Review of the impacts of recent major oil spills on seabirds

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TOR: Review the impacts of recent major oil spills on seabirds ("Erika", "Prestige", "Tricolor") and contribute to the assessment of the long-term impact of oil spills on marine and coastal life for OSPAR [OSPAR 2005/7]

Introduction

The effects of major oil spills and chronic oil pollution on marine wildlife, notably seabirds, are seemingly all too well known. Seabirds are highly vulnerable to oil pollution and hundreds of thousands of seabirds die annually as a result of oil pollution in the North Atlantic alone (Camphuysen 1989; Wiese 2002; Wiese & Ryan 2003). However, oil-induced mortality is surprisingly difficult to assess and few studies have succeeded in identifying changes in population parameters such as trends in population size, caused either by the effect of a given spill or by persistently high levels of chronic oil pollution. One may wonder why it is so difficult to identify the effect of a large spill, killing many tens of thousands of seabirds, on a population numbering a few hundreds of thousands of seabirds, but there are several reasons why the effects may be masked. Seabirds are long-lived, and if a spill kills mostly juvenile or immature birds, any population effect noticeable in the colonies would be delayed at least a few years and spread over several years. Most oil-related mortality occurs in the non-breeding season. Affected seabirds may originate from a large number of different, possibly distant colonies, so that the loss within individual colonies may be modest. Many North Atlantic seabird populations have been growing for several decades as a result of a combination of factors including the relaxation of persecution, reduced human consumption and increases in the availability of food (Camphuysen & Garthe 2000), so that the spectacular growth of most these populations may have masked any adverse effects of oil pollution.

In this chapter, we will evaluate the damage from a number of recent spills based upon investigations done during and following the spill. Next we will see if any population effects have been found, or indeed if any effects have been searched for in a systematic manner. From these case studies, we will evaluate the methods of oil spill impact assessments and if these are adequate to provide the data needed for an effect evaluation. We will discuss expected population level effects following a number of scenarios and evaluate each of the spills according to these scenarios to see why some effect studies were successful and others may have failed.

When we set out to work on the TOR on oil spill effects, six further requests by HOD(1) May 2004 for inclusion in the draft 2005 ICES Work Programme were to be considered. These six items included specific tasks, some of which fitted nicely in the initial TOR, others were different approaches to the oil problem, or were considered beyond the expertise of the WGSE. HOD(1) suggested that an assessment of the long-term effects of oil spills should consider:

a. the distinction between the effects of the oil and what is caused by natural changes;
b. the impacts of oil on different types of habitats (i.e. the nature of the coastline) and ecosystems (variability in rates of recovery);
c. the impacts of oil in different marine regions subject to different climatic influences;
d. the impacts of different types of oil, both toxic impacts (toxic effects and accumulation) and non-toxic impacts (physical properties creating nuisance and hazardous conditions – physical contamination and smothering);
e. the impacts of remedial activities such as the use of heavy equipment and high pressure hosing to clean up oil spills;
f. whether the current framework of environmental risk assessment and toxicology is sufficient to take account of the long term effects of oil pollution.

We will address these issues in the second part of this chapter.

Oil spills

Accidental oil spills caused by maritime transport are still an important source of pollution of the world's oceans, especially along some of the major shipping lanes (Couper 1983; Clark 2001; Vieites *et al.* 2004).

The number of oil spills from tanker accidents has declined from 24.2 year^{-1} during the 1970s to 7.3 year^{-1} in the 1990s (ITOPF 2003), and the amount of oil spilled has varied in each accident. The biggest tanker-related oil spills in recent history were the *Atlantic Empress* off Tobago (West Indies, 1979), the *ABT Summer* off Angola (1991), the *Castillo de Bellver* off Saldanha Bay (South Africa, 1983) and the *Amoco Cadiz* in Brittany (France, 1978), each with >200,000 tonnes spilled (Table 1).

Volume of oil lost, however, is not the most important factor in determining the effects on marine wildlife (notably seabirds), as we will see below. Small amounts of oil in areas with high concentrations of sensitive birds lead to very high numbers of casualties, whereas large amounts of oil in areas with few birds will have only a small effect (Goethe 1968; Camphuysen 1989; Burger 1993; Camphuysen 1998). For the purpose of this evaluation, eight oil spills in Western Europe were analysed, some of which caused substantial wildlife casualties, others of which did little (recorded) damage to seabirds (Table 2-3). Among these were tanker incidents (*Amoco Cadiz, Braer, Sea Empress*, *Prestige*, *Erika*), an incident with a car carrier (*Tricolor*), and a deliberate discharge (*Stylis*). We will evaluate the spills in terms of amount of oil spilled, distance to the coast, seabirds present during the event, timing in the annual cycle of the (main) victims, number of casualties counted and number of casualties estimated to have died. Note that this is not an exhaustive review of all the smaller and larger spills that took place in western Europe over the past 30 odd years, but case studies rather that may be considered representative in various respects.

Table 1. The World's largest tanker spills (>100,000 tonnes), 1960-2004 (White & Baker 1999, ITOPF)

Date	Name	Tonnes	Oil type	Location
19 July 1997	*Atlantic Empress*	287,000	crude	10nm E of Tobago
28 May 1991	*ABT Summer*	260,000	crude	700nm W of Angola
06 August 1983	*Castillo de Bellver*	252,000	crude	70nm NW of Cape Town, South Africa
16 March 1978	*Amoco Cadiz*	223,000	crude	Brittany, France
11 April 1991	*Haven*	144,000	crude	off Genoa, Italy
10 November 1988	*Odyssey*	132,000	crude	700nm off Nova Scotia, Canada
18 March 1967	*Torrey Canyon*	119,000	crude	Scilly Isles, UK
19 December 1972	*Sea Star*	115,000	crude	Gulf of Oman
12 May 1976	*Urquiola*	100,000	crude	La Coruña, Spain

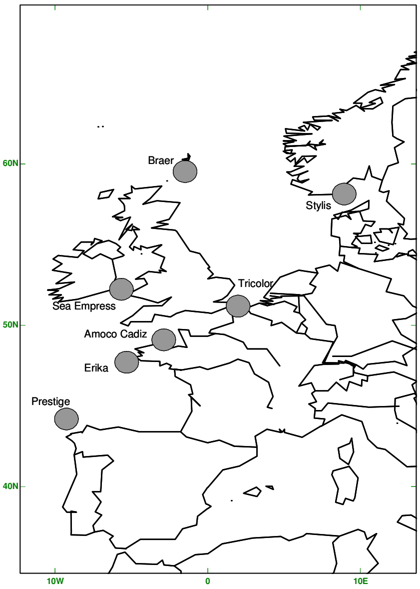

Fig. 1. Approximate locations of oil spills discussed in this chapter

Eight recent oil spills evaluated

The main tanker incidents since the *Torrey Canyon* spill in the late 1960s were the *Amoco Cadiz* in France in 1978, the incident with the *Braer* in Shetland in 1993, the *Sea Empress* in the Irish Sea/Celtic Sea in 1996, the *Erika* in 1999, and the *Prestige* in 2002 (Fig. 1). In these accidents, vast amounts of oil were released at once (whether or not with subsequent leakages), and the spills took place in winter and early spring, between November and March. The amount of oil spilled varied from 15,000 tonnes with the *Erika* to as much as

223,000 tons with the *Amoco Cadiz*. The *Tricolor*, a car carrier, leaked only approximately 170 tonnes of oil during salvage operations on the wreck of the ship that had sunk at month earlier following a collision. The *Stylis* deliberately discharged some 600 tons of carbon black feedstock oil to clean tanks on its crossing from Rotterdam to S Norway (Anker-Nilssen & Røstad 1982).

The *Stylis* incident ranked highest in terms of casualties recovered, but is otherwise mostly forgotten in recent reviews. A similar number of casualties were recovered following the *Erika* and it is of interest to remember that in both events, the slicks travelled considerable distances to reach the shore. The *Tricolor* spill in 2003, an event with relatively little oil spilled, had substantial consequences in terms of affected wildlife and this spill took place in an area of known sensitivity to oil pollution in winter (Carter *et al.* 1993).

Four incidents (*Amoco Cadiz*, *Sea Empress*, *Braer*, and *Tricolor*) were nearshore incidents (groundings or collisions within 10km from land), but both the *Erika* and the *Prestige* were towed into the open sea in an attempt to "minimise" the ecological damage (with quite the opposite effect; Camphuysen *et al.* 2002), and therefore contaminated substantially larger portions of the coastline than most nearshore spills. The *Stylis* discharged oil shortly before entering the Skagerrak and strong southwesterly winds swiftly pushed the oil deeper into the Skagerrak area and towards the Swedish west coast (Anker-Nilssen & Røstad 1981).

The types of oil spilled in each of the selected incidents varied. The *Amoco Cadiz* spilled her entire cargo of 223,000 tonnes of light Arabian and Iranian crude (White & Baker 1999). Much of the oil quickly formed a viscous water-in-oil emulsion ("chocolate mousse"), increasing the volume of pollutant by up to four times. Seabirds were simply smothered in the "mousse", suffocated and died. The *Braer* ran aground and lost its entire cargo of 84,700 tonnes of Norwegian Gulfaks crude oil plus a small amount of heavy bunker oil (Heubeck *et al.* 1995; White & Baker 1999). The spill was unusual in that a surface slick was not produced. A combination of the light nature of the oil and the exceptionally strong wind and wave energy naturally dispersed the oil through the water column. The oil droplets were adsorbed onto sediment particles which eventually sank onto the seabed. The *Sea Empress* ran aground and over a week released 72,000 tonnes of Forties Blend crude and 480 tonnes of fuel oil into the sea (Anon. 1998). Oil came ashore along 200 km of coastline, but the proportion of oil which evaporated (24,000-32,000 tonnes) was higher than at many other incidents due to the large proportion of volatile components in this type of oil.

Table 2. Major oil spills in Western Europe selected for this review: name, location, season and amount spilled (tonnes).

Name	Location and year	Season		Tonnes	Oil type
Amoco Cadiz	Brittany (F), 1978	Mar	pre-breeding	223,000	Arabian & Iranian crude
Stylis	Skagerrak (S/N), 1980	Dec	winter	600	carbon black feedstock[2]
Braer	Shetland (UK), 1993	Jan	winter	85,000	Norwegian gulfaks crude
Sea Empress	Irish Sea (UK), 1996	Feb	winter	72,000	Forties blend crude
Erika	Brittany (F), 1999	Dec	winter	15,000	heavy fuel
Prestige	Galicia (Esp), 2002	Nov	winter	77,000	heavy fuel
Tricolor	Channel (F), 2003	Jan[1]	winter	170	heavy fuel (IFO 380)

[1] Ship sank in December 2002, but leaked oil not before January 2003; [2] Carbon Black Oil (CBO) is a co-product by steam cracking of hydrocarbons (naphtha, gasoil, gas condensate) under high temperature in the presence of steam to product the olefins ethylene and propylene. CBO consists mainly of unsaturated hydrocarbons, predominantly higher than C_{14} and is used as feedstock for the production of (special) Carbon Black (CB).

Table 3. Major oil spills in Western Europe selected for this review: name, most numerous casualties (in declining order), numbers recorded and numbers estimated to have died.

Name	Most numerous casualties	Number of birds found	Estimated total mortality
Amoco Cadiz	Puffin, Razorbill, Guillemot	5000	22,000
Stylis	Guillemot, Little Auk, Eider	45,000	200,000-300,000
Braer	Black Guillemot, Shag	1800	5000
Sea Empress	Common Scoter, Guillemot	6900	10,000-15,000
Erika	Guillemot	44,000	120,000-300,000
Prestige	Guillemot, Puffin, Razorbill	22,000	100,000-200,000
Tricolor	Guillemot, Razorbill	20,000	40,000-100,000

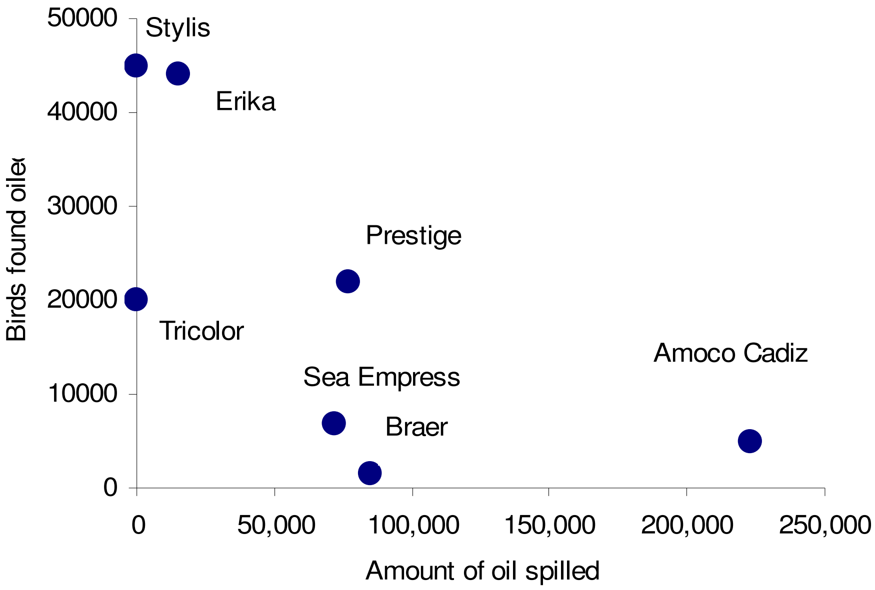

Figure 2. The amount of oil spilled versus numbers of seabirds found dead in recent oil spills in Western Europe.

There was no positive correlation between the number of casualties counted and the amount of oil spilled (Fig. 2). Some spills occurred in areas that were known to be very vulnerable to oil pollution from seabird at sea censuses in the area (e.g. *Tricolor* spill; Carter *et al.* 1993), others took place in areas of unknown sensitivity (no recent at-sea surveys available), but numerous casualties were recovered, possibly partly because the oil travelled a long way before it reached the coast, sweeping vast sea areas clear of birds (e.g. *Erika* and *Prestige* spills).

The spills were different in their impact on resident seabirds (local breeding populations) and wintering birds (breeding elsewhere). The *Amoco Cadiz* spill, for example, affected wintering seabirds such as common guillemots *Uria aalge*, razorbills *Alca torda* and divers Gaviidae, but also substantial numbers of European shags *Phalacrocorax aristotelis* that are locally breeding. Puffins *Fratercula arctica*, the main casualties, originated from breeding colonies in the UK as well as from the local population (Jones *et al.* 1978; Monnat 1978). The *Braer* incident on the south tip of Shetland in 1993 mainly affected resident birds, notably black guillemots *Cepphus grylle* and European shags (Heubeck *et al.* 1995). The *Erika* off Brittanny killed a very large number of guillemots, and while there is a local breeding population, at least according to numerous ringing recoveries a large proportion (if not the majority) of these birds were wintering visitors nesting further to the north, such as within the UK and on Helgoland (Germany). Common scoters *Melanitta nigra* killed in the Sea Empress incident probably mainly originated from the distant Scandinavian breeding population. The *Tricolor* spill killed virtually exclusively wintering birds, notably common guillemots and razorbills (Stienen *et al.* 2004; Grantham 2005; Camphuysen & Leopold 2005), whereas the *Prestige* kill involved a mixture of local residents and wintering individuals (García *et al.* 2003).

Apart from the numbers found dead or "rescued" (picked up oiled but still alive and where a rehabilitation attempt has been taken place), most spills are reported with a number of casualties *estimated* to have died. These estimates usually have a very slender factual basis. Drift experiments should take place during each and every incident to be able to assess the fraction lost at sea, and few spills have been monitored such that the time and resources were available to conduct such experiments (e.g. Jones *et al.* 1978). There is little doubt that in most cases, certainly in the offshore spills, a rather substantial fraction may have gone lost at sea, whereas in some nearshore spills, certainly those with very strong and persistent onshore winds, virtually all the casualties will at least wash ashore and can be counted. We have not evaluated the accuracy of the estimates of total mortality [Table 3], but simply observe that there are no firm data presented in any of the papers consulted showing that the upper end of the estimates published for the *Erika*, *Prestige* and *Tricolor* spill are anything more but a guess.

What population level effects of oil spills should we expect?

Clearly, the effects of an oil spill on the size of breeding seabird populations will depend on several factors in addition to the numbers of birds killed. It is obvious that effects will be more pronounced the smaller the affected population is in relation to the number of birds killed, but determining the size of the affected population is by no means simple. The likelihood of detecting impacts on stable, increasing or decreasing populations is different and the frequency of population monitoring in the years before the oil spill will influence the quality of necessary base-line data. Information on (offshore) wintering populations, pre- and post-spill, is equally important as are data on trends in breeding populations, particularly so for species that breed widely dispersed in very low densities such as divers and seaduck. Among other factors, the most important are the age distribution of birds killed, whether oil mortality is additive or compensatory, and the type of regulation operating in the population. Below, we examine the expected effects under various scenarios and discuss reasons why realized effects may sometimes be difficult to detect with existing monitoring methods.

Adult or immature mortality. It is well known that the population growth rate of long-lived organisms, such as seabirds, is much more sensitive to variations in adult survival than in fecundity or immature survival (Croxall and Rothery 1991). In simple terms, this means that the life of an adult is “worth” more to the population than the life of an immature, simply because it is more likely to survive to the next year and reproduce. Furthermore, in most seabirds recruitment to the breeding population occurs when the birds are 3-7 (up to 12 in northern fulmar) years old, and if mainly first-winter immatures are killed any effect on breeding populations will not be detectable for several years, if at all. On the other hand, large mortality of adults will cause an immediate reduction in the adult population, although this will not necessarily result in a similar reduction in the breeding population (see below). In general, effects on breeding populations should be larger and easier to detect when mainly adults are killed than when immatures are the main victims.

Additive or compensatory mortality. Anthropogenic mortality in general may act in either a compensatory or an additive manner (Burnham and Anderson 1984). Fully compensatory mortality implies that the number of birds alive at the start of the next breeding season is unaffected by the extra mortality, whereas fully additive mortality implies that next year’s population is reduced by exactly the number of birds killed (relative to what it would have been without the extra mortality). Both extreme scenarios are unlikely, and most real situations will fall somewhere in between. When natural mortality is density-dependent, extra anthropogenic mortality will tend to be more or less compensatory. Few if any studies have been able to establish whether extra mortality in seabirds (oiling, hunting or fishery-related) is compensatory or additive. If oil spill mortality is partially compensatory, effects on breeding populations will obviously be smaller than if it is additive.

Population regulation: are breeding populations buffered? There is evidence that many seabird populations are characterised by the presence of substantial numbers of “floaters”, i.e. individuals which, though physiologically capable of breeding, don’t do so in a given year (e.g. Kokko et al. 2004). Some of this evidence comes from experiments, where breeders removed early in the breeding season are immediately replaced, presumably by floaters. If large numbers of floaters are available, even substantial adult mortality may not result in an immediate reduction in the size of the breeding population, simply because their places are immediately filled, and this could be one of the main reasons why population effects of oil spills have been difficult to demonstrate. Although the breeding population is not reduced immediately, the extra mortality of adults may have long-term effects. First, a reduction in the number of floaters will reduce the population’s buffering capacity for future mortality events. Second, floaters are likely to be on average younger and/or of lower quality than established breeders, and the replacement of older high-quality birds by floaters will lead to a decline in the mean quality of the breeding population, which again could have implications for future population growth (Kokko et al. 2004).

A further consideration is that monitoring activity is often not randomly distributed within colonies, but biased towards older, central and by implication more high-quality areas. Even if a mortality event is large enough to cause a reduction in the total breeding population, within-colony redistribution of breeders from peripheral sites to more central ones left empty may lead to effects not being detected.

Monitoring of survival or return rates. Even in cases when breeding populations (total or on monitoring plots) are buffered against substantial mortality events by floaters, turnover among breeders will be increased and this will be detectable through monitoring of individually marked birds. If unusually few marked birds turn up the next year (low return rate), or if survival is subsequently found to be low through capture-recapture analysis, an effect of e.g. an oil spill event is indicated even in the absence of an observed population decline. This provides yet another example of how monitoring demographic parameters rather than just population size improves the ability to detect environmental changes and attribute them to natural or anthropogenic drivers. Because proper capture-recapture analysis allows compensation for e.g. variation in monitoring effort or in the proportion of birds breeding in a given year, it provides the most robust method for detecting change. However, return rates are simple and quick to calculate and thus useful as "early warning" signals of potentially high mortality.

Table 4. Expected, detectable effects on seabird populations according to different scenarios

Main age class killed	Non-buffered population	Buffered population
Immatures	Small delayed effect	No effect?
Adults	Large immediate effect	No effect on breeding population size, reduced buffering capacity

Impact assessments during oil spills

It is clear that in the light of *expected* population effects, apart from the total number of casualties affected and the species involved, two variables are important: the age structure of the casualties and their (breeding) origin. We observed that most of the more serious spills in Europe affected wintering seabirds rather than local birds (with some exceptions).

To be able to measure population effects, high quality data should be obtained from the corpses collected during an oil spill, including accurate information on species composition, sex ratio, age structure, and their geographic breeding origin (Heubeck et al 2003). Estimates of the total number of birds affected has to be based on a combination of dedicated beached bird surveys (effort-corrected data; Camphuysen 1989, Stephen & Burger 1994, Camphuysen & Heubeck 2001) and drift-experiments *during* the incident (Stowe 1982a, Hlady & Burger 1993, Wiese 2003). Only with these two tools can an estimate be made of the number of corpses that may have gone lost at sea, which should added to the numbers found stranded. An assessment should also be made of numbers of corpses missed during beached bird surveys, for example as a result of oil clean-up operations or removals by scavengers (Page *et al.* 1983, Camphuysen 1989, van Pelt & Piatt 1995, Camphuysen 2004).

We observed, that estimates of total mortality from an oil spill have often been based on a general rule-of-thumb (e.g. that the body count represents about 5% or 10% of the overall mortality), and that these estimates should therefore be treated with caution. Burger (1993) analysed total mortality estimates from about 45 oil spills, and identified a conservative figure averaging 4-5 times higher than the body counts. From drift experiments around the globe, we know that the outcomes are highly site- and situation-specific (Bibby & Lloyd 1977, Jones *et al.* 1978, Bibby 1981, Stowe 1982b, Threlfall & Piatt 1983, Keijl & Camphuysen 1992, Camphuysen & Heubeck 2001, Wiese & Jones 2001). In some nearshore spills with onshore winds, nearly all the casualties can be found ashore. Some offshore spills may have caused seabird mortality, but drift experiments showed that only a minute fraction was likely to be found on the beach.

Factors such as density of birds in the affected area, wind velocity and direction, current direction, wave action, distance to the shore and temperature all affect the resultant recorded mortality and so an immediate investigation of these parameters at the time of the spill is needed (Burger 1993; ICES 2003). Characterisation of pre-spill situation contributes to define terms of reference for a certain region and helps to determine the actual effect of the oil spill.

An adequate search for corpses and live oiled birds all over the affected area is important to improve the estimate of total mortality. Such searches should be set-up as the standard beached bird surveys, so that observer effort is known (Camphuysen & Heubeck 2001). Coupled with drift experiments, beached bird surveys are a useful instrument to determine total mortality. A model to estimate actual mortality based on number of corpses found was developed by Ford *et al.* (1991). This model integrates several oceanographic and meteorological parameters. A corpse drift of 2–4% of the wind speed is generally accepted (Bibby & Lloyd 1977; Burger 1993). Drift experiments conducted during oil spills are important, but the permission for a large-scale release of tagged corpses at sea may be difficult obtain (in time). Wooden drift blocks, as developed and recently improved by Wiese & Jones (2001), are easy to produce devices, relatively easy to release from boat/aeroplane, and may be acceptable substitutes for the ideal experiment. It should be realised, however, that drift experiments are at best approaches of the real trajectories and recovery rates of oiled corpses. When unoiled corpses are used for these experiments, it should be realised that these are less likely to sink than oiled corpses. Wooden blocks don't sink at all, and the movements and drift of casualties that are oiled but still alive is impossible to mimic.

Important baseline data have to be obtained from the corpses *during* the spill and require specialist's assistance. Determining the geographic origin of the oiled birds is of major importance if one wants to assess the ecological impact of the spill in seabird populations. Standardised techniques are required and should be implemented to collect useful data (e.g. Asbirk 1980, Kuschert *et al.* 1981, Jones *et al.* 1982, Camphuysen 1995) The information on possible "colonies of origin" is essential to plan post-spill monitoring. Information gathered should include the population structure of the impacted species (sex ratio, age ratio and sexual maturity) as most seabird species are long lived birds, that exhibit deferred maturity. The ageing and sexing of seabirds is not straightforward and again requires specialist's assistance (Anker-Nilssen *et al.* 1981, Van Franeker 1983, Van Franeker 2004). Ringed birds can give information about the origin of the affected seabirds, but relatively few individuals are ringed and the results are biased towards areas where ringing effort is high.

The type of information to be collected from seabirds during oil spills is listed in Table 5, including the rationale.

Table 5. Base-line data collected during recent oil spills in Europe.

Parameters	**Rationale**
Species composition	to identify impacted species
Biometrics	to assess geographic origin
Age	to predict potential impact on population (delayed versus immediate effects)
Sex	to predict potential impact on population (biased, or non-biased to part of the population); contributes to understanding of distribution at sea of sexes of the affected population (sex segregation) [5]
Ringing recoveries	to identify geographic origin (dependent on ringing effort at breeding colonies)
Moult and plumage analysis	to predict potential impact on population (delayed versus immediate effects) • geographic origin (colour of plumage of some alcids); • winter vs breeding populations affected; • immature vs adult birds (eg. gulls)
Muscle, growing feathers or blood	genetic studies, to identify geographic origin (dependent on seabird population genetic structure)
Body condition at the time of the death	contributes to identify impact of oil spill

Most of these parameters were collected during the *Erika*, *Tricolor*, *Stylis*, *Braer* and *Prestige* oil spills. To support an analysis of these parameters, such as the identification of the geographic origin from biometrics or DNA, baseline information on morphometrics and the genetic structure of breeding populations is needed, as well as population trends and distribution at sea of wintering and breeding populations. Information obtained during the above mentioned oil spills enabled identification of the breeding area / colony of the dead birds, so that post-spill monitoring should have become easier. Information from ringing recoveries gave direct information on the "origin colony" of the corpses and frequently on the age of the bird (e.g. Grantham 2005), but was particularly valuable in combination with simultaneously collected data on age structure and biometrics (e.g. Camphuysen & Leopold 2005).

Age composition is of major importance in determining population effects and is essential to predict immediate versus medium term effects on the breeding populations. In the case of the *Tricolor* oil spill, age composition analysis indicated that mature birds in excellent pre-breeding condition of the wintering common guillemot and razorbill populations were affected (Camphuysen & Leopold 2005). Biometrics suggested that Scottish colonies in the NW North Sea were the most likely breeding areas of the affected guillemots. These results were corroborated by the ringing recoveries (Grantham 2005). The sheer number of casualties, as well the high proportion of mature birds, suggested an immediate effect on the breeding population (Camphuysen & Leopold 2005). Biometrics of razorbills obtained during *Stylis* oil spill indicated that both subspecies, *A. t. islandica* (Iceland, Ireland, UK) and *A. t. torda* (Norway, Sweden), were affected (Anker-Nilssen et al. 1988).

Sex identification might be considered as supplementary data, but should help determining effects of oil spill on population dynamics (Cadiou et al. 2004). Information on body condition of (heavily oiled) corpses found dead will provide information on the condition of the birds at sea and if other factors, such as wrecks, may have played a role during the event (Camphuysen & Leopold 2005).

Summary of studies of seabirds oiled during selected oil spills

Amoco Cadiz

- Parameters collected: species affected, biometrics, sex, presence of rings. Corpse drift experiments executed, beached bird surveys implemented. Ageing inadequate in guillemots, but appropriate in razorbills and puffins.
- Results: Species composition: auks (69%), cormorants (12%), divers (4%), Gannets (3%) (n= 4907; Monnat 1978). Age composition: unknown in guillemots (probably mainly immature), 35% first winter and 66% immature and adult razorbills (n= 225), 53% adult puffins (n= 213). Sex ratio: guillemots 1:1, Plumage characteristics guillemots 13% *U.a. aalge*, 59% *U.a. albionis*. Puffin biometrics point at France and SW Britain as main areas of breeding origin; ringing recoveries from the Irish Sea (SW Britain), Outer Hebrides, Shiant Isles, Shetland and SE Scotland. Razorbill ringing recoveries from Irish Sea, Outer Hebrides and Fair Isle. No French ringing recoveries in auks (Jones *et al.* 1978).

Stylis

- Parameters collected: proportion of plumage covered by oil, plumage and rank in shade of colour of the wing, biometrics, sex, age, body condition.
- Results: Species composition: common guillemot (60%), little auk (12%), common eider (11%), razorbill (9%) (Anker-Nilssen & Røstad 1982). Age composition: razorbills 66% adults, 34% immatures (n= 298). Common guillemots 18% adults, 82% immatures (n= 802 birds; Anker-Nilssen et al. 1988); Sex ratio: no significant differences found in razorbills (Anker-Nilssen et al. 1988); Plumage: all birds in winter plumage (Anker-Nilssen et al. 1988); Biometrics: razorbill biometrics enabled to attribute dead birds to subspecies *A. t. islandica* (Iceland, Ireland, UK) and *A. t. torda* (Norway, Sweden) based on the wing length and gonys depth; Little auk: origin could not be established. Guillemots: a wide range of possible colonies of origin (Anker-Nilssen et al. 1988), which was seemingly confirmed by ringing recoveries: Faroes (1 adult), Helgoland (1 adult), northern Scotland (1 adult and 18 immature) (Anker-Nilssen et al. 1988).

Braer

- Parameters collected: number of casualties, species composition, ringing recoveries. Systematic beached bird surveys were implemented. Post-mortems included age, sex, biometrics and stomach contents.
- Results: Species composition: shag (55%), black guillemot (12%), kittiwake (8%), long tailed duck (7%) and great northern eiders (7%) (n=1768 corpses; SOTEAG 1995, Heubeck 1997). Ringing recoveries of shags suggested that the local population should be affected mostly: most of 34 birds found ringed originated from the spill site (15x Sumburgh Head, 11x Fair Isle, 6x Foula, 1x Hermaness).

Post-spill monitoring suggested that European shag breeding numbers were significantly reduced in 1993 season and black guillemots on the SW mainland coast were reduced by 20–40% (Heubeck 1994, Ewins & Heubeck 1995). Some 3-4% of the local eider population ad been killed by the *Braer* spill (Heubeck 1997).

Sea Empress

- Parameters collected: birds collected for detailed examination (body condition, cause of death, age, sex and diet, wing and bill measurements), corpse drift experiment executed.
- Results: Species composition: common scoter (66%), common guillemot (23%), razorbill (5%), red-throated diver (1%) (n= 6935; Anon. 1998). Sex ratio: common scoter 70% male, 30% female, red-throated diver 75% male. Common guillemot, 53% summer plumage males (possibly Welsh breeding

birds), razorbills 30% adult males. Age composition: common scoter 88% adult, 12% first winter, red-throated diver 75% adults. Ringed birds: guillemots were local adult birds (3) and 1 adult bird from the Irish Sea; ringed razorbills originated from SE Ireland. Biometrics: razorbills from one morphological population.

Erika

- Parameters collected: ringing recoveries; biometrics; blood, growing feathers or muscle tissue for population genetic studies (micro-satellite markers; Cadiou et al. 2003, 2004). Total numbers: 32,000 birds alive and 42,000 birds dead were recorded along the coast of Bay of Biscay (Cadiou et al. 2003). Many birds were removed prior to inspection in beach clean-up operations.
- Results: Species composition: common guillemot (83%, n= 74,000) (Cadiou et al. 2003a, 2004). Age composition / ringing recoveries: common guillemots ranged from 1 to 18 years old but 34% (n=184) and 39% were juvenile and 1 year old birds (Cadiou et al. 2003b). Biometrics: majority of individuals originated from colonies located between western Scotland and the Celtic Sea (3.3% North Sea, 3.8% north Scotland, 49% western Scotland and 44% Celtic Sea; Cadiou et al. 2003a, 2004). Ringing recoveries: 90 birds originated from colonies in west Scotland, 64 from south –eastern Irish colonies, 177 from Welsh colonies, 7 from North Scotland colonies, 4 from Britain and 2 from Germany (Cadiou et al. 2003b). In 89% of the cases, birds were ringed as chicks in the colonies. Biometrics, plumage, age and sex data analysis gave general information: common guillemots - female had longer wings than males, older birds had longer wings than young birds (Cadiou et al. 2003c, 2004). Population genetic approach: the low level of population genetic structured prevented to determine reliably the origin of the oiled birds, based on the fact that less than 6% of the individuals were assigned to the population in which they have been sampled). From the genetic view point, results suggest that a management unit could in fact be the whole North Atlantic population (Cadiou et al. 2004).

Results obtained underline that for a full assessment of the ecological impact of an oil spill on seabirds populations, it is necessary to combine information on the dynamics of the distribution of seabirds at sea with knowledge of the different processes involved in the dynamics of the breeding populations. The results also indicate the large spatial scale of the oil's spill impact and underline the usefulness of combining multiple approaches to access the local and regional effects of such accidents (Cadiou et al. 2003, 2004).

Prestige

- Parameters collected: number of casualties, species, biometrics, sex, age, condition at the time of death, moult and ringing recoveries (external inspection and autopsies). Systematic beach searches implemented.
- Results: Species composition: mainly common guillemot (51%), razorbill (17%), and Atlantic puffin (17%; García et al., 2003). Age composition: common guillemots 84.8% juveniles(n=895, García & Fernández-Boán, in prep.). Razorbills 87.8% first winter (n=924; Dopico & Ramos, in prep.). Puffins 52.9% adults, 16.5% first winter (n=1597; Bao *et al.* in prep.). Sex ratio: in common guillemots, razorbills and puffins, females were significantly more numerous than males (guillemots 1 male : 1.6 females, n=922; García & Fernández-Boán *in prep.*; razorbills, 1 males : 1.58 females; n=186; Dopico & Ramos, in prep.; Puffin 1 males : 2.3 females; n=1579; Bao et al. in prep.). Ring recoveries: Most of the common guillemots affected during the *Prestige* oil spill originated in the Irish Sea and western Scotland areas (about 95% of the rings). Razorbills mostly originated from the Irish Sea and western Scotland (88% of the rings). Puffins mostly originated from the Orkney Islands (77% of the rings; García et al., 2003).

Tricolor

- Parameters collected: number of casualties, species composition, biometrics, sex ratio, age composition, body condition at the time of death, moult, ringing recoveries (a conbination of external inspection and autopsies; Camphuysen & Leopold 2005). Systematic beach searches implemented.
- Results: Species composition: common guillemot (63.0%), razorbills (24.8%), kittiwake (3.1%) (n=3302). Age composition: mature birds in excellent pre-breeding condition in both common guillemots and razorbills. Guillemots 76% adult, 6% immature, 18% first year; razorbills 77% adult, 16% immature, 8% first year. Sex ratio: guillemots 65% male (n=246), razorbills 62% male (n= 158; both significantly different from equal; Camphuysen & Leopold 2005). Biometrics: analysis would

point at the *U. a. aalge* subspecies consistent with Scottish breeding birds at aprox 57°N latitude (Camphuysen & Leopold 2005). This suggestion was confirmed by the ringing recovery data (Grantham 2005). Biometrics analysis of immature and adults razorbills are consistent with measurements of the *A. t. islandica* anywhere in Britain Ireland and Iceland (Camphuysen & Leopold 2005). Ringing recovery analysis suggested that the east coast of Scotland is again a likely breeding area from where many casualties may have originated (Grantham 2005).

From the information collected from the corpses it is possible to suggest that NW North Sea are probable breeding areas of both common guillemot and razorbills affected by the *Tricolor* spill, which together with the sheer number of casualties, as well the high proportion of mature birds, might suggests an immediate effect on the breeding population. Isle of May being one of the best studied auk colonies is situated in that area and future data might give some insight into impact of oil spill at population level (Camphuysen & Leopold 2005).

Methods for determining the origin of oiled seabirds

A critical step in evaluating the potential or realised effects of major oil spills is establishing which breeding population(s) the affected birds belong to. The same number of birds killed could have very different implications, depending on whether they originate from a small or a large population. Unfortunately, unambiguous assignment of dead birds to populations or individual colonies is quite difficult. A number of different approaches have been used or suggested, and these differ in utility depending on the species and situation.

Morphology. In some species, birds originating from different parts of the breeding range differ substantially in plumage or biometrical measurements. For instance, common guillemots *Uria aalge* are larger and darker in the northern part of the range than further south, and a higher proportion of northern fulmars *Fulmarus glacialis* from arctic populations belong to the dark phase. However, in both cases this variation is clinal and thus more useful e.g. for testing statistically differences between samples (Cadiou et al. 2004) than for unambiguously assigning individuals to areas of origin. Many other species, such as razorbills *Alca torda* or northern gannets *Morus bassanus*, show limited morphological variation over large parts of their range, making assignment of origin by this method impossible (e.g. Camphuysen and Leopold 2005). Nevertheless, morphological analysis of a sample of oiled birds is also useful for determination of e.g. sex, age and condition and should thus always be part of any oil spill impact assessment.

Ringing. The recovery of ringed oiled birds offers a cheap and unambiguous way of determining the origin of a sample of birds, and this has e.g. been used to show differences between the origin of common guillemots affected by recent major oils spills in Europe (Grantham 2005). Because most seabirds are ringed as chicks, recoveries also provide information on the age composition of the affected birds. The major weakness of this approach is that ringing effort varies enormously over space and time. In particular, some large breeding populations have received no or little attention from ringers (e.g. the Faroes), potentially leading to biases in geographical assignment of effects. Likewise, some species have been ringed much less than others and are less likely to provide sufficient sample sizes for analysis. Nevertheless, ring numbers should be recorded from all ringed birds found dead or alive after an oil spill, and maximum use should be made of this information, taking these limitations into account.

Population genetics. Seabirds are generally considered to be very philopatric and should therefore exhibit strong genetic population structure. By analyzing sufficiently variable regions of the genome, this could in principle be exploited to determine the breeding origin of oiled birds, if reference samples from a range of colonies/areas are available. To date, this approach has not seen much use. In a study of common guillemots from the *Erika* spill, Riffaut et al. (in press) found that this species did not exhibit sufficient population structure within the North Atlantic to allow individuals to be assigned to colonies of origin. Indeed, only 6% of reference samples were correctly assigned to colony in this study. However, other species are known to have a stronger population structure and thus might be more appropriate for assignment using population genetic methods. Costs of collecting and analyzing genetic samples from a large number of oiled birds, as well as from birds from reference colonies, will inevitably be high, and this will limit the general utility of this approach.

Biomarkers. Biochemical methods originally developed for studying trophic relationships, such as stable isotope analysis and fatty acid analysis, can also be adapted to indicate geographical origin. In particular, because of variation in the underlying geology, various regions have different stable isotope signatures, and feathers and hard parts grown at a particular location will preserve this signature. This approach can e.g. be used to infer breeding or wintering areas of birds sampled at different times of the year (Hobson et al. 2001, Lott et al. 2003). To our knowledge, nobody has yet attempted to use this technique to establish the origin of oiled seabirds, but it should be possible for first-winter birds as well as adults of species that grow feathers during the breeding season, such as gulls (BWPi 2004). As for genetic methods, there is a need for a reference collection of feathers from birds of known origin, but in some cases museum specimens may be sufficient. Fatty acid analysis is less likely to be useful, as it would require differences in diet between birds of different origin, as well as fat deposits laid down during the breeding season – both conditions that are unlikely to be met in the majority of cases. Stable isotope analysis seems a promising method for assigning oiled birds to specific geographical origin, and we recommend that this method is tried out on a sample of birds of known origin, e.g. ringed birds.

Table 6. The pros and cons of different approaches to determining the geographical origin of seabirds affected by oil spills.

Method	Pros	Cons
Morphology	Cheap, simple, can be applied to large samples of birds, data also useful for sex and age determination	Limited resolution, some species show no relevant geographical variation
Ringing	Cheap, simple to check, unambiguous assignment of origin	Requires large ringed sample from all potential areas of origin
Population genetics	Can potentially establish origin of birds where no morphological variation or ringing data exist	Expensive, some species show no relevant genetic variation, requires reference collection of genetic material
Biomarkers (stable isotopes)	Can potentially establish origin of birds where no morphological variation or ringing data exist	Only works if species has feathers (claws, bill) grown during breeding season, requires reference collection of e.g. feathers

Observed impacts on seabird populations

Detection of the effects of large oil spills on seabird populations is difficult for a variety of reasons (see above). Large oil spills can cause direct seabird casualties, and sub-lethal effects on timing of breeding, breeding success, future survival, or reduced food supply through fish kills (Eppley and Rubega 1996, Velando et al. unpubl.).

Direct population-level effects such as on survival rates and age-structure are rarely detected because specific long-term studies involving individually marked birds need to be in place in the area affected by the spill, before its occurrence. These types of studies, although becoming more common are still relatively few in number. More commonly, numbers of birds breeding in affected colonies are compared before and immediately after the spill, and sometimes this comparison is made within and outside affected areas, the latter considered the control against which the effect of the spill can be compared. Typically, major spills have occurred in the winter months when marine birds are dispersed from their breeding colonies. Thus it is sometimes difficult to determine which colonies are affected (but see above), and affected birds may breed over a wide area such that impacts are geographically diluted and difficult to detect.

Heubeck (in press) provides an excellent review of the impacts of oil pollution from tanker accidents on seabird populations in the UK over the past 25 years. Early spills described by Heubeck such as the *Amoco Cadiz* occurred at a time when seabird monitoring in the UK was not widespread, and population-level impacts could not detected for this spill. By 1993 when the *Braer* ran aground off the Shetland Islands, seabird monitoring in the UK was well underway (see Lloyd et al. 1991) and so detection of changes in seabird populations was more likely.

In the *Braer* incident, locally resident species and winter visitors were the most commonly found oiled (shag, black guillemot, kittiwake, long-tailed duck and eider). Pelagic species such as fulmars and the larger alcids were much less affected because of the time of year, and the fact that the prevailing storms drove them well offshore. Impacts on colony size were detected for shags breeding in the vicinity of the site of the spill. The number of shag nests counted at Sumburgh Head in 1993 (151) was half that counted the year before (Heubeck 1994, 1997), and numbers are still below pre-spill levels. Black Guillemots nesting around southern Shetland were reduced by 31% immediately after the spill, and again have not recovered to pre-spill numbers (Heubeck in press).

In the *Sea Empress* oil spill (Baines & Earl 1996), species oiled were predominantly common scoters, common guillemots and razorbills. The latter two species breed around the Welsh coast in the vicinity of the spill. Local common guillemot colonies had been increasing before the spill, however, despite this, the 1996 breeding census indicated colony declines of up to 50%. One colony (Skomer) remained stable from 1995 to 1996 however, this was the first time since 1990 that it had not increased. This underlines another problem in detecting population-level impacts of oil spills- the spill may cause a decline in the rate of increase in a particular population that is not sufficient to place the population itself in decline. Negative impacts on guillemot breeding success in 1996 were not detected. By 1997, numbers of guillemots at affected colonies had recovered. Common scoters overwinter in large numbers in the vicinity of the incident and were the most commonly found species oiled in this incident. Peak counts after the spill and in the following winter were about 3-4 times lower than before the spill but returned to "normal" by the winter of 1998-99.

A very large number of marine birds were recovered in the *Erika* spill. The majority were common guillemots, whose origin was likely the Irish/Celtic Seas and western Scotland (based on ringing returns). Many of the oiled guillemots were immature (first year), of which a large proportion would have died naturally rather than have recruited into the breeding population in the years following the spill. It is therefore rather *un*likely that impacts at the colony level would have been detected, even after several years.

The *Prestige* and *Tricolor* oil spills occurred away from major concentrations of breeding marine birds. Both resulted in large numbers of birds recovered and data were collected immediately after the spills that will be useful in identifying candidate colonies that may have been affected. Similar to the *Erika* spill, the *Prestige* spill involved a large number of immature common guillemots, some of which were ringed in the Irish/Celtic Seas. Therefore, delayed colony impacts may be expected. Interestingly, there is evidence that this spill may have had an impact on European shags breeding in the vicinity of the spill (Velando et al. unpubl.). The European shag was not one of the species heavily impacted by the spill, but the effect appears to have been via negative effects of the oil on the benthic feeding habitat of the shag. In the case of the *Tricolor* spill, a large proportion of the ringing returns of common guillemots recovered oiled were from adult birds ringed on the Isle of May. Despite this, Isle of May guillemot numbers increased in the breeding season after the spill (2003), although return rates of ringed birds was "below average", "although not markedly so" (Mavor et al 2004).

Further requests

Further requests considered by HOD(1) May 2004 for inclusion in the draft 2005 ICES Work Programme included six specific tasks, some of which fitted nicely in the initial TOR, others were different approaches to the oil problem. HOD(1) suggested that an assessment of the long-term effects of oil spills should consider:

Distinction between effects of oil spills and natural changes

It is important to be able to distinguish between population effects of oil spills and those caused by other anthropogenic drivers as well as natural environmental variation. There is no failsafe way of making this distinction, and indeed in some cases we will never know if observed effects were due to an oil spill, or if real effects were masked by other counteracting effects. The best way to improve the chances of successful attribution of observed changes to the underlying drivers is to have a baseline monitoring programme allowing replicated before/after and affected/unaffected comparisons, and to employ proper statistical analysis methods that can identify several simultaneous effects.

Impacts of oil on different types of habitats (i.e. the nature of the coastline) and ecosystems

An evaluation of impacts of oil on different types of habitats (i.e. the nature of the coastline) and ecosystems would be beyond the expertise of the WGSE and we suggest that the question is forwarded to an appropriate group of experts.

The impact of oil in different marine regions, subject to different climatic influences

It is important to be able to distinguish between population effects of oil spills and those caused by other anthropogenic drivers as well as natural environmental variation. There is no failsafe way of discriminating between all these influences on seabird populations, in the absence of the appropriate base-line data. In a correlative approach, one might find positive or negative trends according to expectation, but in the absence of a mechanistic understanding, these correlations may not be very meaningful. With oil spill impact assessments, it is very important to be able to certain compare patterns seemingly caused by the spill with long-term trends in the population studied. This TOR is a very complicated one, and if understanding is to be gained from published accounts, it is recommended to reformulate the request more precisely.

The impact of different types of oil

The spills discussed were different in the types of oil spilled and although from these few case studies the TOR on differential impacts of different types of oil cannot fully be addressed, we can make at least some remarks. Different crude oils and oil products vary widely in physical and chemical properties, and in toxicity. Experiments on plants and animals have shown that severe toxic effects are associated with hydrocarbons with low boiling points (particularly aromatics) because these hydrocarbons are most likely to penetrate and disrupt cell membranes (White & Baker 1999). The greatest toxic damage has been caused by spills of lighter oils, particularly when confined to a small area.

High temperatures and wind speeds increase evaporation and lighter oils evaporate easier and faster than the heavy oils. The *Amoco Cadiz* spilled light crude, and much of this formed a "chocolate mousse" simply smothering the seabirds affected. The *Braer* lost 84,700 tonnes of a rather fine crude oil plus a small amount of heavy bunker oil. A combination of the light nature of the oil and the exceptionally strong wind and wave energy naturally dispersed the oil through the water column. *Erika*, *Prestige* and *Tricolor* spilled (very) heavy fuel oil that was difficult to combat in offshore clean-up operations, and that affected seabirds in the most dramatic way: immediately immobilising them and smothering them to death. Affected birds were often so heavily oiled, that each corpse, untreated, weighed 2-3x normal body mass. External examinations, including the basic identification, were seriously hindered.

The *Braer* spill, as a result of a combination of violent storms and rather light oil, was different from most other incidents in that most oil was naturally dispersed before (more) harm to seabirds could be done. The effects of the spill would have been more devastating, had it been calmer weather and had the spill occurred during the breeding season. Yet, despite being a spill where relatively few birds were affected, the localised nature of the event, coupled with a pre-spill monitoring programme, meant that population effects were relatively easy to determine: negative trends, without doubt related to the spill, where found in locally nesting shags and black-guillemots, as well as in resident common eiders (Heubeck 1997).

The impacts of remedial activities such as the use of heavy equipment and high pressure hosing to clean up oil spills

An evaluation of impacts of remedial activities such as the use of heavy equipment and high pressure hosing [on habitats i.e. the nature of the coastline and] ecosystems would be beyond the expertise of the WGSE and we suggest that the question is forwarded to an appropriate group of experts.

Whether the current framework of environmental risk assessment and toxicology is sufficient to take account of the long term effects of oil pollution

At present, to the best of our knowledge, there is no international framework of either oil spill impact assessment, or the environmental risk assessment and what is available is at best incomplete and perhaps outdated (Carter *et al.* 1993, IPIECA 1994, Williams *et al.* 1995, Begg *et al.* 1997). There are no standardised protocols to guarantee a balanced post-spill evaluation of oil spill effects. There seems to have been no formally established communication between oil spill response teams and governmental bodies or scientific groups that should be involved in the post-spill evaluation in most spills. There are a number of initiatives in this direction, such as manuals for and evaluations of oiled wildlife response (often with emphasis on the treatment of live casualties rather than oil spill impact assessments) (Corbett 1977, Oiled Wildlife Care Network 2000, Heubeck *et al.* 2003, IPIECA 2004, Nijkamp *et al.* 2004), but usually it is left to the good intentions of those involved at the time.

Discussion

Our evaluation of recent oil spills resulted in some rather important conclusions. Of seven oil spills examined, the amount of oil spilled ranged from 170 tonnes (*Stylis*) to 223,000 tonnes (*Amoco Cadiz*). The number of casualties recorded, varied from 1800 (*Braer*) to 45,000 (*Stylis*). Most spills took place in winter or in the pre-breeding season, and most events affected winter visitors breeding elsewhere.

There was no positive correlation between the amount of oil spilled and the number of casualties recorded. Some of the smaller spills caused major mortality. There is a large difference in the sensitivity of different sea areas with regard to surface pollutants, and these differences were in part responsible for the observed variability in the impact on seabirds. Seasonal and spatial patterns in sensitivity are rather well known for the North Sea (albeit slightly outdated) and for the west of Britain. For major parts of Europe, however, notably for the Bay of Biscay and for Spanish and Portuguese coastal waters, a lot of additional information is needed.

Even in the absence of a protocol, scientists involved in most of the spills examined, apparently intuitively performed an impact assessment in which most of the required data were indeed collected (Table 7). Although the accuracy varied between spills, an attempt to collect and count the casualties was always included. Often, it was the private achievement of some individuals that the data were collected in a systematic manner. Only the *Sea Empress* spill, the *Braer* spill and the Belgian part of the *Tricolor* spill were dealt with almost entirely by dedicated teams, fully supported by or established by national authorities. The ageing and sexing of birds was not always conducted in a standardised manner, as a result of which, spills are not always easy to compare. It is recommended to produce an oiled wildlife impact assessment protocol for future events, building on experiences from these and other major oil spills, in an attempt to standardise both the field observations, the dissections and the manner in which the results are published, to facilitate future evaluations.

Table 7. Baseline data collected during evaluated oil spills in W Europe

Spill	Species composition	Numbers found	Drift experiment	Biometrics	Age	Sex	Rings	Plumage	Genetic studies	Body condition
Amoco Cadiz	x	x	x	x	x		x			
Stylis	x	x		x	x	x	x	x		x
Braer	x	x		x	x	x	x			x
Sea Empress	x	x	x	x	x	x	x	x		x
Erika	x	x		x	x	x	x	x	x	
Prestige	x	x	?	x	x	x	x	x		x
Tricolor	x	x		x	x	x	x	x		x

In order to establish where seabird victims of oil spills come from, it is necessary to employ multiple methods. Morphological data and ring recoveries should always be collected and will often provide useful pointers, but may not be sufficient to unambiguous assign birds to colonies or areas of origin. Genetic methods have not yet proved very useful, and considering the high cost may not be a fruitful way forwards. Stable isotope analysis may be the most promising method, and as suggested by Cadiou et al. (2004) should be tried out on a sample of birds of known origin.

As stressed above, the effects of most oil spills on seabird populations were difficult to demonstrate. Both the *Braer* and the *Prestige* spills have affected local breeding populations of shags. The *Braer* also caused a decline in local breeding numbers of black guillemots. Declines in (adult) survival rates and changes in age-structures of breeding populations are rarely detected, mainly in the absence of sufficient and specific long-term studies involving individually marked birds in areas affected by oil spills (*i.e.* the breeding sites from where oiled birds found originated), before and after its occurrence. Usually, numbers of birds breeding in affected colonies are compared before and immediately after the spill (population trends). Sometimes this comparison is made within and outside affected areas, the latter considered the control against which the effect of the spill can be compared. Typically, major spills have occurred in the winter months, affecting seabird wintering areas. It is usually difficult to accurately determine which colonies are affected (but see above; general areas could often be pin-pointed), and affected birds may breed over a wide area such that impacts are geographically diluted and were difficult to detect.

Acknowledgements

Martin Heubeck, SOTEAG/Aberdeen University Shetland, kindly commented on a draft of this chapter.

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