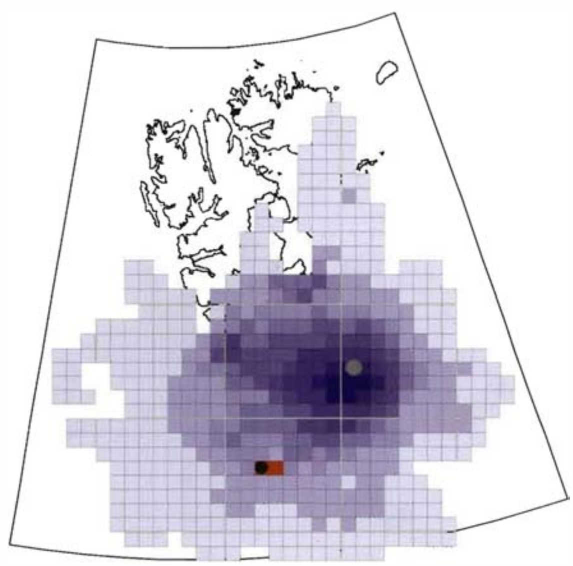
Fig. 2. Brent goose, breeding colonies. Middle spill point. Summer. Consequence index: 0.284.



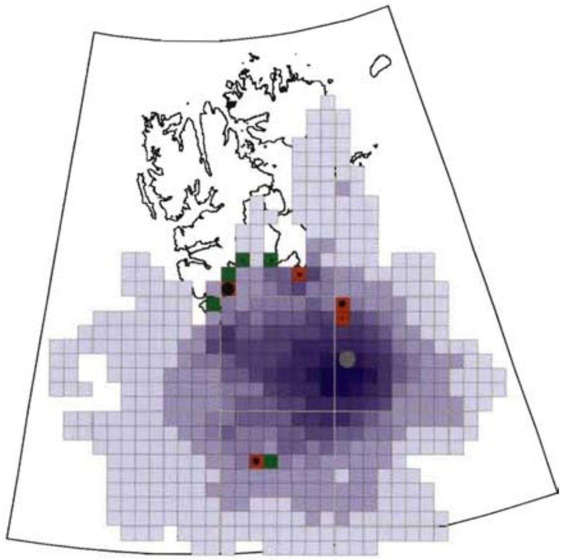
insignificant small medium large

Fig. 3. Common eider, breeding colonies. Western spill point. Summer. Consequence index: 0.132.



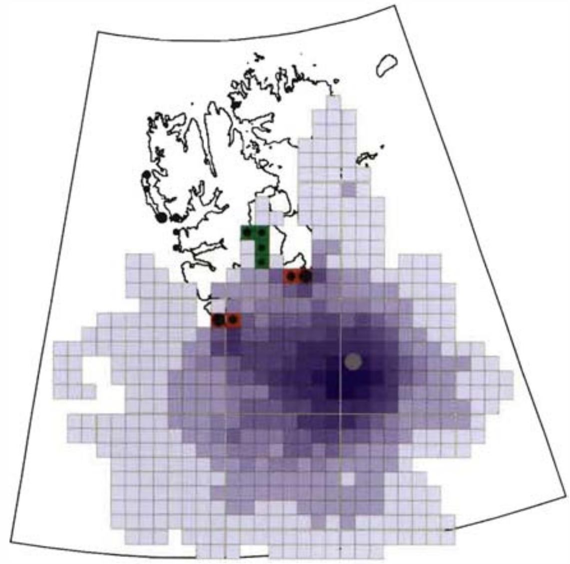
insignificant small medium large

Fig. 4. Common guillemot, breeding colonies. Middle spill point. Summer. Consequence index: 0.141



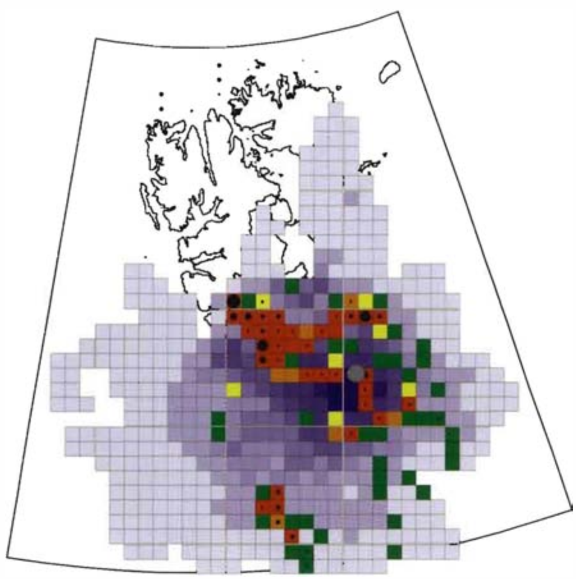
■ insignificant ■ small ■ medium ■ large

Fig. 5. Brünnich's guillemot, breeding colonies. Middle spill point. Summer. Consequence index: 0.126.



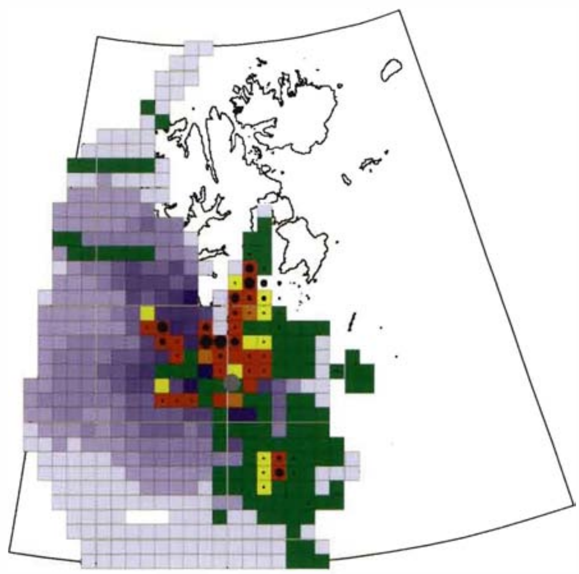
■ insignificant ■ small ■ medium ■ large

Fig. 6. King eider, moulting areas. Middle spill point. Summer. Consequence index: 0.121.



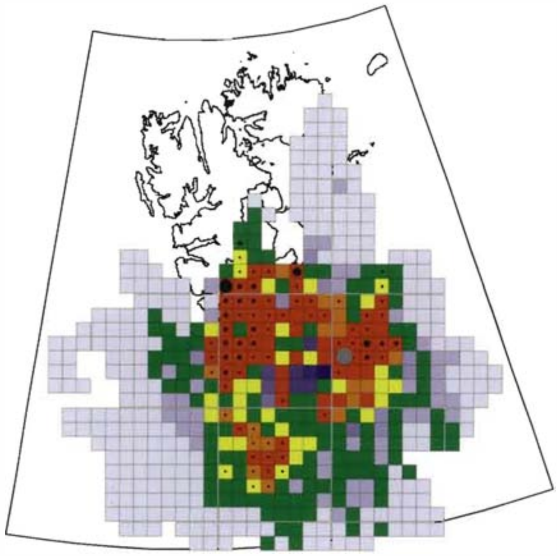
■ insignificant ■ small ■ medium ■ large

Fig. 7. Guillemot (*Uria* spp.) adults with juveniles (20 July–31 August). Middle spill point. Consequence index: 0.240.



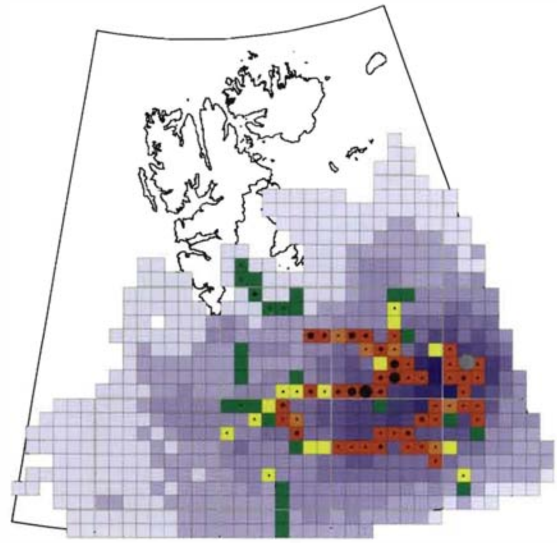
■ insignificant ■ small ■ medium ■ large

Fig. 8. Little auk, at sea. Western spill point. Summer. Consequence index: 0.425.



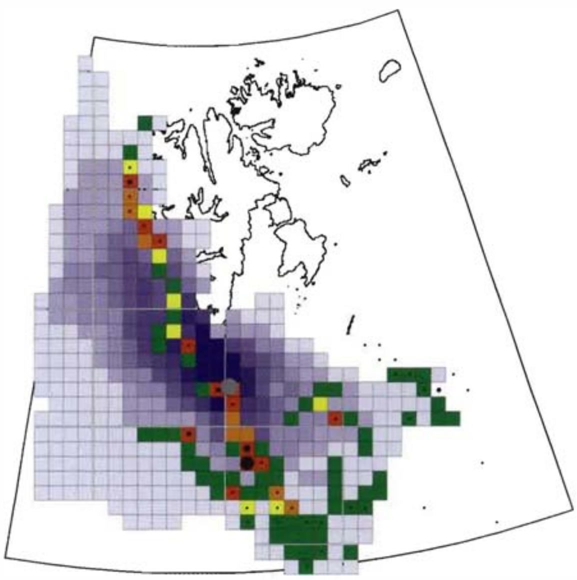
■ insignificant ■ small ■ medium ■ large

Fig. 9. Brünnich's guillemot, at sea. Middle spill point. Summer.
Consequence index: 0.286.



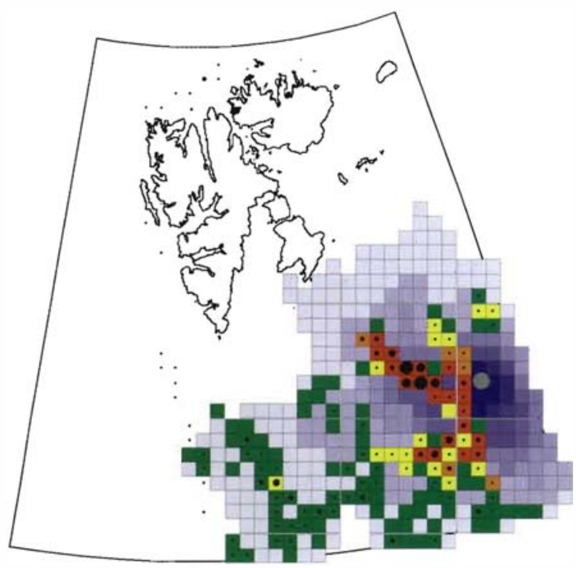
■ insignificant ■ small ■ medium ■ large

Fig. 10. Brünnich's guillemot, at sea. Eastern spill point. Autumn.
Consequence index: 0.458.



■ insignificant ■ small ■ medium ■ large

Fig. 11. Brünnich's guillemot, at sea. Western spill point. Spring.
Consequence index: 0.236.

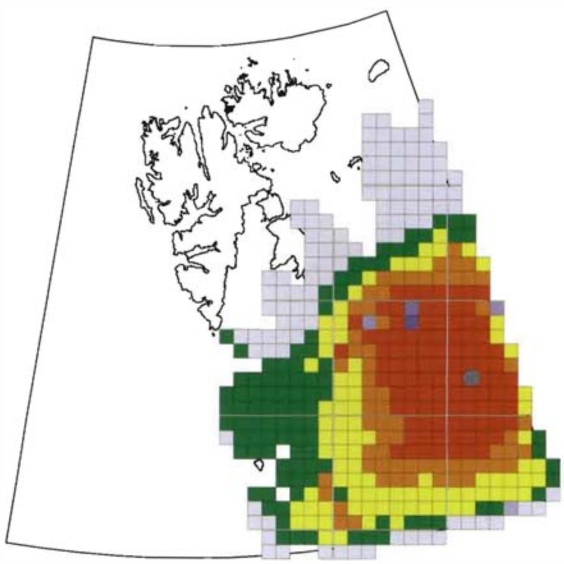


■ insignificant ■ small ■ medium ■ large

Fig. 12. Kittiwake, at sea. Eastern spill point. Spring.
Consequence index: 0.195.

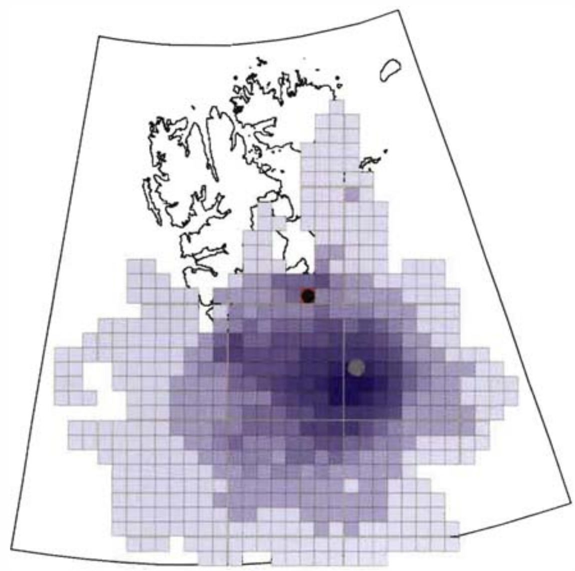
APPENDIX 8. ANALYSIS MAPS FOR MARINE MAMMALS

Maps showing the effects indicated by the SIMPACT model of an oil spill for selected combinations of species, season and spill site.



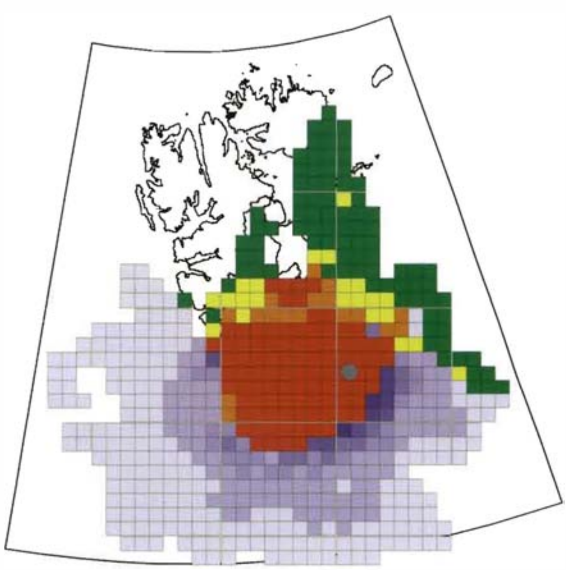
■ insignificant ■ small ■ medium ■ large

Fig. 1. Harp seal. Eastern spill point. Summer.
Consequence index: 0.063.



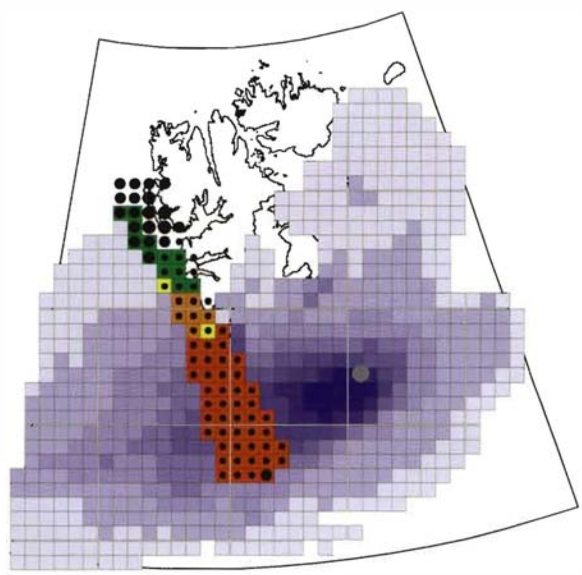
■ insignificant ■ small ■ medium ■ large

Fig. 2. Walrus, males. Middle spill point. Summer.
Consequence index: 0.261.



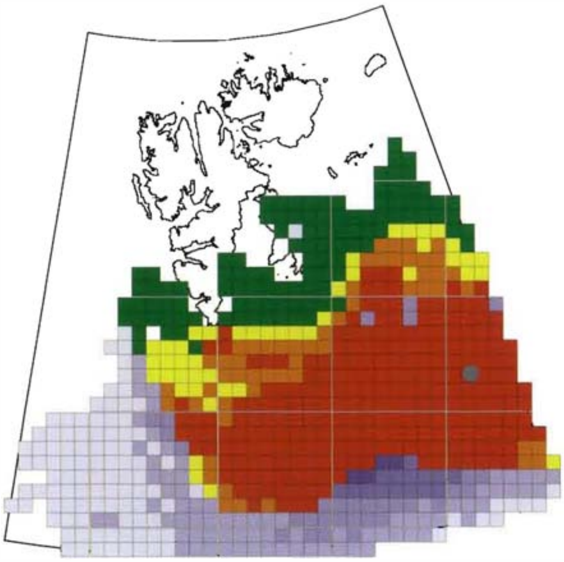
■ insignificant ■ small ■ medium ■ large

Fig. 3. White whale. Middle spill point. Summer.
Consequence index: 0.103.



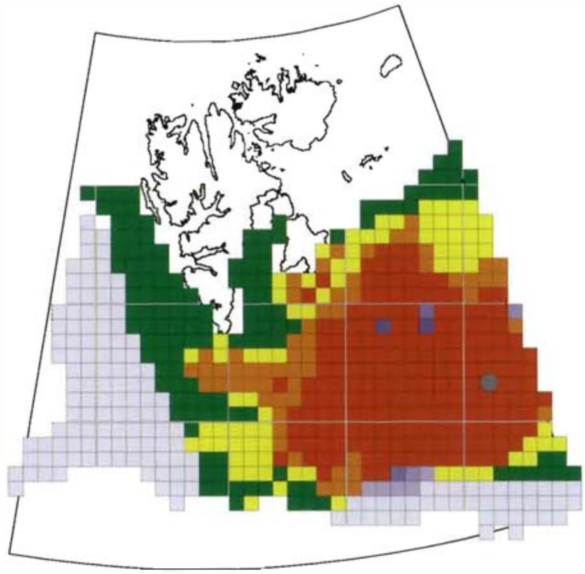
■ insignificant ■ small ■ medium ■ large

Fig. 4. Harbour seal. Middle spill point. Autumn.
Consequence index: 0.177.



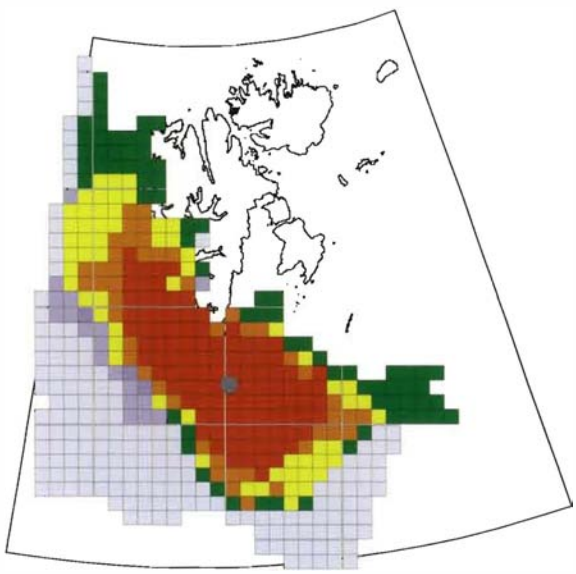
■ insignificant ■ small ■ medium ■ large

Fig. 5. White whale. Eastern spill point. Autumn.
Consequence index: 0.134



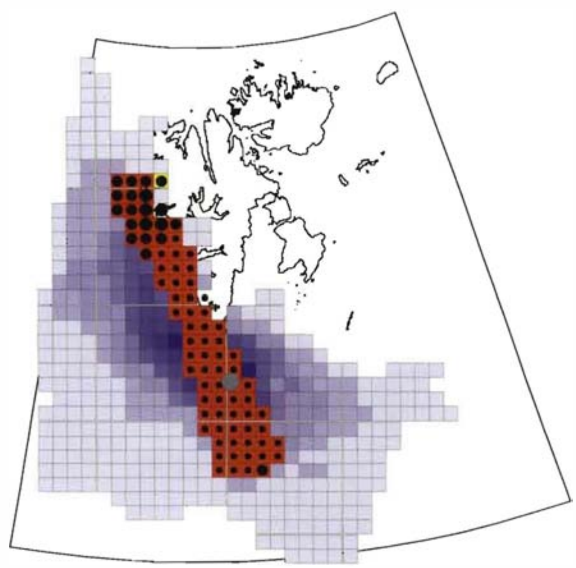
■ insignificant ■ small ■ medium ■ large

Fig. 6. Polar bear, males. Eastern spill point. Winter.
Consequence index: 0.124.



■ insignificant ■ small ■ medium ■ large

Fig. 7. Polar bear, females. Western spill point. Spring.
Consequence index: 0.110



■ insignificant ■ small ■ medium ■ large

Fig. 8. Harbour seal. Western spill point. Spring.
Consequence index: 0.370.