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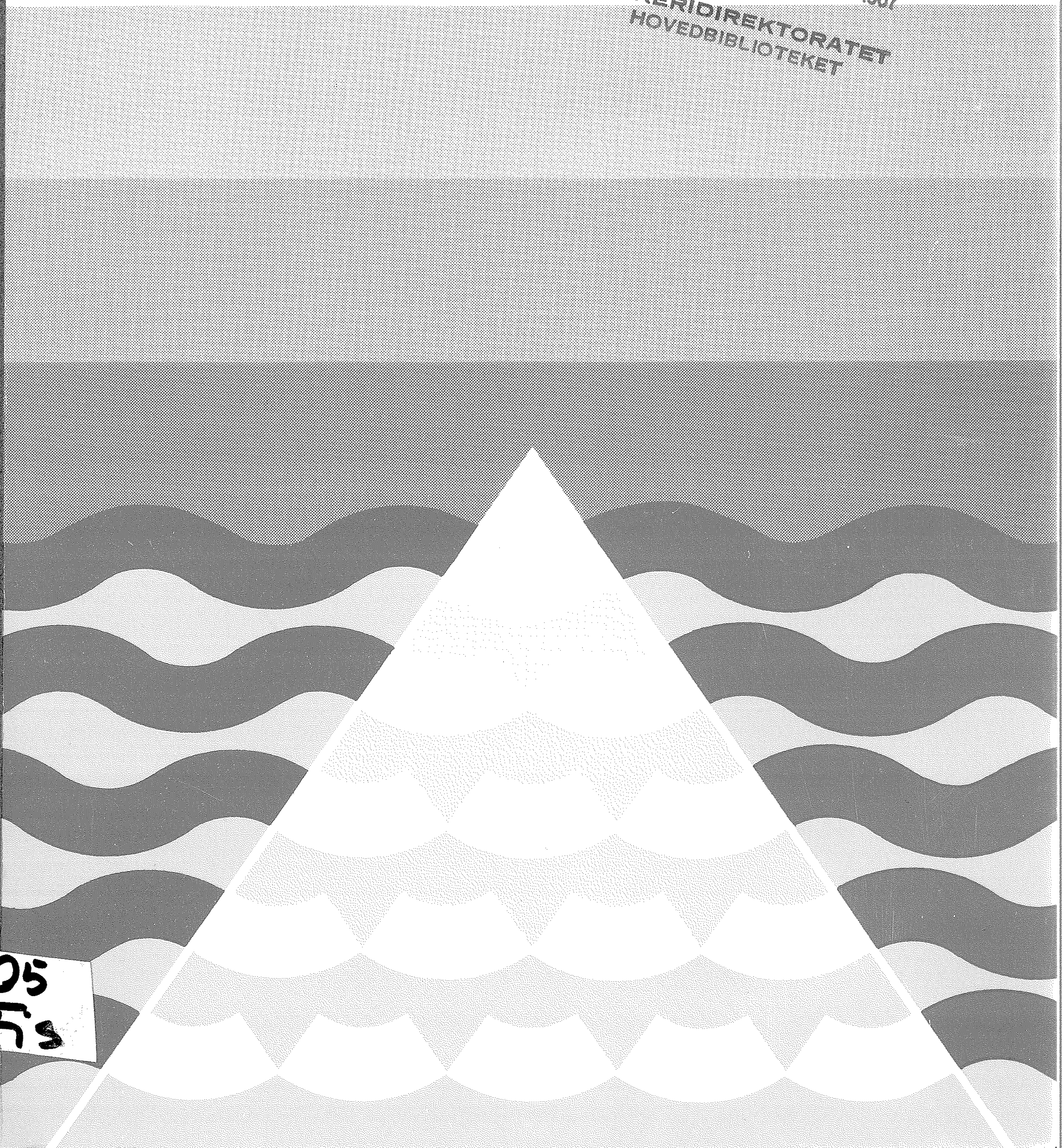

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MARINE MAMMALS AND PETROLEUM ACTIVITIES IN NORWEGIAN WATERS

(SJØPATTEDYR OG PETROLEUMSVIRKSOMHET I NORSKE FARVANN)

A review of the literature on the effects of petroleum on marine mammals and recommendations for further research.

En gjennomgang av litteratur om virkningene av olje på sjøpattedyr, med vurdering av behovene for videre undersøkelser

by (av)

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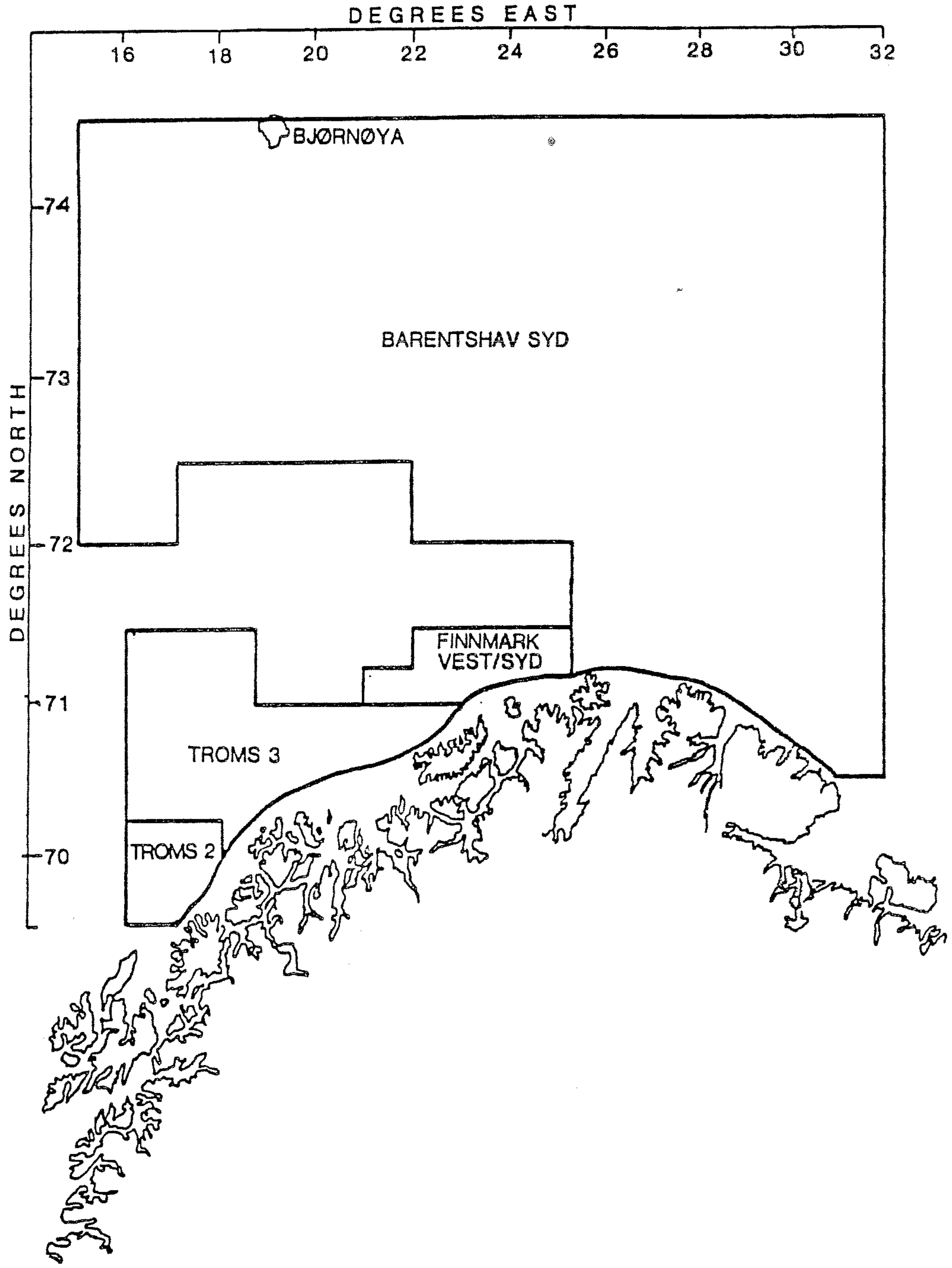

FRONTISPIECE

PROPOSED BARENTS SEA OIL PRODUCTION LEASE AREAS

0. FOREWORD

This literature review is edited from a 206 page document dated January 1986 by D.F. Griffiths and N.A. Øritsland. Through the editing process additional updated and sometimes unpublished information on population size and distribution was contributed. The work has been commissioned by the Ministry of Oil and Energy upon recommendation of its Working Group (OED/AKUP) on Consequence Analyse of Oil Exploration, as an element of a program to review and analyse consequences of opening new petroleum leases in the sea off Troms amd Finnmark counties, northern Norway, for prospecting (Frontispiece).

One purpose of the present work is therefore to critically review literature that can be applied in the Consequence Analysis that the Ministry will direct for the potential northern oil fields. The effects of petroleum pollution on marine mammals, both from normal extraction operations and from spills and blowouts, are evaluated. Whether marine mammals are affected during the exploratory phase of drilling, by noise, blasting during seismic mapping and pollution from drilling muds and other chemicals, is also considered. For this purpose, all sources have been utilized including data on species not indigenous to Norway. Results from actual oil spills and experimental work published in refereed journals, unpublished departmental reports and personal communications have all been used.

The second objective is to identify populations of marine mammals known to use coastal and offshore Norwegian waters which are already or likely to be polluted by oil and the effects of noise and other pollutants of petroleum recovery activities on these populations. By referring back to the known effects of these pollutants on the different species, we then attempt to predict whether these populations will be harmed by exposure to oil production activities, and if so in what way. In doing this we think of marine mammals firstly at the population level but equally important at the level of the individual animal.

The third objective is to identify the gaps in knowledge that prevent us from estimating both the present effect of oil pollution on marine mammals around Norway and the probable effects after future intensification of the search for oil northward into colder and deeper seas, and to propose further research to cover these deficiencies.

Norwegian oil extraction and prospecting operations are extensive in the Norwegian and North Seas and are constantly expanding northward towards polar seas rich in marine mammal life. To our surprise, the consequences for marine mammals of oil pollution have never been seriously evaluated in connection with any of these operations. Elucidation of oil-marine mammal interactions in both northern polar seas and southern open coastal waters thus appeared relevant and is included in this report.

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1. NORWEGIAN SUMMARY AND RECOMMENDATIONS

1.1 Sammendrag

I de havområdene utenfor Troms og Finnmark som er eller forventes å bli åpnet for oljeletingsvirksomhet, vil følgende sjøpattedyr kunne forekomme gjennom hele eller deler av året og påvirkes av olje fra en utblåsing: grønlandssel, klappmyss, storkobbe, snadd (ringsel), vågehval, knøl, finnhval, seihval, blåhval, sperm, spekkhogger, flere arter mindre tannhval som kvitnos og kvitfisk, isbjørn og dessuten grønlandshvalen som er meget sjelden og nærmest utryddet i det nordøstlige Atlanterhav. Alle disse opptrer hovedsakelig pelagisk eller i forbindelse med drivis, men flere kommer også inn i norske kystfarvann. På norskekysten, finnes det i tillegg også lokale bestander av steinkobbe (fjordsel), havert (gråsel) og oter.

Hvilke av disse som påvirkes av olje og oljevirksomhet avhenger av sted, årstid og hvor lang tid som er gått etter et oljeutslipp. I leteområdet i Barentshavet finnes det drivis på senvinteren, men i den isfrie perioden er vannet ikke spesielt kaldt og da kan det ikke forventes at olje vil oppføre seg anderledes der enn i områdene lengre sør som f.eks. ved Statfjord eller Ekofisk.

Olje som slipper ut i drivisen hopes opp mellom flakene, vanligvis i lag på ca. én cm. I tung pakkis og i fast is vil oljen samle seg opp i tykke lag i råker, i selenes pustehull og i de faste landråkene. Bevegelser i isen vil i tillegg presse oljen opp på overflaten av isflakene der den først vil kunne finnes som oljedammer og senere som en sørpe av olje og snø. Olje som tvinges under isen vil bli fanget opp av den ujevne undersiden og bli frosset inn i takt med dannelsen av nyis. Dette er ikke noe akutt problem, men kan bli av betydning som en forurensningskilde for dyr som er i området den følgende sommer når oljen siver opp til isens overflate. Forvitringen av slik olje går langsomt, og oljen forblir giftig i lange perioder, særlig den oljen som er innleiret i selve isen. Pattedyr som grønlandssel, storkobbe, klappmyss, snadd og isbjørn kan bli kraftig tilsølt. Etter fordamping av de lettere komponentene kan oljen bli så tung at den synker og forsvinner fra overflaten. Den vil imidlertid kunne samles i et overgangslag mot saltere vann som finnes mellom fem og ti meter nede i vannmassene.

Olje som slippes ut i åpen sjø, spres pga. vind og bølgevirkninger forholdsvis hurtig til tynne lag. Slike lag kan være fra 10^{-5} til 10^{-4} m tykke med ujevnt fordelte tykkere flak inniblant. En utblåsing i Barentshavet kan medføre at Troms og Finnmarkskysten fra omkring Tromsø til Varangerhalvøya blir tilsølt av olje, med de størst mengder på Sørøya og Nordkinn. Oljen vil kunne komme inn til strendene omkring 2 1/2 dag etter utslippet. I løpet av denne tiden vil de letteste og giftigste oljekomponentene ha fordampet slik at det vil foreligge en sørpelignende emulsjon av oje i vann. Denne emulsjonen kan bli kastet inn på strender og svaberg hvor den vil kunne klebe seg til kystsel (steinkobbe og havert) og oter. Hvis det ikke blir iverksatt opprenskingsaksjoner, vil mesteparten av oljen sannsynligvis likevel vaskes vekk av bølger, mens oljen som ligger høyere enn bølgenes normale rekkevidde vil forvitres til seig tjære som kan bli liggende i flere tiår.

Manglende kunnskaper og data gjør det vanskelig å vurdere skadevirkningene av olje på sjøpattedyr. I noen tilfeller er imidlertid virkningene klare. Det har bl.a. vist seg at olje vil ha en dødelig virkning både på isbjørn, sjøotere og otere. Vi kan si med stor sikkerhet at omtrent alle isbjørn og otere som kommer i kontakt med olje fra Barentshavet, vil dø, både fordi pelsens varmeisolerende egenskaper ødelegges og på grunn av giftvirkninger på indre organer, særlig fordøyelses- og ekskresjonorganene, blodsirkulasjonen og nervesystemet.

Det ser ut til at ekte sel (familien Phocidae), dvs. alle sel i norske farvann, tåler en kort tids kontakt med olje i varmere havområder. Sel med olje på huden synes å oppføre seg normalt uten å være plaget. Utvendig tilsøling av snadd i isfylt farvann synes, i hvertfall for noen individer, å ha en nedbrytende og livstruende virkning, men datagrunnlaget for denne vurderingen er svært ufullstendig. Den første og mest påfallende virkningen er øyeirritasjon og sårdannelse i hornhinnen, og noen få sel vil kunne bli blindet av fersk olje. I realiteten vil imidlertid olje i naturen vanligvis være forvitret og ha mindre irritasjonsvirkning før den kommer i kontakt med selkolonier. I eksperimentelle situasjoner har sel omkommet og vist tegn på reaksjoner i nervesystemet etter kontakt med tykke oljelag. En så konsentrert tilsøling med fersk olje er likevel ikke særlig sannsynlig i åpne farvann, mens muligheten er tilstede i isfylte områder. Noen dyr som svelger olje vil omkomme flere dager senere pga. skader i tarmer, lever eller lunger. De fleste sel klarer imidlertid å unngå å svelge noen betydelig mengde olje.

Langtidsvirkningene av olje på sel er langt fra tilstrekkelig undersøkt. På kort sikt klarer tilsølte sel å opprettholde en normal kroppstemperatur, og enkelte forskere har derfor ment at oljen ikke har noen irritasjonsvirkning på selens hud. Kroppstemperaturen opprettholdes imidlertid ved en balanse mellom varmeproduksjon (metabolisme) og varmetap, og en normal kroppstemperatur betyr m.a.o. bare at balansen er tilstede. Det er ikke gjort målinger, hverken av metabolisme eller av varmetap, hos oljetilsølt sel, og det foreligger endel informasjon som tyder på at langvarig eksponering til olje virkelig medfører irritasjon i huden. Spørsmålet om hvorvidt langvarig oljetilsøling av sel medfører irritasjon eller inflammasjon i huden med tilhørende økning av varmetapet, må klarlegges gjennom praktiske undersøkelser.

Den sterke sammenhengen mellom hudinflammasjon, total energibalanse og selens overlevingsevne tilsier at slike undersøkelser må gis høy prioritet.

Det har vist seg at under eksperimentelle betingelser kan delfiner oppdage og unngå tykke oljelag på vannflaten, men ikke de tynne lagene som dannes i løpet av kort tid etter oljesøl eller utblåsing i åpent hav. Det er observert at flere arter av hval, inklusive delfiner, har oppført seg normalt og spist inne blant oljeflak, og derfor har man antatt at de enten ikke kan eller ikke behøver å unngå olje på havflaten. Eksperimentelle undersøkelser har også vist at kortvarig kontakt med råolje ikke medfører noen vesentlig skade, men at langvarig kontakt med raffinerte oljeprodukter forårsaker skader (erosjon) i overhuden. I praksis vil skader pga. råolje sannsynligvis være ubetydelige hos hval fordi oljen vil bli vasket av igjen straks etter at den er kommet i kontakt med dyrene. Eventuelle indre påvirkninger av olje i hval er ukjente og er ikke tilstrekkelig undersøkt. Oljemengden som en hval kan få i seg vil variere fra art til art, men den kan bli stor hos arter som spiser ved å skumme langs overflaten med åpen munn. Så lenge oljepåvirkningen på de indre organer hos disse dyrene ikke er kjent, vil det heller ikke være mulig å ha noen bestemt oppfatning om virkningen av olje på hval.

Hvorvidt andre utslag av oljerelatert virksomhet, som støy fra boring, undervannseksplosjoner, utslipp av giftige kjemikalier og støy fra skip og luftfartøyer har skadelige virkninger på sjøpattedyr, avhenger av hvilke arter det dreier seg om. Små delfiner og sel er blitt drept av undervannseksplosjoner, men antallet dyr som utsettes for slik påvirkning vil sannsynligvis være lite. Sårbarheten overfor sjokkbølger avtar med økende kroppstørrelse, og det er lite sannsynlig at store hval vil være i faresonen. Det er vist at støy fra skipstrafikk kan forstyrre hval og få dem til å forandre kurs, men det er vanskelig å danne seg noen sikker oppfatning om hva disse atferdsendringene betyr for dyrene. Vi antar imidlertid at de ikke spiller noen særlig rolle for overleving eller bestandsutvikling. De fleste hval har klare årlige vandringsmønstre, men de lokale bevegelsene er opportunistiske, og det har neppe noen betydning at de må forandre trekkretning i korte perioder. Det er imidlertid mulig at et relativt stort antall knølhval kan bli betydelig forstyrret av eksplosjoner og annen støy når de på sine faste årlige vandringer langs Finnmarkskysten passerer gjennom områdene som nå foreslås åpnet for oljeleting. Fordi bestanden i det nordøstlige Atlanterhav er betydelig redusert, er det viktig at man overvåker knølhvalens reaksjoner på oljevirksomheten i områder der dyrene vil passere to ganger pr. år slik at støynivået kan senkes hvis det viser seg å ha en skadelig virkning.

Steinkobbe og havert blir også lett skremt av menneskelig aktivitet og vil uten tvil bli jaget bort når det gjennomføres opprenskingsaksjoner langs kysten. Selen vil sannsynligvis vende tilbake til sine tilholdsteder etter noen dager når virksomheten er avsluttet, men det må forventes en viss dødelighet blant ungene pga. sult hvis opprensingsaksjoner finner sted i selens fødsels- og dieperioder.

På grunnlag av registrerte resultater av oljesøl og data fra eksperimentelle undersøkelser som er gjennomført, kan det med stor sannsynlighet forutsies at de fleste isbjørn og oter som forurenses av olje vil dø, mens sel som utsettes for kortvarig oljesøl i tempererte farvann ikke vil bli særlig berørt. Ytre tilsøling vil i de fleste tilfeller ha liten virkning på hval, men det er ikke mulig å forutsi hvilke indre skader som kan oppstå dersom hval svelger olje.

1.2 Anbefalinger

Manglende kunnskaper om virkningen av oljeforurensninger på sjøpattedyr, spesielt under vinterforhold med lave temperaturer og over lengre tid, gjør at man ikke med rimelig grad av sikkerhet kan vurdere virkningene, hverken av lete- og utvinningsaktiviteter eller av eventuelle utblåsninger i Barentshavet. Det foreligger derfor et klart behov for videre undersøkelser av flere forhold. Aktuelle forskningsoppgaver drøftes nærmere i et eget avsnitt i rapporten. De viktigste undersøkelser som bør igangsettes snarest, oppsummeres i prioritert rekkefølge i det følgende:

1. De ytre påvirkninger av kronisk oljetilsøling på sel under lave temperaturer.

Kronisk oljetilsøling av selenes hud, som vil kunne forekomme etter utslipp i drivisen, kan føre til hudinflammasjon med øket blodsirkulasjon og varmetap under de tilsølte hudflatene. Dessuten vil kompenserende reduksjon av blodsirkulasjonen under den rene huden omkring tilsølte flater kunne føre til forfrysninger når temperaturen er lav. Det er nødvendig å kvantifisere disse effektene før virkningene av oljetilsøling på sel i drivisen om vinteren kan forutsies. Dessuten er det nødvendig å foreta målinger av absorpsjonen av olje gjennom selhud for å kunne vurdere mengden av olje som opptas i kroppen etter utvendig tilsøling.

2. Virkningene av kronisk oljetilsøling på hormonbalanse og forplantning.

Hos sjøfugl fører inntak av olje til flere forstyrrelser i hormonbalansen som igjen kan føre til redusert vekst og øket dødelighet. Akutt oljeeksponering synes ikke å ha tilsvarende virkninger hos sel, bortsett fra at produksjonen av adrenale steroider øker. Undersøkelser av virkningene av en kronisk tilsøling på hormonbalansen i blodplasma vil gjøre det mulig å vurdere de langsiktige virkninger av oljetilsøling på sjøpattedyr. Spørsmålet om hvorvidt kronisk opptak av olje på et lavt nivå influerer på forplantningen på tilsvarende måte som polyklorerte bifenyler (PCB), må også undersøkes. Slike undersøkelser kan gjennomføres, f.eks. for kystsel, ved tilføring av olje til forsøksdyr og intensivert overvåking av kystselbestander på norskekysten.

3. Olje i den marine næringskjeden i norske farvann.

Undersøkelser av oljekonsentrasjoner i kroppsvev, både fra sjøpattedyr og fra deres byttedyr, vil gi grunnlag for en vurdering av oljeeksponeringen gjennom føden. Slike registreringer bør gjennomføres både i rene og i forurensede områder langs kysten. Samtidige undersøkelser av forplantningspotensiale og sykdomsnivå vil bidra til vår viten om virkningene av kronisk oljepåvirkning på forplantning og immunsystem (jfr. punkt 2).

4. Petroleumsnivåer i sel med redusert kondisjon.

Petroleumsprodukter akkumuleres i spekket hos sel og hval. Utnyttelsen av spekket, dvs. forbrenningen av spekklagrene, i de naturlige sultperiodene (hårfellings- og forplantningssesongene) og under sykdom, kan føre til økende konsentrasjoner av petroleum i blodplasma og kanskje også i melken. Undersøkelser av frigjøringen av akkumulert petroleum i dyr med avtagende kondisjon (i sultsituasjon) vil gi bedre kunnskaper om sikre nivåer for oljeprodukter i sjøpattedyr.

5. Patologiske undersøkelser av sjøpattedyr som blir funnet døde i forbindelse med oljesøl.

Det er ofte ikke mulig å vurdere rapporter om oljetilsølte sjøpattedyr fordi det har gått for lang tid mellom døden og en faglig undersøkelse. I flere tilfeller har slike undersøkelser heller ikke vært faglig tilfredstillende, eller de er overhodet ikke utført. I første omgang burde det gjennomføres en opplysningskampanje med sikte på å bedre innrapporteringen av døde sjøpattedyr som blir funnet langs norskekysten. Dernest burde det etableres en liten spesialistgruppe av veterinærer med særlig oppgave å gjennomføre patologiske undersøkelser av slike dyr, spesielt hvis det er grunn til å tro at olje er en medvirkende dødsårsak. Slike undersøkelser vil få betydning, ikke bare for belysning av oljeproblematikken, men også for det offentlige helsestell. Registreringer av patologiske og fysiologiske tilstander sammenholdt med målinger av petroleumsnivåer i kroppvevene vil bidra til kunnskapene om oljens toksiske virkninger.

6. Dødelighet blant isbjørn etter oljesøl.

Det fremgår av tidligere undersøkelser at de fleste isbjørn som blir tilsølt av olje, f.eks. i forbindelse med en utblåsning, vil dø dersom de ikke blir tatt under behandling. Det antas også at problemer i forbindelse med innfanging og transport av disse store pattedyrene i praksis vil gjøre det vanskelig eller umulig å gjennomføre den behandling som er nødvendig. Den eneste muligheten for å øke forståelsen av oljens innvirkning på isbjørn synes derfor å være at det blir gjennomført registrering og tellinger av isbjørn i den sørlige del av Barentshavet om vinteren når det er is i området som ventes åpnet for oljevirksomhet. Slike tellinger vil gjøre det mulig å vurdere hvor mange dyr som kan ventes å omkomme i forbindelse med oljesøl. Foreløpig er forekomstene av isbjørn i disse områdene ikke kjent.

7. Virkninger av støy på hval i Barentshavet.

I Barentshavet er det spesielt knølhvalen som kan påvirkes av støy fra oljevirksomheten, slik at vandringsmønsteret forstyrres og rekrutteringen hemmes. Det er tidligere påvist at knølhvalen er en av de hvalartene som reagerer på undervannsstøy.

Vi anbefaler registrering og tellinger av spesielt denne, men også andre hvalarter for å undersøke bestandsstørrelsen og sesongmessig vandringsmønster. Som en videreføring av slike tellinger anbefaler vi også at virkningene av undervannsstøy på knølhval blir undersøkt nærmere.

2. MARINE MAMMALS IN NORWAY AND ADJACENT WATERS

In this chapter we shall document the species of marine mammals in coastal and offshore Norwegian waters, with emphasis on species that occur in the Barents Sea and adjacent coasts throughout or during parts of the year.

2.1 Seals

2.1.1 Common seal

Common or harbour seals (Phoca vitulina) are coastal seals found (in Europe) from France northward to Svalbard, and around Iceland and Great Britain (Fig. 1a). In Norway localized breeding colonies are found among skerries and smaller rocky islands, both along the outer coastline and in some of the deep fiords along the entire coast (Table 1; Fig. 1b). A small group of common seals has established itself on the western shore of Prins Karls forland, West Spitsbergen, representing the most northerly extent of the species to date (Krog and Bjarghov, 1973).

The species is generally considered non-migratory, although seasonal movements do take place in some areas (Van Bemmel, 1956). In addition, some individuals may travel longer distances such as across the English Channel (Bonner and Whitthames, 1974).

Puberty occurs at five to six years of age in the male and three to four years for the female (Boulva and McLaren, 1979). Whelping extends usually from mid-June to mid-July for European seals (Bonner, 1972). The pups are almost always born on land (Boulva and McLaren, 1979), but are able to swim from the moment of birth and may begin to enter the water from the first day. Lactation in the British population lasts for some three to four weeks (Harrison, 1960; Curry-Lindahl, 1975) and mothers make daily

Table 1.

Common and grey seals in Norway. Minimum numbers estimated from direct counts

County	Common seal Number	Grey seal Number
Finmark	380	350
Troms	700	150
Nordland	450	860
Nord-Trøndelag	240	230
Sør-Trøndelag	450	1400
Møre-Romsdal	1240	10
Sogn-Fjordane	370	50
Hordaland	30	0
Rogaland	105	120
Vest Agder-Swedish Border	455	0
Total	4420	3170
Probable Range	4,500 - 6,000	3,500 - 5,000

(Source: Sea Mammal Section, Institute of Marine Research, Bergen, current Oct. 1986)

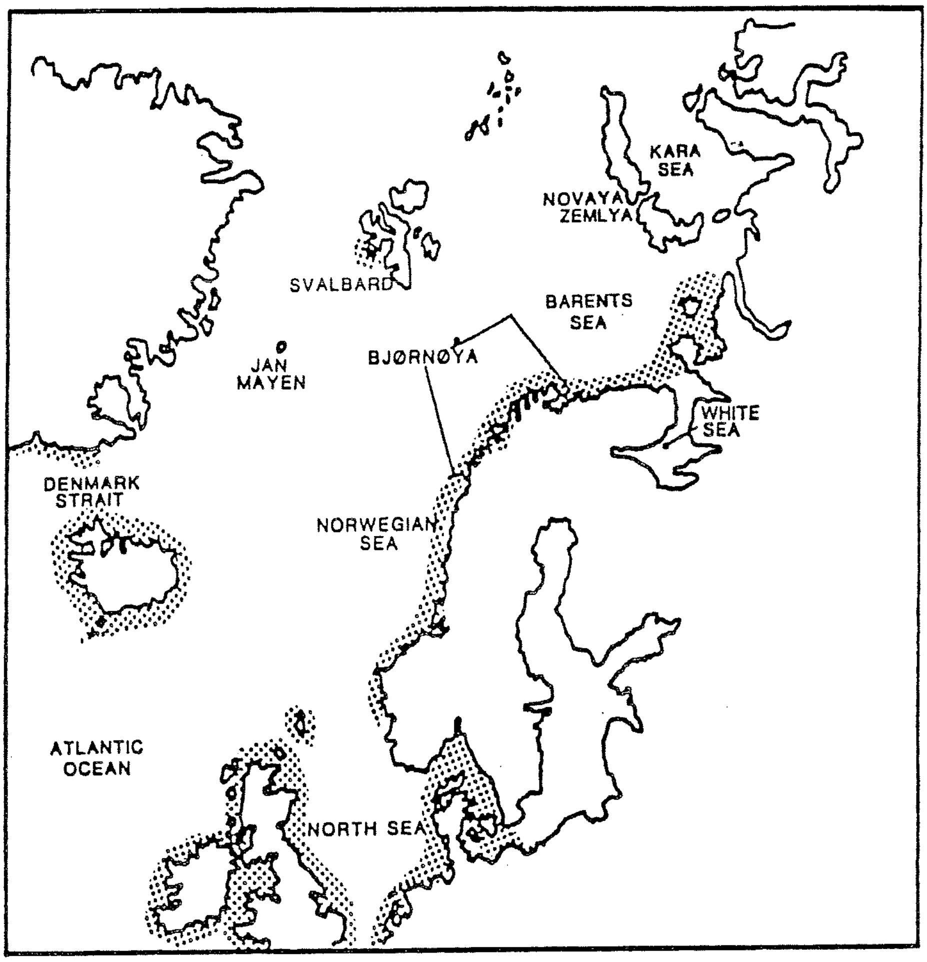

Figure. 1a. Common seal distribution in European waters

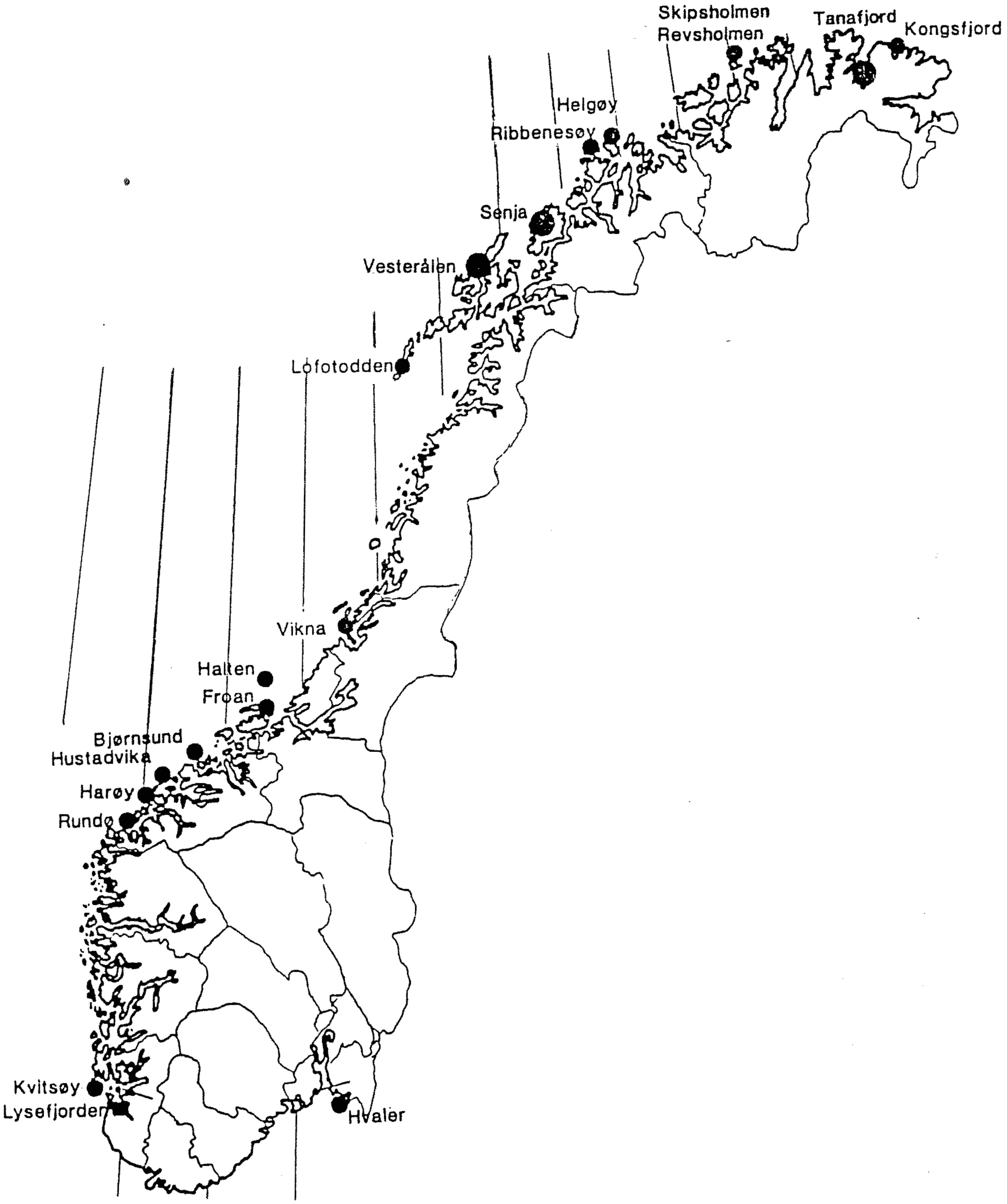

Figure 1b. Distribution of larger common seal colonies along the Norwegian coast

feeding excursions to sea during lactation. Mating occurs in August and early September about two weeks after weaning (Harrison, 1960). The mating period is preceded by fighting between the males than can be violent (Boulva, 1979; Sullivan, 1981). Mating is initiated by the male and always occurs in the water (Venableas and Venables, 1957; Allen, 1985). The length of diapause is not clear for European populations, but implantation probably occurs in early November after a delay of some two and one half months, based on calculations from American populations.

Moulting of the adult pelage occurs annually, probably in July and early August before the beginning of breeding (Venables and Venables, 1957).

Newly weaned pups feed on bottom dwelling crustacea for several months. Older animals feed on a variety of fish, cephalopods and crustaceans including herring, cod, salmon, and flatfish and consume about 5% of the body weight per day. Feeding is thought to occur mostly in the early morning.

Factors of possible relevance to oil pollution:

1. Harbour seal are permanently resident along coasts and do not move great distances.
2. Pups swim at a few days of age and would become oil-fouled by any oil slick.
3. Lactating females would become oil-fouled during their daily feeding excursions, possibly transferring oil to pups.
4. Serious depletion of crustacea and other invertebrates from oil toxicity could threaten first year seals but probably not older animals.
5. Harbour seal are flighty and disturbance during oil dispersal operations could cause temporary abandonment of haul-out sites.

2.1.2 Grey seal

Coastal populations of grey seals (Halichoerus grypus) are found along the coasts of the United Kingdom, Ireland, Iceland, the Færoe Islands, Norway, the Kola Peninsula, eastern Canada and Greenland, while ice-breeding populations occur in the Baltic Sea and the Gulf of St. Lawrence (Fig. 2a). In Norway there is a local coastal seal differing in distribution and behaviour from the common seal, by preferring more exposed skerries and rocky islets along the outer coastline. Discrete populations or individual wanderers can be found on along most of the coast although the bulk of the population and the major breeding groups occur mainly in the South Trøndelag area and further north, from latitude 63°N to 68°N (Fig. 2b) (Wiig, 1985). The population in Norway is currently estimated at between 3,500 and 5,000 animals (Table 1). In England the population is increasing annually at a rate of some 5%-6% (Bonner, 1975), and the same is probably true for Norway. The species does not migrate in the strict sense although a non-directional dispersal takes place after breeding, with a corresponding congregation before breeding (Bonner, 1981).

Most of the knowledge concerning East-Atlantic grey seal biology comes from United Kingdom sources, but the Norwegian population appears not to differ significantly. There are differences in breeding biology between the Baltic and Russian groups and the European group (Hook and Johnels, 1972; Curry-Lindahl, 1975). In principle the details presented here are also valid for Norwegian grey seals.

Whelping is spread over a two-month period with the peak in mid-October, and occurs on rocky islands lying some distance from the coastline (Bonner, 1981). Adult breeding males and pregnant females begin to congregate in the breeding areas in September. However, the pattern of male dominance over groups of females which is pronounced in British grey seal colonies (Henwer, 1960;

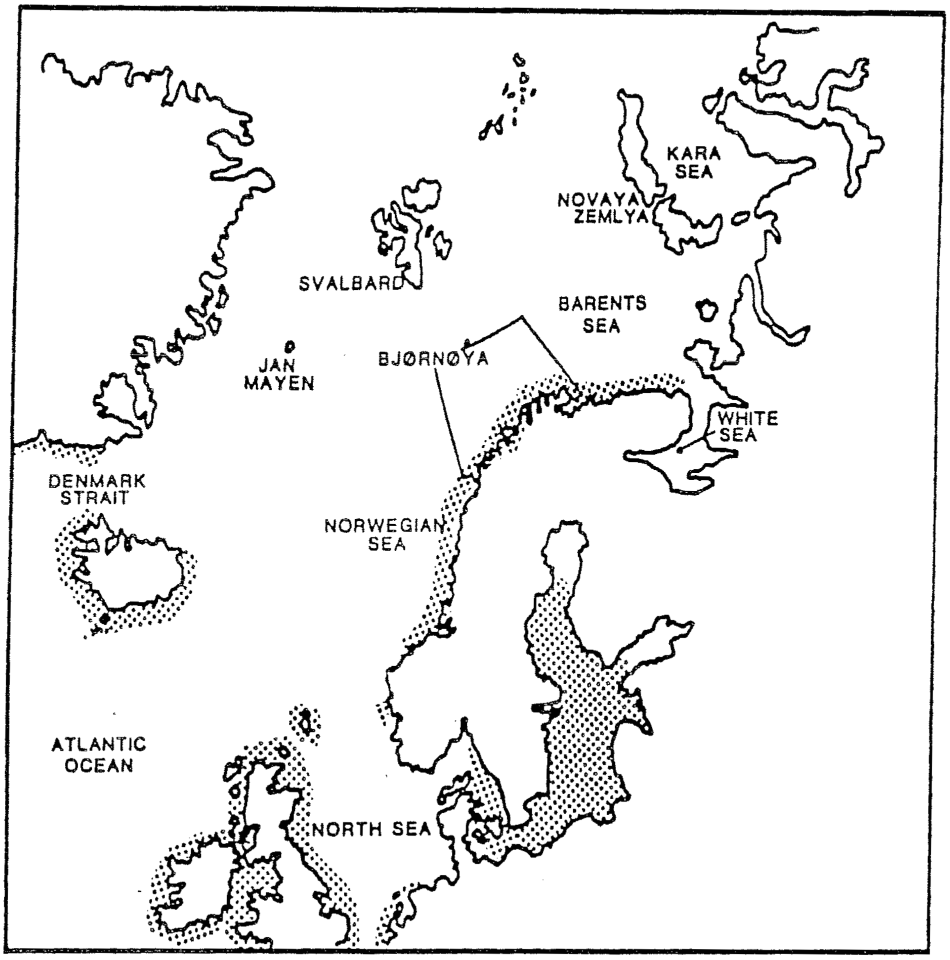

Figure 2a. Grey seal distribution in the Northeast Atlantic

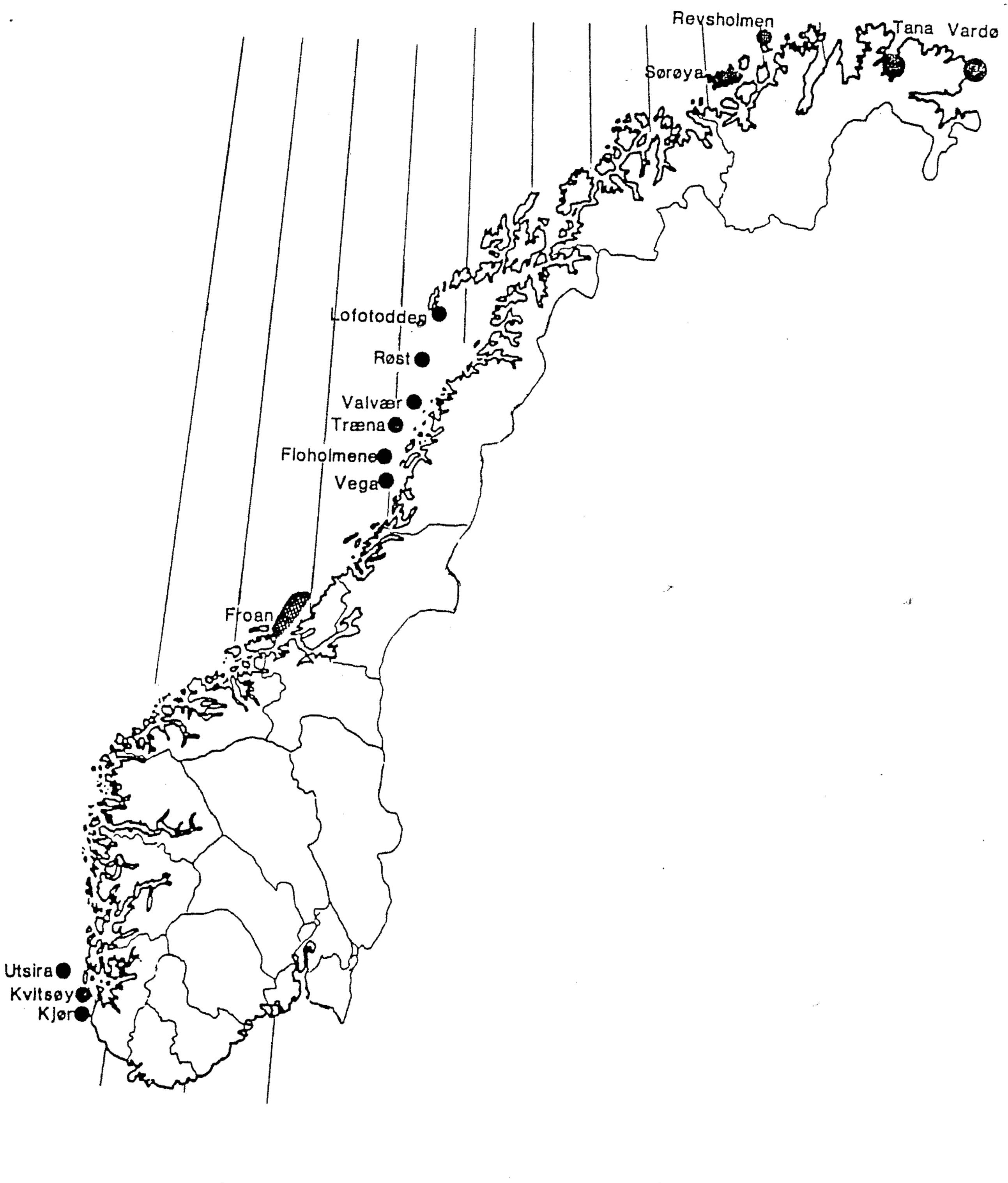

Figure 2b. Distribution of larger grey seal colonies along the Norwegian coast

Anderson, Burton and Summers, 1975) has only been observed at very few locations in Norway, where most breeding grey seals appear to establish family groups (male, female and pup) through the season (Ø. Wiig, pers. comm.)

Lactation lasts for 14 - 17 days and is followed after a few days by oestrus and copulation (November). Females remain on the islands only until they have mated and make trips to sea to feed or if disturbed whilst nursing their pups. After weaning, pups remain on the islands for some weeks after weaning before taking to sea, often lying protected in small pools. They are generally described as avoiding the water but we have seen occasional examples of young pups swimming with their mothers. As in other seals there is a period of embryonic diapause lasting for some 100 days, with implantation occurring in February. For most of this period the pregnant cow is at sea feeding.

Moulting takes place at the beginning of February for the adult females and in March for the adult males (Backhouse, 1960). Animals haul out onto rocky islands for considerable periods during the moult but not neccessarily at the same location as that used for breeding. Feeding is either reduced or stops completely during the moult (Bonner, 1981).

Grey seals feed near the coast (Bonner, 1981). The diet covers a wide variety of fish, with also smaller numbers of crustacea and molluscs. Cod, salmon, herring and flatfish are the prime fish species eaten, apparently by all age classes right from newly-weaned. The daily food intake is estimated at between four and five percent of the body weight.

Factors of possible relevance to oil pollution:

1. The species does not migrate and is found in coastal waters throughout the year.
2. During the breeding season females regularly enter the water and could become a source of oil-fouling for the pups even if the pups

stay on land.

3. The variety of fish eaten suggests that a risk to survival from oil-produced death of prey species would not occur.

2.1.3 Harp seal

Harp seals (Phoca groenlandica) inhabit the North Atlantic Oceans and range from northern Russia through the Barents Sea to the Svalbard archipelago, over the Greenland and Norwegian Seas to Greenland and in the Northwest Atlantic from Nova Scotia through the Davis Strait and Baffin Bay and into Hudson bay (Fig. 3; King, 1983).

Three apparently separate stocks breed and moult on the pack-ice at Newfoundland, in the Greenland Sea near Jan Mayen (West Ice) and in the White Sea and Southeastern Barents Sea (East Ice) from late February to early May. All stocks are exploited by commercial sealers when they congregate on the ice during the breeding and moulting season and are also hunted by aboriginals and coastal fishermen when seasonally available in northern coastal waters. They were all severely depleted by over-exploitation during the 1950's and early 1960's but are now increasing under regimes of strictly enforced quota regulations for commercial sealing. Recent drops in the market for seal skins led to reduced exploitation and boosted the increasing trend in all three stocks. Both the West and East Ice stocks support a Norwegian and Soviet sealing industry. Provisional assessments indicate a current stock of about 250,000 in the West ice and an East Ice stock in excess of one million seals, the latter increasing at an annual rate of 5% - 7% (Øritsland, 1985).

Both stocks migrate with the same general pattern of dispersion, mainly to the North to feed in the summer and coming south in the winter and spring to breed (Ronald and Healey, 1981). During the summer the West Ice stock is found in its northerly feeding grounds between Spitsbergen and Greenland, moving south to

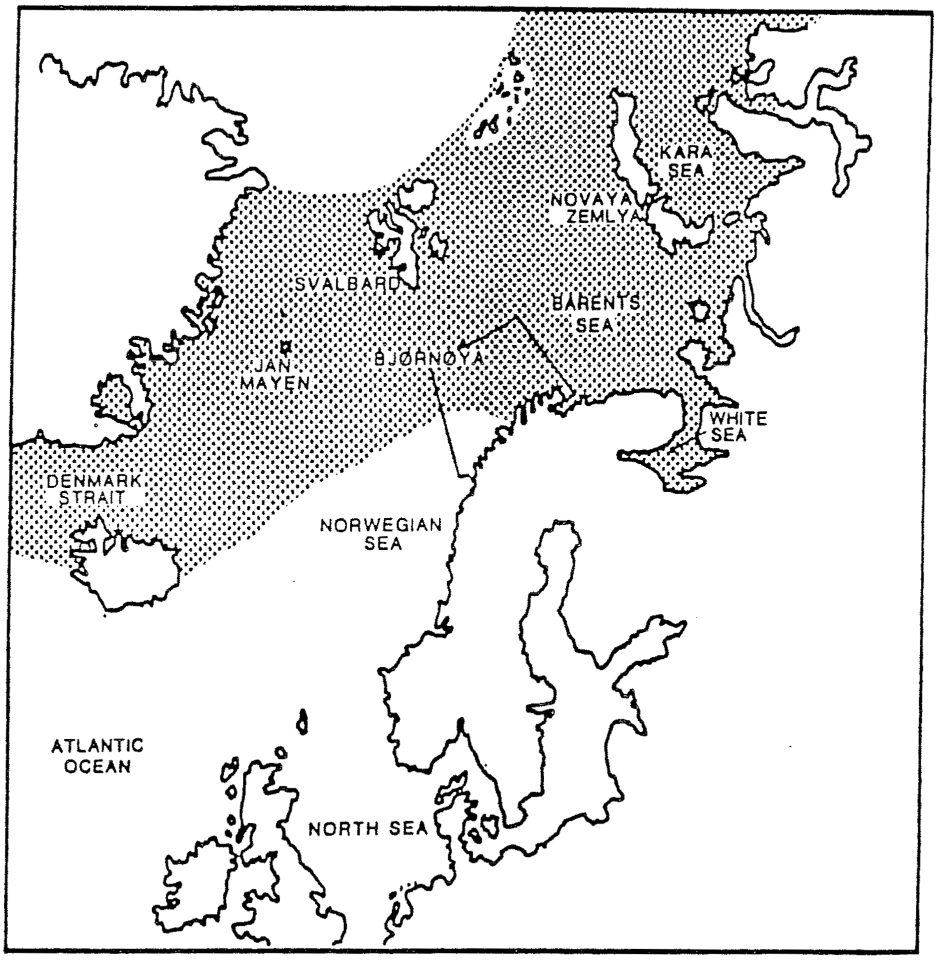

Figure 3. Harp seal distribution in the Northeast Atlantic

Jan Mayen in the winter, with whelping occurring on the ice in March. As the ice drifts south the adults mate and move to the ice north of Jan Mayen where they moult during April and May. By June the herd has returned to their feeding grounds.

The East Ice stock spends the summer, autumn and early winter in the Barents and Kara Seas (Ronald and Healey, 1981). During this time they may also be found in great numbers throughout the Barents Sea. As the ice border extends southward with winter the mature seals congregate in the White Sea where whelping occurs in late-February. In March the ice breaks up and is carried north-west into the Barents Sea, taking with it the weaned pups and other age classes. Sub-adults and adults moult from April to late May and again disperse northwards to begin an intensive feeding phase.

During a period of cooling in the barents Sea from 1978 to 1984, with a consequential westwards distribution of prey species, harp seals invaded the coast of eastern Finnmark in hundreds of thousands each year. The seals appeared to follow the winter capelin migrations to the coasts and sub-adult seals remained in coastal waters through the spring, while mature seals appeared to leave before the breeding season in late February to return in smaller numbers towards the end of the regular moulting season in late April. Each year several thousand seals were accidentally caught in gill nets during the Finnmark spring cod fisheries.

In the winter and spring of 1986 smaller flocks of harp seals invaded coastal waters from western Finnmark south to Nord-Trøndelag. A few thousand of these drowned in fishing gear. The recapture of one seal tagged at Jan Mayen suggests that this year the seals came in from the west (T. Øritsland, pers. comm.).

Puberty occurs at age three to six years for females and five to six years for males (Ronald and Healey, 1981). During the breeding season (late-February and early March) females are gregarious and form large breeding aggregations in the pack-ice. In consolidated ice they maintain breathing holes about 60cm-90cm in diameter. Pups are born on the ice and weaned after ten to twelve days. Concurrent with weaning, the lanugo is shed and pups begin to enter the water. Pups gain weight rapidly at a rate of 2.5kg per day (Ronald and Dougan, 1982). Mating occurs as the pups are weaned, both on the ice and in the water (Merdsoy, Curtsinger and Renouf, 1978). As with other northern seals, males produce a variety of underwater calls during the breeding period which seem to have an agonistic role (Watkins and Schevill, 1979). There follows an eleven week embryonic diapause, with implantation occurring in June. Females normally breed every year.

Young harp seals feed in the surface ocean layers on small pelagic crustaceans and fish. Older seals also feed at greater depths on capelin, herring, polar cod, cod and others, crustaceans and squid (Ronald and Healey, 1981).

Factors of possible relevance to oil pollution:

1. Harp seals are found in the southern Barents Sea at irregular intervals during the pelagic phase (summer, autumn and early winter), and can collect in moderately high concentrations. Large numbers could be fouled by oil.
2. Younger seals that feed in the upper ocean layers may be affected locally by death of prey species due to oil.

2.1.4 Hooded seal

The hooded seal (Cystophora cristata) is a migratory species that ranges from Newfoundland and the Davis Strait east to Bjørnøya and Svalbard (Fig. 4). (Wiig and Lie, 1984). They are a comparatively small group, numbering probably between 500,000 and 1,000,000, with a preference for more remote and thicker ice than the harp seal.

Hooded seals are seasonal visitors to Svalbard during autumn and perhaps winter. In June-July they assemble in polar pack-ice in the Denmark Strait and Greenland Sea off the east coast of

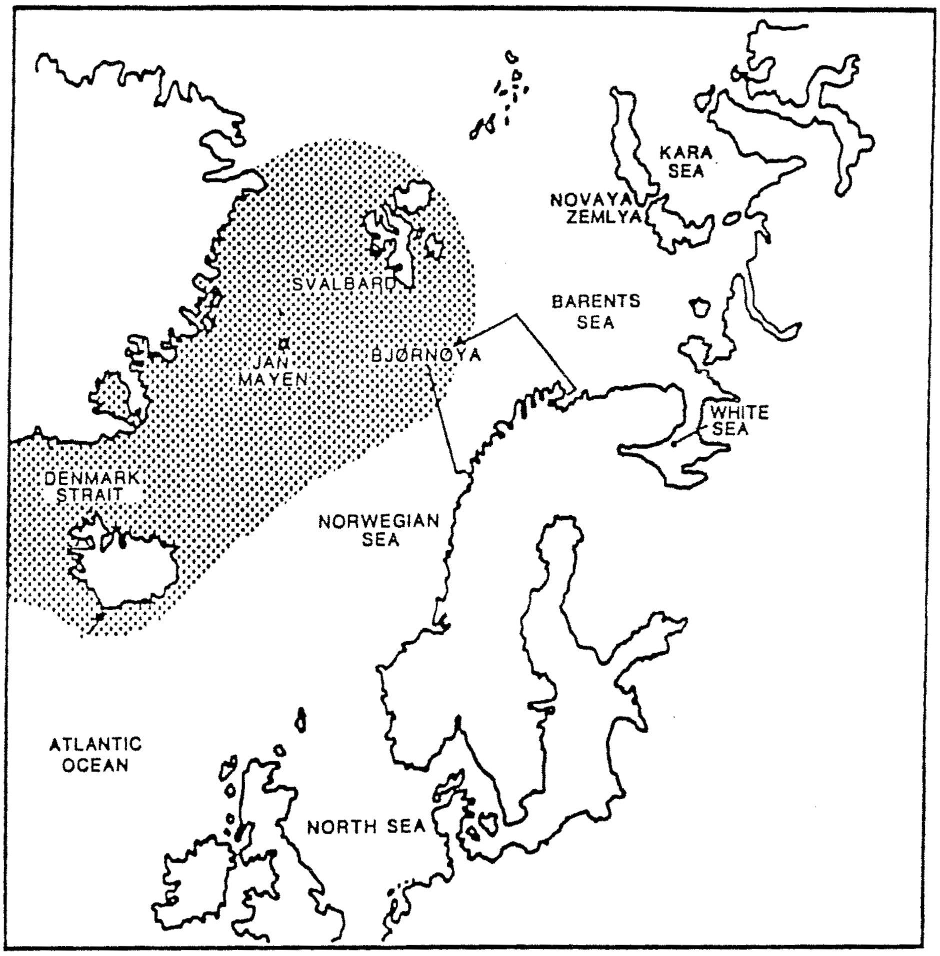

Figure 4. Hooded seal distribution in the Northeast Atlantic

Greenland, to moult (Reeves and Ling, 1981). After moulting, the seals disperse widely in all directions to feed from late summer to early winter. Accidental catches in fishing gear show that they also feed in offshore waters along the coast of northern Norway and in the Barents Sea near Svalbard and Bjørnøya (T. Øritsland, pers. comm.). In late winter these animals again concentrate in areas of heavy ice preparatory to whelping which occurs in the second half of March. Loose congregations of breeding hooded seals are found in the west ice near Jan Mayen and off Newfoundland in the Davis Strait. Occasional breeding also occurs in the East Ice and even on the coast of Norway (Øritsland and Bondø, 1980). After breeding, most adults make their way back to the Denmark Strait and the Greenland Sea for the next moult and completion of the annual cycle.

Hooded seals are hunted by Norwegian and Soviet sealers in the West Ice, Canadian and Norwegian sealers off Newfoundland and coastal hunters in Greenland and along other Arctic shores of the northeast Atlantic. They are protected however in the Barents Sea and in the Davis Strait pack ice (T. Øritsland, pers. comm.).

After the first few moults all age groups are strong swimmers and deep divers and feed on a variety of benthic and pelagic fishes, squid and crustaceans. This catholic diet makes them less susceptible to oil-induced death of prey species than, for example, bearded seals. Feeding is also seasonal, occurring intensively in the spring after breeding and in the autumn and winter after the end of moulting, with periods of fasting during breeding and moulting.

Puberty occurs at three to six years of age for females and at four to six years for males (Øritsland, 1964, 1975; Born, 1982; Jacobsen, 1984). Birth takes place primarily in the latter half of March on heavy ice floes. Adult females distance themselves from each other and may be "courted" by several males at a time even before they are in oestrus. As in other species, males use both above- and under-water sounds during social displays, and in addition distend their expanded nasal cavities and even evert and extend the nasal septum through one nostril as a visual display (Borland, 1965). The pup is born without lanugo and is called a "blueback". Pups weigh about 22kg at birth, and are suckled commonly for only four to five days to attain a maximum weight at weaning of about 42kg, such that weight gain over lactation averages seven kilograms per day (Bowen, Oftedal and Bruces, 1985). In the Newfoundland area, pups leave the whelping areas and become pelagic when only some eight days old (Bowen, 1985). Depending on ice conditions the pups may remain on or near the ice for up to five weeks in the West Ice area. Mating occurs in the water (Øritsland, 1964) some 12 days after birth, and fertilization is followed by a comparatively long diapause of up to 16 weeks. Implantation apparently occurs in late-July to early-August (Øritsland, 1964). Reproduction is annual (Øritsland, 1964, 1975).

Factors of possible relevance to oil pollution:

1. While in coastal and offshore Norwegian waters or in the Svalbard region hooded seals are dispersed, and probably relatively low numbers would be affected by an oil spill.
2. The diet is varied, reducing the likelyhood of death through disturbance of food supply.
3. Pups rapidly gain blubber and thus resistance to the acute thermoregulatory effects of oil-fouling.
4. Pups are born without lanugo.

2.1.5 Bearded seal

The bearded seal (Erignathus barbatus barbatus), is a circumpolar true or phocid seal living in near-shore parts of the Barents Sea, usually in association with sea-ice (Burns, 1981; Fig. 5). In past years it was hunted at Svalbard and in the East Ice (southwestern Barents Sea) by Norwegian sealers (Benjaminsen, 1973) but has been protected in the East Ice since 1970. Bearded seals

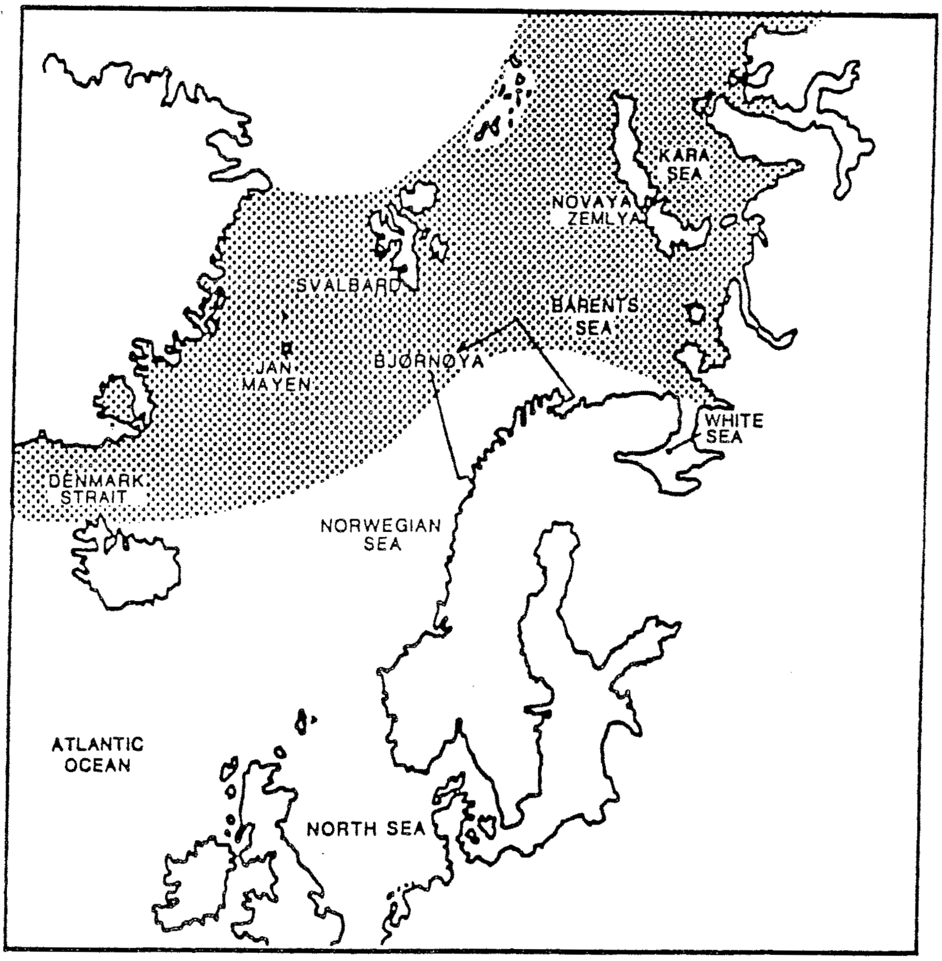

Figure 5. Bearded seal distribution in the Northeast Atlantic

have not been taken by Norwegian sealers since 1973 but in the White Sea area Soviet coastal hunters have caught on average two hundred per year through the last decade (T. Øritsland, pers. comm.). Burns (1981) cites a report of Chapskii (1966) which gives the population size in the north Atlantic as 300,000 animals.

The bearded seal is one of the largest of northern phocids. The average weight and length of adults are 240-250kg and 233cm (Burns and Frost, 1979). The principal prey species are bottom-living invertebrates, mainly crustaceans and molluscs, and some fish. The species is therefore restricted to fairly shallow waters, commonly to water depths of 50m or less and probably with an absolute depth limit of 130m (Burns, 1981). In these seas, bearded seals use areas where the ice is in constant motion, creating leads and polynyas. In winter, when the sea ice is wide-spread, seals make and maintain breathing holes in areas of thinner ice, and are also found distributed in the drifting pack ice. In areas where the sea ice recedes during summer to beyond the limits of shallow water, bearded seal will haul out onto beaches instead.

Puberty occurs at five to seven years for males and five to six years for females, although Potelov (1975) reported that some females ovulate in their third year. Pupping occurs from mid-March through to the first week of May, with the peak in late April (Potelov, 1975). Pups are born on ice, are active and can swim at birth, and begin to catch prey themselves before weaning. The mother-pup bond is strong and mothers remain close to and attempt to protect their pups in case of threat. Lactation lasts for 12-18 days, during which time body-weight increases from some 33kg at birth to 85kg.

Breeding occurs from the end of March to the first half of May for the Barents Sea population (Potelov, 1975) and coincides with the latter stages of lactation and with weaning. Males utter a song-like vocalization as a part of social interaction during the breeding months (Ray, Watkins and Burns, 1969). Breeding occurs annually (Burns and Frost, 1979), although McLaren (1958) considered that reproduction was biennial. Implantation occurs from July to early August after a delay of some two months. There is no evidence for reproductive senility.

Moulting has not been studied closely but probably occurs from April to August with a peak during May-June (Burns, 1981).

Bearded seals are commonly found as individuals on the edges of small drifting floes. They are solitary animals and do not form herds except possibly loosely during pupping and breeding. Seasonal movements of bearded seals in the Barents Sea are not known but can be expected to some degree and to be related to the cycle of progression and regression of the sea ice. For comparison, the northern-Pacific population summers in the Chukchi Sea, but migrates southward in late Autumn through the Bering Strait and into the Bering Sea where it winters, moving northward again in April (Burns, 1981). This seasonal migration follows the movements of the ice front.

Burns and Frost (1979) considered that the effect of an oil spill on bearded seals would be severe due to widespread death of the animals' prey species.

Factors of possible relevance to oil pollution:

1. The young is born with an adult fur and not lanugo.
2. The heavy birth weight and very fast fat deposition rate of the pup suggest rapid development of resistance to the acute thermoregulatory effects of oil fouling.
3. Bearded seals frequent open pack ice where water preponderates over ice. After spillage, oil thickness here should be thin relative to closer pack ice.
4. After spillage, oil penetrates downwards in the water column to at least 50m depth (Campbell and Martin, 1973), which coincides with the practical diving limit of this seal. This may have serious consequences for the survival of bearded seals.

5. The presence of bearded seals in an oil affected area can be established (during the breeding season) by distinctive underwater calls.

2.1.6 Ringed seal

The circumpolar ringed seal (*Phoca hispida*) is the smallest and most abundant Arctic phocid species (Frost and Lowry, 1981). Ringed seals are inhabitants of the permanent pack-ice of the northern Barents Sea but congregate in areas of fast-ice around the Svalbard archipelago during the breeding season in late spring (Fig. 6). In Baffin Bay, and therefore possibly also in the Barents Sea, some populations also breed in stable drifting pack-ice (Finley, Miller, Davis and Koski, 1983). The ringed seal are an extremely important source of food and money for aboriginal people throughout the Arctic. Because of the relatively poor quality of the pelt, it has never been taken in numbers by Norwegian sealers. Soviet landsmen, however, take a few thousand each year in coastal waters of the southeastern Barents Sea (T. Øritsland, pers. comm.).

Both sexes measure about 150cm from nose to tail when adult and weigh about 90kg (Gjertz and Lydersen, 1983). The main prey species in the Svalbard area are pelagic nekton - Arctic cod and amphipods (Lydersen, Gjertz and Weslawski, 1985).

The age of puberty is four to seven years for females and for males six to seven years (Smith, 1973). Most pups are born in March and April although the birth season extends as late as June (Smith, 1973). Births usually occur in specially constructed birth lairs on shore-fast ice (Smith and Stirling, 1975; Gjertz and Lydersen, 1983), although some pups are born in the open on drifting pack ice (T. Øritsland, pers. comm.). Birth lairs are built by the mother in the snow masses that collect in the lee of ice irregularities, and have access to water through a single breathing hole in the ice floor (Smith and Stirling, 1975; Gjertz and Lydersen, 1983).

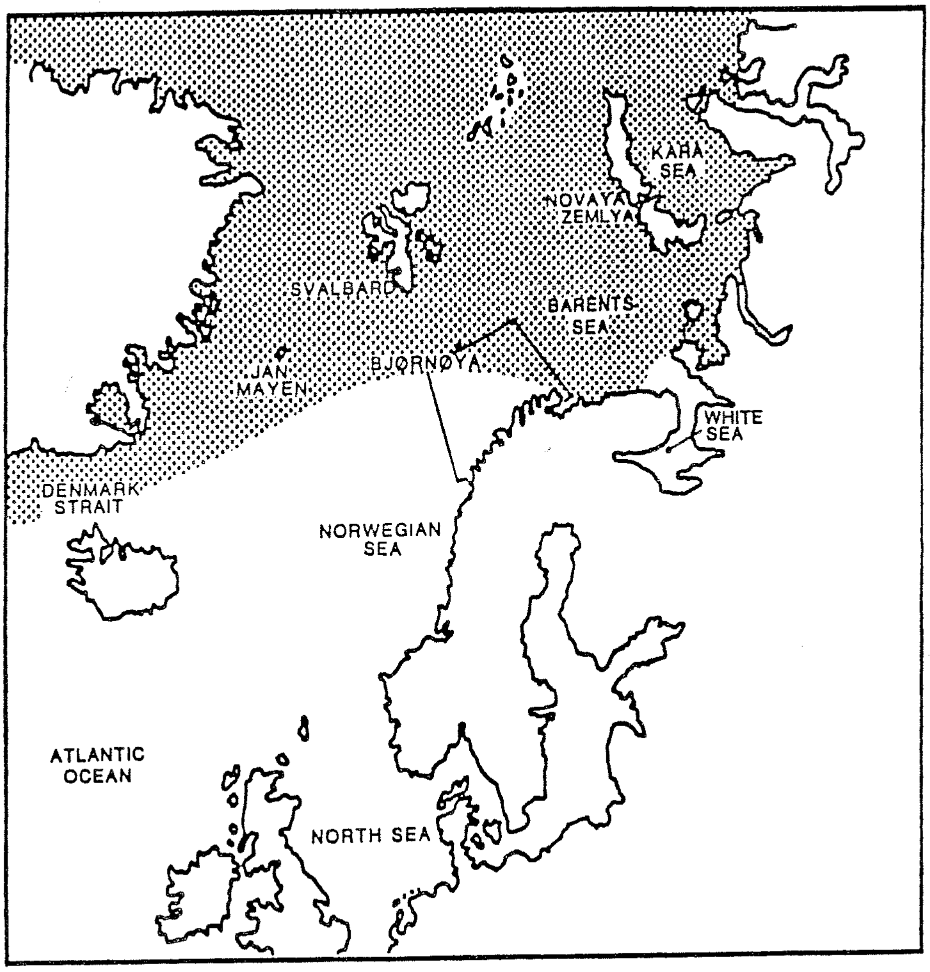

Figure 6. Ringed seal distribution in the Northeast Atlantic

Breeding males also construct smaller haul-out lairs for their own use.

Pups are born with a pelage of white lanugo, which is moulted before weaning (Frost and Lowry, 1981). The weight is some 4.5kg at birth and increases to 9 - 12kg over the relatively long lactation period of five to seven weeks. The pups are able to swim from the lair in the case of its destruction by ice movement or polar bears, but ordinarily stay within the lair and avoid the water until weaned.

Mating occurs in late April and early May within one month of parturition, but implantation of the blastocyst is delayed for some two and a half months, occurring at about the end of August (Smith, 1973). Males are thought to be monogamous and mating to occur in the water (Frost and Lowry, 1981). During the breeding period it appears that dominant males occupy underwater territories and haulout lairs in the more stable ice where most of the birth lairs are and exclude juvenile males to the outer ice areas. Vocalization is part of the social structure of the ringed seal during the breeding season (Stirling, 1973).

Moulting occurs from late March to July with the peak in June, and younger animals moult earlier than adults. During the moult animals spend much less time in the water than during other times of the year and can be observed in large numbers hauled out along leads in the ice. They feed little although do not cease entirely.

As for bearded seals, there are seasonal changes in distribution. During the breeding season in March-April, breeding adults are found in the stable fast-ice, while non-breeders frequent more peripheral ice and moving pack (Frost and Lowry, 1981). Early in the summer the seals moult, still in these same areas. In late summer all age classes and both sexes move out to the edge of the permanent pack-ice or to the remnants of ice near the shore, and spend most of their time in the water feeding. Here they remain throughout the winter and into early spring, until the approach of the next breeding season. In the western Atlantic, this pelagic phase and redistribution may involve journeys of hundreds of kilometres, but there is no evidence for similar long migrations in the Barents Sea (Øritsland, 1985).

As well as seasonal locomotory patterns there exists a daily pattern of activity during the early summer (Smith, 1973). At this time ringed seal haul out around leads and breathing holes during the day hours and spend the evening hours in the water (Smith, 1973). This pattern is lost in mid-summer when the seals moult and spend much longer periods on the ice. Haulout is also affected by weather, as the seals stay in the water during cold and high wind (Smith and Hammill, 1981). For the rest of the year the seals are pelagic and spend little time on the ice surface.

Factors of possible relevance to oil pollution:

1. Fast-ice phase.

a. Most of the adults are found in fast-ice areas with little ice movement. There should be little penetration of oil into this area provided under-ice oil movement does not occur.

b. After a spillage of oil in fast-ice, lactating females could be expected to become oil-fouled during feeding excursions and to deposit some of this oil into the birth lair. The pup can be expected to become partially or totally oil-fouled.

c. The effect of prolonged oiling of the pup in the lair is unknown.

2. Pelagic Phase.

a. Oil in drifting pack ice can be expected to have a thickness of up to one centimetre in water and more on the floe surface.

b. The pelagic existence of the ringed seal in pack ice from late summer to early spring would make it very susceptible to oil-fouling from any local spill.

c. The presence of ringed seals during the spring breeding season may be established by listening for underwater calls.

2.1.7 Walrus

The Atlantic walrus (Odobenus rosmarus rosmarus) is a subspecies of a larger walrus population with nearly circumpolar distribution (Fay, 1981; Fig. 7). There are presently about 30,000 individuals (Reijnders, 1982). They are easy to distinguish from the large size, long tusks (which both sexes possess) and rough skin with short coarse hair. Walrus are inhabitants of drifting pack ice in shallow seas and feed on benthic species to a depth of about 80m (Fay, 1981). There is apparently about 100 walrus summering in the Svalbard area, most of which are males, but numbers vary and up to 300 have been observed (Born, 1984). There appears to be a repopulation of the Svarlbard archipelago taking place from groups around Franz Josef Land and Novaya Zemlya.

Walrus are highly gregarious, travelling and hauling out in groups. Both on land and ice, they lie in close physical contact with their neighbours. Lone individuals are usually adult males. The species is sexually dimorphic. Adult males are 260-345cm long and weigh 790-1,400kg, while females are 218-288cm long and weigh 522-925kg (Fay, 1981). They seem to be migratory animals, following the movements of the ice front South in the autumn and North in the spring, although the details of these movements have not been studied.

Puberty occurs usually at five to six years for females and nine to ten years for males. However it takes a further six years or so before males are large enough to compete socially during breeding (Fay, 1981). Lukin (1978) reported that whelping occurs, at least for the Novaya Zemlya group, in late December and early January, although for the western Atlantic group it is the spring (April-May)(Fay, 1981). There is born usually a single calf that is suckled for about two years (Fay, 1981). After weaning females stay with groups of adult females while males usually wander away to join herds of younger and older males. Mating occurs from January to

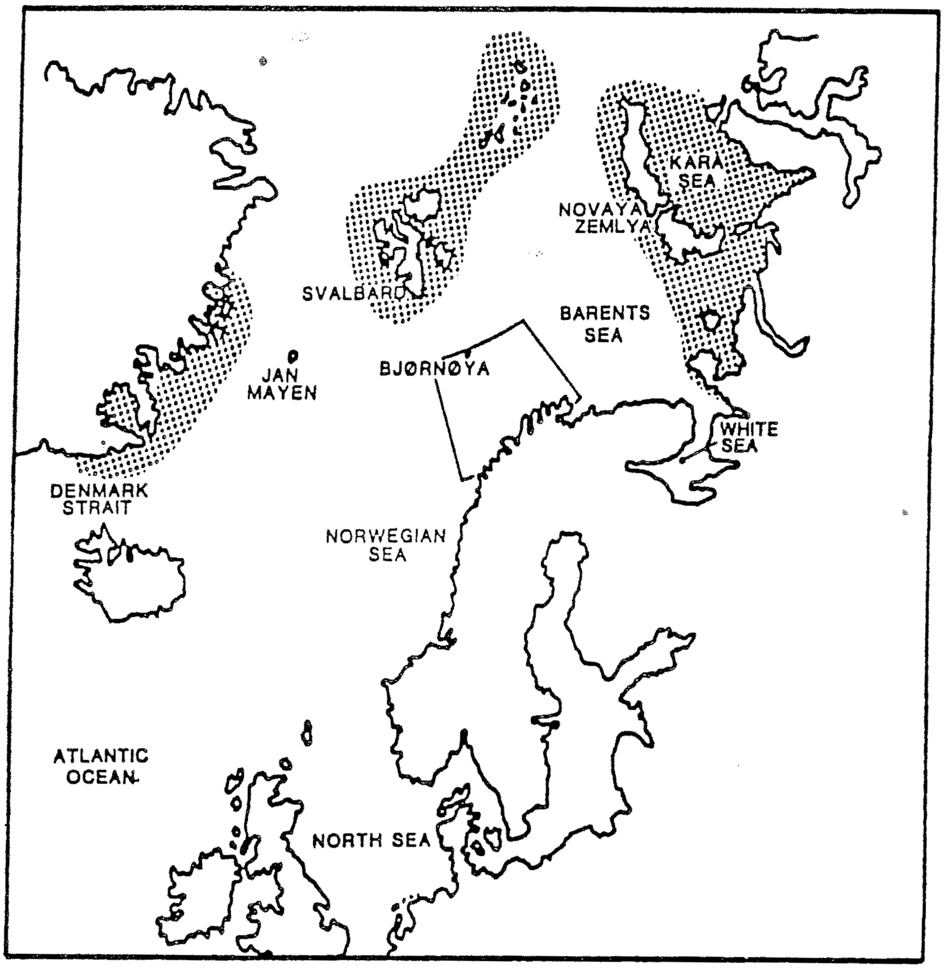

Figure 7. Walrus distribution in the Northeast Atlantic

March (Fay, 1981). The mating system is polygynous. Males compete with each other for proximity to groups of females and then display in the water in front of them with a complex system of calls (Schevill, Watkins and Ray, 1966; Ray and Watkins, 1975). Individual females leave the resting herd to meet a chosen male in the water, where copulation occurs (Fay, 1981). Implantation of the blastocyst is delayed four to five months and occurs in June and July. The birth interval is two years in young adults and four years in older females.

The food consists mainly of benthic organisms, especially bivalve molluscs, but small crustaceans, worms, fish, sea-stars and even other marine mammals are also eaten (Oliver, Slattery, O'Connor and Lowry, 1983; Lowry and Fay, 1984). The daily food intake is some six per cent of body weight.

Factors of possible relevance to oil pollution:

1. Walrus are gregarious so that groups rather than individuals may become oil-fouled.
2. Oil spilled in drifting pack ice forms thicker layers than in open sea and may remain a contaminant over several melt seasons.
3. The prey is primarily benthic invertebrates that are very sensitive to oil toxicity.
4. Walrus are unlikely to be found in the southern Barents sea because of the excessive water depth.

2.2 Large whales

Large whales that have been sighted in the Barents and North Seas include the fin, sei, minke, blue, sperm, humpback, and Greenland whale (Benjaminsen, Berlund, Christensen, Christensen, Huse and Sandnes, 1976). With the exception of the sperm and bowhead, these whales are rorquals, and are strong swimmers with long seasonal migrations (Jonsgård, 1966a). The blue and sei whales probably feed exclusively on pelagic crustaceans (krill). Fin, minke and humpback eat krill and various fish, and minke whales take even larger fish such as cod, saithe and haddock. The food of the sperm whale comprises squid and octopus from mid- and deep-water, and benthic fish (Caldwell, Caldwell and Rice, 1966). The great increase in krill abundance in high Arctic waters during the spring and summer months takes the whales northward in a feeding migration. During the autumn and winter the whales move southward in a breeding migration to the warmer waters of the north Atlantic, where birth and mating occur. The information given here regarding distribution has been collected mostly from whaling reports and is not necessarily comprehensive. In addition, the distribution described here may include regions in which whales are now seldom seen, but these areas can be expected to be reinhabited as stocks increase.

2.2.1 Right whale

The Greenland or bowhead whale (Balaena mysticetus) is a circumpolar species that is extremely rare in the North Atlantic due to several centuries of overhunting. The biology of the species in this region is largely unknown. One Greenland whale with calf was reported near Novaya Zemyla in 1973 and another with a calf off Svalbard in 1975 (Benjaminsen et al., 1976). The 1973 observation was the first recorded for 10 years. A single adult was seen off the Finnmark coast in May, 1982 (Anon, 1983a). Jonsgård (1982) regards these rare sightings to be "stragglers which have strayed into the area during summer". No sightings of live whales have ever been made during survey cruises in the northern Barents Sea, although one carcass was seen at location 79°55'N, 29°49'E in 1980 (Jonsgård, 1982) and two individuals in the pack ice at 79°59'N, 03°25'E (McQuaid, 1986).

A brief summary of the biology of the north-Pacific population is given by Fraker (1984). The whales spend the winter in the Bering Sea and migrate north-east through the Bering Strait along the coast of Alaska in the spring to reach the Beaufort Sea by May. Much of this route is still ice-covered and the whales must make extensive use of leads and even force breathing holes when the ice is thin. This makes the Greenland whale the only large whale to depend on ice leads during migration, causing Engelhardt (1983) to express concern for its welfare in the case of an oil spill in ice. If stray whales at Svalbard show the same behaviour, they could be equally vulnerable to oil pollution. The summer is spent in the Beaufort Sea feeding before moving west again in August towards the Chukchi and Bering Seas.

Three types of feeding activity were distinguished: skim, water column and near-bottom. Skim feeding whales move slowly at the surface with their mouths open. Water column and near-bottom feeding involves the same tactics but at respectively different levels. In the last case mud can be seen streaming from the mouth after surfacing. As with the sei whale, one wonders about the amount of oil that might be ingested during bouts of skim feeding after an oil spill.

Because of the seriously depleted state of the Northeast Atlantic population, great consideration should be given to the possible effects of oil-fouling on these whales and on their prey species. However, very few of these whales could be expected to occur in the proposed oil lease areas of the southern Barents Sea.

Factors of possible relevance to oil pollution:

1. These whales migrate through ice and make extensive use of leads. Oil spilled in drifting ice forms layers up to a centimetre or more thick.
2. The habit of skimming the surface during feeding may predispose these whales to oil ingestion.

2.2.2 Humpback whale

Humpback whales (Megaptera novaeangliae) have a very pronounced migration cycle that includes passage close to the Finnmark coast (Jonsgård, 1966a). After spending the summer, autumn and early winter feeding mostly on capelin, in the Barents Sea, there is a westward migration from January to March along the Norwegian coast. The whales approach the coast around North Cape and follow it closely as far as Sørøya (Ingebrigtsen, 1929), where they swim westward into the north Atlantic or Jan Mayen/Iceland area. They appear to avoid the North Sea (Slijper, 1962), although very occasionally individuals have been sighted along the Norwegian west coast (Benjaminsen et al., 1976). They again appear in the Barents Sea region in summer, with calves, this time moving eastward further out from land than during the winter. In summer the largest numbers have been observed in the northeastern Barents Sea. Humpback whales have been completely protected by Norwegian law since 1955, and in recent years this species has increased in numbers in north-east Atlantic waters.

Ingebrigtsen (1929) describes two techniques for feeding on krill at the surface. The first technique is to swim around the shoal at great speed, lashing the sea into foam with its flukes. This manouevre concentrates the krill, whereupon the whale dives and envelops the krill from below, breaking the surface. The other approach is to to swim in a ring a short distance under the surface while blowing a line of bubbles. This bubble "net" again concentrates the krill for the whale to swallow.

The bulk of the entire humpback population will pass the Finnmark coast through proposed oil leases Troms III and south Finmark Vest from January to March, and again during the summer, this time with sucking calves.

Factors of possible relevance to oil pollution:

1. Feeding below the surface may reduce the amount of oil swallowed during feeding.
2. The whales migrate through Barents Sea oil-lease areas. They do not feed during the migratory phase, which should greatly reduce the chance of oil ingestion. The whales follow a coastline that is expected to be seriously fouled in the event of an oilspill on the Tromsøflaket field exposing them to external oil contamination in the case of an accident.

2.2.3 Blue whale

The distribution of blue whales (Balaenoptera musculus) extends throughout the Barents Sea up to the Svalbard region ice edge (80°N) (Jonsgård, 1966a) and southward through the North Sea, although their numbers are still quite depleted. The Barents Sea appears to be an end-stage in a migratory sweep from both the south-west and south-east north Atlantic (Slijper, 1962), with those coming from the south-east Atlantic passing along the Norwegian coastline. The whales reach the Finmark-Bjørnøya region in June and July and begin the reverse trip south-west in August (Ingebrigtsen, 1929).

Factors of possible relevance to oil pollution:

1. Single animals and small groups can be expected in the proposed oil-drilling areas throughout the year.
2. Blue whales feed primarily on krill.

2.2.4 Fin whale

Separate fin whale (Balaenoptera physalus) populations are believed to exist off west Norway and in the Barents Sea off north Norway, with little or no mixing between the two (FAO, 1978). According to Ingebrigtsen (1929), there are indications that in

March, the northern group approaches the coast of Finnmark from the northern regions of the Barents Sea, and leaves westward in April in a large clockwise circle that takes them past Bjørnøya and Svalbard from May to August, and to eastern Arctic waters for the winter. However, numbers of fin whales have been reported both throughout the summer around Svalbard and in autumn along the Finmark coast (the latter may be members of the western group) (Jonsgård, 1966a).

Concerning the western group, Jonsgård (1966b) reports that fin whales were once seen off western Norway for most months of the year. During the summer migration they fed on krill, but in the winter they followed the schools of Atlanto-Scandic herring during its spawning migration and fed upon herring. They approached the central coast in January and moved south along the coast until April-May before dispersing west or north into the Norwegian Sea. While the size of the northern populaton is undetermined, there were estimated to be 2,700 in the western group in 1946 and about 400 in 1963. Fin whales have not been caught by Norway since 1968. The locations of whales which were caught from Norwegian shore stations is shown in Fig. 8.

Numbers of fin whales may therefore be expected to occur inside the proposed oil lease areas from March through to the autumn (September-October).

1. The most rewarding areas of past hunting and therefore probably of whale numbers correlates well with present and proposed oil lease areas.
2. Fin whales feed at the surface but from below, perhaps reducing their contact with possible oil slicks.
3. Prey species include both krill and fish, possibly reducing the threat of death of prey species after oil.

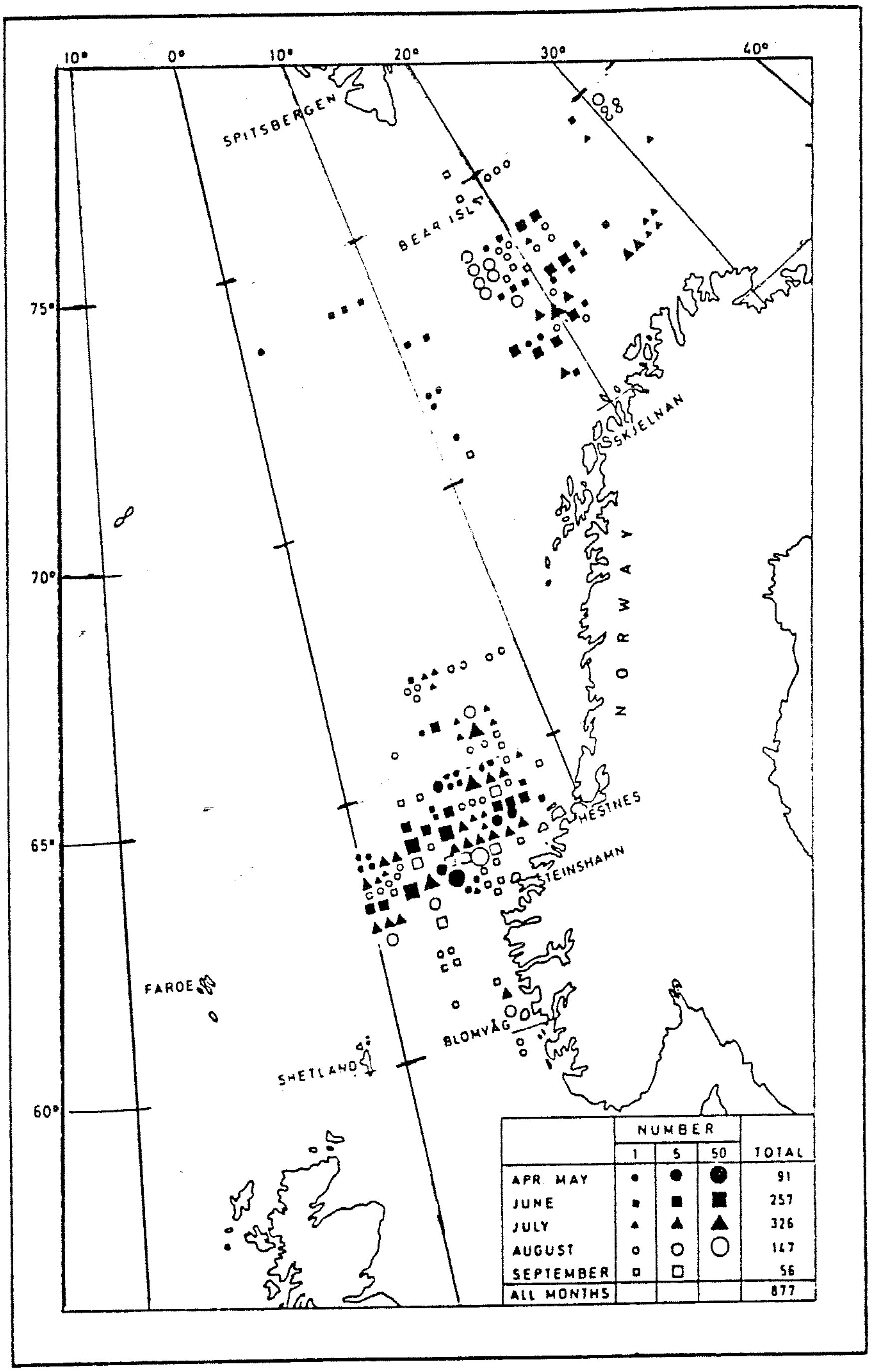

Figure 8. Location of fin whales caught in the Norwegian and Barents Sea in association with Norwegian land-based whaling operations

2.2.5 Sei whale

This whale (Balaenoptera borealis) is a warm-water migratory species with an irregular distribution around the north Atlantic northward to about 72°N, although they are occasionally seen around Svalbard in mid-summer. The species spends the winter in the warmer Atlantic, where it presumably gives birth in February-March, and migrates north past the Shetland Islands to appear off the coast of Møre about the middle of April (Ingebrigtsen, 1929). Depending on food availability, they may continue north to appear off Finnmark at the beginning of July where they may remain to the end of August. However, catch statistics from the whaling station at Skjelnan, Tromsø, shows that sei whales have been seen only sporadically as far north as southern Finmark after the second world war (Jonsgård, 1985).

Ingebrigtsen (1929) has given a description of feeding. The whale swims at speed and "skims" swarms of krill with mouth half-open and its head above water. When the buccal cavity is full the whale dives and swallows the food. This technique is in contrast to the blue, fin and humpback, that approach the shoals of prey from below, ingest most underwater, and break the surface from below. It would seem that the sei whale has the possibility to ingest large quantities of oil if it decides to feed in the vicinity of an oil slick.

Sei whales are unlikely to occur in the oil lease areas in significant numbers.

Factors of possible relevance to oil pollution:

1. The summer distribution in Norwegian waters is mainly off western Norway.
2. Sei whales stay clear of the pack ice.
3. Females approaching the West and North Norwegian coasts in spring have sucking calves.

4. Sei whales "skim" the water surface when feeding with possible consequence for oil ingestion.

5. Death of surface krill after oil spillage could threaten food availability. On the other hand the powerful swimming abilities of the sei whale should enable it to locate other krill stocks quickly.

2.2.6 Minke whale

A presumably separate Northeast Atlantic stock of minke whale (Balaenoptera acutorostrata) is distributed from the British Isles across the North Sea and along the Norwegian coast into the Barents Sea (Figure 9), and has been hunted commercially by Norwegian "small-type" whalers since the early 1930's. Recent estimates indicate a total stock between 44,000 and 60,000 whales and an annual average of 2218 whales have been caught from 1938 to 1985. During the last 15 years about 85% of the catches have been taken in the Barents Sea area including coastal waters of Finmark and Svalbard (Øien,Jørgensen and Øritsland, in press). The northern limit of their range is the edge of the sea ice (Jonsgård, 1966a). A regular migration occurs, southward in the autumn and northward in the spring and early summer, although some younger animals may spend the entire year in the Norwegian and Barents Seas. During the migrations males and females move separately, females and calves usually closer to the Norwegian coast than the males.

Substantial numbers of minke whales may be expected in the proposed oil lease areas during all times of the year, but greatest numbers during the summer and early autumn.

Factors of possible relevance to oil pollution:

1. The range of krill and fish species eaten reduces the threat of oil-induced death of prey species.

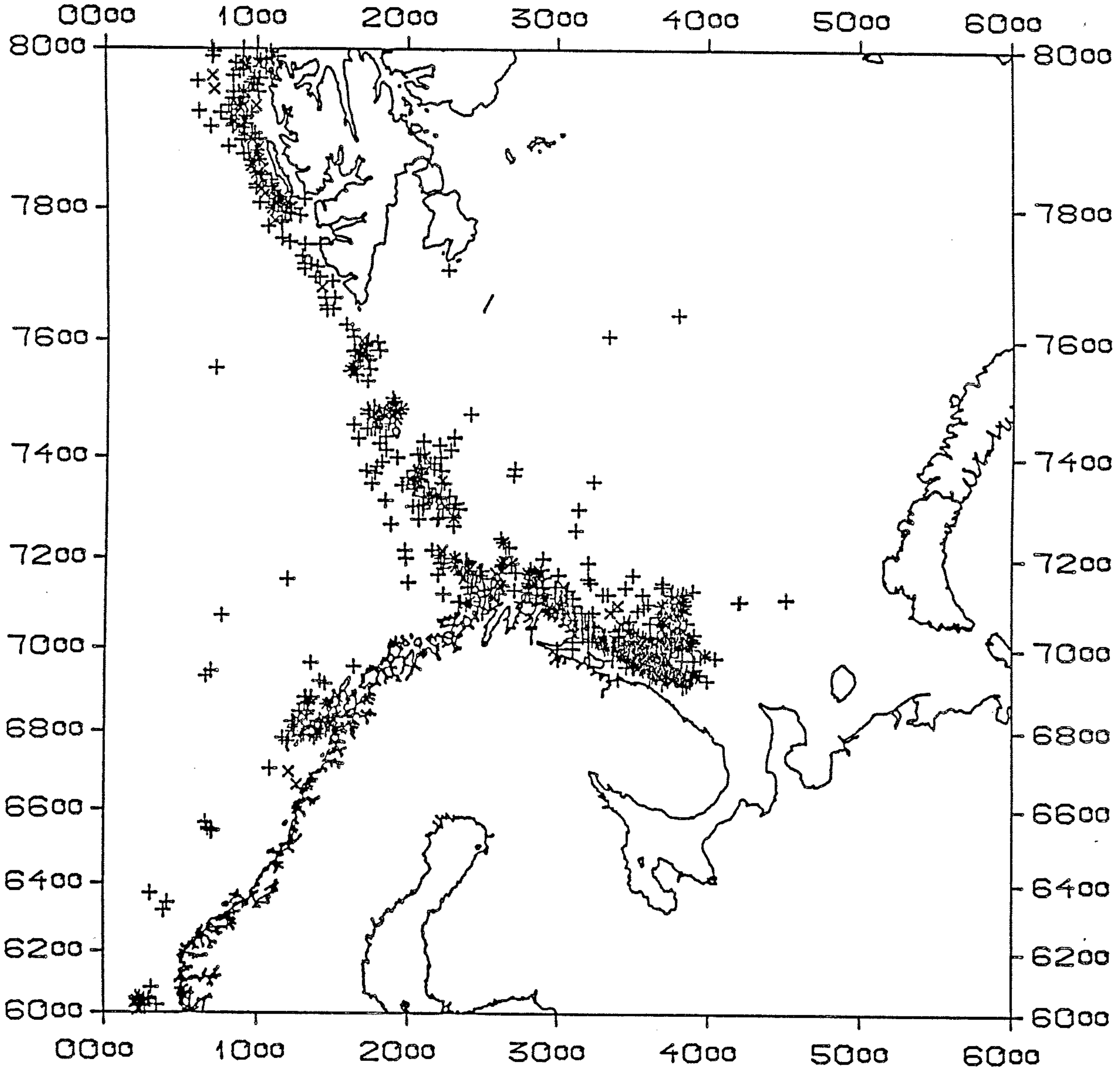

Figure 9. Distribution of minke whales caught by Norwegian small-type whalers in the Northeast Atlantic during 1980 (Øien et al. in press).

2.2.7 Sperm whale .

The sperm whale (Physeter catodon) is a migratory species with adults males moving north in the summer and south in the winter. A single stock is believed to exist in the north-east Atlantic. In the summer sperm whales are found in deep waters off the continental shelf off Møre and Vesterålen northward to Bjørnøya (Jonsgård, 1985). Puberty in the females occurs at an approximate age of nine years and length of nine metres (Caldwell et al., 1966). Parturition occurs in lower latitudes around the Azores from July to September after a gestation of some 15 months and lactation lasts for about 24 months. The birth-birth interval is therefore four years.

Few sperm whales can be expected in the proposed oil lease areas.

Factors of possible relevance to oil pollution:

1. Sperm whales in polar waters are usually single males.
2. The species feed at depth and there is probably little chance of danger to prey species from oil.
3. The distribution extends to the ice edge but not into the ice.

2.3 Smaller whales

The bottlenose whale, common porpoise, killer whale, white whale (beluga) and the white-beaked dolphin are the species of smaller toothed whales that can can be expected to be found in the Barents Sea oil lease areas. Most of them have, however, a much broader distribution throughout the Norwegian and North Seas. Where no other reference is given, the information supplied in this section comes from Jonsgård (1985).

2.3.1 Killer whale

Killer whales (Orcinus orca) are a cosmopolitan species and are common off the entire coast of Norway. They are especially common in the Møre and Lofoten area where they are often found in harbours and fjords. Migrations are associated with the seasonal movements of the herring schools (Jonsgård and Tyshael, 1970; Christensen, 1982)

Adult females reach a length of about 5.8m and males 6.7m (Christensen, 1984), although lengths of up to nine metres have been recorded (Jonsgård and Tyshael, 1970). Adults occur usually in small schools of two to four individuals but much larger groups are also seen. There is no definite breeding season and births occur at all times of the year with a peak in late autumn and winter. A variety of species are eaten, mainly schooling fishes, but also seals and other whales (Christensen, 1982).

2.3.2 Bottlenose

This bottlenose whale (Hyperoodon ampullatus)is an inhabitant of deeper waters. In Norway it occurs off the continental shelf off Møre and Westerålen, but is also seen in the trench area that runs northward, West of Bjørnøya and Spitsbergen, Svalbard. It is a migratory species, moving north in the spring and summer and returning south during the winter. Individuals usually associate with each other in schools, although older males often migrate alone. The species has been protected since 1978 (Benjaminsen and Christensen 1979).

Adult females are commonly about 7.5m long and adult males 8.5-9.0m. Newly born animals are some three metres long. The prey species are fish and cuttlefish. The breeding period lasts from January to June with a peak in April. The gestation period is one year (Christensen, 1973).

2.3.3 Common porpoise

The common or harbour porpoise (Phocaena phocaena) is the smallest of the cetaceans found in Norwegian waters, reaching an adult length of 1.7m. It is very common along coasts and inshore waters, particularly off the West and North coasts. There are apparently no long seasonal movements as are found in some other species. Birth and mating occur in the summer from May to July after a gestation of 11 months, and the size at birth is about one half of the length of the parent.

Prey species comprise small fish of various species.

2.3.4 White beaked dolphin

This animal (Lagenorhynchus acutus) is very common off northern Norway, especially in the waters between Finnmark and Svalbard in the summer months. They occur always in flocks, but of highly variable size. Like the bottlenose whale, they migrate northwards during the summer months. Birth occurs in the middle of the summer in northern waters, and young are approximately a metre long at birth. Adults reach a length of some three metres.

The prey is mostly fish of various species.

2.3.5 White whale

The white whales or beluga (Delphineraptus leucas) is an Arctic species and is common in Svalbard waters where it often forms large herds. Single animals can also be seen in the summer months along the coast of Norway, especially along the coast of Finnmark.

Adult size is about five metres. Birth and mating occur in the spring and early summer, mainly May after a gestation of 12 months. The newly born whale is about 1.6m long. The food consists of fish and cuttlefish.

Factors of possible relevance to oil pollution:

1. The small size of several of the species mentioned makes them susceptible to the underwater blasts used during seismic mapping and platform building. This is particularly so for the common porpoise and white beaked dolphin. In the case of the bottlenosed whale, newly born animals are moving with the herd when it passes by the lease areas. These animals would be sensitive to blasting, although adult animals should be relatively immune.
2. The variety of fish and cuttlefish species consumed by nearly all of these whales reduces possible problems from death of prey species after oil spill. There is unlikely to be severe death of the prey species of these whales.

2.4 Polar bears

The Svalbard polar bear (Ursus maritimus) population is estimated to contain 3,000 to 7,000 individuals diffusely spread over an area from 50°W to 70°E, and from about 82°N southward to the edge of the drift ice (Fig. 10). The western, eastern and northern borders are generally considered to coincide with the shelf or shallow water areas of the Barents Sea (Larsen, 1984), while the southern border, the edge of the drift ice, fluctuates significantly with both year and season. The southern limit of the drift ice overlaps the northern part of the "Barentshav Syd" oil lease area in March and April (Anon, 1946; Vinje, 1980) and so a number of polar bears can be expected within the lease area in those months. The actual density of polar bears along the ice edge is, however, not known.

The polar bear in the Svalbard area is a migratory species and a north-east movement has been noted in the spring (Larsen, unpublished). In addition, male adults tend to segregate from

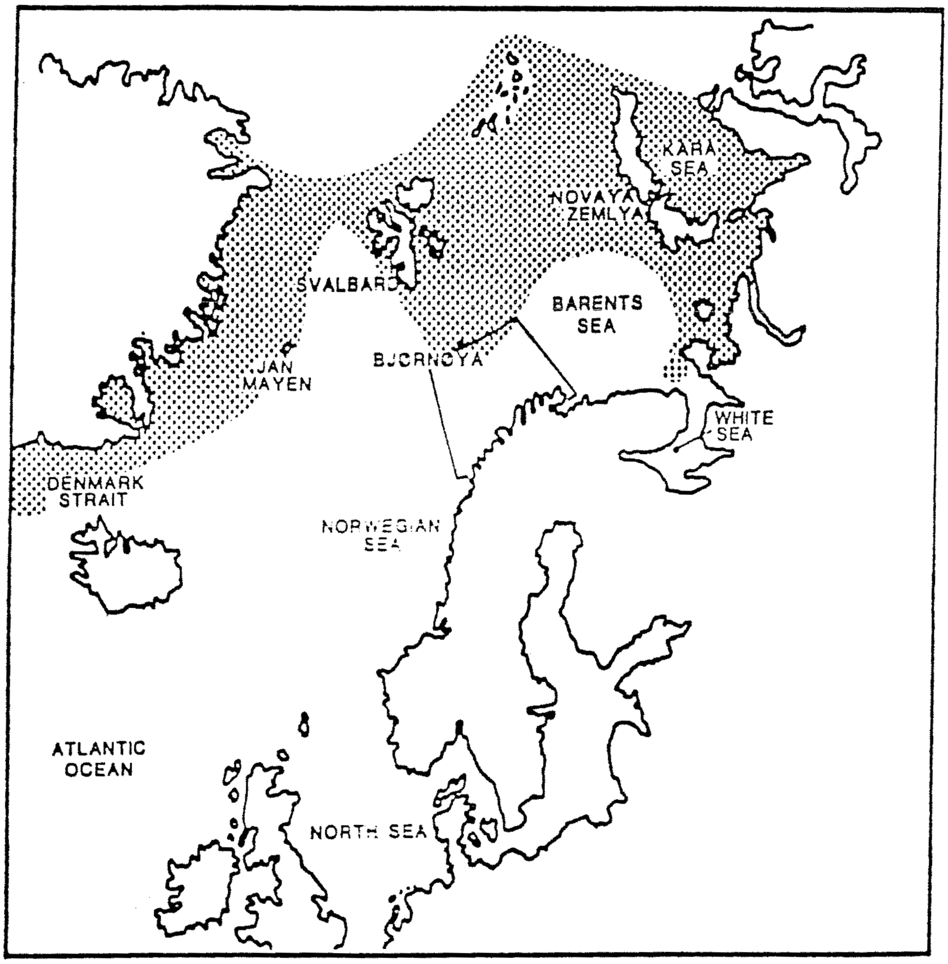

Figure 10. Polar bear distribution in the Northeast Atlantic

females and juvenile individuals (Stirling _et al._, 1977; Latour, 1981) and presumably occupy fringe habitat areas. It can therefore be anticipated that primarily the adult male segment of the population will be exposed to eventual petroleum development in the Barentshav Syd area. It has been calculated that the reproductive potential of the Svalbard polar bear population may allow an annual "take" or mortality induced by man of 2%-5% of the population, especially if mainly males are killed (Øritsland and Schweinsburg, 1983; Larsen, 1984). Computer models allowing analysis of the effects of single incidents with catastrophic mortality, such as would happen after an oil spill, are also available (N.A. Øritsland, 1985; Ugland and Torsrud, 1985).

2.5 Otters

The European otter (_Lutra lutra_) in Norway is not strictly a marine mammal but occurs on coastlines and feeds along seashores. It is included in the report because it will certainly be among the species affected when oil strands on a coastline.

The otter is found throughout Norway but is very rare. The strongest remaining population is found in Finnmark, corresponding to the coastline most likely to be polluted by an oil spill in the Barents Sea.

Little is known of the biology of the otter. Males reach a weight of eight to twelve kilograms and a length of about 120cm, while the corresponding figure for females is six to ten kilograms and 110cm (Harris, 1968). Adults are solitary and are seen together only during the breeding season. In coastal areas, they feed on beaches and up to a hundred or so metres offshore, and eat a wide range of fish, crabs and other invertebrates. When diving, the ears and nose are sealed and animals hunt using vision and tactile sense through the sensitive vibrissae.

The gestation period period is probably 61 days and most births occur in late winter and early spring, although there is no fixed season. The litter size is usually three to five. Mating occurs after weaning of the litter, and there is apparently no diapause. Mating occurs both on land and in the water.

Factors of possible relevance to oil pollution:

1. The species is already rare and declining and careful attention should be given to the harmful effects of oil-fouling and ingestion.
2. Oil is reported to kill a high percentage of otters contacted.

3. OIL AND ITS FATE AFTER SPILLAGE

3.1 Oil and oil products

Crude, or unprocessed, oil consists of hydrocarbon molecules of a size ranging from very short chains up to molecules with over 20 carbon atoms, and with three basic structures: paraffins, naphthenes and aromatics (Evans and Rice, 1974). Each of these fractions has a different viscosity, solubility in sea water and air, rate of decay in the environment, and solubility in animal tissue, but it is the aromatics that are the most toxic in animal tissues. In general, the acute toxicity and carcinogenicity of an oil is proportional to its aromatic content.

The various crude oils have differing proportions of these fractions and so in theory different toxic potentials on marine mammals. Oils mined from the Norwegian fields, which are most relevant to this review are "moderate" to "light"; they contain a greater proportion of small molecules and less from the heavier, more viscous end, and are therefore more fluid. Fresh light crude oil approaches the consistency of a summer-type motor oil.

In addition to crude oils, refined petroleum products are involved in marine pollution incidents, often after shipping accidents, but also from accidents on land where the oil enters rivers and subsequently the sea.

An oil type very often spilled, particularly in the case of accidents involving tankers and other ships, is fuel oil. Fuel oils are processed oils of differing physical characteristics that are classified under a numerical system from one to six (Evans and Rice, 1974). Those rated one are the lightest fuel oils, are the most volatile, have the highest concentration of aromatic molecules, and are the most toxic to animal life. Those rated six are asphaltic (heaviest and thickest), are the least volatile, have low solubilities in sea water, and also are the least toxic, although they may have considerable matting or clumping effects on pelage and feathers.

Finally the third class of petroleum products commonly implicated in marine pollution is oily residues deliberately and often illegally pumped from tankers at sea (SFT, 1985). This is often the sludge left from the separation of fuel oil cargoes, and is highly asphaltic. In practice these residues behave in a manner similar to heavy fuel oils.

3.2 Degradation of oil in the sea

The physical, chemical and biological processes that act on spilled oil to change or "weather" it, have been thoroughly documented in many previous review articles and reports (see for example Berridge, Dean, Fallows and Fish, 1968; Hardy, Mackie and Whittle, 1977; Wheeler, 1978).

In practice, crude oil is subject to weathering or degradation as soon as it enters sea-water, which changes its physical characteristics and its potential for affecting marine mammals. A rapid and significant part of the weathering process is the evaporation of lighter components. Because the lighter molecules, such as the benzenes and toluenes, are considered the most toxic, oils weathered for even short periods should have a considerably reduced toxicity for marine mammals. Continued evaporation and other weathering procedures result in all weathered crude oils having similar physical characteristics whether they were originally light or heavy, so that their behaviour and biological effects can be considered generally.

Once on the ocean surface, oil is subjected to the action of waves, wind, currents, solar radiation, oxidation and oil-degrading microorganisms. The first three factors, waves, winds and currents, spread the spilt oil and reduce its thickness.

Thinning of the slick increases evaporation; the lighter, more volatile components, which are the most toxic, evaporate quickly leaving behind the heavier tarry residues (Berridge et al., 1968). The exact rate at which oil evaporates depends particularly on sea state and wind speed, but even on Arctic oceans is considerable provided wind speed is strong (Wheeler, 1978).

Oil has a limited but definite solubility in sea-water, the lower molecular weight compounds being more soluble, with (in contrast to evaporation) the aromatics having a very high solubility (Wheeler, 1978). Two of the most volatile and toxic hydrocarbons, benzene and toluene, are also the most soluble in the water column, but even with these compounds the dissolution rate is only some 1% of the evaporation rate. In practice, those lighter molecules of greatest toxicity are found in elevated concentration under a slick for the first 30 minutes or so after discharge, mainly because they evaporate so quickly.

In favourable conditions the lighter hydrocarbons are removed by evaporation and dissolution within a few hours (Cormack and Nichols, 1977), such that the danger of a toxic internal effect of oil on marine mammals is greatly reduced within hours of spillage (although its external effect remains). Considering the low concentrations of oil found in sea water after experimental undispersed oil releases (Boehm and Quinn, 1974; Cormack and Nichols, 1977), and the normally small amounts of water ingested by marine mammals, it is highly unlikely that poisoning could occur through ingestion of oil in water, although there might be effects on fish and invertebrate prey species. It must be remembered though that a large amount of oil can be ingested accidentally, through grooming and from eating oil-fouled prey such as sea birds.

Natural emulsification involves the mixing of sea water into the slick though wave action, to form a water-in-oil emulsion containing up to 80% water by volume (Cormack and Nichols, 1977).

The process begins within hours of the release of the oil and the extent is dependent on the asphaltene content of the oil, because it is primarily these molecules that bind the sea water. If the oil has a low asphaltine content (such as North Sea oil), the emulsion formed is still fluid and continues to spread, evaporate and dissolve. The main worry with water-in-oil emulsions is that they are resistant to chemical dispersion. It is oil in this state that is most often involved in cases of natural pollution of marine mammal habitats, unless it is removed from the environment. In the case of heavier, high asphaltene oils, the emulsion formed is irreversible, resulting in the formation of viscous masses of coherent semisolid lumps referred to as "mousse". Mousse is impervious to chemical dispersion and highly resistant to natural weathering and cleanup techniques, and persists as tarry masses on open ocean or shorelines for years, even as long as a decade on low-energy Arctic shorelines (Sendstad, 1980).

The second form of emulsion, oil-in-water, does not form naturally to any extent. Its formation is made possible only through the process of dispersion, or the application of chemical surfactants or detergents. Surfactants reduce the oil into droplets of diameter up to 200>m (Byford, Laskey and Lewis, 1984) and remove it from the surface into the water column (McAuliffe, Johnson, Greene, Canevari and Searl, 1980). While this procedure removes the oil from the surface, removing the threat to sea birds and seals etc., the concentration in the water is greatly increased and so too the threat to fish and invertebrates. However, in an open ocean situation dispersal of the emulsified oil by currents is usually so rapid that even a few metres from the surface the concentration of oil is low. The issue relevant to this review is that chemical dispersion of an oil-slick partly removes oil from the water surface and reduces the threat of direct fouling of marine mammals. However, chemical dispersal of a natural slick that has formed an water-in-oil emulsion in a rough sea and cold ocean may only disperse some

20% of the oil mass (SFT, 1985).

The toxicity of dispersants is another factor to be considered in the overall effects of oil on marine life. Dispersants are themselves biologically active chemicals that have a definite toxic effect on marine life, including sea birds, fish and phytoplankton (Liu, 1983). Largely untested dispersants were used for the first time during the cleanup of oil spilled from the "Torrey Canyon" in the English Channel in 1969, and were responsible for more environmental damage than the oil spilled. However the toxicity of modern dispersants is very low, in the order of 1% of those used during the "Torrey Canyon" wrecking (Baker, Cruthers, Mullett and Wilson, 1979). They can be regarded as effectively non-toxic to higher vertebrates, certainly in the case of marine mammals. Modern dispersants also have a high degree of biodegradability and their use probably does not contribute to significant contamination of the marine environment (Liu, 1983).

All crude oils increase in specific gravity as the lighter components evaporate or dissolve. Heavier crude oil with a high asphaltene content may become denser than sea water (S.G.= 1.025) and simply sink to the bottom (Berridge et al., 1968), but this is very unlikely to happen with low-asphaltine Norwegian oils. Density increase is promoted by adsorption of oil to heavy particles already in sea water, such as plankton and suspended silts and clays (Wheeler, 1978). Even if the oil does not totally sink it may become heavy enough to leave the surface during rough weather and surface again during calm weather. Mackay (1985) reports that light oil masses tend to adopt a position just below the water surface and are continually awash with water, which may increase the amount of oil ingested by, for example, baleen whales that feed just below the surface.

Sedimentation does not degrade oil of course but simply takes it away from potential surface contact with marine mammals. Once on the bottom it has been shown to kill a variety of benthos (Moore and

Dwyer, 1974) and could theoretically apply feeding stress to those marine mammals that feed on bottom-dwelling species, such as the walrus, sea otter and bearded seal.

Oxygen begins to react with liquid hydrocarbons, especially the more complex molecules with side-chains, within hours of spillage, when the slick thickness has been reduced (Wheeler, 1978). The rate of oxidation is greatly increased by sunlight (photo-oxidation), and by a range of metal ions already present in the oil that act as catalysts (Berridge et al., 1968). Some of the products of this breakdown can be highly toxic to animals life but their lifespan is usually quite short. Photo-oxidation is a significant force in the breakdown of floating oil, both under direct sunlight and overcast conditions (FOH, 1984). However, while the photo-oxidative rate is fairly independent of water temperature, it is obviously quite dependent on photoperiod, and would not be significant in the removal of oil from the Barents Sea lease area from at least October to March (FOH, 1984). Even in the absence of external factors such as heat and sunlight, oil molecules will combine with oxygen in sea-water, although at a much slower rate, under the process of auto-oxidation. The main products of oxidation are acids which are water-soluble and quickly dispersed. In addition some of the products, particularly sulphoxides, are effective surfactants that aid in the further emulsification of the oil into water (Wheeler, 1978). The rate of oxidative reaction is limited firstly by the availability of dissolved oxygen in the contact water (400 tonnes of sea water are necessary to oxidize one millilitre of oil) and secondly by temperature. In cold northern waters the rate of oxidation compares poorly with the rate of evaporation, even of aged tarry oils (Berridge et al., 1968).

Numerous bacteria, yeasts and fungi can utilize hydrocarbons aerobically both in sea and on shores (Berridge et al., 1968) and usually at a much faster rate than auto-oxidation (Hægh, 1974). Such petroleumlytic microorganisms are most abundant in chronically polluted waters such as the North Sea off southern Norway (Wheeler, 1978; FOH, 1984). While effective bacterial degradation of oil in a cold environment may take years, the rate on soil can be slightly accelerated by the addition of various fertilizers (Sendstad, 1980) and in water by chemical dispersal of the oil (Wheeler, 1978). It is noteworthy though that beached oil too inaccessable to be removed mechanically will eventually be removed from contact with marine mammals by bacterial and photo-oxidation, even though the time involved may be several decades. Anaerobic degradation of oil also occurs but at a rate insignificant compared to aerobic (Hægh, 1974).

3.3 Oil in polar seas

A discussion of the actions and fate of oil in iced oceans is relevant to the Barents Sea situation, firstly because of the seasonal presence of sea ice in the Barentshav Syd lease, and secondly because of the development of oil exploration in the Svalbard area and the future possibility of accident there.

The physical effects of a large hypothetical oil spill in arctic pack ice have been discussed by Campbell and Martin (1973), Ayers, Jahns and Glaeser (1974) and Martin and Campbell (1974). While the more precise details of the spill are argued about, it is agreed that movement of ice floes by wind and current concentrates oil in leads and polyneas to a mean thickness of between one centimetre and one millimetre (for low windspeeds). Oil splashed up onto the ice surface forms a snow-in-oil sludge containing up to 90% water, that is resistant to burning and chemical dispersion. In addition a significant downward current is generated by floe movement that distributes oil over the underside of the ice, where it is trapped in a layer 0.25 to 1.3cm thick by the irregularities of the ice surface, and incorporated into the ice during later freezing. There was disagreement between the two groups of authors concerning the overall area affected by a "typical" spillage. Taking the most optimistic scenario, a spillage of two million barrels ($320,000m^2$, 280,000 tonnes) would coat an area of pack ice of $240km^2$, allowing for 25% rapid evaporation. This amount of oil approximates that which would be produced from an uncontrolled blowout of an existing well in the Haltenbanken field (2,400 tonnes per day lasting 18 days (SFT, 1985)), so the scenario is easily possible.

In a spillage of oil under ice late in mid-summer, the bulk of the oil should appear quickly on the ice surface due to the porous nature of both first-year and multi-year ice (Buist, Potter and Dickins, 1983). For spillages at other times of the year, the oil would be trapped. Buist et al. (1983) described how a skin of new ice several millimetres thick coated oil deposits within 48 hours, which would effectively prevent any weathering. During subsequent summers this essentially new oil leaches upwards along faults and salt pockets to the floe surface, where it forms into pools of overt oil that can be burnt successfully of otherwise recovered. There was a difference in the removal rate from first-year and multi-year ice, however. Due to the greater ice thickness there may be expected a longer removal time for multi-year ice (Comfort, Roots, Chabot and Abbot, 1983), with effective removal within five melt seasons.

In a slightly different situation, Schulze (1985) investigated the behavour of oil spilled into an area of broken or pancake ice. In this situation, where there was no established lead pattern and the ice was thin, over half of the oil spilled was "pumped" onto the surface of the ice by floe movement to an average depth of some five millimetres (although local thickness could be considerably greater). The remainder was held in thick clumps between the floes, and in a thinner layer on the floe bottom. The first difference then between oil spilled in open ocean and amongst ice is that the slick formed is much thicker, up to one centimetre. Apart from the accumulation of oil in leads, the appearance of the oil is seasonal, and mammals would be exposed to significant quantities in the summer, which corresponds in ice seals to the moulting season. Even after a single spill, there could be expected a seasonal presentation of oil for several years, due to seasonal freezing and release of pockets of emulsified oil.

There are in addition differences in the weathering of the oil. In leads and on other areas of open water, weathering is much as described for open sea, with the exception that the rate is very much slower. Atlas, Horowitz and Busdosh (1978) found that 25% of oil spilled into a lead during summer was lost in two months from evaporation (compared with hours in warmer seas), this amount comprising mainly lighter fractions. Thereafter only minor changes in composition occurred. However, the density of oil amongst ice can eventually become great enough for it to sink (Juszko, Green and Fingas, 1983). This is because the surface water layers of ice oceans, can, through melting, become quite fresh with a density approaching 1.000 g/ml (in contrast to normal salt-water of 1.025-1.027 g/ml). Weathered oil can exceed this density and sink, but before long it will meet a much saltier layer below which it cannot progress, and will sit there.

Atlas _et al_. (1978) also investigated other aspects of weathering in ice. Oil-degrading microorganisms were found in the water, and while their numbers increased greatly after exposure to oil, the influence of biotic degradation was minimal due to the low temperature. In contrast, oil spilled on ice showed only a 5% weight loss during nine months of exposure over winter, and no biodegradation at all. Oil spilled under ice showed a very gradual disappearance of lighter fractions due to dissolution, but significant quantities remained after three months. If one considers that the toxic properties of oil reside in the lighter ends, then oil trapped on, under and in ice retains its toxicity for long periods.

Thus, in contrast to the rapid weathering to tar of crude oil spilled in the open ocean, oil spilled amongst ice may be expected to weather relatively slowly, retain light components and therfore toxicity, form thick layers in leads and polyneas, and persist seasonally on the ice surface perhaps for several years. We can therefore assume that ice-associated marine mammals - walrus, polar bear and ringed, bearded, harp and hooded seals - which use leads to haul out or hunt, can be heavily affected by spilled oil for a long time after the spill. What remains is to assess whether such oil has detrimental effects on these animals.

3.4 Oil in Barents Sea

The southern Barents Sea in the area of the proposed oil prospecting leases is not an especially cold ocean. The annual temperature profiles of the area do not differ all that much from already operating oil-production fields off the lower west coast, especially with respect to winter temperature (Midttun, 1975). The warm Transatlantic current, which follows the coast northward, keeps the lease areas ice free for the entire year with the exception of the northernmost zone in March and April (Anon, 1946; Vinje, 1980).

In essence, there appears to be little difference between the behaviour of oil in a temperate and a polar sea. After spillage, evaporation begins the weathering process. According to Wheeler (1978), the main factor governing rate of evaporation is wind and sea state, rather than temperature, so that we can expect evaporation of crude oil in the Barents Sea to proceed relatively rapidly. In moderate seas, the lightest components can be expected to be removed in a few hours (Clark and MacLeod, 1977). The same reasoning should apply to emulsification, for it is wave action that mixes water into the oil. Dissolution can be expected to be less vigorous, but this is a minor weathering procedure for light crude oil compared to evaporation. The other physical processes, sedimentation and adsorption, exert an action even in warmer seas over a period of weeks rather than days, and in the Barents Sea would probably work over a similar time span. In summer, photo-oxidation would have a considerable effect on floating oil because of the long photoperiod, even at low ocean temperature, but in autumn, winter and spring the effect would be much less. Auto-oxidation could be expected to be minor at all times of the year.

Perhaps the most noticeable difference in the behaviour of oil in a cold marine environment would be in its persistence after stranding on coastlines, particularly on sloping, low-energy beaches. The Finnmark coast has the advantage that the surrounding ocean is continually ice-free and beaches are generally high-energy (wave action is available to degrade any oil mass). Results applicable to the Finnmark coast are available from the Baffin Island Oilspill (BIOS) programme, a Canadian experimental research project into the effects of oil on Arctic shorelines. Results from this study indicate that on open beaches natural removal of oil is rapid (Owens, Robson, Foget and Harper, 1983), with often 10% or less of the original oil loading remaining after one year. Results for cold, low-energy beaches, for example around Svalbard, or in the case of oil thrown up out of the reach of subsequent wave action, show that persistence is much greater. Visible oil can be expected to last for at least one and up to several decades, with little loss of volume (Owens, 1978). The rate of microbial degradation in the Arctic is very slow (Sendstad, 1980), and fertilization of oil in the hope of increasing the rate of microbial breakdown has not proven very successful (Sendstad, Sveum, Endal, Brattbak and Ronning, 1984). This introduces the potential for yearly refouling of marine mammals from a single oil-spill.

A useful case for the prediction of how oil might behave during a spill in northern Norway is that of the tanker "Arrow", which spilled some 40,000 barrels (600,000 litres; 500 tonnes) of Bunker C fuel oil into Chedabucto Bay, Nova Scotia, in February, 1970 (Thomas, 1973). The water temperature was about -1°C and ice was present at sheltered locations. Heavy fuel oil disperses very slowly at this low temperature, and initially shores and tidal pools became heavily covered with oil. Over the few months following the grounding, wider areas became heavily coated with oil, and areas previously oiled and cleaned became re-oiled. Lagoons acted as oil traps and became more heavily fouled than ordinary shores with coverings of oil commonly several centimetres thick, and once to 30cm thick, being reported. These areas, where wave and ice action was low, acted as reservoirs for the re-fouling of the rest of the coast in later years. Although the stranded oil weathered to form a firm surface, this process involved only a thin skin, and during warmer temperatures the relatively fresh oil under the skin softened and began to move. After several years, re-oiling was still occurring in the bay during summer. In more exposed areas where contamination was more even, the oil formed thinner layers and weathered to a stable surface. Under wave action oil disappeared fairly quickly (within a year) from rocky shores. The special feature unique to the cold environment was the chronic aspect to the pollution caused by seasonal hardening and softening of the oil.

There was total death of invertebrate species in heavily fouled areas, either from smothering or toxicity. Bottom-dwelling species, such as clams, were badly affected and were continuing to die two years after the spill. This introduces special concern for the possible consequence to the bearded seal and walrus, that feed on these species.

The direct effect of the Chedabucto Bay spill on local seal populations is described in a very incomplete report (Anon, 1970). Normally in the bay there lived a group of several thousand "grey harbour" seals, presumably grey seals. After the spill only about 500 were seen, of which 13 were dead. The others could have been forced away by the oil, but also by the unusually heavy concentration of boats, aircraft and clean-up personnel. Most of the seals were lightly oiled, but only some 5% were found dead. The report claims that the main effect of the oil was a coating of vital orifices, causing death from suffocation rather than internal toxicity, and occasionally "considerable pain and suffering". The report does not address the question whether the orifices could have become fouled after death, and caution should be exercised in accepting the results outright.

A more recent report of Bunker C fouling of seals in colder waters concerns the wrecking of the tanker "Kurdistan" in Cabot Strait, Canada. Eight thousand tonnes of Bunker C fuel oil was spilled, some mixing with pack ice off the coast of Cape Breton, and the remainder fouling open water. An initial report (Parsons, Spry and Austin, 1980) indicated that both common and grey seals were affected by the oil and suggests that some seals were killed by oil. However, the initial nature of the report does not allow many conclusions to be drawn. The picture seems to be similar to other cases of fouling with heavy oil (Anon, 1970; Davis and Anderson, 1976)- no indication of immediate direct toxicity, but a low percentage of animals killed perhaps due to physical encumberance. None of the reports provide information on possible skin or body temperature problems. This is unfortunate because it may only be in these colder areas that such problems become significant.

4. SOURCES OF OIL POLLUTION IN THE SEA

4.1 Present sources of spillage

Relevant information on the present situation regarding oil pollution in Norwegian waters has been supplied by the Norwegian State Pollution control (Statens Forurensningstilsyn, SFT). We are particularly grateful to (Mr.) Geir Jørgensen for his assistance. All material received here was provided by SFT unless specifically achnowledged.

Oil pollution of the sea and its life occurs after shipping accidents, deliberate release of oils from ships, dumping of oil-containing waste during exploratory oil-drilling activities, oil platform mishaps, normal oil-production operations and accidents on land that ultimately spill oil into the sea. A smaller cause, but an important one in some localities, is leakage from wrecks. Of the oil that pollutes the world's oceans today, one half comes from spillages on land, a little under a half from shipping and just 2% from oil extraction activities. In local areas of active production such as the Norwegian continental shelf, however, the contribution from oil activity is much higher. To the present most of the oil releases in Norwegian waters have been under 10 tonnes and have occurred close inshore in the areas Sør-Vestlandet, Oslofjord and around Mongstad. Further, most releases, both on land and sea, occur in and near harbours.

4.1.1 Pollution from ships

The majority of oil spillages around Norway (about 70%), originate from ships. In respect to oil pollution, the Finnmark coastline is presently the cleanest in Norway, and future pollution developments depend on the degree to which general shipping activity will increase in connection with oil exploration and production.

The estimated amount of oil released into the North Sea annually is about 1,200,000 tonnes, of which 400,000-500,000 tonnes is considered to come from shipping. Ninety percent of this is released during normal ships' operations and only 10% from accidental spill. Of the oil-slicks reported off the Norwegian coast, 70% result from the illegal release of oil (cargo ships must be 12 nautical miles from land, and tankers 50 nautical miles, before dumping can occur). Two thirds of the oil slicks reported are seen within four nautical miles of the coast, and a high percentage of these must eventually strand. A further 11% are seen between four and 50 nautical miles out. One happier note is that the number of oil slicks reported off the coast that originate from shipping has decreased over the last five years, from some 90 per year to about 60 per year, while the level of shipping activity has remained fairly even over the same period. Concerning accidental release, the great majority occur in harbours or very close to the coastline, with a high likelihood of pollution of coast. Accidents usually occur during bad weather and oil is consequently thrown high up onto beaches where it is out of reach of the cleaning effect of future wave action.

An overview of the main oilspills from ships that have caused shore contamination was presented by Klokk, Danielsen and Sendstad (1985). In the last decade there have been only two spillages in excess of 1,000 tonnes - the sinking of the tanker "Drupas" in 1976 off Tananger, and the sinking of the ore-carrier "Deifovos" off the Helgeland coast in 1980.

4.1.2 Pollution from oil platforms

On a world wide basis, about 0.1% of all extracted oil is spilled during recovery, transfer to tankers, transport, storage and refinement, as part of "normal" operations, most of this into the sea (MacNiell, 1984). If this figure is realistic for the North Sea, this amounts to some 25,000 tonnes per year from Norwegian fields alone (assuming present annual oil production to be 25 million tonnes). This oil comes from several sources. Firstly, small spillages of up to ten cubic metres usually occur at least once from each production platform each week of operation. Secondly, the oil collected and stored in tanks on the platforms contains some seawater. Some oil is lost with the release of this water back into the sea. Thirdly, oil (and various chemicals) is also spilled during processing of produced oil and gas. The estimated amount of oil lost to the sea during 1982 from the two latter factors was 1165 tonnes. Finally, up to several cubic metres of oil is spilled each time a tanker couples and de-couples from a floating loading-buoy. At present most of these spillages come from the Statfjord installations and the coastlines most severely affected by oil production activity and faced with the greatest threat, are from Sognefjorden to Smøla, in the nearest future from Bergen to Trondheim.

The hydrocarbon concentrations of Norwegian seas away from areas of drilling activity are among the lowest of any sea, ranging from 10 mg/kg in the sediment to 10 >g/kg in the water (see also Levy, 1984). The hydrocarbon content in the sediment is up to 1000 times this figure in areas 5-10km^2 around present platforms. Concentrations up to 10,000 mg/kg have been measured 500m from platforms, with 2,000mg/kg being common. This has led to changes in the benthic animal community and an increase in the hydrocarbon content of fish caught near platforms. Very significant effects have resulted among plankton, but a further discussion is outside the scope of the report, other than to note that such species are the prey of baleen whales and certain pinniped species. The concentration of oil-digesting bacteria, an indicator of the level of chronic oil pollution of the ocean, is higher in the Ekofisk area than in any other part of the North Sea (FOH, 1984).

Apart from the recent blowout on the Haltenbanken field, that released only gas, the only significant accidental oil spillage from a Norwegian oil platform was that of the Bravo blowout on the Ekofisk field, on April 22, 1977. In this accident, about 20,000 tonnes of crude oil were released before the well was capped after seven and a half days (Grahl-Nielsen, 1978). The blowout occurred at a location some 280km south-west of Lindesnes, and through exceptional luck no oil reached any shore (Audunson, 1978). The resulting oil slick drifted in various directions under the influence of wind and current before dispersing, but drift cards released into the slick were subsequently found in Denmark, Germany and Holland, indicating that these shores, instead of Norway, would be the areas most likely affected.

4.1.3 Pollution during field development

To date, the main cause of pollution in association with exploration has been the use of oil-based drilling muds. A lesser source is release during building of undersea pipelines.

At present oil-based drilling muds are used almost exclusively in Norway, and in 1982 resulted in the release of at least 4,000 tonnes of oil into the sea. The use of oil (usually diesel oil) based mud is at present increasing rapidly and today accounts for 80% of the chronic oil spillage on the Norwegian continental shelf. The toxicity of water-based or paraffin-based mud (used for example in Canada) is about one percent of that of diesel-based mud (Robson, 1983). Alterations to the benthic animal community are much greater when oil-based muds are used than with water-based.

The construction of pipelines is also associated with pollution. Some $40m^2$ of corrosion inhibitor, $20m^2$ of biocide and $40m^2$ of colouring agent were spilled during the building of the Statpipe pipeline. Other pipelines are presently under construction. The contribution of pipeline activities to oil release in the

Norwegian Sea is unknown, but in some other fields such as the Gulf of Mexico, pipelines are seen as a significant source of pollution.

4.1.4 Land-based sources of spillage

Spillage of petroleum on land can occur during transport, storage, loading and unloading involving connecting of pipes and lines, and during refining. Most of this oil finds it way into rivers and ultimately into the sea. In 1978, for example, 17 million tonnes of chemicals were transported across Norway's borders, of which petroleum products comprised 85%, or 14 million tonnes. During the period 1978-1982, there occurred some 171 accidents involving tanker-trucks, of which 112 resulted in spillage of the contents. The total amount of petroleum spilled was $560m^3$, or about 500 tonnes. In addition some 50-100 spillages of petroleum products are reported annually from other sources. While a number of these spillages have killed fish and tainted water supplies, none have been considered to have significantly harmed the environment.

There are approximately 3,800 oil-storage tanks in Norway containing 2.7 million cubic metres of oil (excluding military stores). Each year for the last decade, there have been registered between 20 and 60 cases of leakage from tanks and refineries (corrosion, breakage of pipes and valves etc.) and in addition occasional significant spillages due to incorrect filling of over-filling. The quantity of oil lost annually has been given as between $87m^2$ and $1073m^2$. In fact the products which has been spilled most commonly are light and refined such as jet fuels and distillates, which could be expected to evaporate quickly and pose little ultimate threat to marine mammals life.

The most serious recent accidents involving oil storage have in fact occurred on Svalbard.

4.1.5 Petroleum on the Svalbard archipelago

There are very few sightings of oil slicks on the sea around the Svalbard archipelago. This indicates no doubt that the area is relatively free from spilled oil, but may also result from the low level of human habitation and aircraft activity to see and report such occurrences. The use of oil and the risk of oil spillage on Svalbard, was analysed by Hustoft and Seip (1985).

During the last 20 years, there have been no reports of shipping accidents that resulted in oil spillage in Svalbard waters. The supply of petroleum to Norwegian installations on Svalbard is presently catered for from stores in Tromsø and Honningsvåg. Two tankers are used for the supply, of capacity 1500m^2 and 760m^2 respectively. In special instances smaller ships are sent with loads of 300-400m^2. Most of the oil deliveries to Svalbard occur between May and November. Unloading of oil occurs in harbours at all places with the exception of Isfjord Radio and Bjørnøya, where tankers unload through fuel hoses at sea. The annual consumption of petroleum has decreased in recent years, from 13,000-15,000 tonnes in 1980-1982 to 6,000-9,000 tonnes.

Coal loading ships from various countries visit Svalbard. There are some 50-60 visits annually to Longyearbyen, about ten to Svea, and also traffic between the two ports. These ships carry oil loads of between 20 and 500 tonnes heavy fuel oil or diesel oil.

Fishing fleets fish in the waters around Svalbard and use local ports to refuel. These activities occur usually in the period April to December due to ice conditions. Up to 300 fishing boats work in the area annually, carrying fuel stores of 100-500 tonnes, primarily diesel oil. In addition 30-35 whale catching boats work in the Barents Sea during the period May to September, although not all come as far north as Svalbard. The mean oil capacity of these ships is about 100 tonnes.

These figures have so far considered only Norwegian sources of oil carrying ships. In addition Soviet ships deliver a total of some 2,000 tonnes of petroleum products to Svalbard annually, and there are about 45 visits per year by coal loading ships, each of which carries up to 400 tonnes of oil as fuel. Foreign shipping companies operate between 25 and 30 tours to Svalbard per year. Each of these ships carries as fuel some 600 tonnes of heavy fuel oil and 200 tonnes of lighter oils. Finally there is a small but increasing number of trips made by smaller tourist ships and sailing boats each year, and the number will almost certainly increase with time, as Svalbard becomes a more popular tourist destination. An important feature of these cruises is that they approach as close as possible to concentrations of marine mammals and sea birds, where oil spillage would have the worst consequences.

The calculated probability of an accident involving shipping around Svalbard with release of oil onto the sea is: 0.1 per 10 years for tankers; 0.7 per 10 years for coal ships; 2 per 10 years for fishing boats; and 0.4 per 10 years for cruise ships.

Six commercial interests, both Norwegian and Soviet store oil at nine different locations around Svalbard. To date there have been no leakages reported from Soviet land-based oil stores, but three leakages have occurred from tanks at the Norwegian mine of Svea and one at the research station at Ny-Ålesund.

In the first of these incidents, $130m^2$ of diesel fuel spilled from a storage tank at the Svea coalmine between April 20 and May 16, 1978, and leaked into the adjacent Van Mijenfjordfjord. Numerous smaller spillages have occurred before and since. In this incident oil melted through the snow and travelled at ground level out onto the fjord ice, again under snow, such that the spillage remained invisible. Most of the oil was trapped by the ice and transported out of the fjord during breakup (Carstens and Sendstad, 1979). The shore fauna and plankton community in the vicinity of the tank was destroyed, but the long-term effect on the fjord ecosystem has apparently been negligible (Gulliksen and Taasen, 1982). This particular fjord beach has a very simple sand and boulder ecology and normally very little life, so it was not possible to derive many conclusions as to the effects of oil on the littoral environment of Svalbard. A detailed report on the effects on the spillage on local animal life is given in the two reports. There is no mention whether seals or polar bears were affected by oil, through both species are found in Van Mijenfjord.

Two lesser incidents occurred at Svea in 1983. In June, 5,200 litres of petrol were lost due to leakages from a faulty fuel-line and a faulty pump. In November 1,200 litres of diesel oil were lost from a valve due to human error. We have not found any report of the environmental consequences of these two smaller leakages.

While this report was being compiled, another spillage of petroleum occurred on Svalbard. On November 15, 1985, 85,000 litres of diesel fuel oil leaked from a broken fuel-line at Ny-Ålesund onto a beach and then into the adjacent Kongsfjord (Øritsland and Sveum, 1985). At the time there was no ice in the fjord and the investigation of the spill was hampered by stormy weather and total darkness. A part of the oil has saturated the beach to a depth of approximately 50cm and has been incorporated into the beach by freezing, perhaps to pollute Kongsfjord locally in the future. Despite intensive searching of the fjord with boat and helicopter, no trace of a floating oil slick was found. The effect of this spillage, if any, on the small colony of harbour seal on Prinz Karls Forland, or on harp, ringed, hooded and bearded seal that could be expected in the area, is as yet unknown and under investigation.

4.2 Potential sources of future oil pollution

4.2.1 Future spillage from shipping

The greatest source of pollution of the Norwegian coastline and therefore of coastal marine mammals by oil is ship traffic and smaller chronic releases from platforms and other sources. Ships frequent the entire coastline, but it is logical to expect that those areas with the heaviest volume of shipping will be the most likely to sustain pollution from ships. The likelihood of an accident involving a tanker has been calculated by the SFT (1985) for different sections of the coastline, based on present tanker activities. The Finnmark coast has the lowest likelihood for tanker accident, with one accident expected approximately every three years, and an expected annual release of 270 tonnes of oil into the sea. The possible exception being Honningsvåg which is presently the seventh busiest port in Norway. The highest expectancy, with nearly one accident (0.91) and a release of 730 tonnes per year, was calculated for the coastline from Trondheim to Tromsø. However, if one also considers oil pollution from all shipping, the quoted figures would certainly be much higher.

It is expected that the likelihood of oil pollution of the Mongstad-Sture region in Hordaland will also increase significantly in the near future due to the increase in the volume of oil transported to this section of coast from offshore production fields.

4.2.2 Pollution from offshore oil fields

The increase of some 40% is expected by the year 2000 in the daily production of oil from the Norwegian continental shelf, from some 25 million tonnes per year now to 30-35 million tonnes. At the same time, production activity is spreading northward towards deeper depths and more severe climatic conditions. While, on a world-wide basis, platform accidents are responsible for only about two percent of the oil pollution in the seas, they pose the greatest potential threat for pollution of the southern Barents Sea and Finnmark coastline. If future Barents Sea fields produce comparable amounts of oil as present fields, and it is assumed they will, then the daily production per well (and daily spillage in the case of accident) will be between 4,000 and 15,000 tons. Based on present figures, a significant platform blowout, either exploration or production, will occur once every five to ten years.

The drift of an oil slick after an uncontrolled blowout from four Norwegian oil fields - Ekofisk, Statfjord, Haltenbanken and Tromsøflaket, is considered in a report from the Norwegian Continental Shelf Institute (IKU, 1985) and also in various reports from the Norwegian State Pollution Control Authority. This assumes that an oil slick resulting from a blowout in one of the proposed Barents Sea fields would behave similar to one originating in the Tromsøflaket field. Spills from the Ekofisk field are not likely to affect coastal marine mammals because of the low likelyhood of oil from this field contacting a Norwegian coastline.

The most important <u>production</u> oil field for Norway, now and up to year 2000, will be the Statfjord field west of Sognefjord, and the greatest likelihood for pollution of the sea also comes from this field. The coastline most susceptible to pollution after a blowout but also from normal operations from Statfjord is the stretch from Sognefjord to Smøla. The situation with <u>exploratory</u> oil drilling is different. Today about 15 of the 45 exploratory wells drilled annually are drilled north of the Statfjord field and by the year 2000 nearly all exploratory activity is expected to occur in the North. In addition to the threat of blowout of an exploratory well, exploratory activities release large amounts of oil-based drilling muds into the sea that are a significant cause of marine oil pollution. The amount of petroleum released into the northern marine environment will therefore increase, even if the greatest threat of pollution remains in the Bergen - Trondheim area.

As yet only gas has been found on the Tromsøflaket field. For the purpose of modelling an oil blowout, the IKU (1985) report assumes that a blowout on an operational platform will produce a quantity of oil similar to the Haltenbanken field to the south, namely 2,400 tonnes per day, the blowout lasting for ten days. After such a blowout, an oil slick would drift in an easterly direction and pollute the coastline from north of Tromsø east to the Varanger Peninsula. The coast between Sørøya and the Nordkinn Peninsula would have an approximate 50% chance of oil pollution. Seasonal differences in current and wind would mean a greater chance of drift toward the open sea during autumn and winter but toward land during spring and summer. A blowout during the summer is calculated to put the greatest amount of oil onto the shore, while the minimum drift interval to shore occurs during winter - 2.3 days to Sørøya.

Production of oil from the Haltenbanken field is not expected before the middle of the 1990's, but the danger of a blowout on an exploratory well will arise much earlier. After a spill on the Haltenbanken field (a predicted 2,400 tonnes per day for 10 days) oil would drift primarily northwards and contaminate a stretch of coastline from about Smøla in the south to Senja in the north. The area most affected would lie between the border of South and North Trøndelag and Sandnessjøen. There is very little difference between the seasons in the amounts of oil that could be expected to strand but the minimum drift interval to land is somewhat shorter in autumn and winter than in spring and summer (IKU, 1985).

In its calculations the IKU (1985) report assumes that a blowout on the Statfjord field will release some 9,500 tonnes of oil per day for 10 days. This field is further from the coast that the northern fields and the drift interval before stranding is correspondingly greater. This would allow a greater quantity of oil to evaporate and otherwise disperse so that the percentage of the spill that would strand is lower than for the northern fields. Oil would drift directly eastwards and spread primarily towards the North. The region of coast where oil will probably strand lies from North of Sunnhordaland to North Trøndelag, while the most vulnerable area is considered to lie between Florø and Ålesund. Minimum drift interval is slightly shorter in winter that in summer (3.5 and 4.3 days respectively).

5. MARINE MAMMAL POPULATIONS VULNERABLE TO OIL CONTAMINTION

By matching available information on the biology and distribution of marine mammals (Chapter 2) to predictions of the spatial distribution of oil pollution (Chapter 4), an attempt is made in this chapter to assess the risks and identify those populations of marine mammals which have the greatest probability of contact with oil. It must not be assumed, however, that direct oil contamination will be the only problem that marine mammals will face in the case of an oil spillage. The coastal waters of western and northern-Norway are extremely important spawning areas for a number of fish species, and death of fish larvae during a spill may, after some delay, produce shortages of prey species for local mammals.

5.1 Seals

We consider that grey seals,
common seals and
harp seals are particularly susceptible to contact with oil in Norwegian coastal waters, and that
ringed seals,
bearded seals and
walrus are susceptible to oil pollution in the waters of Svalbard.

The distribution of grey seals in Norway was indicated in Table 1 and Fig. 2b. The most important breeding area is the coast of South Trøndelag, particularly the islets and skerries in the Halten-Froan archipelago. It is precisely this part of the coast that is considered most at risk from oil pollution from the Haltenbanken and Statfjord fields, and where fouling of grey seals by oil is already significant. Over a third of the grey seals born at Halten-Froan in recent years have been partially or heavily coated by oil which has probably drifted from the Statfjord field (Wiig, in press). Oil-fouling of this grey seal population can be expected to increase in the coming years. The situation is better for Nordland, which contains the next greatest population of grey seals. The calculated likelihood of fouling of this coastline from offshore petroleum activity is low to moderate. In fact the grey seal population here is large mainly because of the long coastline. In reality individual grey seal colonies are quite small and dispersed and perhaps not a great number would be affected by any given spillage. The seal population of the Lofoten-Vesterålen region is poorly documented, not having been properly surveyed since 1964 (Øynes, 1964). Seal numbers along this coast can therefore only be guessed. The Finnmark coastline also contains a large grey seal population, that would certainly be affected by spillage of oil from the Barents Sea leases no matter what the season. In any case it is the South Trøndelag grey seal population that will take the brunt of oil pollution in the immediate future.

Much the same picture applies to the Norwegian harbour seal population (Table 1, Fig. 1b). The greatest concentration is located on the Sogn-Fjordane, Møre-Romsdal and South Trøndelag coasts, which will probably be the most polluted Norwegian coastline for at least the next decade, due to petroleum activities on the Statfjord field. To the south, in Hordaland and Rogaland, there are fewer harbour seal (Table 1) and it is these two counties that are considered the most likely to receive pollution from shipping. The Oslofjord, the other region liable to pollution from shipping, supports a population of some 1,000 harbour seals on the Koster and Hvaler islands. These islands lie directly adjacent to shipping lanes into Oslo, Fredrikstad and Moss, and must be considered liable to fouling. If, for example, the ship that grounded recently on Koster had broken up, oil-fouling of harbour seals would probably have been severe. In Nordland and Troms, the threat of contact between oil and the large population of harbour seals, both from shipping and blowouts, can be considered low. The Finnmark coast has also a moderate number of harbour seal that would likely be affected in the case of a spill from the Tromsøflaket field.

During the active feeding phase of their annual cycle (late-summer to winter) large numbers of harp seals are found in the southern Barents Sea and along the east-Finnmark coast. The seals also penetrate deep into Varangerfjord and Tanafjord. The coast and fjords of east-Finnmark are only moderately to slightly susceptible to pollution in the case of a blowout on the Tromsøflaket field, but free-swimming harp seals in the southwestern Barents Sea would likely contact oil if a blowout occurred during the appropriate season. These seals are, however, free swimming and do not normally haul out on shore, so that we can speculate that oil contact might be brief and quickly rinsed off by clean sea water.

While platform blowouts around the Svalbard archipelago remain a problem for the distant future, the threat of oil spillage from shipping accidents and leakage of stores on land is here now. Depending on the season, oil following spillage will collect on beaches, in leads and holes of fast ice, or among leads in moving pack ice. In late summer, autumn and early winter, large numbers of ringed seals, smaller numbers of bearded seals, and low numbers of harp and hooded seals and walrus can be expected to become oil-fouled, as they swim in open water and haul out onto smaller floes. In late winter, spring and early summer the situation could be considerably more serious, especially for ringed seals. By late winter, ringed seals have constructed and are using caves and small breathing holes in land-fast ice. Bearded seals and walrus remain on drifting floes but are also found into the fjords and close to land. Petroleum would collect in thick layers in the holes and leads of fast ice and ringed seals could be expected to become heavily coated every time they hauled out. Oil would be transported into and would accumulate in the lairs, ultimately fouling the pups. The reduced time spent actively swimming in open water could mean that oil would not be easily rinsed away. Because bearded seals and walrus remain on drifting floes in open water they would be expected to become more lightly fouled. Hooded and harp seals are not found in the area in appreciable numbers during the fast ice season.

5.2 Whales

We consider that several smaller toothed whales,
minke whales,
humpback whales,
fin whales and
sei whales are susceptible to contact with oil in Norwegian waters.

Toothed whales, in particular the killer whale, common porpoise and white beaked dolphin, occur widely and in large numbers in Norwegian coastal waters in all seasons. Bottlenose whales frequent deeper water but are also occasionally found in the Barents Sea lease areas. White whales or Belugas are seen off the Finnmark coast only in summer and in low numbers. All of these species could be expected to contact oil from a platform blowout. Because most shipping accidents happen in harbour areas or within a few kilometres of the coast, where cetacean numbers are not as high, the risk of contact after a shipping accident is lower.

Minke whales are found throughout the Barents Sea to Svalbard and in northern coastal waters during the summer and also in more southern coastal waters during the winter. Some individuals are therefore likely to be contacted by oil after spillage from platform or ship, whatever the season or area.

Groups of humpback whales migrate twice yearly within several kilometres of the coast between Nordkapp and Sørøya. These migrations occur during the winter and again during the summer. The coastal migration phase coincides precisely with the area expected to receive the heaviest shore pollution after a blowout on the

Tromsøflaket field, and also leads through the proposed Barents Sea lease areas, so humpback whales would certainly be fouled by a spill at the appropriate season. These whales feed only to a moderate extent during the migrations so the intake of oil after a spill should be small. The greatly reduced size of the Barents Sea humpback whale population requires that close consideration be given to the possible consequences of oil fouling of these animals.

Fin whales are found singly or in small groups in the southern Barents Sea and off the north Norwegian coast during spring, summer and autumn. As the whale and herring stocks recover, fin whales can also be expected to be seen along the coasts and fjords of western and ultimately southern Norway during the summer. Fin whales would be included among the marine mammals contacted by oil after a spillage in the southern Barents Sea, when oil drilling activity begins there, but also sooner along the western coast of Norway as fin whale numbers in the Norwegian Sea increase.

Sei whales occur seasonally during late spring and summer around the Shetland Islands in the southern Norwegian Sea. Some individuals could conceivably be contacted by oil after a spillage on either the Ekofisk or Statfjord fields. Sei whales are fast swimming and active feeders after the style of the minke whale. The potential for oil ingestion is therefore high.

5.3 The otter

The otter population of Norway has been greatly reduced, and the strongest local population is presently found in Finnmark. Otters can be expected with near certainty to become heavily fouled by stranded oil from the Barents Sea oil fields or from a shipping accident along the Finnmark coast. Because of the reduced population size the effect of oil-fouling on the otter should be carefully evaluated.

5.4 The polar bear

The polar bear is an inhabitant of land-fast ice and drifting pack ice. It is unlikely that polar bears would be affected by an oil spill from the present Barents Sea leases and certainly not from any fields further south. However, its widespread distribution around Svalbard, mobile nature, frequenting of human habitation and use of fast ice and water for hunting, makes it highly vulnerable to contact with oil should a spill occur in this area.

6. THE EFFECTS OF OIL ON MARINE MAMMALS

Marine mamals are "higher" mammals that are almost certainly capable of feeling pain, probably also suffering and fright. The assumption that mammals feel pain in a way similar to humans comes from the similarity of the pain conducting nervous pathways in the two groups (Dubner and Bennett, 1983) and from the release of identical chemical transmitters and other substances after exposure to noxious stimuli (Hayes, Bennett, Newlon and Mayer, 1978), although animals do not always seem to perceive pain in the same way humans do (Erickson and Kitchell, 1984). In addition, mammals in pain show characteristic but sometimes subtle behaviours which should allow alert observers to detect the presence of pain (Dubner, 1983; Morton and Griffiths, 1985). We will not discuss these in detail other than to say it should be possible to assess whether or not an oiled marine mammal is suffering. This we must consider, both if we decide no to treat an oiled animal, whereupon it may suffer from the irritant effects of oil, or if we decide to capture and restrain it, whereupon it may suffer from the simple fright of being handled. The treatment and rehabilitation of oiled marine mammals into the wild is more than a matter of scrubbing them with detergent or solvent. In most cases it will involve confinement for several weeks (in the case of polar bears several months) for treatment and restoration of skin oils, and probably the skilled use of tranquillizers, antibiotics and other drugs. Finally, the intense international public interest in marine mammals, along with the certain close coverage of oiled animals by television, will bring strong pressure to ensure that the welfare of animals as individuals is considered. Guidelines for the humane physical and chemical capture, antibiotic therapy and euthanasia of marine mammals already exist, although it is outside the scope of this introductory report to discuss them, and will undoubtedly find a place in the management of marine mammals after future oil spills.

6.1 Oil and seals

The true or phocid seals, including all seals in the Northwest Atlantic, as well as the sea lions and the walrus, all have a relatively short coarse pelage with poor heat conserving abilities, and rely rather on dermal and subcutaneous blubber for insulation. The possible consequence of oil spillage on these animals deserves attention because of the great numbers of phocid seals found on the coast of Norway and Svalbard and in the Barents Sea. In particular, colonies of grey and common seals are found along almost the entire Norwegian coastline, ringed and bearded seals in the fast ice of Svalbard and drifting pack-ice of the Barents Sea, and herds of harp seals throughout the Barents Sea and occassionally also along the coasts of northern Norway. Considering present tanker routes and the present and proposed distribution of drilling platforms it is almost certain that some seals would be affected by any future oil spillage.

Grey and common seals were fouled by number six fuel oil following the breaking up of the tanker "Arrow" in Nova Scotia in 1969. A report on the effect of this spill on seals (Anon, 1970) was brief and vague, but seemed to indicate that some seals suffered "considerable pain and suffering" due to contact of the oil with eyes, ears, nose, mouth and throat, and that the prime cause of death from oil was physical suffocation. This suggests that live oil-fouled seals were observed actively reacting to the presence of oil but unfortunately details of the observations that led to the interpretation of pain and suffering were not listed. In the case of dead seals, it is usually not possible to tell if a particular animal was suffocated by oil, because oil may easily find its way into the mouth, nostrils and throat after death during rolling in waves. If the seals described above were actually observed alive and showing signs of pain, then the greatest likelihood is that it was due to the irritant and erosive action of fresh crude oil on the pinniped eye. The irritant and erosive action of fresh crude oil on the pinniped eye has been described by Smith and Geraci (1975). This action is mainly caused by the lighter volatile components of the crude oil which are absent in heavy fuel oil, but the possibility remains. If the oil was so viscous that it could fatally clog the large pinniped nostril it is difficult to visualize it entering the narrow pinniped external ear canal and more doubtful that its presence would be so distressful as to produce the pain and suffering mentioned. Further, other case reports involving number six fuel oil (Davis and Anderson, 1976) indicate that a live and alert seal probably would not allow oil to accumulate in its nose or throat, as Anon (1970) suggests, but would instead simply swallow it (Babin and Duguy, 1985).

To predict the consequences of oil pollution on coastal common and grey seal populations, we can use as a model the case of oil that drifted into a breeding grey seal colony in west Wales, U.K., in September, 1974 (Davis and Anderson, 1976). In this incident, beaches inhabited by grey seals became polluted with fresh, fluid crude oil that weathered rapidly to tar. Twenty-five of 62 pups born became partially or totally fouled, and in addition a number of adults. The authors thought that most of the pups were not polluted directly, but through contact with their mothers who had become thickly coated by oil floating on the sea. Some pups became coated directly through swimming in oil-covered shallow pools.

Cows were able to locate and feed their pups successfully whether they were oiled or clean, so the oil itself did not appear to disturb normal mother-pup relations. Oiled pups had smaller weaning weights, causing some concern for their future survival. The authors could not discern if this effect was directly due to the oil or to the additional disturbance these pups received during cleaning operations, veterinary inspection and from visiting observers. It would have been useful to study lactation duration and frequency, and pup behaviour, to decide if pups from oiled mothers fed as ofter and ingested as much milk as clean mother/pup pairs, in case oil-fouling interfered with sucking or the milk was distasteful to pups. Increased metabolic rate in compensation for increased skin heat loss could also produce lower weaning weights, but this was not investigated. There were instances of adoptive suckling by both clean and fouled mothers.

Two of the 25 oiled pups became so heavily coated that they apparently could not swim and so drowned. However, the neonatal mortality rate was high in both groups (23 of 58 live births, 10 oiled and 13 clean). Considering the high death rate, the low sample sizes and also the fact that artificial factors (fishing nets) contributed to deaths, it is difficult to compare death rates in the two groups. Six of the oiled pups were necropsied. None had ingested oil, supporting the conclusion that oil was not a direct cause of death.

Five oiled pups were successfully cleaned with a variety of detergents but one became recoated with oil. The authors concluded that there was little justification in cleaning pups unless all sources of recontamination could also be treated. Pups coated with fluid oil moulted their natal coat normally, beginning at the head and flippers and extending over the body. However, pups fouled with tar did not moult until the entire hair coat was loose and ready to come away, due to the binding action of this thicker oil. Moulted pups were almost oil-free but became recontaminated by their shed pelage if they remained in the same place after moulting.

This incident demonstrates that fouling with weathered oil has little acute effect on survival of adult grey seals and **pre-weaning** survival of grey seal pups as a group, with the exception of the deaths of unlucky, heavily coated individuals. It does not shed light on the post-weaning survival rate among oil affected pups nor is there description of pathological processes acting on individual seals that could be used to predict such survival. Oil fouling at any other time of the year would contaminate only adults and subadults, with probably even fewer immediate deaths from the physical effects of oil. The possibility of a more severe action on animals during the moulting season has not been investigated for any species of seal.

The oil-fouling incident described by Davis and Anderson (1976) affected grey seals breeding on a sandy beach. In Norway grey seals mostly breed on larger vegetated skerries, but the result concerning percentage of animals fouled would very likely be similar. In addition the disruption of colonies by the inevitable human clean-up activity after a spill would force all adults into the water with potential for repeated oil fouling of adults and subsequently pups.

Common seals in Norway inhabit a similar physical environment to that of the grey seal and therefore could expect similar results from oil contamination. Due to behavioural differences between the two species, oil-fouling of common seal would be more extensive than with grey seals, and with worse results. Harbour seal pups are smaller with consequently a higher surface area-to-weight ratio. If oiling occurred early in life before deposition of blubber, thermal stress would be more severe. Common seal pups are more pelagic and may enter the water shortly after birth. Extensive heavy coating of pups can be expected with a more severe physical effect and more seals drowning from simple physical impediment. Common seal pups suck milk for nearly one month as opposed to 17 days for grey seal, and have therefore a longer period available to ingest repeatedly small amounts of oil. Lactating common seals also make regular daily feeding excursions which increases the probability of extensive oil transfer to the pelage of the pup. If we consider that the heaviest cases of oil-fouling reported by Davis and Anderson (1976) were due to swimming through floating oil, then the effects of oil on breeding common seals could be expected to be considerably worse than for grey seals due to the more pelagic behaviour of this species.

The conclusion that external oiling does not contribute significantly to acute mortality among phocid seals is supported by other accounts, although many of these are unfortunately anecdotal, poorly reported and poorly investigated. Davies (1949, cited by Davis and Anderson, 1976), observed grey seal pups on the English coast that were thickly coated with number six fuel oil. Although some drowned due to the physical encumberance, most seemed unaffected. Hess, Morris and Dickason (1970) report on an oil pollution incident along the western Alaskan coast in April, 1970. A sheen of unidentified oil, perhaps number two fuel oil, contacted some 400 "hair" seals, probably common seals. Following an apparent aerial survey, these seals were reported to be "acting in an unusual way and had a white glazed look in their eyes" (p. 154), although no deaths were observed. It was not reported if the seals had actually come into contact with the oil. Another slick of thicker oil in the same region contacted some 500 marine mammals, mostly phocid seals (Hess and Trobaugh, 1970). Again no deaths were reported, although contaminated skins were damaged and brought reduced prices for hunters. In the eastern Canadian Arctic oil-fouled ringed seals are apparently a seasonally common occurrence near tanker routes (Mū ller-Wille, 1974). No details of behavioural or pathological results of this oiling are given in the report.

The studies of grey seals by Davis and Anderson (1976) and Davies (1949) indicate that normal grey seal pups ingest little or no oil during the relatively short (14-17 day) lactation period. They do not provide information as to whether oil has an effect on the skin or whether oil is absorbed through skin to produce measureable tissue levels. If prolonged oil-fouling causes dermatitis there must necessarily be a concurrent increase in dermal blood flow, increased heat transfer from the skin and a resultant thermal stress to the animal. Van Haaften (1973) in fact suggested this possibility. In this case report, Dutch common seals showed inflammatory skin changes under clumps of oil on the skin. However, similar skin lesions were also seen on other seals that did not have oil on them, so the relationship of oil to skin damage was not proven. Recent surveys along the German and Dutch Wadden Sea coasts has revealed that some 20% of common seal have various skin lesions, but the observation has not been linked to any causal agent (Stede, 1985).

To date all well-documented cases of oil on seals have come from temperate waters, where any such thermal stress might be successfully compensated for. There is a gap in the knowledge of thermal effects of oil-fouling of seals in ice. Apart from the work of Smith and Geraci (1975), there are very few case reports of oiling of seals in Arctic waters, and those mentioned above do not contain enough information to assess even short-term oil effects on hair seals.

At least in temperate seas, oil-fouling of nursing seal pups seems also not to affect their longer-term post-weaning survival. LeBoeuf (1971) studied a population of neonatal northern elephant seals fouled by oil from the Santa Barbara Channel oil blowout in 1969. He tagged 58 pups that were at least 75% covered in oil and detritus, and 58 clean pups, and followed sightings and tag returns over the subsequent 15 months. His conclusion was that the crude oil which fouled the weaned seals "had no significant immediate nor long term (1-15 months later) deleterious effect on their health" (p. 280). Had the oil come earlier when the pups were still sucking, it is possible they would have had shown more serious oil-related effects, such as reduced weaning weight, that would have reduced their longer-term survival (see Davis and Anderson, 1976, above). The two situations reported by Le Boeuf (1971) and Davis and Anderson (1976) are not directly comparable.

Oil from the Santa Barbara blowout in 1969 also fouled the beaches of San Miguel and San Nicholas Islands, where some 1000 California sea lions bred the following June (Brownell and Le Boeuf, 1971). While many dead and oil-fouled pups were found, the authors' conclusion was that the overall death rate was no higher than for previous years and that "contamination with crude oil did not have a marked effect on pup deaths". California sea lions, like phocid seals, do not rely on pelage for insulation but rather on blubber (Kooyman, Gentry and McAlister, 1976; Kooyman, Davis and Castellini, 1977). The heat conductance of sea lion pelts is not increased by oil exposure as happens in for example the northern fur seal and the sea otter, with a resultant severe and often fatal thermal stress (see below). Had the oil washed into the northern fur seal breeding rookery that has since been established on San Miguel Island (Temte, 1985), the outcome could have been much more severe.

The occurrence of dead oil-fouled seals following the Santa Barbara blowout was widely reported in the press (for discussion see Brownell, 1971; Le Boeuf, 1971) and has perhaps left an impression of that blowout as a major marine mammal disaster. Brownell and Le Boeuf (1971) do not say that **no** seals were killed by oil. These and other authors faced a difficult problem, namely the accurate determination of the cause of death. In seal rookeries, regardless of location and species, up to 50% of more of the new year-class dies in the rookery due to separation from mothers, trampling, starvation and disease. The finding that oiled pups comprised 67% of the deaths at San Miguel Island was considered to be misleading, because abandoned pups wander widely in search of food and so have a higher than average chance of becoming fouled in an oil polluted environment. The very few necropsies that were done indicated that none of the seals had ingested oil, supporting Brownell and Le Boeuf's (1971) conclusion. An additional problem more specific to the California area, which the authors discuss, is the very high levels of selenium, mercury, and organic insecticide concentrations that have been implicated as a cause of a high incidence of still and premature births found in local seal populations (Gilmartin, Delong, Smith, Sweeny, DeLappe, Risebrough, Griner, Bailey and

Peakall, 1976). In such an environment with a very high "normal" death rate (20% of the pups born die due to premature parturition), it is often difficult to state with confidence that a particular seal pup was killed by oil.

As a summary we can say that at the population level seals in temperate seas will survive the direct effects of oil contamination with few deaths. However the outcome in cold seas with seasonal or permanent ice cover is not clear, nor is there knowledge of the effects of oil on moulting animals. The low weaning weights of oiled grey seals (Davis and Anderson, 1976) need to be explained and the significance of this for their long-term survival needs investigation. The threat to seal populations due to the indirect actions of oil spillage, such as death of prey species, should also be investigated.

At the individual level, there is not a great deal known of the effects of oil on seals. Two experiments have been conducted on live ringed and harp seals under summer Arctic conditions (Smith and Geraci, 1975), and other studies have been done on isolated pelts. The first part of the Smith and Geraci (1975) experiment comprised several trials - exposing adult ringed seals to crude oil for twenty-four hours, coating nursing harp seals with crude oil for up to four days and feeding oil as a bolus to weanling harp seals. The second trial involved exposing adult ringed seals to floating crude oil in warmer water for twenty-four hours, at laboratory facilities at Guelph University, Canada.

Six adult ringed seal were placed in a sea pen at their capture site and exposed to floating light crude oil (depth one centimetre) for 24 hours at water temperature 7°-9°C, after which they were removed to clean water. The behavioural reaction to the oiling was described. Seals were killed at two, six and seven days post-exposure, and the amount of petroleum uptake into various tissues measured.

The seals apparently did not recognize the oil as foreign and did not attempt to avoid it, and were totally covered within twenty minutes. The first visible effect was eye irritation (excessive lacrimation, blinking, head shaking) which appeared after seven minutes exposure (Geraci and Smith, 1976). After 24 hours this had progressed to severe conjunctivitis, keratitis and corneal ulceration. All the seals survived the exposure. After three hours in clean water, the visible signs of eye irritation had reduced and after several days there was little sign that the seals had been exposed to oil at all.

Deep body temperature as measured by telemetry remained constant throughout the study, at first glance suggesting no interference by oil on thermoregulation. However, no measurement of metabolic rate or estimate of skin heat conductance was made nor was there any histological study of the skin for inflammatory changes. Since stable body temperature is merely an indicator of balance between heat production and heat loss, it does not by itself mean a lack of effect of oil on seal skin. While the experiments of Kooyman et al. (1977) indicate that oiling of isolated seal pelt does not appreciably increase heat loss, there could in fact be a substantial increase in the live animal if oil is an irritant and causes an inflammatory reaction in the skin. We are concerned that the short duration of the oil exposure would not have allowed enough time for the possible skin inflammatory effects of oil to become evident and feel that in this part of the trial a conclusion was drawn too hastily.

In contrast to some reports of physical impairment of movement by heavy fuel oil, the light crude oil used here did not block any body openings or impede swimming. The external effects were confined to the eyes and the authors considered the more volatile fractions were partially responsible. If so the danger of eye damage would be somewhat reduced after one or two days of weathering of the oil. On the other hand, the eye effects were ameliorated by exposure to clean water, but in a natural spill situation oil-fouling would persist so that eventually more severe eye effects might be expected than resulted here. Particularly the mention of "some evidence of corneal erosion and ulceration" is concerning. The authors do not say how they measured the presence of ulcers but the usual way is by staining the cornea with the dye fluorescein. Corneal ulcers in animals are at best slow to heal and untreated often progress to corneal perforation with loss of sight. We feel the authors have not considered seriously enough this aspect of the results. In an actual spill, however, the lighter fractions that would have produced a lot of the eye damage would evaporate quickly and the eye effects might not be so significant.

The immersion study was repeated at Guelph University at a temperature of 12°-14°C and resulted in the deaths of all three seals used, after 21, 60 and 71 minutes of exposure. In this experiment the seals reacted almost immediately to the oil with vigorous shaking, eye blinking and forceful exhalation and long periods spent underwater, followed by loss of swimming co-ordination, trembling, thrashing on the surface and death. The authors considered that the stress of captivity was central to the cause of death. Another possibility they do not comment on is a direct action of the lighter components of the oil on the central nervous system especially the brain. The behavioural signs exhibited by the seals - trembling, thrashing and loss of co-ordination - are all signs of acute cerebral inflammation, which intoxication by the lighter components of oil is known to produce. The authors do not record appearance of the brain on necropsy. While it difficult to estimate the concentration of petroleum products in air over an oil slick (Geraci and St. Aubin, 1982), it is possible the hotter temperature of the second experiment increased the concentration of petroleum inhaled enough to be clinically significant. The authors commented on the "pungent fumes" in the seal pen. The blood picture observed in two of the three seals after death - leucopenia and eosinopenia - supported the picture of relatively unstressed animals subjected suddenly to a stressful event but was otherwise inconclusive. It would have been useful to repeat the experiment with weathered crude oil, from which the most toxic elements had evaporated.

In a later paper (Geraci and Smith, 1977), absorption of oil into the body during immersion is discussed. Following necropsy of seals in the field immersion trial, oil was found in all tissues except the lungs which contained traces only. The greatest concentrations were in the urine, bile and kidney (see also Engelhardt, Geraci and Smith, 1977; Engelhardt, 1978), indicating concentration and excretion through the liver and kidney. Kidney damage was detected on histology in two of the seals in the field trial and there was also posible liver damage. The authors thought the low level in the lungs was due to rapid volatile loss. Oil was found in the oral cavity but not in the rest of the alimentary tract, and it was concluded that the uptake path was through the skin and respiratory surfaces (Engelhardt _et al._, 1977), although Engelhardt (1983) subsequently maintained that most of the uptake occurred through the alimentary tract. Therefore oil effects on liver and kidney could well be significant in a natural spill where animals would remain coated probably for at least several weeks.

In addition to adult ringed seal, weaned white-coated harp seal pups were coated with the same crude oil, and the effect on behaviour and body temperature noted. The seals were killed three and four days post-oiling. No lesions were observed under necropsy or histopathology, nor were any changes in behaviour observed. The seals lost weight during the period of fasting but it is not stated if the rate of weight loss was altered after oiling.

The conclusion reached from these immersion trials was that the external effects of oil, particularly irritation of the eyes, has a greater impact on phocid seals than does absorption, and that oil does not pose any thermoregulatory problems for phocid seals (Geraci and Smith, 1977). While this may be the case for a brief single exposure to oil, the experiment does not simulate a natural spill, particularly in ice, where seals would be re-coated every time they entered and left the water, possibly for several weeks or longer. Considering that the weathering rate of oil on and under ice is slow (Atlas et al., 1978), such oil would contain relatively high amounts of lighter and irritant components. We feel particularly that it is premature to conclude from a one-day exposure that oil-fouling has no thermoregulatory effect in phocid seals, and that further experimental work is necessary to clarify this.

Five ringed seal were each fed five millilitres of oil in fish per day for five days, and two groups of six neonatal harp seal received 25ml and 75ml oil as a single dose. Tritiated benzene was used as a marker molecule. In a subsequent trial (Engelhardt, 1978, 1982), four juvenile ringed seals were fed five millilitres of oil per day for four days, with radiolabelled naphthalene as the marker. Petroleum concentrations in all tissues and particularly whole blood peaked on the second day of dosage, with highest levels in the blubber and liver (Engelhardt, 1983) and then declined, reaching low levels by 28 days post-dosage. There was a selective handling of different molecules. Benzene was concentrated much more in the liver than naphthalene, for example, while the concentrations of the two in other tissues was similar.

In seals receiving a single high dose, oil appeared on the rear flippers one and one-half hours after ingestion. The lanugo was subsequently stained by the oily faeces but became clean when the seals were transferred manually to clean snow. Following dosage, the seals grunted and generally vocalized more than controls, and were more active for several hours post-dosage (Smith and Geraci, 1975), although the authors subsequently stated there were "no behavioral alterations in any of the experimental animals" (Geraci and Smith, 1976). This seems in fact not to have been the case, for the increased vocalization and motion is a behavioural change that suggests a pain effect. There were no deaths nor was there any consistent evidence of damage to any organ or system. In the second trial dosage resulted in diarrhoea and excessive production of dark urine (Engelhardt, 1982). Dosage was evidently stressful for the animals as evidenced by a more than doubling (mean value) of plasma cortisol concentration.

This experiment indicates that fresh crude oil applied locally to the gut is not seriously toxic to at least some hair seals, even in relatively large doses. Hair seals do not groom their pelage and normal individuals are unlikely to ingest much oil after surface fouling. In contrast to the authors, we regard the acute ingestion study on harp seals as providing a strong suggestion that there was a temporary irritant effect, probably on the gut, that caused pain.

While the above experiments suggest that phocids seals, in the short term, tolerate well exposure to petroleum, certain case reports indicate that at least common and grey seals do occasionally swallow quantities of oil with fatal results. Duguy and Babin (1975, 1976), Prieur and Duguy (1979) and Babin and Duguy (1985) documented a series of strandings of grey and harbour seals on the French coast over the past 10 years which apparently resulted directly from oil intoxication. Eighteen harbour seals and 42 grey seals were rescued from beaches, of which 15 harbour and 20 grey seals died. On necropsy, the intestines of ten of the 35 dead seals were found to contain petroleum in quantities up to 47% by volume of the contents. Oil metabolites and tissue destruction were found in a range of organs but the main damage was to the small intestine in the form of ischaemic local lesions causing necrosis of the micro-villi. The diagnosis of death was "necrotic enteritis of a toxic nature" (Duguy and Babin, 1975). In addition, there was necrosis and haemolysis in the liver, severe pneumonic changes (cellular infiltration or "hepatization") in the lungs and haemolysis and thrombi in the kidneys. The authors commented that these changes were also very similar to those seen in birds after oiling. Four grey seals, oiled to various degrees, were also found stranded and dead after the wrecking of the "Amoco Cadiz" tanker off Bretagne. While this is a low number, it nonetheless represents a considerable proportion of French grey seals (Bonner, 1972).

What do these results mean for Norwegian seals fouled by floating oil? The available information is too conflicting to permit a clear answer. There would likely be few acute deaths after contact with oil. Small numbers of seals would probably die due to physical encumberance after a heavy fuel oil spill, especially in the case of pups. A certain number would likely ingest enough oil to die, but it is not possible to say what proportion. More would suffer probably serious discomfort or pain due to sub-lethal intoxication. What may be significant, particularly in winter, is skin effects following chronic exposure to oil. There is some evidence that long-term oil exposure in phocid seals may cause dermatitis, but there needs to be experimental work to clarify this. If this is the case then the longer term results for badly fouled seals, especially seals inthe pack ice, would probably be serious. Pups would not have the necessary weight gain to sustain life over the first year, and adults may suffer fatal frostbite.

6.2 Oil and fur seals

In contrast to the situation for phocid seals and sea lions, there is very little knowledge of the effects of oil pollution on fur-seals. The information available suggests that oil poses a much more serious threat to fur seals, due to the thinness of the subcutaneous blubber layer and in the reliance on the insulative properties of the fur (Engelhardt, 1983).

Apparently the only experimental work on the effects of oiling on the fur seals is that of Kooyman et al. (1976, 1977) on the northern fur seal. The pelt of the fur seal consists of a dense, smooth fur that forms a good water-resistant barrier. Heat conductance of isolated blubber-free pelts of two adults was a relatively low 26 Watts(W)/m^2/°C while that of a single pup was 40W/m^2/°C. The authors quote Scheffer (1962) as finding a fur density figure of 57,000/cm^2, while pups had only 9,000 fibres/cm^2. The control conductance of the adult pelts was considered unrealistically high due to the lack of a grooming effect under experimental conditions. Oiling treatment, consisting of the application of 0.02ml Prudhoe Bay oil/cm^2 pelt, increased heat conductance by factors of 2.0 and 1.7, while subsequent cleaning with detergent reduced conductance to 1.5 times the control value. The increase in the conductance of the fur seal pelts was among the highest of all the marine mammals tested.

In addition to isolated pelts, three northern fur seals were oiled with Prudhoe Bay crude oil. The oiling treatment consisted of brushing 100-180 ml oil onto the pelage of the neck and mid-back, covering some 30% of the total pelage surface. Oiling was light enough that treated pelage was indistinguishable from untreated. Control values for resting metabolic rate in cold water (6°C) were very high, about two and a half times that expected for a land mammal of similar size. Following the single oiling, metabolic rate increased by a mean of 50% and remained at this level for at least two weeks. Cleaning with either detergent or solvent did not reduce metabolic rate; solvent cleaning in fact seemed to worsen the condition, perhaps by depleting natural fur oils.

One of the animals experienced extremely heavy loss of hair and underfur about two weeks after oiling. All animals were very reluctant to enter the water, and when in the water would swim with as much body surface as possible exposed to air.

Evidently a single oil-fouling is a serious event for the northern fur seal and probably for all fur seals. The authors doubted that oiled animals could sustain themselves for very long in cold water, especially considering the experimental treatment was very mild compared to what could be expected after a true oil spill. Two events the authors did not investigate were (1) the loss of hair from one of the seals and (2) the prolonged effect of oil treatment, both of which may indicate a skin inflammatory reaction to oil. Smith and Geraci (1975) showed that oil at least from the outer pelage can be washed off quickly by exposure to clean water. Considering that the oil was not visible on the coat of the seals, it would not have been easy to estimate the amount of oil remaining after two weeks, but this should have been done in order to investigate the prolonged nature of the metabolic rate increase. Severe loss of hair is at least suggestive of an inflammatory reaction, but apparently no skin histological investigation was carried out.

Oil-fouled polar bears and otters ingest large quantities of oil during grooming (see below). The amount a fur seal would ingest is unknown, but some degree of ingestion could be expected. The internal actions of oil, which have been shown to be severe in polar bears and common seals, therefore needs consideration also in fur seals. Because fur seals are not found in Norwegian seas, these animals will not be considered further in this report.

6.3 Oil and the walrus

To our knowledge no study of the effects of natural or experimental oil pollution on the walrus or its prey species has ever been reported, nor has there been any experimental study of the subject. The subject deserves study, because the walrus is still regarded as a threatened species due to the effects of past hunting, and because its range overlaps leases for Norwegian oil prospecting in the Barents Sea.

Kooyman _et_ _al_. (1977) measured the thermal conductance of a single blubber-free walrus pelt. The clean skin, which was hairless and nearly five centimetres thick, had the lowest thermal conductance of any seal. In addition, the sub-cutaneous blubber layer would further reduce thermal conduction. The conclusion may be drawn that the walrus is therefore fairly resistant to the short-term thermal effects of oiling due to the low conductance of the thick skin, the thick blubber layer and the large body size.

6.4 Oil and the polar bear

The polar bear, by its existence in fast-ice and drift-ice areas, its strong swimming abilities and its dependence on seals for sustenance, qualifies as a marine mammal in every sense. Because of its long seasonal migrations over ice and its widespread distribution, it would very likely be affected by any severe oil-spill in a sea-ice area. Because ice occurs in that part of the Barents Sea covered by the Barentshavet Syd lease from February to April, it is important to consider the known effects of oil in this species. In a spill situation, bears might become contaminated by swimming in oil concentrated in open water leads among drift-ice, by oil splashed onto the surface of floes or by eating oiled seals. This oiling could be expected to heavily coat the pelage. Alternately, bears could be fouled even several years after a spill by oil, originally trapped under and in ice, that leached upward onto the ice surface during the following summers. Considering that the water in the surrounding lead system might in this case be clean, the fouling might be less severe and partially removed during swimming. To our knowledge, there have never been any reports of oil-fouling of polar bear after actual oil spills, because there have not been to date any such marine accidents in a true sea-ice area. However, the experimental effects of crude oil on the polar bear have been investigated by N.A. Øritsland (1976), N.A. Øritsland, Engelhardt, Juck, Hurst and Watts (1981) and Hurst and N.A. Øritsland (1982).

In their first investigation, the heat conductance of isolated sections of polar bear pelt was measured in air before and after oiling in a water bath covered by a one centimetre thick oil layer.

In contrast to sea otter pelage that traps a layer of air bubbles in the underfur during immersion, polar bear fur allows water to penetrate to the skin and traps instead a layer of stagnant water, creating a "wet-suit" effect (Hurst and Øritsland, 1982). Following oiling, the conductance of the pelts rose by factors of between two and five, and by a higher factor when subjected to wind. Disturbance of conductance was greater at lower ambient temperatures due to the higher viscosity of the oil. Lighter oil, for example Norman Wells crude, and oil at higher temperatures, had a less serious effect on conductance because it was more fluid and consequently had less of a matting action on the pelage. A second environmental factor to have an effect on the oiled pelts was solar radiation. Solar heat absorption by the pelt was greatly increased by oiling, suggesting a danger of excessive heat loading in wild oil-fouled bears on warm still days. However, oiled bears would presumably enter water if they felt hot.

The second experiment investigated the effect of crude oil on live, sub-adult polar bears. Three animals were used, two males and one female. The oil-fouling treatment consisted of forcing the bears into a pool of saltwater at 0°C-2°C, which was covered with a layer of Midale crude oil one centimetre thick. The oil had been weathered for 36 hours. This thickness of oil corresponds well to that bears would be exposed to in a sea-ice environment. The first bear received 15 minutes oil exposure and became coated with 9kg oil, or 6.2% of the body weight. The areas most severly fouled were the legs and shoulders where oil penetrated down to the skin. While washing apparently cleaned the pelt, it subsequently became fouled again due to outward re-distribution of oil from deeper layers. The second bear four was oiled for 30 minutes and adsorbed 27kg oil which was about 18% of the body weight. The third bear which received 53 minutes exposure, absorbed 21kg oil representing 13% of the body weight. Much of the superficial oil was removed by grooming and through contact with snow and litter, but the deeper oil was retained (Engelhardt, 1980). Grooming also spread the oil more evenly over the pelage surface. The three bears were washed 17 days post-oiling.

The experimental situation did not allow the bears free choice; they were forced to enter the oil pool. When confronted with crude oil, however, the bears showed no obvious aversion to it (N.A. Øritsland *et al.*, 1981). Following emergence from the pool, the bears began to lick their fur immediately and continued grooming for several hours, particularly their forequarters (Juck, 1980). They also licked oil from walls and other structures. Vomiting and diarrhoea began within 12 hours of exposure. Analysis of the vomitus showed that it consisted of between 52% and 60% crude oil (Engelhardt, 1980) and that the some of the lighest molecules (for example benzene) had been quickly absorbed by the body. Similar analysis of faeces also showed large quantities of oil (up to 90% by volume), and loss in the faeces was the predominant route of hydrocarbon removal (Engelhardt, 1980). There continued to be oil and fur in the stomach contents for up to five weeks after exposure, due to grooming activity (up to 3.7% of faecal bulk). The oil trapped deeper in the pelt remained a source of fouling, indicating that even after a single brief immersion polar bears would be exposed to constant although decreasing levels of oil for a month or more. Due probably to the dehydration resulting from the diarrhoea and vomiting, snow intake increased substantially.

The ingested oil, and perhaps also the external oil, was absorbed by the bears and found in the blood. Plasma oil concentrations reached a peak in the first week (31-36>l/l) and gradually decreased over the subsequent four to five weeks, to concentrations of a few >l/l. However, any new ingestion of oil, for example of oil found in the litter, would produce new peaks in plasma concentration (Engelhardt, 1980). Concerning other tissues, very high levels were found in bone marrow, brain (to 325>l/l) and kidney, then in descending order in liver, lung, skeletal and heart muscle. Surprisingly, no residues were found in blubber or other fat.

Internally, the main defect was nephrosis or kidney damage (Juck, 1980) leading to renal insufficiency (insufficient ability of the kidneys to filter blood). This defect was produced at two levels - pre-renal and renal. The pre-renal insufficiency was due simply to the bears being too sick to drink adequately, leading to dehydration, lowered blood volume (haemoconcentration), and therefore insufficient blood pressure to perfuse the kidneys. The renal insufficiency was due to direct kidney damage by the oil. The end result of both processes was uraemia (buildup of urea in the body), dehydration and haemoconcentration. In addition the kidney damage led to an inability to maintain normal blood electrolyte balance, with a retention of potassium and abnormal loss of sodium. There was oil present in the urine for the duration of the experimental period. Extra-renal pathology secondary to the uraemia included ulceration of the tongue and oesophagus, stomach haemorrhage, gut inflammation and degeneration of the brain and liver.

The oil had a direct action on the blood system. Bone marrow tissue was destroyed, preventing formation of new blood cells. Juck (1980) thought this result was due particularly to the benzene component of the oil. Circulating red blood cells were also directly destroyed, leading to a non-regenerative anaemia. There was a resultant reduction of the haematocrit from approximately 50% pre-exposure to between 14% and 30% after five weeks. Considering that there was haemoconcentration, true blood cell volume would have been even lower. Haemoglobin and bilirubin, products of red cell breakdown, accumulated in the kidney during attempted clearance from the blood, and would probably have contributed to the kidney damage. The blood picture of the first bear, the only bear not to die, returned to normal after five months of treatment.

About two weeks post-oiling, signs of brain dysfunction began to appear, which became progressively worse and ultimately caused the deaths of two animals.

The external effects of the oiling were also severe. Bear number three (53 minutes exposure) lost pelage from the back, and the remaining back hair was loose and easily removable. In both bears number two and three there was evidence of skin irritation (hyperkeratosis or abnormal proliferation and thickening of the epidermis) (Juck, 1980).

There were changes in metabolism and body and skin temperature following oil exposure (Hurst, N.A. Øritsland and Watts, 1982) that indicated severe thermal stress to the animals. Oxygen consumption (metabolic rate) during both rest and exercise increased between 24% and 86% following oiling as compensation for decreased skin insulation and increased skin heat loss. N.A. Øritsland et al. (1981) suggested also that some of the increase in metabolic rate could have been due to a direct central pyrogenic effect of some components of the oil. Further evidence of thermal stress was provided by frequent occurrences of severe or violent shivering. Even with these compensations, one of the bears could not maintain normal deep body temperature after oiling. Artifically generated wind reduced deep body temperature considerably more after oiling, suggesting that in nature polar bears would have great difficulty in countering the thermal stress of oil-fouling. Skin temperatures rose in all bears, whereas a fall would be expected in a thermal stress situation. The authors suggested that the observed temperature rise was a result of the irritant inflammatory effect of the oil on the skin. Both the metabolic and body and skin temperature reactions of polar bears to oil-fouling were very similar to those of another furred marine mammal, the sea otter.

In summary, the experimental oiling of polar bears with crude oil on a single occasion loaded the pelage with a depot of oil which the bears groomed and ingested over a period of weeks. In addition to an irritant action on the skin, the oil provided a thermal stress to the animals through destruction of the insulative abilities of the fur, that bears in nature probably could not compensate for. The ingested oil caused disruption of both the blood and nervous system, pathology that proved fatal even in the absence of the thermal effect.

The experimental oiling of the pelage was complete and so the experiment provided no estimate of the severity of graded dosages of oil. In a natural spill situation, where a polar bear might swim over an oil-covered lead, oiling would likely be complete. However, in the case of oil suspended in ice that was let free during subsequent seasons, fouling might be less severe. Because the drugging and cleaning of a polar bear is a major undertaking, it is important to derive, through experimental work if necessary, what degree of loading bears can receive without needing treatment. In the case of a spill, clean-up personell would need such an estimate to be able to decide which bears not to treat.

In the above experiment, the oiling of the bears resulted in pathological changes which would have undoubtedly proved fatal in the absence of veterinary treatment, even in the mildest case of 15 minutes exposure. Even though this was a single experiment using only three animals, it seems therefore reasonable to conclude that a single brief oiling in nature would kill a high proportion of the polar bears fouled.

6.5 Oil and otters

While otters are technically land mammals, their habitat includes fresh water streams and sea coasts, and they would almost certainly be affected by beached oil. Otters prey on bottom-living fish and crustaceans within 100m of shorelines, and their sleeping and breeding places are also close to the shore (Baker, Jones, Jones and Watson, 1981). This group represents the most extreme development of pelage as insulation, with up to 130,000 hairs/cm^2

and little or no subcutaneous blubber (Costa and Kooyman, 1982). While there are no sea otters in Norwegian oceans, it appears that both groups are similar in their heat conservation strategies and response to oil, so that results from sea otter trials can be used to predict how otters would be affected by oil spilled onto the Norwegian coast.

Several studies into the effects of oil on sea otters have been carried out and one is presently underway at the Hubbs Marine Research Institute in California (Kastelein, 1985). It is clear that sea otters are the most vulnerable of all marine mammals to oil contamination, with even moderate fouling leading to destruction of the insulative ability of the pelage and to death from hypothermia. Sea otters are completely lacking in insulative blubber (Kastelein, 1985). For thermal balance, they rely firstly on increased metabolic rate (resting metabolic rate is over twice that of a comparable land mammal). As payment sea otters must consume 20%-30% of their body weight in food daily (Costa and Kooyman, 1979). Secondly dense underfur that traps an insulative layer of air bubbles (Kooyman, Davis and Castellini, 1977) and thirdly have a well developed ability to constrict the arterial blood supply to the skin, reducing skin blood flow, skin temperature and skin heat loss (Costa and Kooyman, 1979).

The internal actions of oil have not been specifically investigated but can be inferred to be of lesser consequence than the external effect. In practice, oil-fouled sea otters could be expected to die from hypothermia before showing the toxic effects of oil.

Kooyman et al. (1977) investigated the direct effect of oil on sea otter pelage by measuring the thermal conductance in water of isolated sea otter pelts before and after oiling, and after subsequent cleaning. The brushing of 10-20ml of Prudhoe Bay crude oil onto adult pelts increased heat conductance by 10% and 30% (only two animals used), while saturation of pup pelts increased heat conductance two-fold. In the adult, conductance was restored to control values by washing. While this method provides a quantitative comparison of the effects of oiling and cleaning, its accuracy for predicting heat loss in the live animal is poor because it cannot consider the additional efffects of blood flow through the skin (which increases heat loss) or the effect of grooming and other behaviours (which decreases heat loss). As an example, the authors considered the control values for heat conductance through adult pelts to be some five times too high.

In a later experiment, Costa and Kooyman (1979,1982) measured metabolic rate and heat loss in live, oil-fouled sea otters, and after subsequent cleaning of the pelage. After the application of 38-60ml fresh crude oil to up to 25% of the skin surface area, oxygen consumption (metabolic rate and therefore heat production) rose an average of 40%, and after cleaning further rose to 100% over control values, indicating that both oiling and cleaning disrupted skin insulation. Subcutaneous temperature below oiled areas dropped between 5°C-10°C due to local vasoconstriction, but it is important to note that this response was of limited duration. In washed animals and in those left oiled and unwashed, subcutaneous temperature increased, which the authors attributed to a limited ability to maintain this response. Another possibility they did not mention is that washing and prolonged oiling may be irritant procedures, elucidating an inflammatory reaction that increases skin blood flow and temperature and overrides the vasoconstriction response. A skin biopsy would have helped to determine if this was the case. When these heat conservation responses proved inadequate and deep body temperature fell, animals responded with shivering and increased physical activity.

At least eight days was required for the animals to restore pelage integrity and reduce metabolic rate to normal. Washed animals had to be artificially housed for at least this period at over 20°C to ensure survival. Two animals that were housed below this temperature both developed pneumonia and one died.

Thus in an experimental situation, sea otters can combat the thermal stress of **mild** oil fouling to a degree by increasing metabolic rate and heat production, reducing blood flow to the skin and by becoming more active. The increase in metabolic rate after cleaning indicates further depletion of the natural oils of the pelage and depletion of trapped air in the underfur, but also indicates that the original oiling only partially depleted the thermal integrity of the pelage, did not saturate the underhair, and did not push the thermal response of the animal to the limit. One experimental condition that must be remembered is that the animals were fed ad lib and that in a natural environment where food was more limited the animals might not survive the energetic cost of increased metabolic rate.

The authors concluded that "any contact with oil at any time of the year would have a profound influence on the health of individual sea otters through increases in the animal's thermal conductance and the subsequent increase in metabolic rate. It is probable that death may follow from pneumonia or hypothermia depending on the amount of the animal's fur fouled. Rehabilitation of oil-fouled sea otters would be very costly requiring holding facilities to keep the animals for at least two weeks. Even if adequate facilities were available the success rate of rehabilitating oil-fouled sea otters is likely to be rather low" (Costa and Kooyman, 1982).

As part of the same study, the authors studied the behaviour of four free ranging sea otters that had had between 10 and 30ml crude oil applied to 1%-10% of the pelage. Behaviour patterns (proportion of time spent active and resting) did not differ from oil-free control animals, as measured by telemetry. Siniff, Williams, Johnson and Garshelis (1982) applied 25ml Prudhoe Bay crude oil to some 10% of the pelage area of four sea otters, then cleaned one and released all four with attached activity transmitters. All animals showed significant increases in activity during the first week after release, which the authors interpreted as grooming, with feeding activity remaining normal. Activity was greatest in the cleaned otter, suggesting, as in the previous experiment, that cleaning increased thermal stress.

It is clear from these experiments that even small amounts of oil disturb the functional organization of sea otter pelage by depleting the layer of air normally held in the underfur and increasing heat loss. In the first experiment of Kooyman et al. (1977), in which isolated pelts were used, oil was applied with brush strokes in the direction of the hair, which would certainly have matted the guard hairs but perhaps not penetrated the underfur. In the live animal, oil applied even to the outer pelage layer may be distributed deeper by grooming attempts, further displacing air and increasing heat loss. There were some differences in the results between experiments, particularly regarding the effect of cleaning which restored the thermal integrity of isolated pelts but aggregated it in the live animals.

These experiments illustrate the behavioural and physiological reponses of sea otters to oil fouling. In an actual oil spill situation a much higher percentage of the coat could be expected to become fouled. The oiling treatments used in the two experiments on free-ranging animals were the least stressful of all, both in terms of the quantity of oil used and the area of pelage covered (although presumably the oil would have been spread further by grooming). Heat loss (and therefore compensatory metabolic rate increase) would have been relatively small and a significant increase in feeding activity therefore not expected. All the animals survived not only the thermal insult but the ingestion of oil that must have occurred during grooming. Both experiments were also done during the summer, when water temperature is high. If they had been repeated during the winter the survival could have been reduced. Costa and Kooyman (1979) estimated that in practice, heavy oiling of more than 20% of the body surface would probably be fatal.

The effects of ingested oil were not considered during any of the experiments, nor was the effect of weathered oil or mousse. On the one hand we might expect less risk from weathered oil because it is more tar-like and should not easily penetrate the pelage. However, being tarry, it may bind to the hair causing severe hair loss during grooming by the animal, as is the case in the polar bear, thus aggravating the damage. Kooyman et al. (1977) described a naturally oil-fouled sea otter pelt as being heavily clumped in contrast to pelts fouled with fresh oil, and the oil as being more tarry.

While these experiments indicate clearly that oil is detrimental to sea otters they do not indicate whether these animals can recognize oil at sea and avoid it in an actual spill situation. The answer is given in part by the experiment of Siniff et al. (1982) who set two sea otters into a tank partially covered by fresh crude oil to a depth of 0.01mm (a good approximation of slick thickness in open sea). The animals were immediately aware of the presence of the oil and tried to avoid it. Over the 12 hour period of confinement they spent on average less than one minute per hour in the oil, but eventually became totally covered. One sea otter, which was not cleaned, died from hypothermia after 24 hours while the other was treated and saved. The animals in this experiment were in a confined experimental situation and it is possible that in an actual spill situation they could have successfully avoided the oil completely. It is also possible that they were alerted to the fresh oil by inhaling the irritant volatile fraction, and that if exposed to a weathered slick in which most of these components had evaporated, they would not have the sensory cues enough to detect the oil at all.

While there have not been any controlled investigations into the effects of oil on otters, it may be relevant that otters have not been seen on the coast of North Trondelag since the sinking of the "Deifovos" polluted that coast with oil in 1981 (SFT, 1985).

Another observation of an actual spill situation suggests that otters are equally as vulnerable to oil as are sea otters. After a spillage of 1,200 tons of Bunker C fuel oil off the Shetland Islands from a tanker on December 31, 1978, some 110km of coastline eventually became polluted with oil and between 15% and 50% of the estimated total otter population died (Baker et al., 1981). Otters were observed swimming and feeding in oil covered sea until they became heavily covered, indicating that they either did not recognize the oil as an entity or were not concerned by it. While there were only seven post-mortems done on autolysed carcases, the consistent finding and apparent cause of death was haemorrhagic gastro-enteritis, presumably due to the eating of oiled sea birds and the ingestion of oil from their own pelage during grooming. In comparison with the sea otter, there was in this case more of an internal effect contributing to death, although the authors suspected that hypothermia was also a factor. Hypothermia would not be expected to be nearly as significant as in the sea otter, because while otters hunt in the sea they sleep in burrows on land where the heat conductance into air is much less.

From the account of the spill and of postmortem findings, it appears that the way otters were affected by oil changed with time. By January 20, three weeks after the spill, the oil had collected in patches along the shoreline and very little was left on the water surface. Before this date heavily oiled carcases were discovered on beaches usually close to the water, while later deaths occurred up to 150m inland and were less heavily oil-fouled. It appears that these later animals contacted beached oil and died after ingesting it during grooming. Animals found earlier had contacted oil on the water, become heavily coated and died quickly from a combination of hypothermia and direct toxicity. No quantitative data were given as to percentage of the coat oiled on affected animals.

One possibility that has not been investigated is that otters and sea otters might also be at risk from chronic intoxication due to the continual ingestion of oil in food polluted by a spillage. Crustaceans and molluscs, which comprise a high percentage of the animals' diet, accumulate petroleum products which may be further concentrated in otter tissue due to their high metabolic rate and daily food intake (Stede, 1985). In addition, the death of food species following a spill may limit the ability of oil fouled otters to increase their metabolic rate, thus reducing survival following oil-fouling.

In summary, it is clear that the aquatic Mustelidae, which rely on pelage for insulation, are placed at serious risk through contact with oil. The main effect that oil has is a matting of the pelage which disturbs the layer of air normally held in the underfur and increases heat conductance leading to hypothermia and often death. Animals that survive are at risk firstly from gastroenteritis from the oil they ingest during grooming, and secondly from lung and other infections secondary to the stress of prolonged hypothermia.

6.6 Oil and whales

Compared with the information available on the effect of oil on seals little is known about the effects on whales. Actual observations of whales in spill situations are very few and seem to indicate that at least the large whales and some dolphins either do not recognize floating oil or are not disturbed by it, for they continue to feed and exhibit other normal behaviours in its presence. Goodale, Hyman and Winn (1981), reported in Engelhardt (1983), found that whales and dolphins continued to swim and feed in both oil-covered and oil-free water after a shipping accident that released Bunker C and diesel fuel. In this incident, normal surface and below-surface feeding was observed in humpback whales, fin whales and white-sided dolphins.

There is some equivocal suggestion that grey whales may alter swimming speed and direction, and breathing behaviour, in the presence of floating oil clumps but definite evidence is lacking (Geraci and St. Aubin, 1982). These authors commissioned groups of observers to study the behaviour of California grey whales during the migration through the Santa Barbara Channel to their breeding grounds of Baja California. The seabed of the Santa Barbara area leaks a considerable quantity of oil that pollutes the sea surface either as oil sheens or more weathered tar lumps. On several occasions grey whales changed their swimming direction when approaching oil. There was, however, no change in breathing pattern or swimming speed and no certainty that the behaviour was in fact a conscious response to the presence of oil. Other whales would swim through oil, but would change swimming speed although without any consistent pattern. The authors felt that the whales spent less time at the surface when swimming through oil and that they breathed less often and at a faster rate. There seems, however, not to have been a consistent pattern of detection and active avoidance of floating oil by the whales.

Whether oil released in actual spill situations harms whales is also equivocal. The probable answer in most cases is that some animals definitely die after oil-fouling but that the proportion of deaths among fouled animals is low. Often it is hard to form an opinion after reading case reports because details of necropsy examinations on suspect animals are not given, and because of the ever-present uncertainty as to whether oil-fouling caused the death on an animal or occurred post-mortem. In one recent case, seven dolphins (and a number of dugongs, turtles, snakes and other marine animals) were found dead after a spillage of oil in the Arabian Gulf (Anon, 1983b). In this case necropsies were done, although no details were given, and the cause of death was attributed to "respiratory stress, presumably as a result of inhaling oil". This does not make it clear whether evidence of oil was actually found inside the dolphins.

Given the rapid and forceful nature of cetacean breathing, it would seem feasible that a small quantity of oil could be inhaled if a dolphin or even large whale surfaced through an oil slick. Suffocation was also listed as the cause of death of a dolphin after the much discussed Santa Barbara Channel oil platform blowout, although Brownell (1971) indicated that this was a fabrication. This blowout occurred on January 28, 1969, in the migration path of the California grey whale and the entire northward migration passed through, or westward around, the contaminated area. In the two months following the spillage, six grey whales, one sperm whale, one pilot whale, five common dolphins, one Pacific striped dolphin and one unidentified cetacean washed onto California beaches. No petroleum products were found in any of the tissue samples collected from these animals, although there was a film of oil on the baleen of one of the grey whales which the author thought had occurred post-mortem. This sampling of number and species that stranded was also considered consistent in number with stranding records from Californian beaches in previous years.

It therefore appears that the spilled oil did not cause the deaths of any California grey whales during their migration, despite the widespread contact that must have occurred. This contact would in any case probably have been limited to the skin. Grey whales apparently do not feed during the initial part of their migration (Brownell, 1971), which would have limited the amount of oil expected to be ingested. In addition, the prey of the grey whale consists primarily of benthic species and, with some exceptions, the animals do not feed in the upper water column where the oil concentration would have been the highest (Oliver, 1983). The situation therefore should not be extrapolated directly to Norwegian whales such as the minke, that also feed at the surface and may actually ingest some amount of oil after a spillage.

Geraci and St. Aubin (1982), conducted a detailed examination into the effects of oil on various cetacean species but primarily on the bottlenosed dolphin.

The authors designed and carried out experiments to determine (1) if dolphins could detect various floating petroleum products (2) if dolphins would of their own accord avoid floating oils (3) the effects of petroleum on cetacean skin (4) the internal effects of petroleum (5) whether petroleum had an effect on baleen and (6) if California grey whales could detect and avoid floating oils and tars.

In the first experiment, dolphins were trained to observe a water surface from below, both visually and acoustically, and signal if they could detect any object or substance (Geraci, St. Aubin and Reisman, 1983). The results indicated that, under optimal visibility conditions, dolphins can visually detect dark crude oil to a limit of six millimetres, and diesel oils to a limit of 17mm, from a distance of one metre. Using echolocation alone, they can detect oil films of some 12mm thickness. This should mean that dolphins at sea could detect lighter crude oils and thick fuel oils soon after spillage, which occur in thicknesses up to 20-30cm. They probably could not detect (before actual contact) diesel oil at any time, older oil slicks in open water which have a thickness down to 10^{-2}mm or slicks in turbid water.

When confronted with a thin surface film of coloured oil during daylight, three dolphins avoided the oil, even before contact, for five to 53 minutes (Smith, Geraci and St. Aubin, 1983). The animals appeared to be startled by physical contact with the oil, and, after contacting it several times, avoided further contact during the remaining six hours of the trial and during a further eight hour exposure several days later. At night, animals detected after contact and subsequently avoided a one centimetre thick layer of both heavy dark oil and heavy clear oil (St. Aubin, Geraci, Smith and Friesen, 1985). There was evidence of detection but little reaction to an oil sheen surface layer at night. Mineral oil was used during the test and it might be expected that the avoidance reaction would have been even stronger if crude oil, which gives off irritant fumes, had been used.

These two experiments indicate that under controlled and optimal conditions, dolphins can detect and choose to avoid coloured oil, and so should have at least the potential to avoid spilled oil at sea. Observations of wild dolphins and other whales feeding and swimming among oil slicks, discussed above, indicate however that under less than optimal conditions, they do not have or do not use these abilities.

Geraci and St. Aubin (1982) also investigated the effect of different petroleum products on the skin of live dolphins and dead or dying stranded whales of other types. In the first trial, localized areas of the skin of bottlenosed dolphins and a Risso's dolphin were exposed to crude oil and petrol for 15 - 75 minutes, without gross evidence of inflammation. Histological examination showed that damage was moderate or mild and limited to the outer layers of the epidermis, except after 75 minutes exposure to petrol, after which damage extended to the deeper epidermis and even to the dermis. The surface of the skin was never broken and there seemed to be no evidence of irreversible cell change. Following removal of the petroleum, skin integrity was quickly restored. In contrast, the superficial and intermediate layers of the epidermis of a sperm whale that was exposed to petrol for 17 hours were either eroded completely away or severely damaged. The deeper stratum germinativum, however, was not affected. The action of the petrol seemed to be due to the its solvent effect on natural skin oils. In an extension of this trial, experimentally induced skin wounds were contaminated by crude oil and petrol in an investigation of wound healing. Contamination with petroleum products did not delay the healing of the skin wounds compared with controls.

In addition to anatomical and histological studies, the effects of oil on skin biochemical parameters was measured. The synthesis of phospholipid, an important component of cell membranes and other cellular structures, was depressed by petroleum. Inhibition of phosolipid synthesis and subsequent loss of cell integrity may have been responsible for the transient damage observed in the epidermis. Skin metabolic activity and certain enzymic reactions were not altered.

It therefore appears that brief external contamination with oil is not threatening to cetaceans. Geraci and St. Aubin (1982) were of the opinion that oil would not adhere to the extremely smooth cetacean skin and that whales would not suffer skin effects from oil. However, the bowhead whale, a rather slow-moving cetacean, has now been shown to have a more conventional skin (Haldiman, Henk, Henry and Albert, 1983). Exposure of 75 minutes or 17 hours to petroleum are unlikely to be encountered by wild animals after actual spillages, and the skin damage described is unlikely to be sustained. In the case of skin erosion, which occurred after the long periods of petroleum exposure, one must however, consider the possibility of problems of osmotic homeostasis and introduction of pathogenic microorganisms. We have experienced that dolphin skin is very sensitive to infection with pyogenic bacteria if broken or eroded (Griffiths, 1983).

The internal effects of petroleum products on whales after ingestion and inhalation were only estimated indirectly, from a comparison with the known toxic effects in other mammals and from an investigation of the physical effects of oil on baleen _in vitro_. Without conducting any experimental study, but from the use of toxic doses in other species, Geraci and St. Aubin (1982) calculated a bottlenosed dolphin would need to swallow between one and five litres, and a fin whale 200 - 1,000 litres, to suffer a fatal result. Further, they estimated that it would be almost impossible for a cetacean in open sea to inhale enough petroleum vapour to do any significant damage, even under the most unfavourable conditions (rapid evaporation and low wind speed). They did, however, investigate the result of crude oil ingestion in rats, and found that oil was a very potent inducer of the liver enzyme Cytochrome

P_{450}. The authors recommended that the activity of this enzyme be measured in cases of suspected petroleum exposure in cetaceans as a possible measure of the degree of exposure.

Some information from an earlier experiment was included in the report, on the internal effects of refined machine oil ingestion. In one experiment 12ml oil was applied five days per week for three months to the surface of a tank holding four dolphins, with an extra 236ml every two weeks, while in the other test five millilitres per day, five days per week, was fed to a single animal in fish. A second dolphin, fed mineral oil, acted as a control. In response to the application of oil to the water surface, one only of the four animals showed evidence of mild liver damage, with plasma levels of the enzyme glutamic pyruvic transaminase (GPT) increased two- to three-fold after a month. The authors thought this to be more characteristic of trematode damage than oil damage. The experiment does not, however, indicate how much oil the dolphins actually inhaled or ingested, since no tissue samples were collected for measurement of petroleum concentration. It is also not reported if the animals exhibited the same dramatic aversion to contact with surface oil as occurred in the previously described experiment (St. Aubin *et al.*, 1985), or if instead they became habituated to it. In the second experiment a single dolphin received 225ml oil orally over some three months. In this animal there was no elevation of blood GPT concentration and no suggestion of liver damage. It is impossible to say if the dolphins ingested oil at all, but if they did then it would appear that chronic ingestion of low levels of some types of petroleum does not harm dolphins significantly.

In their investigation of a possible effect of oil pollution on the large whales, Geraci and St. Aubin (1982) investigated the fouling action of certain oils on baleen *in vitro* at 15°C. In this trial the flow of water through leaves of baleen was measured before and after fouling the baleen with oils of various densities (medium crude oil, light crude oil, Bunker C fuel oil and roofing tar).

Crude oil fouling of baleen increased water flow resistance for five to 40 seconds before flow returned to normal, while Bunker C fuel oil and roofing tar severely impeded flow for 10 to 15 minutes. Thereafter flow returned to normal although the hairs remained oil-fouled. These effects were consistent with repeated exposure to oil and were not additive. Continuous rinsing of the baleen with clean sea-water removed most of the crude oil in one hour, and most of the Bunker C fuel oil in 20 hours. Corresponding figures were not given for roofing tar. It could be expected that the effects would be somewhat more persistent under Barents Sea conditions with water temperatures of below 8°C.

It appears from this latter experiment that fouling of the buccal cavity of a baleen whale by light crude oil would not pose any lasting impediment to its feeding efficiency, while thick fuel oil would be retained and would impair water flow out of the mouth for some hours, particularly at very low water temperatures. In the live animal, however, most of the oil attached to the inner surface of the baleen would presumably be quickly removed mechanically by movement of the tongue and food, and swallowed. Unfortunately, the authors do not provide any estimation of the amount of oil likely to be trapped by the total baleen surface and subsequently swallowed.

If we consider the application of this work to the Barents Sea, it would seem that both large whales and smaller dolphins will not be threatened by transient contact with floating surface oil after a spillage. While smaller toothed whales were shown to be able to detect and avoid thicker layers of floating oil under optimal conditions, oil at sea would quickly form layers too thin to detect. There are also examples from actual spills where dolphins did not avoid spilled oil and continued to feed in its presence. Larger whales have also been seen swimming and feeding in oil-stained water. However, Geraci and St. Aubin (1982) have shown that even prolonged skin contact is most unlikely to be harmful. The only reservation remaining is the internal effect of oil ingestion.

Migrating whales would probably not take in much oil. Actively feeding whales, could, however, take in larger quantities. While trace amounts of oil administered chronically to dolphins had no harmful effect, the effect of a substantial amount of crude oil over a short time could be harmful. We refer to the situation in seals, where oral administration of oil to seals under controlled experimental conditions caused little ill effect yet seals have repeatedly died in nature from oil intoxication, particularly if they already had other health problems such as a parasite load. The effects of ingested oil in cetaceans remains unknown. We can surmise, however, that the number of cetaceans that would be killed after an oil spillage would be very low, while the discomfort caused to certain individuals might be significant.

7. OTHER EFFECTS OF PETROLEUM EXPLORATION AND PRODUCTION ON MARINE MAMMALS

To this point we have limited the discussion to the direct effects of petroleum on marine mammals after contact. However the establishment of a petroleum industry in the Barents Sea will have consequences for the marine mammals of the area long before the first oil is extracted. These other consequences we will review here.

7.1 Noise

The establishment and operation of drilling platforms, drilling ships and pipelines involves the production of noise under water. Normal service shipping and helicopter traffic involves both over- and under-water noise. We may expect a variety of noise types, not all of which may have effects on the surrounding life, and noise must therefore be characterised before it can be adequately discussed - continuous or intermittent, loud or faint, constant in pitch and intensity or variable. We can in theory divide the possible effects of noise on marine mammals populations into four: (1) The noise may be benign and animals may ignore it. (2) It may be of a loudness and frequency that matches that which marine mammals use for social signalling so that it interferes with communication. (3) It may be of a loudness and duration which initially produces alarm but to which animals may habituate. Finally, (4) it may be of an intermittent and irregular nature to which animals cannot habituate. In the evaluation of the possible effects of noise one can use actual experimental and case data where animals have been exposed to noise, or one can measure the frequency and loudness of produced noise and compare it to the known frequency ranges of hearing in marine mammals.

Noises may be divided into those that directly damage acoustic sensory structures and those that have a non-auditory effect (Turl, 1982). In the former category, damage to auditory structures may be produced by brief exposures to very intense sounds or by prolonged exposure to lower levels of sound. High frequency pure tones or narrow bands of noise tend to produce changes in localized regions of the inner ear, low frequency or random and broadband noise produces changes throughout the cochlea. The actual extent of the damage depends on the intensity, spectrum, duration and the exposure pattern of the noise source, and rest periods between exposure significantly reduce the extent of permanent damage. The non-auditory effects of noise are those of physiological stress, with signs similar to those seen after exposure to extreme heat or cold. These responses include a variety of measurable physiological changes, such as increased blood pressure, increased corticosteroid level and increased adrenal gland weight. Prolonged stress of this type can exhaust an animal's resistance to infection and disease and, in extreme cases, can result in death. According to Turl (1982), noise produced at deeper depths such as will be used in the Barents Sea, affects larger areas than shallow water drilling (for example the Gulf of Mexico), because sound is transmitted better at greater depth. In shallow water, there may be considerable transmission loss at the sea surface and at the bottom.

The mechanism of sound conduction to the inner ear varies between the different marine mammals. In dolphins, sound is transmitted through the medulla of the lower jaw through the mandibular joint directly to the inner ear (Norris, 1969). In the larger whales and in pinnipeds, sound is transferred directly through the skull to the inner ear whilst animals are in the water, although aerial sound transmission in seals is apparently typically mammalian (Turl, 1982).

Published measurements of the wavelengths and intensities of underwater sounds generated by drilling platforms are presently limited (Turl, 1982), although there is considerable interest in the subject, particularly in the Beaufort Sea off Canada, which can be expected over the coming few years to considerably increase the amount of knowledge available. Comparison of noise characteristics of oil recovery operations with marine mammal audiograms can therefore be only partially accomplished. In general, the frequency range of noise from offshore oil and gas drilling activities is from ten Hertz to ten kiloHertz with peak source levels between 130dB and 180dB (Turl, 1982). Greene (1982), quoted by Fraker (1984) measured levels of noise originating from various ships, aircraft and drilling devices in the Beaufort Sea and found a frequency range of 0-2,000Hz and an intensity at 100m distance of 180dB to 100dB. After consideration of peak noise output level from platforms and ambient ocean background noise level, Turl (1982) calculated that minimum detection ranges by marine mammals were 38km at 0.02kHz and 174km at 1.00kHz.

Accurate estimation of the effects of noise on marine mammals is also limited by poor understanding of the frequency range to which these animals are sensitive, particularly at the lower frequencies (Turl, 1982). Hearing sensitivities in large whales have not been measured at all. One guideline presently used is to measure the frequency range of sound production and to assume that animals are at least sensitive to their own frequencies. Four categories of sound are produced by mysticete whales (Turl, 1982). The first include low frequency moans of frequency range 12 - 500Hz. The second group comprise grunts, thumps and knocks of short duration in the 40 - 200Hz range. Group three sounds consist of short, discrete pulses of higher pitched chirps and whistles around 1,000Hz, while the last sound group is clicks or pulses that have peak energy at high frequencies, often between 20 and 30kHz. We can therefore assume that larger whales hear sounds at least between 12Hz and 30kHz. Actual audiograms of smaller whales and pinnipeds indicate that peak hearing sensitivity of toothed whales occurs between 5 and

100kHz (the notable exception is the killer whale whose hearing begins to fall away at 12kHz), and of pinnipeds 1to 12kHz.

The conclusion reached by Turl (1982) was that the possibility exists for marine mammals to be disturbed by noise from petroleum activities, in particular during feeding, mating and in protecting young. The lower frequency sounds produced by large whales are well suited for long-range communication and interference could substantially reduce the detection range. The possibilities for such a disturbance may be very real. Cowles, Hansen and Hubbard (1981) reported that the sounds of large Arctic class tankers will be clearly heard underwater over an area of 30,000km^2.

These theoretical calculations are supported by actual observation. There is some experimental evidence that whales avoid noise from oil development. Tyack, Clark and Malme (1983) played recordings from a production platform, drilling platform, drillship, helicopter, semi-submersible drill rig and finally from killer whales, to southward migrating grey whales off the Californian coast. Grey whales exposed to killer whale, production platform, helicopter and exploration platform sounds showed an avoidance response and swam away from the source of the sounds, or slowed down in the vicinity of the sounds. Fraker (1984) reported seeing beluga whales within four km of an artificial island drilling site in the Mackenzie Estuary, and bowhead whales three to six km from active drill ships in the Beaufort Sea. All these whales appeared to be behaving normally although the noise level in the area was well above ambient. There is also some evidence that certain areas of the Beaufort Sea, once frequented by bowhead whales, have been abandoned since the establishment of petroleum recovery operations, but adequate survey results are lacking (Fraker, 1984). There is also a suggestion that walrus distribution in the Canadian Arctic may have been affected by the establishment of permanent logistical bases (Cowles et al., 1981).

As a summary it appears that hearing in marine mammals is good and that most species can detect sounds in the 10Hz to 50kHz range. There is good evidence that the behaviour of at least some species of whales is altered by high levels of unnatural noise and also some evidence, although unconfirmed by systematic survey, of long term disturbance of the migration of bowhead whales after establishment of oil operations. The effects of such activities on pinnipeds has not been shown. We predict that pinnipeds of the Barents Sea coast will be disturbed by boat and helicopter traffic servicing petroleum platforms but that the effect of animals in the open sea will be smaller. Seals are known to react strongly to certain high frequency noises (Mate, Brown and Greenlaw, 1983) but the amount of experimental evidence does not allow further speculation.

7.2 Blasts

By blasts we mean shock waves generated by actual blasting operations, but also the shock waves produced during seismic mapping of the ocean floor in search of petroleum.

It is no secret that the shock waves from underwater detonation of explosives can kill animals. Yelverton, Richmond, Fletcher and Jones (1973) described the effects of such blasts on sheep, dogs, monkeys and ducks and calculated by experiment safe distances from underwater explosions. Detonation of various charges typically produced a positive pressure wave of 7 - 14kg·cm^{-2} lasting from 40 - 80>sec, followed by a weaker wave of negative pressure lasting about 10>sec. Effects of blasts were worse in shallow water due to the creation of further shock waves reflected from the sea floor. Lung injury occurred at an impulse of about 2.4kg·cm^{-2}·msec, gastrointestinal injury at impulse 1.8kg·cm^{-2}·msec and no damage was recorded below the level of 0.7kg·cm^{-2}·msec. Most damage was confined to the lungs and the gastrointestinal system and consisted of widespread but localized bruising, some of which was severe enough to result in mucosal ulceration and melaena. Eardrum rupture occurred in 50% of dogs at an impulse of 1.6kg$\cdot$cm^{-2}$\cdot$msec. In general, the more gas an organ contained, the greater was the incidence of pathology. Explosives with a slower detonation velocity and slower pressure increase rate (dynamite) were less destructive than fast-burning explosives (TNT).

Using the formula developed by Yelverton et al. (1973), Geraci and St. Aubin (1980) calculated that the safe distance from a 5kg charge for a harbour seal swimming at a depth of 25m is 360m. They thought that marine mammals would be more tolerant of such shock effects than terrestrial mammals, because they have thicker body walls and are adapted to withstand the effects of pressure. Susceptibility also increases with decreasing size. In one case, a California sea lion was killed by an underwater explosion while grey whales in the same area apparently went unharmed (Fitch and Young, 1948). Sea otters and harbour seals were also found dead during the Aleutian Islands nuclear testing programme (Geraci and St. Aubin, 1980), but this blast was hopefully outside the range of blasts likely to be encountered in the Barents Sea.

Modern seismic exploration uses as a sound source the rapid release of compressed air in units (air-guns) towed behind vessels (Fraker, 1984), with shocks produced usually every ten seconds or so. At a distance of 100m from one such source, a sound level of 206dB was measured. Shock waves so produced differ from those of explosives in that peak pressures are low and both the rise and fall times of the shock pulse are relatively long. Shock waves so generated are harmless to fish and almost certainly to marine mammals (Geraci and St. Aubin, 1980). However, whether they produce disturbance to individual animals or to groups has not been adequately investigated.

In one experiment (Fraker, 1984), bowhead whales did not react to air-gun discharges at a distance of ten km but at four and a half km there was a significant reduction in the amount of time the whales spent at the surface. There was never observed any obvious aversion to air-gun detonation and in other experiments no tendency to move away from seismic boats. One behaviour that was noted in the presence of air-gun use was the formation of tight groups by several animals but it was not clear if this was a reaction to the sound of the guns. Grey whales off the Californian coast reacted more vigourously to similar sounds. When detonation was started at a location four and a half km away, the whales slowed down, turned away from the source and increased their respiration rates (Clark, Tyack, Bird and Rowntree, 1983). If humpback whales in the Barents Sea react similarly to such sounds, there is the possibility for disturbance of their annual migration pattern.

There is apparently no data available on the effects of air-gun noise on behaviour of pinnipeds.

It seems that marine mammals are unlikely to be directly harmed by the types of detonations used for seismic mapping activity. However, there is a good chance that behaviour of large whales will be altered within some, as yet unknown, critical distance. This avoidance reaction is unlikely to be violent enough to be harmful, for example to separate mothers from offspring. If detonation of explosives is to be used in the establishment of drilling platforms to the sea bed, then a number of pinnipeds and smaller cetaceans will almost certainly be killed quickly and others die from injuries, although not enough to threaten any population. In particular, steps should be taken to ensure that the humpack whale migration through the south-western Barents Sea is not disturbed by the effects of noise and blast, by organized survey of numbers and by experimental investigation. According to Geraci and St. Aubin (1980) there is still a large deficiency of information on the effects of blast on behaviour which needs to be filled by experimental studies.

7.3 Drilling muds and other chemicals

A large quantity of various chemicals is used in the drilling of an oil or gas well and eventually these chemicals are usually dumped into the ocean. In this section we shall describe the nature of these substances and discuss the possible consequences of this dumping.

Drilling muds are fluids used to lubricate the drill bit when a shaft is being bored in the ocean floor,return cuttings to the surface and to counteract pressures in the well (Berry, 1983). The base for these muds can either be water or petroleum, with the addition of various compounds to aid the drilling process. Clay is used to increase viscosity. Barite is used to increase hydrostatic pressure and make the mud heavier and a typical well will use between 20 - 500 tonnes. About 20 tonnes of gel, consisting of the chemicals potassium chloride and ferrochrome lignosulphonate are also used. One Canadian report (Offshore Labrador Initial Environmental Assessment, Petro-Canada, 1983) lists that about 320,000 litres of cuttings are produced from the sea floor during the drilling of a typical shallow water well and that these cuttings can also contain a significant amount of heavy metals. Provided that the water depth is reasonably great, these muds and cuttings are all dumped into the sea. Cuttings sink to the sea floor while the other components disperse and dissolve. The report concluded "that drilling mud disposal from exploratory drilling would cause localized but environmentally acceptable perturbations to --- marine life" (p15).

The Petro-Canada report expressed considerable concern about the potential for chronic pollution by heavy metals in drilling muds. Chromium was the heavy metal of greatest concern. Ferrochrome lignosulphonate is used in substantial quantities in mud systems and considerable amounts of chromium could enter the sea during mud dumping. In addition, some sources of barite (20-500 tonnes per well) contain high concentrations of arsenic, cadmium, mercury and other heavy metals. There was a recommendation that calcium lignosulphonate replace ferrochrome lignosulphonate in order to reduce the quantity of chromium released and that areas around drilling operations be regularly monitored for a buildup of heavy metals.

In Norway, oil-based drilling muds are used during the drilling of wells, which releases large quantities of oil into the sea. The SFT (1985) report quotes that in the course of a single year (1982) on the Norwegian continental shelf, 6,500,000m^2 oil based drilling mud was used, as compared with 100,000m^2 water based mud. This activity resulted in the release of 4,000 tonnes of hydrocarbons into the ocean. This amounts to about 80% of the hydrocarbon spillage on the Norwegian continental shelf. The amount of chemicals and heavy metals that went out with this oil was not known. The report noted that the extent of biological changes around platforms using oil-based mud was greater than around platforms where water-based mud was used and that the use of oil-based mud is today the biggest source of continual hydrocarbon pollution from Norwegian offshore petroleum installations. Furthermore the use of oil-based mud is steadily and strongly increasing. The report advised that cleaning units be installed on oil installations where oil-based muds are being used, and that instead of diesel-based mud, paraffin-based mud should be used which has only about one percent of the toxicity of the other. We have not investigated the use of oil-based mud and therefore cannot criticize its use other than to say that if a conversion to water-based mud was made, a major source of oil pollution of the sea around Norway would be avoided.

The specific effect of drilling mud use of marine mammals has not been investigated, but the direct toxicity would probably be low. It is hard to conceive of a seal or whale being harmed by swimming in the area of an exploration platform. Furthermore, it is not known if there is an appreciable buildup of heavy metals around exploration platforms which then becomes introduced into the food chain and hence seals. If there is any harmful effect it would most likely be as a contribution to the high levels of petroleum and possibly heavy metals in water and sediment that exist in the vicinity of petroleum drilling platforms.

7.4 Boat and aircraft traffic

Boats and helicopters will presumably be a common sight in the vicinity of petroleum platforms as service vehicles, and also will be widely used in the cleanup of any marine oil spillage. It appears that most marine mammals do not react to the presence of vessels until they approach beyond a certain critical distance, after which they actively avoid them. Beluga whales are not disturbed by boats until they are about one and a half miles away, whereupon they move away. In one case all beluga whales within this critical distance moved away from an approaching vessel. Two hours after the vessel's passage there was a strip a mile wide containing no whales, but the whale distribution had returned to normal after 30 hours (Fraker, 1984). There was no evidence of any long term disturbance of migration patterns. It was suggested that the whales might be reacting with their sonar to the trail of tiny bubbles left in the wake of the vessel. Humpback whales in Glacier Bay, Alaska, also reacted to boat traffic and they possess sonar in the same way that toothed whales do. At ranges between one and two miles whales tended to move away from vessels and at ranges of less than a mile they chose to dive (Fraker, 1984). In another study, humpback whales increased dive times, reduced surface intervals, breached and actively avoided ship traffic, beginning at a distance of over three km (Baker, Herman, Bays and Bower, 1983). In several contrary episodes, humpback whales in the Denmark Strait and the Barents Sea have not reacted strongly to the approach of a ship and in some cases seemed attracted to ships, swimming alongside for periods from several minutes to over an hour (Christian, Griffiths and T. Øritsland, unpublished observations). California grey whales were reported to have abandoned a lagoon where there was considerable boat traffic, and to have reoccupied it when the boat traffic was stopped (Fraker, 1984). These whales seem, however, to adapt to the close presence of a large number of boats, as indicated by their tolerance of the large number of tourist boats that regularly visit the breeding lagoons of Baja California. Coastal seal colonies, particularly of grey and harbour seals, can also come to tolerate the close approach of regular boat traffic such as ferries, although they will take to the water if an unfamiliar type of boat approaches. On two locations along the coasts of Denmark and England, they have also managed to hold to their original colony locations after the establishment of airforce bombing ranges in the vicinity (Tougaard, 1985).

Airborne noise sources also produce disturbance among marine mammal groups. Cowles _et al_. (1981) stated that harbour seals are susceptible to disturbance from low flying aeroplanes leading to mass exodus from hauling-out areas. If this happens during the breeding season, pups may be separated from their mothers with reduction of pup survival. Repeated disturbance can further lead to temporary or total abandonment of colony sites, both in phocid seals and in the walrus. Burns and Harbo (1977), quoted by by Cowles _et al_. (1981), reported that spotted seals reacted strongly to the sounds of aircraft by running erratically across floes and diving off, whereas bearded seals reacted much more mildly. One of the authors (D.G.) observed that humpback whales off the eastern coast of Australia consistently dived when a twin-engined survey plane (Partenavia) flew directly over them at a height of 400m, although they did not react when the plane passed further away.

In summary, coastal pinnipeds may tolerate an increase in service shipping and aircraft provided that the traffic is regular, but will be frightened and may even abandon their haul-out sites if subjected to a heavy traffic that comes at irregular intervals or approaches too closely. Most whales will probably actively avoid single ships in the open sea by swimming away from them but the disturbance can be expected to be temporary and they will resume their original behaviours once the ship has passed. There may be a threshold amount of boat traffic, as yet undetermined, beyond which permanent changes in behaviour and distribution become established. In particular, the humpback whale has been shown to react more than most species to boat and aircraft traffic, which may lead to disruption of its annual migration through the Barents Sea lease area.

8. THE CONSEQUENCES OF LONG TERM OIL EXPOSURE

Having reviewed the more immediate effects of direct oil exposure, noise, shock, chemicals and traffic on marine mammals, we will now look at the wider spectrum of clinical findings that have been recorded in mammals including man, to provide some idea of what could be anticipated in marine mammals known to have been in contact with oil. We also examine the possible longer-term effects of chronic exposure of marine mammals to smaller amounts of oil. For this it is most convenient to examine the results of chronic occupational and accidental exposure of humans to petroleum.

There have already been several reviews of the clinical pathology in various species of mammals exposed acutely or chronically to petroleum. Man as well as other mammals react to petroleum exposure in similar ways although most clinical case reports in humans concern the ingestion or inhalation of refined petroleum products. The earliest and most commonly seen effects after sudden exposure are usually in the pulmonary, gastro-intestinal and central nervous systems. In many cases where oil is ingested and swallowed, a small amount of the load is also inhaled leading to the onset of acute pneumonia. Following this acute phase there is often seen a more chronic pneumonia with a granulomatous reaction leading to fibrosis (Beermann, Christensson, Møller and Stillstrøm, 1984). The pulmonary part of the clinical picture is usually, at least in man, the most serious and the one responsible for the most deaths. Hydrocarbons in the vapour phase are absorbed rapidly and can reach high blood levels (Juck, 1980). However, it is only the lighter petroleum fractions that do damage after inhalation; molecules larger than C_{15} are not dangerous (Carpenter, Geary, Myers, Nachreiner, Sullivan and King, 1976).

Enteritis (inflammation of the intestine) is another common finding, due to the direct irritant action of petroleum on the gut mucosa. This effect is common in ruminants (Juck, 1981) and has already been discussed in Chapter 6 in relation to intoxication of polar bears, otters, and phocid seals (Babin and Duguy, 1985). Signs exhibited include vomiting, haematemesis (vomiting of blood) and melaena (blood in faeces) (Juck, 1981). Lighter petroleums such as gasoline may actually have their greatest action through the lung, even after swallowing, due to the very high vapour pressure generated by warming the fluids up to body temperature (Carnevale, Chiarotti and De Giovanni, 1983).

Damage to the third system commonly affected, the central nervous system, is usually demonstrated as depression and stupor, although excitation may also result, particularly if it is the lighter fractions that are involved (Evans and Rice, 1974). We discussed in Chapter 6 the possibility that thrashing seen in ringed seals after exposure to fresh crude oil (Geraci and Smith, 1977), could have been due to nervous system excitation. Albino rabbits dosed daily for five days with undiluted kerosene became sluggish and stuporous, and also had swollen stomach and intestinal mucosae (Gerarde, 1959, quoted by Juck, 1981). In many cases of accidental petroleum inhalation, especially of lighter fractions, death is actually due to action on the nervous system after rapid absorption into the blood, involving progressive medullary paralysis leading to respiratory failure (Carnevale et al., 1983). Symptoms experienced by people more lightly intoxicated by petroleum include hallucination, confusion, dullness, loss of balance, distortion of colour vision, loss of appetite, headache, vomiting, convulsions and death (Geraci and St. Aubin, 1982). Long term inhalation results in degeneration of the brain and peripheral nerves. Long-term occupational exposure to the lighter petroleum fractions has also been associated in people with progressive mental disturbance - depression, anxiety, fatigue and personality change (Struwe, Knave and Mindus, 1983).

Other clinical effects described include inflammation and degeneration of the kidney (nephritis) and liver (hepatitis) with subsequent loss of function, enlargement and inflammation of the heart with subsequent dysrhythmia (Juck, 1981), and intravascular haemolysis followed by haematuria and haemoglobinuria (Adler, Robinson and Binkin, 1976). Systemic absorption of benzene and of molecules in the C_9-C_{12} range produces in a number of species degenerative changes in the bone marrow resulting in anaemia (Juck, 1980). This effect was also seen in polar bears coated by crude oil (Chapter 6).

Chronic application of petroleum products to the skin may result in inflammatory change (dermatitis) or even neoplasia. Dutton (1934) attributed the irritant effect to the content of sulphur compounds in the oil, particularly hydrogen sulphide. The resultant dermatitis can be of an eczematoid exfoliating type, with drying, scaling, cracking and flaking of the skin. If the cracking is serious enough there is leakage of extracellular fluid onto the skin surface. This dry form of dermatitis has also been observed after the application of pure hydrocarbon in the absence of sulphur (Foged, 1984). Alternately an acne type of dermatitis may result that is more pustular. In one study in Poland, such an acne condition was found in 68% of people working with oils and petroleum-based coolants in a machining works (Santarius-Kaczur, 1984). Other research has shown that the lighter fractions of petroleum are also very irritant to the skin. Benzene application caused dermal fibrosis in rats while application of slightly heavier molecules resulted more in the effects described above (Dutton, 1934). Topically applied kerosene has caused hair loss in the horse and severe dermatitis in cattle (Juck, 1981). Considering the consistent history of pathology after the application of hydrocarbons to skin, it is surprising that there have not been any reports of similar results in pinnipeds after coating with crude oil. It may be that in the few trials that have been made, the oil has not been left on long enough to produce an effect.

Hydrocarbons can be extremely irritant if they find they way into subcutaneous tissue, depending on the size of the molecule involved. Such situations have been described in people after accidents with appliances that use solvents under high pressure and after the intentional but misguided injection of petroleum. In some cases, for example when kerosene is used, reaction is immediate, although it is noteworthy that oil may lie dormant for long periods before causing inflammation. In a particularly interesting but extreme case, two men in their mid-60's were treated for purelent cellulitis of the scalp with draining sinuses after having received subcutaneous injections of paraffin oil for pattern baldness some 30 years previous (Klein, Cole, Barr, Bartlow and Fulwider, 1985). In another case, subcutaneous injection of five millilitres of kerosene resulted in abscess formation followed by ulceration (Qaryoute, 1984). Other cases of abscess formation have been reported after the injection of kerosene (Rubinstein, Segal, Tirosh, Dolev and Findler, 1985).

One feature that really only becomes apparent after long-term exposure to oil is its neoplasia producing ability. An increased incidence of various cancers and tumours, both at the site of oil exposure and distant to it, has been described repeatedly among workers in the petroleum industry (Savitz and Moure, 1984). As an example, two studies in the United States revealed that the incidence of lung cancer among oil refinery workers was 1.6 and 3.0 times higher than in the general population. Other studied revealed, however, much weaker associations. There is better agreement that lymphatic and haemopoietic tumours (for example lymphoma and leukemia) occur more often among oil industry workers. Other neoplasias that have been reported as being relatively more common after hydrocarbon exposure are brain tumour and stomach cancer (Thomas, Maxweiler, Crandall, White, Moure-Eraso and Fraumeni, 1984), skin cancer (Purde and Rahu, 1979), Sertoli cell tumour (Mills, Newell and Johnson, 1984) and bladder carcinoma (Mommsen and

Aagard, 1984). Neoplasia was not limited merely to those people who had had direct contact with petroleum. In one study in the Netherlands, it was found that children of women employed in the petroleum industry whilst pregnant, developed leukemia at a rate two and a half times greater than in the general population (van Steensel-Moll, Valkenburg and van Zanen, 1985). One possible effect that has not been investigated in this chapter is hormonal disturbance. Ingestion of oil by seabirds raises plasma corticosterone and thyroxine concentration and can lead, through endocrine disfunction, to retardation of growth, impairment of osmoregulation and hypertrophy of adrenal and nasal gland tissue (Peakall, Tremblay, Kinter and Miller, 1981). We have not found information in the literature on disturbance of reproductive or other hormonal homeostasis by petroleum. Either it has not been investigated or there is no effect. We propose that this subject be investigated as part of any future study of the effects of oil in marine mammals.

This chapter has revealed that both acute intoxication by and chronic exposure to petroleum products can produce a much wider range of pathology than that which has been previously described in marine mammals. We do not suggest, of course, that the oil effects described here will become common in Barents Sea seals after establishment of a petroleum industry there. At the same time one will discover in a carcase during necropsy only as much as one is prepared to look for. By collating this list of published pathological findings we hope to alert people to the pathology that could conceivably be found inside or on a marine mammal, in order to stimulate interest in the examination of animals after oil contact and the collection of relevant tissue samples during necropsy.

9. VALUED ECOSYSTEM COMPONENTS (VECs)
A CONCEPT FOR EVALUATING THE EFFECTS OF OIL IN AN ECOSYSTEM

The objective of a Consequence Analysis is of course to evaluate the consequences of establishing a petroleum industry in a region. Implicit in this aim is the need to identify environmentally important parameters in the region and then to monitor them for signs of change as the industry becomes progressively established. A major problem is to select the parameters to be measured. One approach to the problem which may have merit is that of Beanlands and Duinker (1983), who developed the concept of Valued Ecosystem Components (VECs). VECs are defined as any resource or environmental feature that could: either 1. be important to the local human population, or 2. have national or international profiles, or 3. be important in evaluating the impacts of development and in focusing management or regulatory policy, if altered from their existing status. A VEC can therefore be an indicator species that is sensitive to oil, a quality of life that a local community considers important such as clean air and water, animals that have conceptual value to people in other lands such as baleen whales, a species that occupies a central position in the food-web, a species whose commercial harvest is economically important, and so on. The VEC concept has subsequently been used in the Beaufort Environmental Monitoring Project (BEMP) survey of the potential effects of petroleum extraction from the Beaufort Sea in the northwest of Canada.

In its consideration of consequence analysis using the VEC approach, the BEMP study used the following sequence:

1. Identification of Valued Ecosystem Components.
2. Review of probable industrial scenarios.
3. Definition of the study area.
4. Definition of the temporal horizon for monitoring.

5. Identification of impact hypotheses that relate development activities to VECs.

6. Preliminary screening of impact hypotheses for validity, relevance and credibility.

7. Evaluation of impact hypotheses.

8. Definition of research and monitoring programmes necessary to test valid impact hypotheses.

Such a full consideration of the VEC concept is outside the scope of this preliminary report, but we will identify those ecosystem components related to marine mammals which we consider to be of value in the Barents Sea lease area. We will then suggest preliminary hypotheses whereby Barents Sea VECs may be affected by petroleum development. It is important to point out however that the VEC approach can have one potential deficiency. Because those species important in the eyes of the general public are often higher mammals and top predators, it is possible to over-emphasize as VECs, and subsequently monitor, species such as seals and whales whose dynamics do not reflect the state of the ecosystem as a whole. If one is to use this system, it is important also to identify a representative range of indicator species sensitive to the level of oil in the environment, even though they may be, for example, benthic bivalves which most members of the human community have never heard of.

In this preliminary consideration of the effects of oil in the Barents Sea lease area, we have identified the following as Valued Ecosystem Components:

1. The harp seal (_Phoca groenlandica_) and its commercial harvest, because it is a source of income to communities in northern Norway and because of its interaction with fish stocks and fisheries in the Barents Sea. Harp seals of the White Sea (East Ice) population are found in large numbers throughout the Barents Sea in summer and autumn, during the pelagic feeding phase of their annual cycle.

2. The ringed seal (Phoca hispida), because of its importance as a prey species for the polar bear, the polar fox, and bird life in ice areas.

3. The bearded seal (Erignathus barbatus barbatus), because it feeds on bivalves and other benthic invertebrates in shallow seas, and is therefore is a possible indicator of the effect of oil on benthic species.

4. The greenland right whale (Balaena mysticetus). While very few greenland whales can be expected in the proposed lease areas, this animal deserves VEC classification because of its status as an endangered species.

5. The minke whale (Balaenoptera acutorostrata) and its commercial harvest, because it is an important source of income to communities in northern and western Norway.

6. The humpback whale (Megaptera novaeangleae), because of its international profile.

7. The polar bear (Ursus maritimus), because of its internationally protected status and international profile, and because of its extreme sensitivity to petroleum intoxication.

8. The capelin fishing industry, because of its commercial value, the importance of capelin as prey of cod, seals and whales, and its possible value as an indicator species of the amount of oil in the marine environment.

9. The scallop harvest, because the scallop is a prey species for the bearded seal, is susceptible to petroleum toxicity and may therefore be a valuable indicator species for the amount of petroleum in the marine ecosystem and because it is a developing industry.

10. Petroleum-induced skin and internal irritation of marine mammals, because marine mammals are higher animals that probably have the capacity to feel pain and to "suffer".

11. Recreational hunting of seals, if this has an importance to local human communities.

12. The fast-ice ecosystem, because petroleum spilled in a sea-ice environment weathers and disperses very slowly and has a prolonged effect on local life.

Other components may be equally important in a general list of relevant VEC's. However, this review is concerned only with mammals and further discussion is limited to the effects of oil on mammals.

In developing the possible scenarios involving VECs and the petroleum industry, we can consider as possible factors:

1. Noise and destruction of ice from service shipping activity.
2. Noise from aircraft activity.
3. Noise and shock from seismic exploration activity.
4. Regular operational noise from stationary oil-drilling platforms.
5. Chronic oil leakage from established rigs and pipelines.
6. Acute accidental oilspills from rigs and tankers.
7. Toxic effects of drilling muds and other chemicals spilled during the drilling phase of operation.

Having identified the VECs for the Barents Sea and factors involved in oil extraction that might affect them, it is possible to proceed with some hypotheses of how the two might interact, based on previous knowledge of the effects of oil and noise on marine mammals. Such hypotheses represent possibilities for effects, some of which will inevitably be highly probable, some unlikely and others very difficult to investigate even though perhaps probable. The following is an initial list of hypotheses applicable to VECs in the Barents Sea, covering the most serious possibilities. The coverage necessary in a complete Consequence Analysis would need to be considerably more extensive.

Hypothesis 1. Skin inflammatory reactions to oil will increase the food energy requirements of seals in water and lead to death from hypothermia and starvation.

Dermatitis (skin inflammation) may occur if the skin of seals is coated with oil for prolonged periods. This situation may occur if (a) oiling occurs during the moulting period when seals spend considerable periods on shore or ice, so that oil is not washed from the pelage, or (b) an undispersed oil slick drifts into a colony such that seals are recoated with oil every time they enter the water, or (c) seals are contacted by heavy fuel oils that matt the pelage and do not wash off, or (d) seals are contacted by refined petroleum products with a more irritant solvent action on the skin.

Should an inflammatory skin reaction occur, particularly during winter and spring with water temperatures of 0° C or below, we can surmise that (a) normal physiological mechanisms for limitation of skin blood flow and heat conservation will be overridden, or (b) an increase in blood flow, an integral property of inflammation, will increase skin heat loss and provide thermal stress, or (c) metabolic rate will rise to compensate for thermal stress, or (d) food energy requirement will increase, or (e) subcutaneous blubber thickness will decrease as blubber is consumed as an energy source, further increasing heat conductance from the body and increasing thermal stress (f) as a result of increased heat loss from dermatitis and from a reduced blubber layer, seals will not be able to maintain body temperature and mortality rates will increase.

We think this is a realistic scenario for seals exposed to an acute oil spill in the colder waters and shorelines of the Barents Sea, and that the following points should be further investigated:

A. The reaction of the skin to prolonged local application of petroleum products.

B. Measurement of metabolic rate change, skin heat loss, food energy consumption and blubber thickness for graded dosages of oil-fouling and different temperatures.

C. Development of a model for the estimation of the metabolic effects of external oil-fouling of hair seals.

Hypothesis 2. Skin inflammatory reactions to oil, and other oil effects, will change the normal haulout behaviour of seals and alter (a) the level of predation and (b) population estimation and census techniques.

Oil contamination leads to increased solar heat absorption that on still days may cause excessive heat loading and force animals to increase the proportion of time spent in the water, where further oil-fouling may occur. Further fouling may exaggerate the irritant actions of oil and lead to dermatitis (see hypothesis 1). Subsequent thermal stress and difficulty in maintaining body temperature may force seals to remain hauled out when they would normally be in the water, leading to (a) fewer feeding excursions and use of blubber as an energy source, reducing insulation and increasing thermal stress (b) increased predation (c) over-estimation of the population size during census.

We think this hypothesis is possible but that investigation of it would be very difficult on an experimental basis. Evaluation of those oil effects that would act at a population level could be predicted from the model developed for the solving of Hypothesis 1.

Hypothesis 3. Skin inflammatory reactions to oil will interfere with the moulting process.

Any inflammation that extends deep enough to involve the hair root will probably interfere with the production of new hairs and compromise the moult. In practice, the root of the hair lies deep in the dermis and only severe inflammation would affect it directly. This hypothesis is meant to emphasise that no studies have yet been carried out on the effects of oil on moulting animals.

Hypothesis 4. The lanugo of pups will act as a reservoir for oil, increasing the possibility of skin inflammatory reaction to oil.

Acute experiments have indicated that brief exposure of fat lanugo-coated pups to oil produces few or no short-term effects. Longer-term effects have not been investigated. Ringed seal pups in lairs wear lanugo for at least two months and, if fouled, may suffer irritation after chronic exposure.

Hypothesis 5. Skin inflammatory reaction to oil will retard seal pup weight gain during lactation and will accelerate weight loss in weaned pups, thus increasing the mortality rate in the 0^+ age group.

Pups fouled by oil before they have accumulated blubber may suffer increased heat loss due to reduction of the insulative properties of the pelage. If this occurs an increased proportion of the energy ingested in the milk will go towards the maintenance of deep body temperature, resulting in reduced weight gain and reduced blubber thickness, and ultimately reduced long-term survival.

Hypothesis 6. Oil transported into the subnivean lairs of ringed seal will be spread widely around the lair, will increase the solar heat absorption of the walls of the lair, and will result in partial melting or collapse of the lair leading to increased predation by polar bears and foxes.

Lactating ringed seals make regular feeding excursions during the two month lacation period, leaving the pup in the lair. During these excurions, mothers may make contact with oil trapped in breathing holes, leads and under the ice, and may transport a proportion of this oil back to the lair. Spreading of this oil around the interior of the lair by the mother and pup may darken it to the extent that the micro-climate of the lair is altered and partial melting of the structure occurs. Because polar bears and

Arctic foxes locate lairs by smell, any thinning of the lair will increase the likelyhood of its discovery.

We feel this is a realistic hypothesis that can be investigated experimentally by:

A. Application of crude oil into inhabited lairs and studying the subsequent distribution of the oil around the lair.

B. Documenting the fate of each study lair.

Hypothesis 7. Lactating ringed seal will transport oil into subnivean birth lairs over the two month lactation period, where it will accumulate and have toxic effects on the pup and perhaps the mother.

Ringed seal mothers make regular feeding excursions during lactation, leaving the pup alone in the lair. On each excursion, mothers may make fresh contact with oil trapped in leads, breathing holes, and under ice, and transport a proportion of this oil back to the lair, progressively increasing the degree of fouling of the lair. Because oil in ice environments weathers extremely slowly, this oil may be expected to contain relatively large quantities of light petroleum components, which are also the most acutely toxic. Because of (a) the increased temperature in the lair, (b) spreading of the oil onto surfaces of the lair by the seals and (c) the small volume of the lair, concentrations of petroleum in the air may increase to a degree where toxic, especially neurotoxic, effects may occur. Before this happens, avoidance reaction of pungent fumes may force the mother and pup to other lairs or onto the ice surface, with increased predation by polar bears, arctic foxes and birds.

We think this scenario of the effect of an acute crude oil spill in fast ice is possible, depending on (a) the amount of oil transported into the lair by the mother, (b) the quantity of lighter components in the oil, (c) the size and age of the pup, (d) the susceptibility of ringed seals to inhaled petroleum products (e) whether oil can evaporate significantly in the lair at low temperatures. This hypothesis should be investigated by:

A. Experimental application of fresh crude oil into actual birth lairs in fast ice with measurement of subsequent petroleum vapour concentrations.

B. Experimental determination of the susceptibility of ringed seal to the neurotoxic effects of petroleum.

Hypothesis 8. Oil ingested acutely or chronically with prey will have toxic effects on marine mammals.

While the affects of direct exposure to petroleum have been investigated in marine mammals, there is a shortage of knowledge concerning the long-term effects of small quantities of oil ingested in food over a long period. To our knowledge it is also unclear if prey species from polluted regions have an appreciably higher level of oil in their tissues than those from unpolluted areas.

Hypothesis 9. An acute oil spill in a fast-ice area would kill a high percentage of the polar bears contacted.

Experimentation has shown that a large amount of oil is taken up by polar bear pelage after external exposure and that, through grooming, most of this ends up inside the bear where it is often fatally toxic. Further, up to several months of supportive treatment are necessary to reverse the toxic effects of oil in polar bears. In practice, such facilities probably could not be supplied in the case of a spill in the Barents Sea and bears would die. The most practical research into this situation is surveying the density of bears on sea ice to establish the probable number of animals that would die after a spillage.

Hypothesis 10. Toxic effects of drilling muds and chronic oil releases would kill a substantial percentage of benthic invertabrates, subsequently affecting (a) the bearded seal population of the Barents Sea and (b) the commercial scallop harvest.

That oil reduces and sometimes exterminates local benthic fauna both by direct physical smothering and by toxicity is known. What is unknown is the area over which these species would be affected and so whether the effect would show itself as a reduction in numbers of predator animals such as the walrus and bearded seal. In practice the margin of error involved in most surveying techniques of marine mammals makes this hypothesis very difficult to investigate.

Many other hypotheses, likely and unlikely, are worth considering but may prove quite difficult to confirm experimentally before a petroleum industry actually becomes established in the Barents Sea. Among these hypotheses the following may be considered:

11. Noise from service boats and aircraft will frighten coastal seal colonies, interfering with breeding.

12. Underwater blasting for seismic surveying will kill seals, disrupt the humpback whale coastal migration, and disturb other large whales causing changes in behaviour and distribution.

13. The increased human population of service towns will disturb local coastal seal populations through hunting pressure and sight-seeing.

10. RECOMMENDATIONS FOR FURTHER RESEARCH

In conclusion of a fairly exhaustive review of the effects of petroleum exposure on marine mammals, we feel there is clearly enough information from experimentation and actual case studies to be able to predict what will happen to seals in the case of oil exposure during summer temperatures, at least in the short term, and also to polar bears and to otters. Most of the polar bears and otters fouled by oil would die; most seals would be little disturbed. The situation in whales is not so clear. External fouling would in most cases have little acute effect. The internal damage done by ingested oil is unknown and has not been investigated. We are concerned that we are unable to predict confidently what would happen to marine mammals fouled for long periods by oil or fouled under winter conditions (for example in the Barents Sea in winter or around Svalbard). This is because there is still a deficiency of information in certain critical areas of knowledge. In this chapter we list the information which must be obtained to fill the gaps and the investigations necessary to get that information.

1. The external effects of oil-fouling of seals in cold temperatures.

This first area of deficiency has become our main concern in the course of preparing the review and concerns particularly the thermoregulatory effects of oil-fouling of seals in cold climates. At present the lowest temperature to which seals have been subjected during an oil-fouling experiment is plus seven degrees (Smith and Geraci, 1975). In the Barents Sea the surface water temperature during winter is approximately plus three degrees which is not too much different, but air temperature is considerably lower, especially when wind chill is considered. As one travels northward to Svalbard the situation is even more extreme.

The next factor contributing to a lack of understanding of the thermoregultory effect of oiling is the short time course of previously conducted experiments. During the Smith and Geraci (1975) trial, adult ringed seals were oiled for one day before being transferred to clean water, and weaned harp seals for approximately five days before being killed. The conclusion was that external oil-fouling had no permanent effects in these animals. We are concerned that the experimental conditions did not match those which would occur after accidental oiling of the ringed seals' natural environment. In this case oil would collect in leads and breathing holes in the fast ice to a thickness of several centimetres, under ice floes (where it would quickly be incorporated into the ice) and in moving ice would also collect on floe surfaces. Because land-fast ice normally is very stable the oil would remain and foul ringed seal each time they entered and left the water, possibly for weeks.

The third factor in the story is the existence or not of an irritant effect of oil on seal skin. The conclusion of Smith and Geraci (1975) was that crude oil had no such effect. Considering that external oil exposure leads to dermatitis in a wide range of species, we are concerned that chronic oil exposure will eventually produce a dermatitis in seals. We are also concerned that signs of dermatitis have already been seen in marine mammals but have never been properly investigated, for example widespread loss of hair in an oil-exposed northern fur seal (Kooyman et al., 1976), loss of the skin vasoconstriction reflex in a sea otter after ten days of oiling (Costa and Kooyman, 1979), raw skin under oil on harbour seals (van Haaften, 1973), loss of skin quality in oiled ringed seals (Muller-Willie, 1974).

When these factors are considered together we may ask the question whether chronic exposure of oil to seal skin, such as would happen after an oil spill in ice, may lead to dermatitis or skin inflammation with increased skin blood flow and heat loss under the oiled areas. If seal skin behaves in a similar way to sea otter skin, seals would not be able to exert compensatory heat-saving vasoconstriction but would continue to lose heat. Compensatory vasoconstriction in the flippers and in the surrounding clean skin might, under below zero temperatures and wind, result in a deficiency of blood flow severe enough to produce frostbite.

Investigation of this possibility is needed to be able to predict the effects of oil-fouling on seals. Localized application of oil to captive seals for extended periods under controlled temperatures should be followed by histological examination of the skin after biopsy and other testing to measure inflammation, rate of heat flux and rate of absorption of oil through the skin surface. In the case of the ringed seal, further investigation should be commenced to investigate consequences of petroleum deposition in the lair, which would presumably occur through the movements of the parent seal.

2. The effects of chronic oiling on hormone balance and reproduction.

Marine mammals are being fouled already by oil along the coasts of Norway. These animals could provide useful information to predict the effect of oil on pinnipeds after the establishment of an oil industry in the Barents Sea. Unfortunately there is not enough published information on the biology of these seals or the effects of oil fouling on them to draw any conclusions.

We recommend long-term surveys of selected populations of seals living on polluted coasts, supplemented with experimental studies, to investigate the question whether chronic oil contact affects reproductive and immunological abilities. Deficiencies in these areas would result in lowered reproductive rate and rate of population increase, and increased incidence of illness and neoplasia respectively. Apart from the question of the affect of oil on seals in cold, this question of the long-term effects of oil on marine mammals is presently the most serious deficiency in the knowledge.

In sea-birds, oil ingestion produces a number a hormone inbalances that reduce growth rate and are eventually fatal. According to published works, acute oil exposure in seals seems to produce few short-term hormonal upsets in marine mammals apart from increased secretion of adrenal gland steroids, but we doubt that reproductive hormone effects have been looked for. If so they have not been reported. Studies of the effect of chronic fouling on the plasma hormone balance will enable better estimation of the long term survival of oil fouled marine mammals.

The common seal population in Danish waters is increasing at an annual rate of some 10%-12%, while the corresponding rate off the German and Dutch coasts, which are polluted with petroleum products, is less. The rate of population increase off the Norwegian west coast, which is similarly polluted, also appears to be less although censusing has still not been completed. Whether chronic low-level ingestion of petroleum leads to interference with reproduction in a manner similar to that polychlorinated biphenyls (BCBs) should be investigated to enable prediction of the possible longer-term effects on Norwegian marine mammals. This aim could be achieved by oil administration to individual animals and intensified censusing of Norwegian seal populations.

We further recommend there be more active liasion with those countries of Europe that have seals on their coasts and are already engaged on building up a picture of the levels of petroleum and other pollutants in their marine mammals.

3. Documentation of the amount of oil in the marine food chain in Norwegian waters.

There is presently a deficiency in the knowledge whether chronic oil pollution of a sea actually results in an increased tissue level of oil in animal species in that sea. It is further unknown if petroleum accumulates in tissues of top-level predators.

We recommend measurement of the tissue levels of petroleum in marine mammals and their prey species along clean and polluted sections of the Norwegian coast. This will provide information concerning the behaviour of petroleum in the tissues of marine mammals after a petroleum industry becomes locally established. This information will be relevant to the future situation in the Barents Sea.

4. Levels of petroleum in animals losing body condition.

Petroleum products accumulate in the blubber layer. Utilization of the blubber during moulting, breeding and illness increases the release of stored petroleum and may raise the concentration of petroleum in the plasma and possibly milk to a level where clinically visible results can be seen. Documentation of the release of petroleum stores in animals losing condition will increase knowledge of the safe levels of petroleum in marine mammals.

5. Immediate necropsy of marine mammals found dead in association with oil contamination.

Objective evaluation of case reports of oil-fouling of marine mammals has often not been possible due to the length of time between death and professional examination and because of less than adequate veterinary examination of oiled animals. In many such reports necropsy examinations have been performed poorly or not at all.

Seals and presumably whales are already being fouled by oil along the Norwegian west coast (Wiig, 1985). If a similar situation exists here as on the coast of France (see Babin and Duguy, 1985), then common and grey seals will occasionally strand after oil ingestion and eventually die.

Firstly a campaign of public awareness in the reporting of stranded marine mammals should be launched. Secondly a small team of specialist veterinary pathologists should be formed to investigate stranded marine mammals, particularly if the involvment of oil is suspected. In addition to petroleum investigation there are public health reasons why this should be done. Physiological state (eg pregnancy, moulting) and pathological state (diseases, parasites etc) may then be correlated to the level of petroleum products in tissues and an increased understanding of petroleum toxicity.

6. Prediction of polar bear mortality after oil spillage.

It is apparent from the work of N.A. Øritsland *et al.* (1981) that most of the polar bears oiled after a blowout in the Barents Sea would die if not treated. We speculate also that the logistics of capture and transport of these large animals would preclude treatment. It therefore appears that the only method of improving our immediate awareness of the possible interaction between oil and polar bears is through survey of polar bear numbers in the southern Barents Sea during winter when there is ice in the lease area, which will enable an estimate of the number of animals likely to die in the event of a spillage. At present the concentration of polar bears in the lease areas is not known.

7. Investigation of noise effects on whales in the Barents Sea.

The concern here is that the migration of the humpback whale through the Barents Sea oil lease area may be disturbed during the establishment of a petroleum industry there, hindering the recruitment rate of this depleted species. Humpback whales are among those species that have been shown to react to underwater noise.

We recommend surveying of these whales to establish an estimate of population size and of migration route and timing. We further advise, as a progression of this study, to investigate the effects of underwater noise and shock on the species.

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