LITTER NSV

Marine litter monitoring by Northern Fulmars (a pilot study)

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Alterra-rapport 401

Alterra, Green World Research, Wageningen, 2002

ABSTRACT

Franeker, van J.A. & A. Meijboom, 2002. *LITTER NSV, marine litter monitoring by Northern Fulmars; a pilot study*. Wageningen, Alterra, Green World Research. Alterra-rapport 401. 72 pp. 12. figs.; 9. tables; 43 refs.

The Northern Fulmar is a seabird known to consume litter such as plastic. The Dutch government has asked for an investigation of the possibility to use stomach contents of beachwashed Fulmars as a monitoring tool for the abundance of marine litter in the North Sea. Such monitoring is of importance in view of the implementation of the EU Directive on Port Reception Facilities and the development of Ecological Quality Objectives by ICES and OSPAR.

project: Pilot Study 'LITTER NSV'
commissioned by: Ministry of Transport, Public Works and Water Management
North Sea Directorate and Transport Safety Directorate
contract nr: NZ 1331 (1 mei – 14 Dec 2001)
conducted by: **ALTERRA – Texel** *Marine and Coastal Zone Research*
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ALTERRA project nr. 095-11232.01

Keywords: chemicals, Ecological-Quality-Objective EcoQO, EU-Directive, Fulmarus glacialis, graadmeter, ICES, ingestion, marine litter, monitoring, OSPAR, plastic, Port-Reception-Facility, stomach-contents

ISSN 1566-7197

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Summary

The Dutch Ministry of Transport, Public Works and Water Management has asked ALTERRA to conduct the pilot study 'Litter NSV'. The acronym NSV refers to the Dutch name of the Northern Fulmar, the Noordse Stormvogel (*Fulmarus glacialis*). The aim of this project was to investigate the feasibility of developing a monitoring-tool for marine litter in the Southern North Sea based on the stomach contents of a seabird, the Northern Fulmar.

Like virtually all tubenosed seabirds, the Fulmar is well known for its habit to mistake marine litter for food. Wear-resistant and indigestible items, especially plastics, accumulate in the stomachs of the birds. Considerable loads of plastics in stomachs of Fulmars beachwashed in the Netherlands had already been demonstrated in the early 1980's. Industrial plastic granules ('pellets') and remains of a wide variety of 'user-plastics' were about equally abundant.

Regional differences in plastic loads in stomachs indicated that stomach contents of Fulmars reflect pollution levels in their foraging area. This means that they could also be suitable to monitor local time-related changes in such pollution levels. Fulmars beachwashed in the Netherlands forage over large stretches of the offshore sections of the Southern North Sea. Litter contents in their stomachs integrate the frequency of their encounters with small sized marine litter over a number of weeks. Integrated monitoring of small sized litter in the offshore North Sea environment is not covered by any other means of litter survey. In addition, ingestion by the Fulmar is representative for litter consumption by virtually all groups of marine organisms and the lethal and sub-lethal consequences of ingested waste. Fulmars thus not only monitor levels of litter abundance, but also reflect specific ecological consequences.

A total number of 329 Fulmars, beachwashed in the Netherlands between 1982 and 2000 was used for this pilot study. At dissection, the sex, age, origin, condition, likely cause of death and finding date were determined. Stomach contents were sorted into main categories of plastics (industrial and user-plastics), non-plastic rubbish, pollutants, natural food remains and natural non food-remains. Each of these had a number of subcategories of specific items. For each of these we recorded presence or absence ('incidence'), the number of items, and the mass of items per category.

Analyses were conducted to check whether time-related changes could be confused by variables such as sex, age, origin, condition, deathcause, or season of death. If any of these would substantially affect quantities of ingested litter, changes in sample composition over the years could hamper or bias the detection of time-related trends. Only age was found to have some effect on ingested litter, adults having somewhat less plastics in their stomachs than younger birds.

Significant long term trends from 1982 to 2000 were detected in incidence, number of items and mass of industrial plastics, user plastics and chemical pollutants (often

paraffine-like substances). Only industrial plastics decreased; others significantly increased. Although age did affect absolute levels, changes over time were the same in adults or non-adults. By using individual sample data rather than annual averages, optimal use of data was made. An analysis for shorter term recent trends (1996-2000) revealed only continued significant decrease in industrial plastics and suggests stabilization or very slight decreases in other litter categories.

Current levels of major litter categories in Fulmar stomachs are: industrial plastics incidence 64% with 3.6 granules or 0.08 g per bird; user-plastics incidence 97% with 27.8 items or 0.53 g per bird; and suspected chemicals 28% incidence with 2.2 items or 0.54 g per bird.

Analysis of variability in data and Power Analysis revealed that reliable figures for litter in stomachs are obtained at a sample size of about 40 birds per year and that reliable conclusions on change or stability in ingested litter quantities can be made after periods of 4 to 8 years, depending on the category of litter. Mass of litter categories, rather than incidence or number of items, may be considered the most useful unit of measurement in the long term, and also is the most representative in terms of ecological impact on organisms.

It is concluded that stomach content analysis of beachwashed Fulmars offers a reliable monitoring tool for (changes in) the abundance of marine litter. By its focus on small sized litter in the offshore environment such monitoring has little overlap with, and high additional value to potential coastal surveys of larger waste items. Furthermore, stomach contents of Fulmars reflect the ecological consequences of litter ingestion on a wide range of marine organisms and create public awareness of the fact that environmental problems from marine litter persist even when larger items are broken down to sizes below the range of normal human perception.

It is recommended to start an annual monitoring program in the Netherlands to continue the 1982-2000 trend analyses presented in this pilot study. The availability of a longer time-series will allow proper evaluation of the effect of the EU Directive on Port Reception Facilities, which has to be implemented by February 2003. Approximately 40 birds per year should be sampled with assistance from the Beached Bird Survey group (NSO) of the Dutch Seabird Group (NZG.) Stomach contents should be analyzed on the basis of mass of different litter categories. Recommended formal indicators are mass of industrial plastic, mass of user plastic, and mass of chemical suspect substances. The latter is not easy to quantify, as substances may vary from solid lumps to fluid-like. However, incidence of such substances in 28% of birds indicates that it may be an important type of marine litter which is not monitored otherwise and may have considerable ecological impact. Chemical characteristics need to be determined.

The Biodiversity Committee of OSPAR has recently drafted **Ecological Quality Objectives for the North Sea (EcoQOs)**. One of the EcoQOs, as proposed by the ICES Working Group on Seabird Ecology, concerns the number of plastic particles in seabirds, i.e. the Northern Fulmar in the whole North Sea area. Although this report focuses on a ‘measurement system’ for the Dutch situation, its relevance for OSPAR is evident, and specific discussions on the aspect of the EcoQO and its targets have been added in the final chapter. It is recommended to support initiatives for a international one-off study to assist in an efficient implementation of the EcoQO in the wider North Sea region.

Litter ingestion by seabirds is a powerful tool to create public and commercial awareness of the marine litter problem and thus to promote support for policy measures, and to enhance a cooperative attitude towards implementation.

Samenvatting

Het Ministerie van Verkeer en Waterstaat heeft ALTERRA verzocht een verkennend onderzoek uit te voeren naar de mogelijkheden om maaginhouden van Noordse Stormvogels te gebruiken als graadmeter voor zwerfvuil op de Noordzee. Gezien het internationale karakter van zeevervuiling is de rapportage in het Engels opgesteld.

Vele zeevogels, en stormvogelachtigen in extreme mate, staan bekend om hun gewoonte om zwerfvuil op te eten. De in de Noordzee algemene Noordse Stormvogel (*Fulmarus glacialis*) is hierop geen uitzondering. Vooral onverteerbare harde objecten zoals plastics hopen zich in de vogelmaag op. Al in de eerste helft van de jaren tachtig werden in magen van op de Nederlandse kust aangespoelde Noordse Stormvogels belangrijke hoeveelheden plastics aangetroffen. Gemiddeld 12 stukjes plastic per dier, waarvan ongeveer de helft industrieel plastic granulaat en de andere helft restanten van plastic gebruiks voorwerpen (user plastics).

Kleinere hoeveelheden plastic in magen van stormvogels uit minder vervuilde gebieden wijzen erop dat de hoeveelheid plastic in de maag een afspiegeling vormt van de hoeveelheid plastic op zee in hun fourageergebied. Dit betekent dat maaginhouden in principe ook geschikt zijn om op een bepaalde locatie veranderingen in de tijd te registreren. Hoeveelheden afval in de magen van in Nederland aangespoelde Noordse Stormvogels zijn een afspiegeling van hun ontmoetingen met klein zwerfvuil over een aantal weken voorafgaand aan hun dood in de zuidelijke Noordzee (open water, op ruime afstand van de kust). Het monitoren van klein zwerfvuil op open zee wordt niet gedekt door andere monitoring systemen. Bovendien weerspiegelt de stormvogel de negatieve effecten van het consumeren van afval door vrijwel alle groepen organismen in zee, van juvenile vissen tot grote zeezoogdieren. Daarmee is de Fulmar niet alleen een graadmeter van vervuilings-niveaus maar ook van de ecologische effecten daarvan.

Voor dit verkennend onderzoek waren 329 kadavers van Noordse Stormvogels beschikbaar, verzameld tussen 1982 en 2000. Op de snijtafel werden geslacht, leeftijd, herkomst, lichaamsconditie, vermoedelijke doodsoorzaak en vinddatum geregistreerd. Maaginhouden werden gesorteerd op de categoriën plastic (industrieel en gebruiks plastic), niet-plastic afval, verontreinigende stoffen, natuurlijk voedsel, en natuurlijk niet-voedsel (bv steentjes). Ieder van deze categoriën werd nog onderverdeeld in specifieke subcategoriën. Voor ieder van deze werd bepaald: het al dan niet aanwezig zijn, het aantal objecten, en het gewicht van de objecten per categorie.

De gegevens werden uitgebreid geanalyseerd om te controleren of trends in de tijd niet verbloemd of vertekend zouden kunnen worden door variabelen zoals geslacht, leeftijd, herkomst, conditie, doodsoorzaak of jaargetij. Als dergelijke zaken een belangrijke invloed hebben op de hoeveelheid gegeten afval dan zou een wisselende samenstelling van bemonsterde vogels kunnen leiden tot foute conclusies. Van de

onderzochte factoren bleek alleen leeftijd enige invloed te hebben in de zin dat volwassen vogels wat minder plastics hadden dan jongere dieren.

Statistisch significante lange termijn trends tussen 1982 en 2000 werden gevonden in zowel het percentage ‘besmette’ vogels, het aantal objecten en het gewicht van industrieel plastic, gebruiksplastic en vermoedelijke chemische substanties (veelal paraffine achtige stoffen). Slechts industrieel plastic vertoonde een afname. Andere categorien namen allen toe. Hoewel leeftijd het absolute niveau beinvloedde, waren de trends in verschillende leeftijdscategoriën hetzelfde. Door in tijdsanalyses niet uit te gaan van jaargemiddeldes, maar van individuele vogels kon optimaal gebruik worden gemaakt van de gegevens. Een analyse op recente korte termijn trends (1996-2000) liet zien dat industrieel plastic significant bleef dalen. Gegevens voor de andere categoriën suggereren stabilisatie of een zwakke afname in recente jaren, doch zijn statistisch niet significant. De huidige niveaus van de belangrijkste zwerfvuiltypes in stormvogelmagen zijn: industrieel plastic 64% van de vogels besmet, met gemiddeld 3.6 granules of 0.08 gram per vogel; gebruiksplastic 97% besmet met gemiddeld 27.8 stukjes of 0.53 g; vermoedelijk chemische substanties 28% besmet, met 2.2 voorwerpen of 0.54 g.

Een analyse van variantie in de gegevens en een zogenoemde ‘Power Analyse’ toonde aan dat met een monstergrootte van ± 40 vogels per jaar betrouwbare gegevens kunnen worden verzameld en dat betrouwbare conclusies over trends (of het ontbreken daarvan) mogelijk zijn over periodes van 4 tot 8 jaar bemonsteren, afhankelijk van de categorie zwerfvuil. Gewicht per categorie zwerfvuil is op langere termijn de meest betrouwbare maat in een meetsysteem in vergelijking met besmettings percentage of aantal objecten. Gewicht is ook de meest representatieve maat in ecologische zin, d.w.z. in termen van effect op organismen.

Geconcludeerd mag worden dat analyse van maaginhouden van aangespoelde Noordse Stormvogels een betrouwbare graadmeter vormt voor (veranderingen in) de hoeveelheid zwerfvuil op zee. Doordat deze graadmeter zich richt op klein zwerfvuil in het ‘offshore’ milieu bestaat er weinig overlap met eventuele kustgebonden monitoring systemen van grof zwervuil. Bovendien heeft maagonderzoek als belangrijke toegevoegde waarde dat het een graadmeter vormt voor de ecologische gevolgen van zwerfvuil op allerlei vormen van marien leven. Belangrijk is tenslotte dat maagonderzoek bijdraagt aan publiek bewustzijn van het feit dat milieuproblemen van zwerfvuil niet ophouden op het moment dat voorwerpen zijn opgebroken in objecten van een formaat dat ontsnapt aan het gebruikelijk patroon van waarneming.

Aanbevolen wordt om een jaarlijks graadmeter onderzoek op te starten dat voortbouwt op de 1982-2000 trendanalyses uit dit rapport. De beschikbaarheid van een lange tijdserie maakt het mogelijk om op juiste wijze het effect van een beleidsmaatregel als de EU-Richtlijn voor HavenontvangsInstallaties te evalueren (de ‘HOI-Richtlijn’ moet in februari 2003 in Europese havens zijn doorgevoerd). Voor het graadmeter onderzoek zijn per jaar ±40 vogels nodig, die verzameld kunnen worden in samenwerking met de werkgroep Nederlands Stookolieslachtoffer-

Onderzoek (NSO) van de Nederlandse Zeevogelgroep (NZG). Aanbevolen indicatoren zijn gewichten van industrieel plastic, gebruiks plastic en vermoedelijk chemische substanties. Deze laatste categorie is niet altijd eenduidig te registreren omdat substanties kunnen variëren van vaste klompjes materiaal tot vloeistofachtig. Maar het feit dat 28% van vogels met deze categorie zwerfvuil te maken heeft, wijst op een belangrijke verspreiding die niet op andere manier gemeten wordt en die bovendien belangrijke ecologische effecten kan hebben.

Het Biodiversity Committee van OSPAR heeft recent concepten voor 'Ecologische Kwaliteits-doelstellingen voor de Noordzee opgesteld (**Ecological Quality Objectives for the North Sea - EcoQOs).** Zoals geadviseerd door de ICES Working Group on Seabird Ecology, betreft één van de opgestelde EcoQOs het toelaatbare aantal plastic objecten in de magen van Noordse Stormvogel in het gehele Noordzeegebied. Hoewel dit rapport is gericht op een meetsysteem voor zwerfvuil in de Nederlandse situatie, heeft het een duidelijk belang voor OSPAR. Derhalve zijn in het laatste hoofdstuk onderdelen toegevoegd die specifiek gericht zijn op het aspect van OSPAR kwaliteitsdoelstellingen in het hele Noordzeegebied. In dit verband wordt aanbevolen om steun te verlenen aan initiatieven voor een internationaal kortdurend onderzoek dat kan helpen bij een efficiente implementatie van de EcoQO voor het hele Noordzee regio.

Het eten van zwerfvuil door zeevogels vormt een krachtig middel om bij publiek en bedrijfsleven bewustzijn te bevorderen van de problemen van zwerfvuil op zee. Zulk bewustzijn is onontbeerlijk voor acceptatie van ingrijpende beleidsmaatregelen en voor de bereidheid tot medewerking bij de uitvoering daarvan.

1 Introduction

1.1 Marine litter and the need for monitoring

Marine litter in the North Sea is well known for causing serious pollution problems on touristic beaches. Coastal communities spend considerable resources on combatting beachwashed litter because it presents an aesthetical problem and a health/safety risk for tourists. Fisheries are affected by bycatch of litter in their nets. Larger debris may pose hazards to shipping, for example by floating nets or ropes being caught in ship's propellers.

Major sources of litter in the North Sea are commercial shipping and fisheries (Vauk & Schrey 1987). These are supplemented by coastal recreational activities and offshore industry, although the latter is thought to be a minor source because of strict waste management practices. Finally, litter may enter the North Sea by wind, currents, or river-tranport from landbased sources. It has been estimated that the North Sea has to cope with about 70.000 m^3 of litter per year and that plastics may constitute 95% of the total amount of litter in many areas (OSPAR, 2000).

The effects of marine litter are not limited to the economic damage and safety hazards mentioned above, but include negative impacts on a wide variety of marine organisms. The most direct eye-catching effect is the entanglement of marine birds and mammals in lost or discarded fishing gear and packaging materials. In the North Sea area, the Gannet *(Sula bassana)* especially becomes frequently entangled in remains of ropes, nets and fishing lines. Less obvious, but more widespread is the phenomenon that seabirds and other marine organisms mistake litter for food and ingest them. Indigestible litter items, in particular plastics, accumulate in their stomachs. Ingested litter may not be a major direct cause for mortality, but reduces fitness of the animal for survival and reproduction. Seabirds thus signal that litter in the marine environment is not just an economical problem, but also a serious ecological problem.

Various policy measures are in force to stop litter from entering in the marine environment. Dumping of waste into the sea is prohibited under the OSPAR Convention. Coastal communities in the North Sea region put major efforts in reduced littering by tourists. Litter disposal by ships (household waste, cargo waste, packaging remains, fishing equipment) has been dealt with in Annex V of MARPOL 1983. Under this annex, disposal of any sort of plastics is completely prohibited. In 1991, the North Sea area was declared a 'Special Area' under Annex V, which should have led to an even more rigid reduction of waste disposal practises. So far, these different measures have not resulted in indication of any improvement with regard to marine litter (OSPAR, 2000).
Because of persistent problems, national and international policy-makers continue to search for ways to reduce litter input. Since shipping (commercial and fisheries) is considered to be a major source of marine litter and other waste, the European

Union has recently decided to bring into force a Directive on reception facilities for waste reception from ships (**Directive 2000/59/EC of the European Parliament and of the Council of 27 November 2000 on port reception facilities for ship-generated waste and cargo residues** *Official Journal L 332 , 28/12/2000 P. 0081).* The directive includes mechanisms like indirect financing of waste reception and processing in ports, and obligatory waste disposal by ships when entering ports. Implementation by member states has to be completed by early 2003.

Linked to new policy and legislation, there is a growing awareness of the need to monitor the scale and impact of marine litter in the current situation and future. Following recommenations of the ICES Working Group on Seabird Ecology (ICES-WGSE, 2001), the Biodiversity Committee of OSPAR has been working on the development of **'Ecological Quality Objectives for the North Sea (EcoQOs)'**. In the seabird issue, one of the proposed EcoQOs is the number of plastic particles in gizzards of Fulmars (OSPAR-BDC, 2001) although it was recognized that this objective is in a less advanced stage and needs more work before it can be finalised.

From the perspective of general environmental quality and shipping-policy, the Dutch government is actively searching for monitoring tools to detect time related trends in marine litter pollution in the North Sea. For example, Sweden and the Netherlands have submitted a proposal to OSPAR for monitoring quantities of beachwashed litter (BDC 00/7/8-E). Measuring accumulation of marine litter on shorelines focuses on the coastal economic aspect, but not necessarily provides a complete measure for litter in the marine environment itself, nor for the effects of such litter in an ecological sense. Therefore, ALTERRA was asked to conduct a pilot study into the feasibility of developing an additional monitoring tool based on seabirds, more in particular on the stomach contents of Northern Fulmars because of the link to the issue of Ecological Quality Objectives.

1.2 Why consider the Fulmar as a potential monitoring tool for marine litter?

The request for a pilot study on marine litter using Northern Fulmars and the proposed EcoQO find their origin in earlier work. During the early 1980's, the Dutch Seabird Group (NZG) and the Zoological Museum of the University of Amsterdam facilitated a study of stomach contents of Northern Fulmars *(Fulmarus glacialis)* that had been found dead on Dutch beaches. Marine litter was commonly found in stomachs of these beachwashed Fulmars. Most of the birds (92%) had plastic fragments in their stomach, averaging at almost 12 particles per bird (Van Franeker 1985). Beachwashed birds often die starved and during their final days, they could have ingested more 'unsuitable' food than normal healthy birds. However, a similar incidence (92% with plastic) and average number of plastic items (10.6 per bird) in a small sample of 13 'healthy' Fulmars from the Shetland Islands (Furness 1985a) suggested that stomachs of beachwashed birds were representative for the Fulmar in the North Sea in general.

At the same time, dissections of Fulmars collected in the far northern Atlantic (Bear Island and Jan Mayen) showed lower incidence of plastics (± 80% of birds; average ± 4.6 pieces per bird; van Franeker 1985). On St. Kilda, in the open Atlantic to the west of Scotland, 4 out of 8 Fulmars had plastic in the stomach, averageing at 3.9 particles per bird (Furness 1985a). Thus, Fulmars from areas where low pollution levels may be assumed, had less than half the number of plastic items in their stomach as compared to their conspecifics from the polluted North Sea. This suggests that stomach contents of Northern Fulmars reflect pollution levels in their foraging areas.

Further support for the assumption that stomach contents reflect spatial patterns in pollution levels was found in studies of seabirds in the Antarctic, widely considered the worlds most pristine environment. Stomach contents of Antarctic Petrels (*Thalassoica antarctica*), Snow Petrels (*Pagodroma nivea*), Southern Fulmars (*Fulmarus glacialoides*) and Cape Petrels (*Daption capense*) were studied in the framework of the Netherlands AntArctic Program (NAAP). All four species are very close relatives of the Northern Fulmar with similar foraging habits. Antarctic and Snow Petrels had hardly any plastic in their stomach, but increased levels were observed in S. Fulmar and especially the Cape Petrel. Explanation for this is that prior to breeding these birds differ in foraging areas, with Fulmars and especially Capes occuring north to temperate waters near e.g. New Zealand, whereas the other two species always reside in or very near the ice covered parts of the Southern Ocean. Some types of 'wear-resistant' hard plastics may persist over long periods in bird stomachs, and the differences between the Southern relatives of the Fulmar can be explained by foraging in areas with different pollution levels. The pattern is shown in Fig. 1, which includes a further species, the Wilson's Storm-Petrel (*Oceanites oceanicus*). This is a less closely related and ecologically different bird, but was included because it is a Antarctic breeding species that migrates further north, even into the northern hemisphere where apparently it picks up considerable quantities of plastic. Chicks ingest the plastics with the food regurgitated for them by their parents (for details zie Van Franeker & Bell 1988).

In Northern Fulmars from the northern Pacific (*F.g.rodgersii*) Day (1980) demonstrated similar regional differences in plastic ingestion rates: Fulmars in arctic Alaska had a mean of 2.8 plastic particles per bird, whereas 11.3 were found in wintering birds in polluted waters off California. Very similar patterns were seen in Sooty Shearwater (*Puffinus griseus*) with 1.1 versus 6.9 items, and Short-tailed Shearwater (*Puffinus tenuirostris*) with 5.4 versus 21.7 items in Alaska and California respectively. Both shearwater species breed in the southern hemisphere and are only wintering and migrating in the northern Pacific.

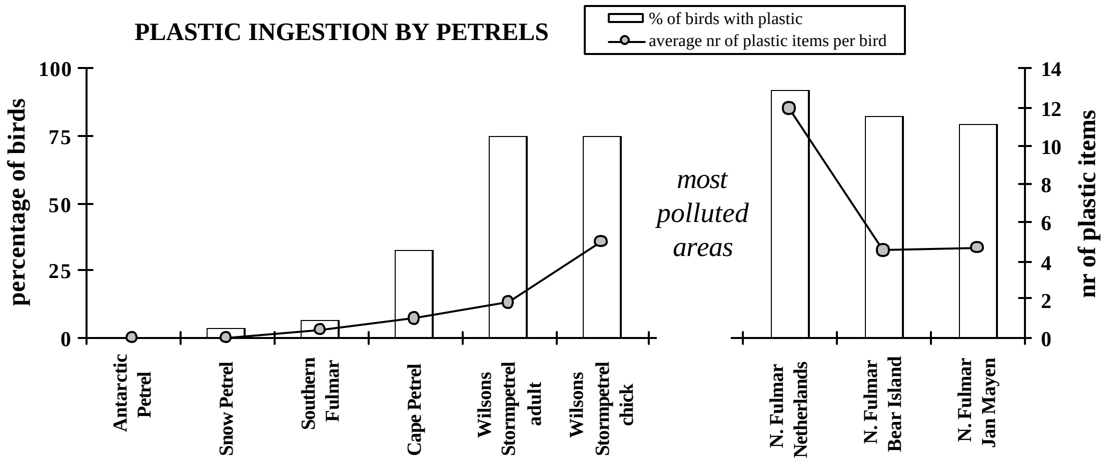


Figure 1 Incidence and abundance of plastic litter in stomachs of Northern Fulmars from the North Sea and north Atlantic (right) and those in related petrel species in the Antarctic (left). Bars show incidence of plastics (percentage of birds having one or more plastic items in the stomach; scale on left y-axis) and the circles show the average number of plastic items per bird (scale on right y-axis). The x-axis represents a geographical scale from south pole left to north pole right. Among the Antarctic species, resident ones have very few plastics, whereas the more migratory species have more. Cape Petrels migrate to southern hemisphere temperate waters, and Wilson's Stormpetrels even cross the equator to northern hemispere temperate waters. Accumulated plastics are transferred to chicks when fed.

The lower levels of plastic ingestion in birds foraging in remote arctic, and especially Antarctic zones as compared to birds foraging in oceanic regions near centers of human activity, may be considered as a good indication that stomach contents of seabirds like petrels reflect regional differences in pollution levels.

This implies, that at a single location, stomach contents of a species like the Fulmar *may* be an effective monitor of time related changes in the occurrence of marine litter, i.e. plastics at sea. Thus, the aim of this pilot study is to establish whether data resulting from stomach content analysis in Fulmars are suitable to detect time related trends, and if so to advise on indicators and an efficient set-up for a longer-term monitoring program.

In the North Sea area, the choice for the Fulmar rather than another seabird species is a practical one. Firstly it has a well documented habit to accumulate litter in the stomach, and secondly it is an abundant species, with a 'guaranteed' annual supply of some tens to hundreds of beachwashed corpses in the Netherlands (Camphuysen 1995) and other countries (OSPAR-BDC, 2001). In the Netherlands, no other species meets both conditions in a similar way. Finally, an important advantage of the Northern Fulmar is the availability of a dataset from the early 1980's, which is of major benefit in an attempt to develop a tool capable of detecting time related trends.

1.3 Spatial and temporal aspects of Fulmar litter monitoring.

An important question when studying the stomach contents of beachwashed Fulmars is the area where these birds had been foraging before their death. In other words, what is the marine area sampled by this potential monitoring tool? Two issues are relevant here. Firstly, how fast, and over what sort of areas or distances do Fulmars move around? And secondly, how long does littter persist in the stomachs of birds?

Northern Fulmars are ‘oceanic birds’ that is they are offshore feeders. In the Dutch Continental Sector (NCP) of the North Sea, numbers between the coast and the 40 m depth-contour are usually low and increase further outward (Berrevoets & Arts, 2001). During winter, numbers of Fulmars in the North Sea strongly increase and largest numbers of Fulmars usually occur in the more northern parts of the North Sea (Skov et al., 1995). Fulmars are extremely good flyers and especially under conditions of high wind speeds they can cover distances of hundreds of kilometers within a single or few days. Thus the potential foraging range of Fulmars is very large. For Fulmars beachwashed in the Netherlands at least the southern half of the North Sea and possibly a much wider area should be considered as the potential foraging area prior to their death. Similarity in plastic loads of Fulmars from the Netherlands and the Shetlands may suggest North Sea wide foraging, with differences only arising with birds on locations well away from the North Sea (Furness 1985a; Van Franeker 1985) However, sampling locations are too few, and sample sizes too small to be considered as conclusive evidence for North Sea wide foraging. Evidence for more limited foraging ranges may be seen in the more or less distinct distributional patterns of Fulmars within the North Sea over particular seasons (Skov et al., 1995). Such patterns suggest that the majority of Fulmars, although capable of travelling huge distances, is not constantly ‘on the move’ but spends longer periods of time foraging within limited specific sub-areas of the North Sea.

This means that at the moment there is no conclusive evidence for the extent of the marine area monitored by Fulmar stomach contents. Although not directly relevant for a local study of trends over time, this issue becomes important in terms of the OSPAR Ecological Quality Objective for plastic loads in Fulmars over a wider area. Only an integrated North Sea wide study, with many sampling locations, can provide the information required for implementation of the EcoQO over a wider area (presence or absence of regional differences within e.g the North Sea, and in relation to that the number and location of future sampling locations). The current hypothesis would be that stomach contents of Fulmars ‘mirror’ pollution levels over a wide area and for example would show little variability within the North Sea, but this urgently needs confirmation.

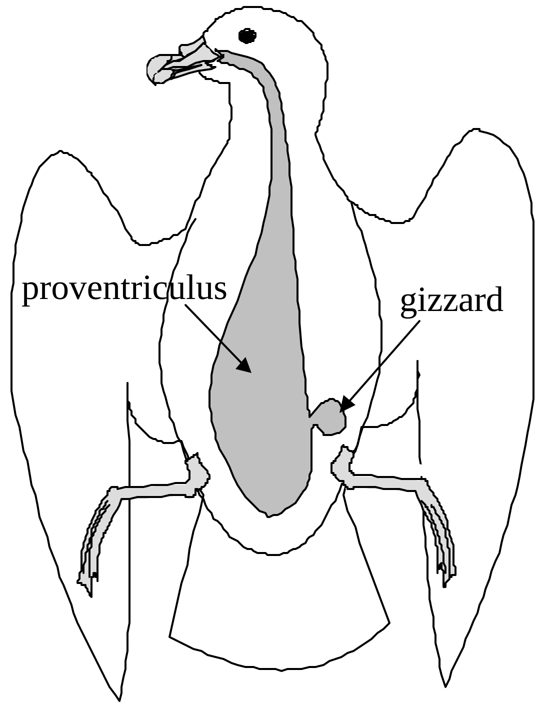
As implied in section 1.2, some ingested litter, especially hard plastic granules (see methods), may remain in the stomachs of birds for considerable periods of time. Plastics will accumulate to a level at which there is a balance between consumption-rate and loss-rate through wear or degradation in the stomach and excretion via the intestines.

Unlike in for example gulls, cormorants and albatrosses, there are no indications that Northern Fulmars regurgitate undigestable items from their stomach (Furness 1985a, 1985b). Only breeders regurgitate part of such material when feeding chicks or in defensive oil spitting, but not all due to stomach morphology (see inset on stomach morphology).

No dedicated studies are available on the disappearance rates of ingested items in Fulmars. Undoubtedly these are highly variable depending on the type, size and number of the plastic objects ingested and the amount of natural hard items in the stomach. Literature suggests long residence times of plastic items. For example, Day (1980) suggested that mean residence times in Short-tailed Shearwaters for soft plastic items might be in the order of 2 to 3 months, and maybe around a year for hard cylindrical plastic items. However, as concluded by the author himself (Day et al., 1985) considerable differences in in plastic quantities between Alaskan and Californian wintering groups and also breeders indicate that such residence times were unlikely, and the estimated residence time for hard plastic granules was reduced to ± 6 months (Day et al., 1985). Based on initial wear of hard plastic granules in a 12 day experiment using chicks of White-chinned Petrels *Procellaria aequinoctialis*, Ryan and Jackson (1987) suggested that the hard plastic granules could have a half-life of a year but this seems a rather too bold extrapolation of a short experiment (Spear et al., 1995).

There are several good reasons to argue that residence times of plastics as discussed by the above authors are strong overestimates. Firstly, by focusing on hard plastic granules, calculations represent the upper limit of the range of residence times of plastics in bird stomachs. Softer materials, in particular sheetlike and foamed plastics, will have much shorter residence times. Secondly, both Day et al., (1985) and Ryan & Jackson (1987) assumed that plastic particles were not passed into the intestine at all, implying that items would remain in the stomach until wear and digestive degradation would have transformed them to ‘dust’. For Northern Fulmars this is not correct, as plastics are occasionally found in the intestines (personal observations). Thirdly, we had the opportunity to look at stomach contents of Cape Petrels in Antarctica that had returned from ‘polluted’ wintering areas and were collected at various later dates after foraging in the ‘plastic free’ Antarctic environment. The Cape Petrel is a close relative of the Fulmar and ecolocigally similar. Stomach contents of Cape Petrels suggest exponential decreases in number of plastic items in stomachs by about 75% per month after arrival in the clean Antarctic environment (van Franeker & Bell 1988). Squid-beaks, similar to hard plastics in indigestibility and wear-resistance, disappeared at very similar rates in all Antarctic relatives of the Fulmar (Van Franeker, 2001). Spear et al., (1995) support shorter residence times of plastic because they found that tubenosed seabirds breeding in polluted areas but wintering in relatively clean waters, showed sharp reductions in plastic loads in their stomachs over winter, with up to 90% of birds purging themselves of *all* plastics. Concluding on the aspect of residence times of plastics in Fulmar stomachs it seems possible that some particularly hard pieces of plastic could be present for ‘months’, but that the number of plastic items in a stomach responds rapidly to changes in ingestion-rates, that is within periods of a few weeks at most. Digestable litter will evidently disappear at even much faster rates.

Stomach morphology



Stomachs of Fulmars are basically structured as a two-unit system. Below the oesophagus ('throat') lies a large, soft-walled stomach. This so-called proventriculus is a baglike structure extending throughout the abdominal cavity to nearly the position of the cloaca. During the breeding season, birds can store large quantities of food here, of over 25% of their body-mass (van Franeker, 2001), probably somewhat less during the non-breeding seasons. Digestive processes start in the proventriculus. The fulmar and its allies are remarkable in the fact that they tend to accumulate considerable quantities of fatty fluids in the proventriculus, extracted from the food. The stomach oil is not only a valuable energy reserve under adverse conditions, it is also a powerful defense system against predators or competitors. They can spit out this oil with remarkable force and accuracy. The second stomach (gizzard) is much smaller, and has a hard muscular wall lined with a rough inner surface. Its function is to grind harder bits and pieces in the food mass to sizes that can pass on into the intestines. The hardest and indigestible prey items, like fish-eyelenses and squid-jaws are not easily grinded and tend to accumulate in the gizzard over longer periods of time.

The passage from proventriculus to gizzard is narrow in most petrels, and it seems that items once in the gizzard can not go back. Because of this, if stomach contents are regurgitated, as in birds feeding chicks or birds spitting oil, it is only contents of the proventriculus that are ejected: the gizzard is not emptied. Like squid-jaws, hard plastic items accumulate in the gizzard and from there can only leave the body via the intestines. Although usually it seems that only amorf predigested substance can pass on into the intestines, the odd plastic particle can be found further down the intestine. Apparently, not always hard items need to be worn down completely in the gizzard before they are excreted.

When ingestion rates of hard prey remains and plastic items are in excess of the rate of processing in the gizzard, the latter becomes totally filled and hard items also start accumulating in the proventriculus. This 'overflow' of accumulating plastics into the proventriculus is frequently the case in Fulmars from the North Sea region. Data in this report refer to the combined amount of litter in both gizzard and proventriculus.

The combination of foraging ranges and disappearance-rates of litter determines the interpretation of Fulmar stomach contents as a monitoring tool. From the above it is provisionally concluded that stomach contents of Dutch fulmars, depending on the type of litter, **integrate ingestion of small sized marine litter over a large offshore North Sea area over a time frame in the order of weeks.** This is thus basically different from beachwashed litter monitoring which reflects local coastal and near-shore situations of large litter items with considerable variation in measurements due to short term variability in force and direction of winds prior to beach inspection.

1.4 The ecological significance of Fulmar litter monitoring

The ecological impact of marine litter has already been touched upon in Chpt 1.1, but needs further detail in order to consider the ecological significance of monitoring litter in stomachs of Northern Fulmars. Marine litter affects a wide range of marine wildlife, both through entanglement and ingestion.

Worldwide, large numbers of fishes, sharks, turtles, seals, dolphins, whales and marine birds become entangled in lost or discarded nets and die (Breen 1990; Laist 1996). In the North Sea, among beached victims however, it is very difficult to distinguish between mortalities due to ghost-net entanglements (litter problem) and those due to bycatch in nets during active usage (fisheries problem). It is not just net-remains that take their toll through entanglement. Also rope fragments, nylon fishing line, circular packaging straps, plastic six-pack holders for beercans are all well known for entangling marine animals, often leading to a slow death by starvation or injury. Entanglement has been shown to negatively affect animal populations (e.g. for Fur Seals in the North Pacific – French and Reed 1990), allthough usually there is a problem of sufficient demographic data. In the North Sea area, regular examples are seen of seals entangled in ropes or net remains, but it is impossible to quantify the negative effects of entanglement mortality in the mix of factors (bycatch, chemical pollution, disturbance, food competition, habitat loss… etc) that affect marine mammal populations in the area.

In the North Sea, the best documented record of litter entanglement problems is probably that of the Gannet *Sula bassana.* On Helgoland, the first ever born Gannet chick did not fledge because it became trapped in plastic wire used by the parents to build their nest (Schneider 1991). Many seabirds using seaweed like materials for nest construction also incorporate litter (Montevecchi 1991). On Helgoland, entanglement rates among free flying Gannets were 2.6%, whereas up to 29% of beachwashed Gannet corpses suffered entanglement (Schrey & Vauk 1987). In the Netherlands, the extensive and long term beached bird surveys revealed that during the 1980's 5.2% of beachwashed Gannets were entangled, a proportion increasing to 7.5% during the 1990's, in which an increased role of nylon fishing line was noted (Camphuysen, 2001).

Ingestion of litter, like entanglement, is an extremely widespread ecological problem affecting all groups of marine vertebrate wildlife. Nearly endless lists have been compiled of species of fishes, squid, sharks, sea-turtles, seals, whales, dolphins and seabirds in which marine litter, especially plastics have been found (Laist 1997). Some groups are clearly more prone to ingest plastics than others, but it is remarkable how common the phenomenon is. Intuitively, one would expect that litter ingestion would be largely limited to species using 'indiscriminate' filter-feeding (e.g. baleen whales) or those of indiscriminate scavenging feeding habits (e.g. many gulls and petrels). However, such limitation clearly does not exist. Partly this can be explained by resemblance of particular litter items to prey normally taken. For example, resemblance between hard plastic granules and fish eggs has often been suggested as an explanation of presence of granules in specialised feeders like some smaller alcids. The most vivid example of resemblance is that of jellyfish to pieces of soft plastic sheets: ingestion of such sheets is extremely common in especially turtles and most likely a consequence of the fact that jellyfish are a major part of their natural diet (Carr 1987; Lutz 1990; Laist 1996,1997). Litter can also be ingested because 'normal' food is attached to it. Very large quantities of plastic litter are consumed by albatrosses in the northern Pacific; often items of which it is very hard to image that they would resemble food themselves (sigarette lighters, tooth-brushes etc). Their ingestion is thought to be linked to the fact that strings of fish eggs, a normal part of their diet, are often attached to floating litter (Sievert & Sileo 1993; Auman et al., 1997). Nevertheless, the list of animals found with plastics in their stomach is far much longer than what can be explained by the above hypotheses. For example, it remains unclear why many toothed whales and seals, highly intelligent animals with specialised feeding habits, would consume plastic.

The impact of ingested litter, i.e. plastics, on either the individual animal or on populations is difficult to quantify. To start with, a number of effects of non-degradable litter ingestion should be distinguished (Day et al., 1985; Laist 1997; Ryan 1987a, 1990):

1. physical damage. Larger or sharp objects may damage or puncture the stomach wall
2. reduced digestive functioning. Flat plastic fragments occasionally become 'embedded' in the mucous layer of the stomach; thus excluding the normal digestive functioning of that part of the stomach wall
3. partial or complete blockage of the digestive tract. Some items, especially soft plastic bags or sheets but also for example large objects like onions, can effectively seal off the digestive tract.
4. Satiation effects. The urge to feed (in chicks the urge to beg for food) partly depends on having an empty stomach: larger quantities of useless litter may thus reduce foraging effort, affecting the general condition of the animal
5. reduced maximum food load. The marine environment is patchy, and many animals have adapted to taking large quantities of food during short moments of abundant food supply. In that situation, irrespective of satiation effects, the useless volume of accumulated litter, will reduce the food that can be instantaneously ingested again affecting condition of the animal

6. toxic substances within plastics. Even though plastic molecules are thought to be of a size too large to be biologically relevant in digestive processes, many of the additives are not. Many of the added substances like colourants, anti-oxidants, fillers, weakeners, etc., are known or suspect in terms of toxicity (Ryan et al., 1988; Summer et al., 1995).
7. toxic substances adhered to plastic litter. At the beach, it is immediately evident that fluid surface pollutants like mineral oil tend to be absorbed onto the surfaces of floating litter. The same has been shown to occur with persistent organic pollutants (Mato et al., 2001). Litter ingestion may thus result in elevated 'secondary' ingestion of toxic environmental pollutants.

The above list of effects focuses on accumulated non-degradable plastic litter. Added to these should be at least:

8. Direct ingestion of lumps of tar or chemical substances. These have evident negative toxic effects.
9. Ingestion of food scraps discarded by humans. Food wastes are thought to be a risk for the introduction of 'alien' disease into populations of wild animals (e.g. Gardner et al., 1997).

Only in part of cases, the death of animals can be directly and with certainty linked to one of the above effects of litter ingestion. In seabirds, evident total blockage of the digestive tract by for example plastic bags does occur, but is limited to incidental cases. Even for sea turtles, in which such blockage and individual death is a highly frequent phenomenon, it would be difficult to provide solid evidence that ingestion is a significant factor in their worldwide population declines caused by a mix of factors including hunting, bycatch, habitat loss, egg-harvesting etc.

Almost all of the above listed effects operate at the 'sub-lethal' level, that is they result in a 'reduced fitness' of the individual animal negatively affecting its potential for survival or reproduction. In experiments with chickens, such effects of reduced fitness have been shown to occur (Ryan 1988); in a number of seabird studies correlations were found between reduced body condition and litter quantities in the stomach, although other studies did not and the correlation does not prove a solid cause-effect relation (Auman et al., 1997; Ryan 1987b, 1990; Spear et al., 1995).

In the North Sea, some Fulmars undoubtedly die as a direct consequence of plastic ingestion, but there is no factual evidence of consequences of direct or sublethal effects affecting the Fulmar population. In fact, since the cessation of hunting and harvesting of eggs and chicks early last century, the Fulmar population has continued to grow, in spite of for example evident mortality from oil pollution. However, the impossibility to quantify population effects does not affect the ecological significance. Ingestion by Fulmars stands as a reference for litter ingestion by a wide variety of marine organisms from the largest whales down to the smallest forms of life with unknown consequences for individuals or populations. For example, juvenile fish have been shown to ingest minute plastic particles, the extent and effect of which in natural populations remains totally unknown. And we simply do not know effects of even smaller sized degrading plastics on marine life forms.

The interpretation of 'ecological significance' should not be narrowed down to to situations where populations are in decline and where causal relationships have been proven beyond doubt. Mortality incidents and sublethal effects as a consequence of litter ingestion do occur with certainty in the North Sea area among many animal groups and the Fulmar may provide a suitable unit of measurement .

The major ecological significance of monitoring stomach contents of Fulmars could thus be formulated as:

1. signalling the occurrence of, and providing a measure for the problem of plastic ingestion in a wide variety of marine animals
2. creating continuing awareness and providing evidence for the fact that the impact of marine litter is not limited to visual fouling of beaches and entanglement of animals, but continues at the sub-visual level after gradual breakdown of the original products

This ecological significance is thus basically different from that of monitoring beached litter or animal entanglement rates because these unintentionally adapt to the erroneous feeling that environmental problems are gone once they are out of sight.

2 Material and methods

2.1 Sample size

A previous study of litter in stomach contents of Fulmars beachwashed in the Netherlands was conducted from 1982 to 1984 (van Franeker, 1985). In that study, the number of litter items (plastics) in stomachs of 65 birds was considered. In the current monitoring pilot study we wanted to reevaluate that material, for example to include mass of items. In the initial phase of the earlier project some samples had been stored, but others not. To avoid usage of a biased set of samples, the current study has not used those incidental early samples, but only those after the moment that systematical storage of samples had started (42 of original 65 samples). Volunteers from the Dutch Seabird Group (Nederlandse Zeevogelgroep NZG) who had been collecting the Fulmars, continued to send in some material during the 1980's resulting in a total of 69 samples for the decade.

In 1996 volunteer help was invited again to start a new sampling period for the current pilot study, which resulted in large samples for 1998 and 1999 especially. A major part of the collection was made available by the 'Windbreker' Organization operating in the province of Noord-Holland. Many other birds were collected on Texel, with smaller numbers of birds originating from various other locations in the Netherlands. A total number of 276 Northern Fulmars from the Netherlands were dissected for the second phase of the project. As some corpses had incomplete or no stomachs, the remaining sample for the 1990's (incl 2000) was 260 stomachs. The overall sample size for this study was thus 329 birds with complete intact stomachs over the period 1982 to 2000, with the emphasis of samples on the early to mid 1980's and late 1990's.

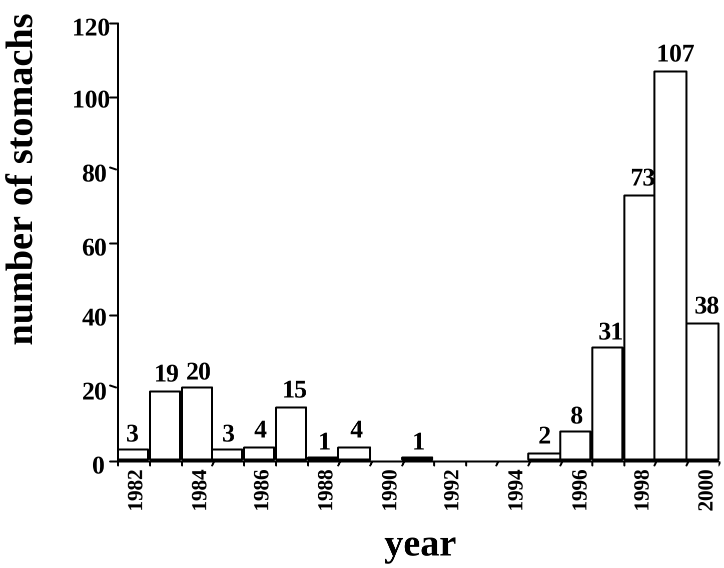


Figure 2. Number of complete stomachs of Northern Fulmars used for this study (total n=329)

2.2 External examination and dissection

Collected birds were kept frozen at –20°C, and were thawed one day prior to external examination and dissection. After internal examination, the stomach was removed by cutting the intestine close to the gizzard, and cutting the oesophagus as high as possible around the throat level. Stomachs were then refrozen for later analysis. The following issues were recorded during external examination and dissection:

- **date, finder and location details**
- **plumage colour** was recorded in four colourphases: LL Double Light; L Light; D Dark; DD Double Dark (van Franeker & Wattel, 1982) and afterwards simplified to White (=LL) versus Coloured (L+D+DD). Coloured Fulmars are virtually absent in the southern subspecies (*F.g.auduboni*) but abundant in most populations of the arctic subspecies (*F.g.glacialis*). Coloured plumage thus indicates an almost certain arctic origin of the bird (van Franeker & Wattel, 1982; van Franeker, 1995).
- **moult and plumage condition** Moult of primaries (hand flight feathers) and tailfeathers was recorded according to BTO moult score system (zere for an old feather; 1 to 5 score for moulting feathers; 5 being new full grown; the date at which new fullgrown feathers become old was arbitrarily set at the 1st of april). Moult of secondaries and body feathers was simply noted as absent, moderate or strong. Moult records can assist in deciding between age classes juvenile (first year of life) and young immatures (>= 1 year). Extremely worn feathers or arrested moult can indicate that a bird has been in poor condition for a longer period of time.
- **external measurements**. Headlength, billdepth at gonys, billlength, tarsuslength and winglength were taken as measurements may assist in determining sexe in cases where internal organs are not present or too decayed. In this pilot study measurements were only used to calculate a size-index (van Franeker & ter Braak, 1997) as an additional tool to look at origin. Arctic birds are smaller than birds from the temperate climate zones.
- **plumage fouling** by oil or tar or other external contaminants was recorded as the % of plumage that was fouled, giving an indication of the cause of death
- **external signs of injury** (e.g. fractures) or abnormalities were checked to pinpoint potential causes of death like collisions causing broken legs or wings.
- **Condition** was recorded by looking at quantities of subcutaneous fat, intestinal fat and breastmuscle condition, each of them in a score of 0 to 3, in which zero indicates total depletion and three optimal condition (van Franeker, 1983). Addition of the three scores result in the overall condition index ranging from zero (completely emaciated) to nine (bird in excellent condition).
- **internal injuries** were checked by e.g. noting heavy internal bleeding, bruises or fractures not discovered during external examination
- **organ health** was checked for obvious problems or diseases: stomach, lung, kidney, liver and gut were classified on a zero (poor condition) to three (fine condition) scale, with notes being made on remarkable situations
- **sexe** was determined on the basis of the sexual organs

- **age** was primarily derived from the development of the sexual organs in which size, shape and colour are relevant. An index for male age was based testislength * testiswidth (in mm). Female age was scored by maximum follicle size (in mm) * oviductdevelopment code (code 1 to 4 from juvenile to breeding phase adult). The basic age distinction made was juvenile (1st year), immature (never bred, incomplete development of organs; probably usually in age range 2 to ± 6 years) and adult (organs showing signs of previous breeding or full capability thereof). In addition, we checked for presence and size of a Bursa of Fabricius, a glandular structure on the dorsal side of the cloaca that is present in juveniles but rapidly disappears at ages over one year. Finally, absence of moult and uniform fresh plumage was used to decide if internal organs left doubt on juvenile or immature age. In a later phase of analysis age classes were grouped into Adult (AD) versus Not-Adult (NA)
- **Cause of death** At the end of the dissection procedure all available information was integrated into a subjective personal judgement of the likely cause of death. Different causes recognized are described in table 1. below, with acronyms (DEATHC) and grouping in later analysis (DEATH2). As stomach contents had not yet been examined at this stage, ingestion problems (e.g. oil, chemicals, excessive preened feathers, excessive plastic load) were not considered in these potential causes of death.

Table 1 Description and codes used for subjective deathcauses assigned at dissection

suspected background of death	DEATHC	DEATH2
oil or tar on plumage likely to have caused or strongly contributed to death	OIL	D_OIL
other contaminants on plumage ('glue' type substances) caused death	EXT	
Cementcloaca (ball of solidified faecal material blocking cloaca)	CEM	D_SIC
Gut problems (other gut or internal problems affecting digestion)	GUT	
Plumage indeficiency (extreme wear; arrested moult)	PLU	
Collision (broken bones & other physical damage)	COL	D_ACC
Drowned in fishing gear? (good condition, except lungs)	DRO	
Entangled in artificial materials	ENT	
Caught healthy at sea	ME13	
Starved without further indications of cause	STA	D_STA

2.3 Stomach sorting methods

After thawing of stomachs, proventriculus and gizzard were separated. Reason to treat stomachs separately is that information on proportions of different materials in each of the stomachs, and their degree of wear or desintegration, may assist in process studies of digestion-rates in these birds, both for natural and non-natural materials. Such detailed work was not possible in this pilot project, but databases and storage of samples has been organised in such a way that later study remains possible. For the purpose of this project, the data from proventriculus and gizzard of each bird have been combined to a single stomach-contents list.

Stomachs were opened over their full length, and contents were carefully flushed out with cold water over a 0.5 mm mesh to ensure that no small particles were left behind on stomach walls. Totally amorf material was rinsed out under running cold water, which usually cleaned contents sufficiently for further processing. However, part of the samples were more or less glued together with sticky substances like mineral oil or suspected chemical substances. In these cases, we first collected a subsample of the oily or chemical material, estimated its total mass in the sample, and then rinsed the sample with hot running water sometimes in combination with detergents until sticky layers from stomach items were removed.

The sample was then sorted under binocular microscope, separating items of different categories. The following categorization was used (see table 2 for summary and acronyms used):

I PLASTICS

a) **Industrial plastic pellets.** These are small, often cylindrically shaped granules of ± 4 mm diameter, but also disc and rectangular shapes occur. Various names are used, such as pellets, or beads or granules. They can be considered as 'raw' plastic or a half-product in which plastics are usually first produced (mostly from mineral oil). The raw industrial plastics are then usually transported to manufacturers that melt the granules and mix them with a variety of additives (fillers, stabilizers, colourants, anti-oxidants, softeners, biocides, etc.) that depend on the user product to be made (see below). The industrial pellets can be lost at factories entering the marine environment throught effluents, but most are likely lost during transport due to damaged packaging or bulk transport and subsequent at sea cleaning of ships' decks and holds. For the time being, included in this category is a relatively small number of very small usually transparent spherical granules, also considered to be a raw industrial product.

b) **User plastics** (all non-industrial remains of plastic objects) differentiated in the following subcategories:
   i) **sheet**like user plastics, as in plastic bags, foils etc., usually broken up in smaller pieces
   ii) **thread**like user plastics as in (remains of) ropes, nets, nylon line, packaging straps etc. Sometimes 'balls' of tightly packed threads are found in gizzards.
   iii) **foam**ed user plastics, as in foamed polystyrene cups or packaging or foamed polyurethane in matrasses or construction foams.
   iv) **fragments** of more or less hard plastic items as used in a huge number of applications (bottles, boxes, toys, tools, equipment housing, toothbrush, lighters etc)
   v) **other**, for example sigarette filters, rubber, elastics etc., so items that are 'plastic like' or do not fit a clear category.

2) RUBBISH other than plastic

a) **paper** which besides normal paper includes silver paper, aluminium foil etc, so various types of non-plastic packaging material
b) **kitchenfood** for human food wastes such as fried meat, chips, vegetables, onions etc, probably mostly originating from ships' galley refuse
c) **various rubbish** is used for e.g. pieces of timber (manufactured wood); paint chips, pieces of iron etc.
d) **fishhook**

3) POLLUTANTS (industrial or chemical waste remains)

a) **slags** that is the remains of burning ovens, eg remains of coal or ore after melting out the metals. Often pumice like material: if doubtful materials classified as pumice.
b) **tar** is the category for lumps of tarry substances or for more fluid heavy mineral oil
c) **chemical** is used for lumps of parafine like materials or sticky substances arbitrarily judged to be unnatural and of chemical origin.
d) **featherlump** is used when excessive amounts of preened feathers were found in the stomach, indicating excessive preening by the bird of feathers sticky with oil or chemical pollutants. Presence of a few remains of preened feathers in the stomach is normal and was recorded separate, not under this category. Featherlumps of other species were considered as 'natural food' from scavenging on corpses, unless it was evident that these feathers were heavily polluted.

4) NATURAL FOOD REMAINS

5) Numbers of specific items were recorded in separate subcategories (fish otoliths, eye-lenses, squid-jaws, crustacean remains, jelly-type prey remains, scavenged tissues, insects, other), but details of these subcategories are not used in this litter survey study.

6) NATURAL NON-FOOD REMAINS

7) Numbers of subcategories plant-remains, seaweed, pumice, stone and other were counted separately, but details are not used in analyses. Separately we also made rough estimates of numbers of parasitic worms in the stomach and of 'normal' remains of preened feathers.

Different categories and subcategories are summarized in Table 2, with 3-digit acronyms as used in data analysis and presentation. In combination with this listing, an subjective attempt is made to indicate likelihood of the source of origin of a litter item from a particular category. In this, expected sources in the **offshore** environment are considered.

Table 2 Summary of stomach content categories, including acronyms, and probability for sources of origin of litter (0 impossible; 1 unlikely; 2 possible; 3 likely; 4 very likely)

MARINE LITTER				shipping commercial	shipping fisheries	offshore platforms	coastal recreation	land & riverine
	IND	INDUSTRIAL	**IND**	4	0	0	0	3
PLASTIC **(PLA)**	**USER (USE)**	SHEET	**SHE**	4	4	2	3	3
		THREAD	**THR**	4	4	1	1	1
		FOAMED	**FOA**	4	4	2	2	3
		FRAGMENT	**FRA**	4	4	2	3	3
		PLASTIC OTHER	**POT**	4	4	2	3	3
RUBBISH	**RUB**	PAPER	**PAP**	4	4	2	2	2
		KITCHEN	**KIT**	4	4	2	1	1
		VARIOUS	**RVA**	4	3	2	1	1
		HOOK	**HOO**	0	4	0	2	0
POLLUTANTS	**POL**	SLAGS	**SLA**	3	0	0	0	3
		TAR or OIL	**TAR**	4	2	2	0	0
		CHEMICAL	**CHE**	4	1	1	0	0
		FEATHER LUMP	**FEA**	4	1	1	0	0

NATURAL STOMACH ITEMS			
FOOD	**FOO**	various not specified here	**FOO**
NONFOOD	**NFO**	various not specified here	**NFO**

2.4 Units of measurement

After sorting out under binocular microscope all above categories, we recorded for each stomach and each (sub)category:

- **incidence** (**P**resence or absence) and
- **abundance by number** (count of **N**umber of items)

for all subcategories on data sheets. However, abundance by number, is not always an easy or practical unit, because of extreme variability in size. For example, in a 'number' system, a big plastic bag in one stomach would score the same as a tiny piece of plastic sheet in another. Similarly, a small lump of parafine like material would score the same under chemicals as a stomach filled with a huge mass of treacly chemical substance that could not be separated in distinct units. In some samples, containing hundreds of tiny pieces of plastic we only made partial exact counts and estimated the remainder. Thus, for both litter monitoring and the ecological significance (effect on the animal) a unit of measurement that reflects 'stomach-loading' would be more relevant. Therefore, using Sartorius electronic weighing scale, we determined:

- **abundance by mass** (**W**eight in grams)

after a one to two day period of air drying at lab temperatures. For marine litter (categories I to III above) this was done separately for all subcategories. The natural-food and natural-non-food categories were each weighed as a whole only, without details for subcategories. Weights were recorded in grams accurate to the 4th decimal (= tenth of milligram).

Volume would probably be the best unit of measurement in terms of ecological significance. Many of the sublethal effects of litter in birds stomachs depend on the relative volume of litter in comparison to stomach capacity. However, we've been unable to come up with a practical method to measure volume accurately. Recalculation of volumes of items using specific weights of different materials was considered. For plastics we had especially in mind the sharp distinction between foamed and non-foamed materials. However, foamed materials from bird stomachs proved to be in highly different stages of compression and desintegration and were sometimes soaked with oily materials, that contributed to weight also after air drying. Weight to volume calculations would thus not improve accuracy or information value of our data.

Different units of measurements are summarized in Table 3, and prefix letter used in combination with category acronyms is given.

Table 3. Units of measurement

		expressed as	
	prefix to category	***per stomach***	***average***
INCIDENCE	P *(presence)*	0 or 1	ratio or % of positive records
Abundance by NUMBER	N *(number)*	number	n/bird
Abundance by MASS	G *(gram)*	gram	g/bird

Examples:

PIND = 0.5 (or 50%) means that incidence of industrial granules was 50%, i.e. half of the birds in the sample had one or more industrial granules present in the stomach. 'Frequency of occurrence' is another common terminology for Incidence.

NUSE = 20.5 means that in a sample of stomachs the mean number of items in the user plastics category was 20.5 pieces per bird

GTHR = 0.1250 means that the mean mass of threadlike userplastics in a sample of birds was 125 mg per bird.

Please note that both arithmetic means (from original data) and geometric means (back calculated from means of ln transformed values) are used in this paper.

2.5 Analyses

Marine litter abundances in Fulmar stomachs show time-related trends by definition: in the pre-pollution era, no litter was present in the environment and thus in the Fulmar. The aim of environmental policy is to return to such a situation in future. As indicated by regional differences, stomach contents of Fulmars will increase or decrease with time-related changes in litter abundance in their environment.

However, trends could be 'blurred' ore even wrong if litter ingestion by birds depends on specific conditions or bird-characteristics **and** if these show a directional change over time. For example, it is possible that birds that slowly starve to death show a tendency to eat anything encountered and would end up with much higher litter contents in their stomachs than 'healthy' birds that died instantly for whatever reason. If such an effect is strong, different proportions of starved versus healthy birds in subsequent annual samples could seriously blur the data, and if such proportions show directional change over longer periods of time, the trend seen in birds could even be different from the trend actually present in the environment (which is the one we want to monitor).

In addition to possible changes over years, analysis should first evaluate a number of such issues that could influence plastic or other litter quantities measured in Fulmars. The following issues were considered to be of potential relevance:

- **Period** Time of year could have influence on plastic ingestion, for example by different foraging habits in different seasons. The year was split into four three month periods: Period 1 for January to March; Period 2 for April to June; Period 3 for July to September and Period 4 for October to December. Because seasonal differences could vary independently, Period was defined as a factor in the analyses
- **Sexe** Male and female fulmars are somewhat different in size, which could be related to different foraging habits.
- **Age** Breeders raising chicks have diets that differ from their normal diet, and there could be other age related differences, like experience, influencing foraging locations and habits. Initially we have looked at age classes Adult, Immature and Juvenile.
- **Origin** As shown in earlier chapters, Fulmars from remote arctic regions have less litter in their stomach. Especially during the winter season, large numbers of Fulmars come to the North Sea from breeding populations elsewhere, including remote arctic ones. Depending on the length of their stay in the North Sea before their death, birds from elsewhere could have different amounts of litter in their stomachs. Fulmars with Plumage Phase Coloured (PP_C) were analysed as opposed to White Fulmars (PP_W). Part of the analyses were repeated with addition of the smallest 10% of birds to the coloured category, to account for the fact that white birds, but small sized, do also occur in arctic populations.
- **Condition** A potential relation between condition and litter amounts ingested has been discussed in the example above. The 0 to 9 scale for condition was used as a variate in analyses as it may be expected that effects
- **Deathcause** Although it would be expected that potential deathcauses would largely overlap with condition, this is not necessarily the case. Also, deathcause is analysed as a factor. We used the simplified categories of deathcauses (Death2) as shown in Table 1.

Analysis for influences of each of these factors is complicated, because many of them may interact, or coincide in different ways. For example, it would be possible that it is mainly particular age groups that are of arctic origin, or that sexes have different distributions in different seasons. This requires that all variables are looked at simultaneously.

Canonical Correspondence Analysis (ter Braak, 1995) was used for an initial multivariate evaluation of the influences of different factors. Next, Generalized Linear Models were applied to further explore importance of various variables in the data (Genstat, 1993). Within these models the distribution was assumed to be Poisson, and a logarithm link function was used. Finally we used Stepwise Multiple Regression (Genstat, 1993) to evaluate the importance of different independent variables on the amounts of litter in bird stomachs.

Logarithmic transformation of data was necessary in all analyses. The data on litter abundance and weight have distributions with many samples of relatively low numbers/weight of litter with a skewness towards smaller numbers of samples of sometimes extremely high numbers/weight. For number of items data were transformed as ln(x+1) and for weight data as ln(x+0.001), the additions to the original figure being necessary because of zero values in the samples. When calculating geometric means by taking the exponential of the mean value of ln transformed data, these additions were again subtracted.

After these analyses for influences of different variables, Simple Linear Regresssion (Genstat, 1993) was used to look for time related trends.

In all our analyses we used original data from individual birds rather than for example mean annual figures. However, for comparative reasons, trends in annual means for **incidence** of plastics were also analysed using the methods applied in monitoring oil-rates in seabirds (Camphuysen, 1995). In this method simple linear regression is applied to logit transformed values for annual mean oiling rates (oiling rate = proportion of the number of birds having oil on plumage divided by the total number of birds found).

Power analysis (Van Zutphen et al., 1998) was applied to the data in order to estimate the number of samples required to reliably detect significant changes in litter loads. The technique is based on variability in the data with reference to the mean.

$$n = 2 \{((z_{\alpha/2} - z_{\pi})(VC/100)\mu_I)) / (\mu_I - 100)\}^2$$

in which

n = sample size required for statistically significant effect

z = t - value

α = unreliability (type I error)

π = discriminating power (type II error)

μI = difference to be shown + 100 (e.g. if 10% difference μI = 110)

VC = Coefficient of variance (= standard deviation as percentage of mean)

We applied the commonly used values:

α = 5% (95% certainty that detected differences are real), and

π = 90% (90% certainty that real differences are detected)

in which case $z_{\alpha/2} - z_{\pi} = 1.960-(-1.282) = 3.242$

Variability in data from different years and different sample size was also used to estimate suitable sample sizes required to calculate a reliable value for litter ingestion at a particular point in time (a year). The combination of power analysis and 'instant' sample size gives an indication of time lapses needed to reliably detect specified levels of change.

3 Results

3.1 Data survey

A major feature in data for number of litter items, or litter mass per bird stomach is the skewed distribution of the data. Because statistical analysis requires data to be ‘normally’ distributed around the mean, logarithmic transformation is required. An example is shown in Fig. 3 for the mass of plastic loads in stomachs of Fulmars (all plastic categories combined). The original data (Fig. 3A) show a strongly skewed frequency distribution with most samples in mass classes at the lower end of the range, but with a very long ‘tail’ of data to the right. No plastics were present in 4% of the samples. Note that in Fig. 3A classes at the lower end of the x-axis refer to 0.05 gram groups, but that above value 1g they change to 1 gram, and above value 10g to 5 gram groups.

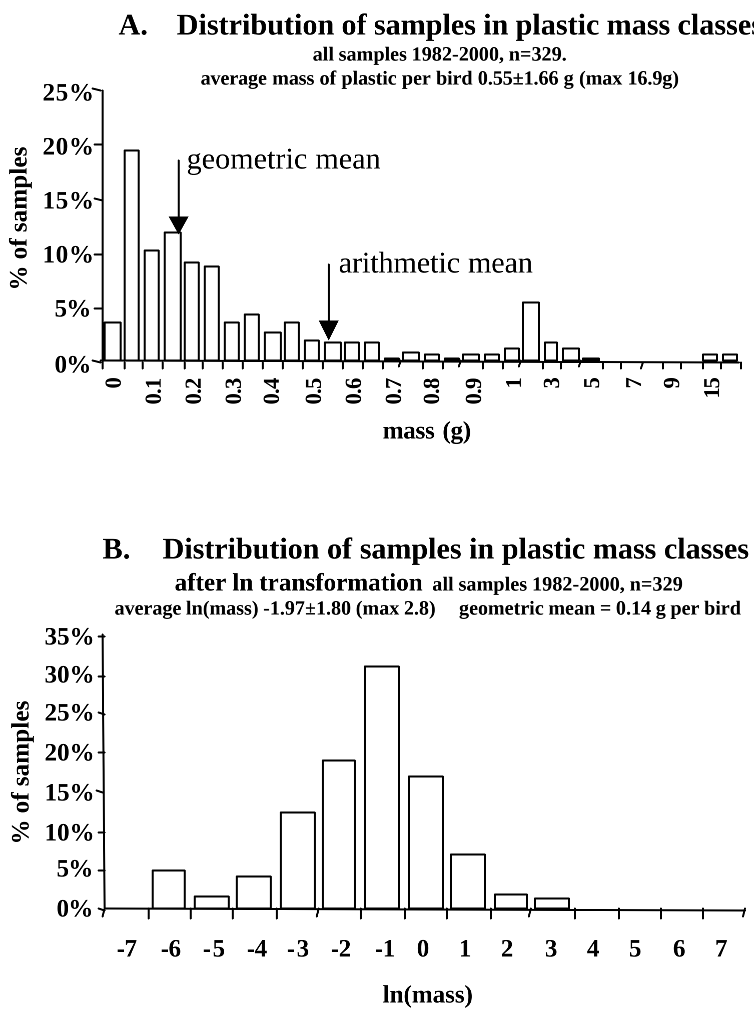


Figure 3. Frequency distributions of total plastic mass per bird to illustrate skewed data distributions (A.; see text for notes on x axis) and effects of logarithmic transformation (B.).

The relatively infrequent high mass values (up to 16.9g per bird) have a strong impact on the average value (arithmetic mean), which calculates at 0.55g plastic per bird. Fig. 3B illustrates how the original data are normalised by using the ln transformed value of plastic mass per bird. The skewness of data, and influence of higher values on the mean is illustrated by the strong difference between arithmetic mean (calculated from original masses) and geometric mean (calculated from ln transformed data). The geometric mean of 0.14g plastic per bird resembles more the median value of original data.

Because logarithmic transformations in further analyses somewhat obscure the underlying original values, Table 4 summarizes original data for the different categories of litter found in the bird stomachs. At the same time, these data give a first impression of potential trends over time, by splitting data for the 1980’s (1982-1990) and 1990’s (1991-2000). Food and Non-food categories of the 1980’s lack weight data, as items had not been collected; incidence and abundance by number were derived from original notes, but could not be checked in a manner similar to that in later samples.

Table 4. Litter in stomachs of Northern Fulmars beachwashed in the Netherlands 1982-2000. Incidence as percentage of birds; abundance by number of items and mass as arithmetic mean per bird stomach. For all birds combined and for the 1982-1990 and 1991-2000 periods separately.

	LITTER 1982 - 2000			**LITTER in the 1980's**			**LITTER in the 1990's**			
	(n=329)	arithmetic means		*(n=69)*	arithmetic means		*(n=260)*	arithmetic means		
	Incidence *(%)*	Number *(n)*	Mass *(g)*	Incidence *(%)*	Number *(n)*	Mass *(g)*	Incidence *(%)*	Number *(n)*	Mass *(g)*	
plastic litter										
PLA	96%	27.7	0.55	91%	14.6	0.34	98%	31.2	0.60	all plastic
IND	67%	4.3	0.09	77%	6.8	0.15	64%	3.6	0.08	industrial
USE	94%	23.4	0.45	84%	7.8	0.19	97%	27.6	0.52	all user
SHE	57%	3.6	0.03	42%	1.3	0.02	61%	4.2	0.04	sheet
THR	46%	1.2	0.04	41%	0.7	0.02	48%	1.3	0.04	thread
FOA	57%	4.8	0.08	30%	1.2	0.03	63%	5.8	0.09	foam
FRA	84%	10.2	0.25	67%	4.2	0.09	88%	11.7	0.29	fragment
POT	23%	3.7	0.05	23%	0.4	0.04	23%	4.6	0.06	other
rubbish other										
RUB	13%	0.4	0.13	7%	0.3	0.09	15%	0.5	0.14	all rubbish
PAP	8%	0.1	0.03	4%	0.1	0.01	9%	0.1	0.03	paper
KIT	6%	0.2	0.10	3%	0.2	0.09	7%	0.2	0.11	kitchen
RVA	2%	0.1	0.00	0%	0.0	0.00	2%	0.2	0.00	various
HOO	0%	0.0	0.00	0%	0.0	0.00	0%	0.0	0.00	hook
pollutants										
POL	43%	2.4	0.73	20%	0.2	0.28	50%	3.0	0.85	all pollutants
SLA	11%	0.3	0.01	0%	0.0	0.00	14%	0.4	0.01	slags etc
TAR	3%	0.2	0.05	0%	0.0	0.00	4%	0.2	0.06	tair/oil
CHE	24%	1.7	0.46	10%	0.1	0.18	28%	2.1	0.53	chemical
FEA	18%	0.3	0.22	10%	0.1	0.10	20%	0.3	0.25	featherlump
natural contents										
FOO	78%	6.9	0.22	62%	3.4	*	82%	7.9	0.22	food
NFO	78%	6.2	0.15	64%	3.6	*	82%	6.9	0.15	nonfood

Data in the top line of table 4 indicate an increase in ***total*** plastic litter incidence in stomachs of Northern Fulmars since the early 1980’s. Frequency increased from around 91% to 98% of birds having plastic in their stomach, and number/weight of particles per bird doubled. However, a remarkable difference exists between subcategories. In the late 1990's***, industrial*** plastics occurred less frequent than in the early 1980's (reduction from 77 to 64% of the birds with pellets; average number ± halved). User plastics however seem to have strongly increased, as had other litter categories.

3.2 Factors influencing litter loads

Before looking into details of monitoring trends over years, various factors need to be considered that could influence litter loads in birds from a particular sample. Should structural differences exist between stomach contents of particular bird groups, they need to be accounted for in a monitoring instrument or sample taking needs to be restricted to particular birds and/or seasons. In the methods section it was explained that, in addition to time trends, seasonal variation (period), sex, age, origin, condition and deathcauses should be considered as potentially relevant for litter quantities in stomachs. A relation between starving and increased litter consumption was considered as the most realistic risk that could introduce bias in time trends. Fig. 4 shows this relationship, which fortunately shows that plastic loads in stomachs are not related to gradual starving of the bird. Only the very few (3) birds in the very best body condition had lower plastics, but this has no statistical impact.

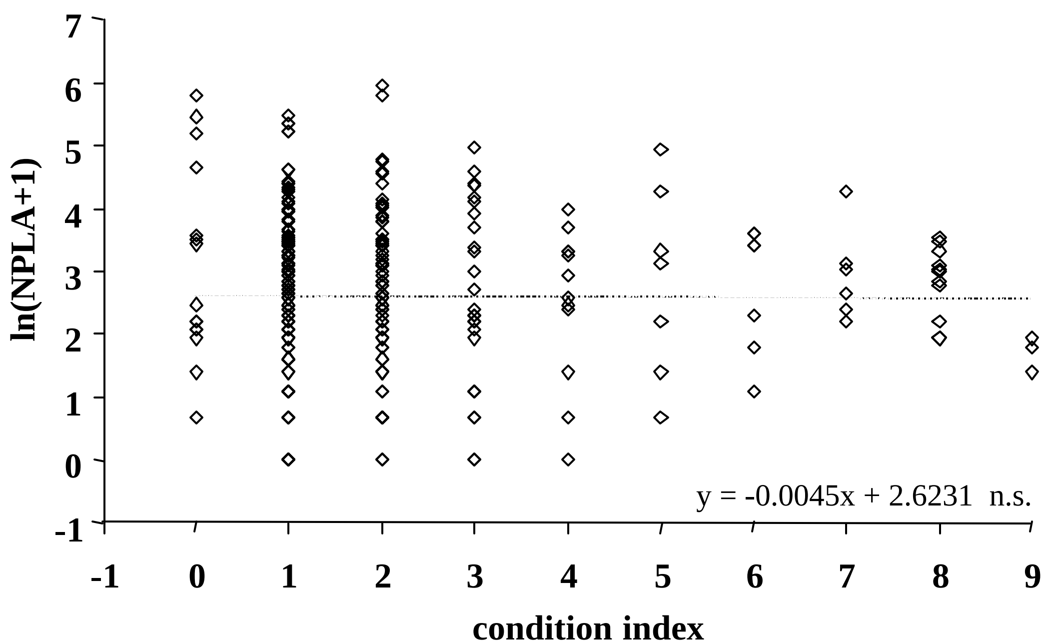


Figure 4. Relation between condition of bird (CON_IDX) and the amount of plastics in its stomach (number of plastic items, logarithmic transformed values), as a potential cause of bias in time related trends.

However, looking at simple relationships is not an optimal approach, as various factors could interact. A multivariate analysis, which considers interactions between the variables should be applied for reliable conclusions.

As a first approach in this, Canonical Correspondence Analysis (CANOCO) was applied. In this multivariate analysis all the above independent variables were compared with quantities of different litter categories (the dependent variables). CANOCO was applied on a number of different data combinations, for example using all or part of the independent variables and comparing them to either the main litter categories or different series of subcategories, by either number of items or by mass. Two examples based on litter mass are illustrated by their biplot output in Fig. 5.

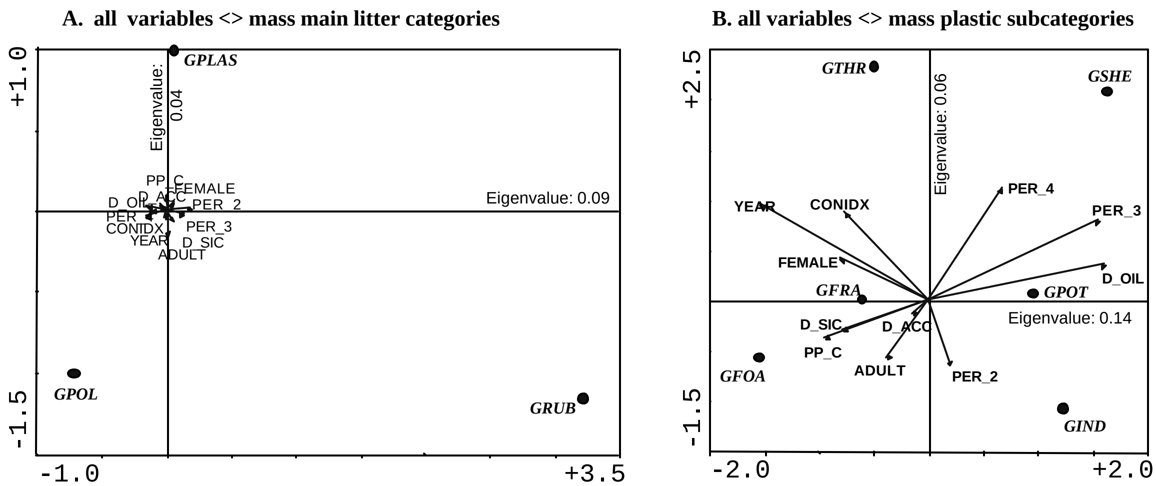


Figure 5. Examples of biplots resulting from CANOCO analyses, in this case showing relationships between mass of litter in Fulmar stomachs (dependent variables, circles with italics text) and potentially relevant independent variables (arrows, normal text). Axes are significant but have very low Eigenvalues (shown along inner axes). See methods for acronyms used. Examples of interpretation: in B. the long arrow for the variate year in the opposite direction of the position of mass of industrial plastics (GIND) suggests a negative relation between increasing years and industrial plastics; the short arrow for factor plumage colour suggests relatively weak differences between coloured birds (PP_C) and white birds in the centerpoint of the graph: the arrow direction towards mass of foamed plastics (GFOA) could suggest a weak positive relationship between arctic origin and foamed plastic.

The general outcome of analyses was that axes generally reached levels of significance, but that the ‘Eigenvalues’ of the axes were low to very low, which implies that no firm conclusions on relationships should be made. The very clustered occurrence of arrows around the center in Fig. 5A suggests absence of relationships between main litter types and the different independent variables. Fig. 5B displays a little clearer relationships, but Eigenvalues are low, and in various other analyses no single factor showed consistent relationship with litter quantities. A cautious conclusion could be that none of the variables considered has a dominant influence on litter ingestion by Fulmars.

Because no firm conclusions were possible from CANOCO analysis, evaluation of potential influences of independent variables was continued using multiple linear regression techniques. A first analysis by Generalized Linear Modelling procedures showed AGE as an influential factor on plastic loads. However, the output of the analysis contained a considerable number of warnings on ‘high standardised residuals’ and ‘high leverage’, resulting from outliers mainly occurring in immature birds. Normal Multiple Linear Regression had much less warning on outlier problems, hence the latter statistical approach was adopted.

Stepwise Multiple Linear Regressions were applied to all independent variables and the data for incidence, number and mass of total plastics, industrial plastics and user plastics (Table 5). Stepwise regression searches for the major variable influencing the data, and then attempts adding and dropping further ones to test for their additional influence. This procedure is repeated a number of times before a final model is produced in which the major variable is given and tested first, and then further variables in sequence of their ***additional*** effect and significance.

Table 5. Summary of output of stepwise multiple regressions modelling all variables (year, age, sex, origin, condition, deathcause, and period) on ingested plastics (PLA= all; IND=industrial; USE=user; prefixes P=presence, N=number, G=mass). Based on all samples 1982-2000 for which all variables were known: n=305). In case of factors, Genstat gives differences with the first factor level (Period Per_1 Jan-Mar; Age Adult; sex Female; deathcause ACCidental; origin PP_Coloured). Listed are those variables included in the final model, with details of slope, standard error and significance only included where p<0.05.

PLASTIC CONTENTS BY INCIDENCE (presence/absence)

PPLA (Fprob 0.039*)

	nr	est.	s.e	t prob	
PER_2	1	+			
PER_3	2	-0.0700	0.0341	**0.041**	*
PER_4	3	+			
AGE IM	4	0.0546	0.0254	**0.032**	*
AGE JU	5	+			
YEAR	6	+			

PIND (Fprob .001 **)

	nr	est.	s.e	t prob	
AGE IM	1	0.5605	0.0374	**<0.001**	***
AGE JU	2	0.1462	0.0658	**0.027**	*

PUSE (Fprob .001 **)

	nr	est.	s.e	t prob	
YEAR	1	0.0086	0.0024	**<.001**	***
SEX M	2	-0.0558	0.0259	**0.032**	*
DEATH2 oil	3	+			
DEATH2 sic	4	+			
DEATH2 sta	5	+			

PLASTIC CONTENTS by NUMBER OF ITEMS (ln transformed values)

lnNPLA (Fprob .002 **)

	nr	est.	s.e	t prob	
YEAR	1	0.0338	0.0131	**0.010**	*
AGE IM	2	0.3890	0.1790	**0.031**	*
AGE JU	3	+			
DEATH2 oil	4	+			
DEATH2 sic	5	+			
DEATH2 sta	6	+			

lnNIND (Fprob <0.001 ***)

	nr	est.	s.e	t prob	
YEAR	1	-0.0330	0.0107	**0.002**	**
AGE IM	2	0.2930	0.1460	**0.045**	*
AGE JU	3	+			
DEATH2 oil	4	+			
DEATH2 sic	5	+			
DEATH2 sta	6	+			

lnNUSE (Fprob <0.001 ***)

	nr	est.	s.e	t prob	
YEAR	1	0.0639	0.0128	**<0.001**	***
PP W	2	-0.0598	0.2410	**0.014**	*
DEATH2 oil	3	+			
DEATH2 sic	4	+			
DEATH2 sta	5	+			
SEX M	6	+			

PLASTIC CONTENTS by MASS IN STOMACH (ln transformed values)

lnGPLA (Fprob <0.001 ***)

	nr	est.	s.e	t prob	
AGE IM	1	0.8020	0.2540	**0.002**	**
AGE JU	2	+			

lnGIND (Fprob < 0.001 ***)

	nr	est.	s.e	t prob	
AGE IM	1	0.8510	0.3260	**0.010**	*
AGE JU	2	+			
YEAR	3	-0.557	0.0239	**0.020**	*
DEATH2 oil	4	+			
DEATH2 sic	5	+			
DEATH2 sta	6	+			

lnGUSE (Fprob 0.001 ***)

	nr	est.	s.e	t prob	
YEAR	1	0.0600	0.0202	**0.003**	**
DEATH2 oil	2	+			
DEATH2 sic	3	+			
DEATH2 sta	4	+			
PP W	5	+			
SEX M	6	+			

Stepwise analysis of plastic ingestion confirms canonical analyses in that no single factor seems to dominate the ingestion of litter. An influence of the variable YEAR is regularly but not consistently observed (negatively related to industrial plastic; positively to user plastic). Secondly, immature AGE regularly appears as an important factor correlated to elevated levels of plastics in stomachs. Other factors are occasionally included in final models, but rarely to a significant level. Such inconsistent appearance and significance in multiple tests may be coincidental.

So, AGE apparently has an influence on plastic quantities in stomachs. Immatures apparently are the strongest different from adults, as they are ranked as first and significant in stepwise regressions, without significant *additional* effect from the inclusion of the factor level juvenile. This implies that juveniles and immatures differ from adults in a similar way, which may be seen confirmed in Table 6. Considering the similarity of plastic loads between juveniles and immatures, they have been combined to the age category 'Non Adult (NA)' in further analyses as opposed to 'Adults (AD)'. Non-Adults tend to have higher plastic loads in their stomachs than adults.

Table 6. Incidence and abundance of plastics in different age groups

		mean Incidence	mean number of plastic items per stomach		mean mass (g) of plastics per stomach		
	n	PPLA ± sd	NPLA ± sd	**geometric**	GPLA	± sd	**geometric**
Adult	169	0.95 ± 0.05	30.0 ± 60.0	**10.3**	0.44	± 1.36	**0.10**
Immature	78	0.99 ± 0.01	25.7 ± 26.4	**16.1**	0.87	± 2.65	**0.21**
Juvenile	80	0.96 ± 0.04	25.0 ± 30.1	**15.0**	0.47	± 0.70	**0.17**

A correlation between age (or any of the other factors) and plastic quantities in stomachs only becomes problematical for monitoring trends over time when strong temporal changes in age proportions would occur. Strong but random age variations would reduce detectability of time related trends. If such changes are directional, conclusions on trends could be wrong.

Changes in age composition in annual samples are given in Table 7. Considerable interannual variation exists, but there is no evidence for directional change over longer periods of time. Although no effects of other variables has been demonstrated, all have been included in Table 7 to show interannual variability in sample composition.

Table 7. Interannual variations in characteristics of birds in samples

		PROPORTIONS AGE	SEX	ORIGIN	DEATHCAUSE				average	average
YEAR	***n***	**adult**	**male**	**white**	**acc**	**oil**	**sic**	**sta**	**month**	**condition**
1982	*3*	0%	33%	67%	33%	0%	0%	67%	11.0	3.0
1983	***19***	**37%**	**37%**	**89%**	**11%**	**37%**	**16%**	**37%**	**5.1**	**2.1**
1984	***20***	**40%**	**40%**	**75%**	**0%**	**45%**	**20%**	**30%**	**2.6**	**2.1**
1985	*3*	33%	33%	33%	33%	67%	0%	0%	9.0	3.7
1986	*4*	25%	50%	100%	0%	0%	0%	100%	7.3	2.0
1987	***15***	**67%**	**60%**	**100%**	**7%**	**0%**	**13%**	**73%**	**7.4**	**2.1**
1988	*1*	0%	0%	100%	0%	0%	0%	100%	3.0	2.0
1989	*4*	50%	50%	100%	25%	25%	0%	50%	7.5	2.5
1991	*1*	0%	0%	0%	0%	0%	0%	100%	5.0	0.0
1995	*2*	50%	100%	100%	0%	0%	0%	100%	8.5	1.0
1996	*8*	63%	75%	88%	0%	38%	25%	38%	8.4	2.3
1997	***31***	**16%**	**55%**	**97%**	**6%**	**29%**	**3%**	**61%**	**8.0**	**1.7**
1998	***73***	**47%**	**45%**	**88%**	**8%**	**47%**	**18%**	**27%**	**7.1**	**3.4**
1999	***107***	**68%**	**31%**	**95%**	**6%**	**22%**	**9%**	**63%**	**2.1**	**1.3**
2000	***38***	**58%**	**37%**	**87%**	**21%**	**26%**	**21%**	**32%**	**2.7**	**2.3**
total	***329***	***51%***	***41%***	***90%***	***9%***	***30%***	***13%***	***48%***	***4.7***	***2.1***

3.3 Time trends

In the Netherlands, beachwashed birds are used to monitor oil pollution: the system is based on the proportion of birds that have oil in their plumage ('oil-rate'): logit-transformed values of mean oil-rates for subsequent winterseasons are tested for trends over time by Simple Linear Regression (Camphuysen, 1995). Long time-series of data have shown slow but significant decreases in oil-rates over the past few decades.

A data-type matching that of oil-rate is the ***incidence*** of litter such as plastic. Incidence is the number of birds with one or more pieces of plastic, divided by the total number of birds in the sample. Annual means for incidence of plastic could thus be named 'Plastic-rate'. A first evaluation of trends could thus be conducted using the methods from oil-monitoring on beached birds. Analyses are focused on plastic litter in stomachs. Results are shown in Fig. 6. No significant change in incidence of all plastics is present. However, when data are split into industrial and user plastics, it can be seen that underneath there are two opposite trends, each significant: increased incidence of user plastics and decreased incidence of industrial plastics (Fig. 6A.). All subcategories of user plastics show increased incidence, mostly significant (Fig. 6B).

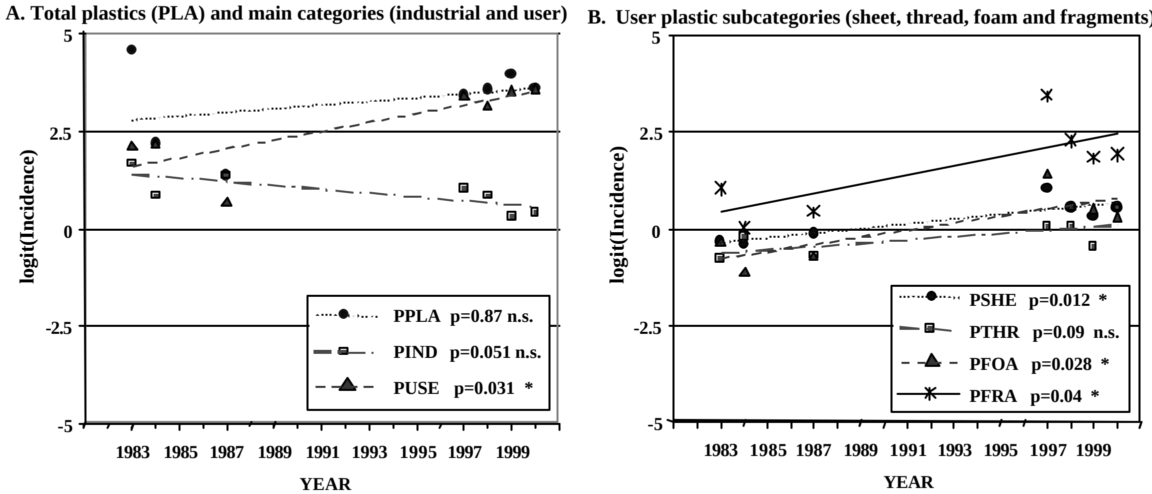


Figure 6. Trends in annual mean 'plastic-rates' (Incidence). The y-axis represents logit transformed values of mean annual incidence of plastics for years in which at least 15 samples were available. For reference to original values: logit figures approaching +5 represent near 100% incidence; 0 represents 50% incidence and data near –5 would represent near 0% incidence. See Table 4 for incidence levels in the 1980's and 1990's.

Annual means can only be determined at a minimum sample size, which was arbitrarily set at 15 birds for the analysis in Fig. 6. As will be discussed in chapter 3.4 such a number of samples is probably too low. However, already this criterion was met by only 7 of our study years. If it would be necessary to have larger samples, or to explore for example the influence of age the number of available annual samples would soon be minimized. In the oil monitoring scheme, sufficiently large samples are usually not a problem, but in Fulmar stomach analyses it is, firstly because not each year sufficient corpses become available, and secondly because dissection and stomach analysis of a single bird are labour intensive and thus expensive.

Therefore, for litter monitoring in Fulmar stomachs, it would be beneficial to use a system in which original data for each individual bird are used in trend analyses. By doing so, also years of small samples are incorporated in trend analyses. Furthermore, individual variability is not obscured and can be explored in the final analyis.

Therefore linear regressions were performed for litter against year, using individual data from all stomachs over the full period 1982-2000 (329 birds). Regressions were calculated for all different litter categories and were repeated for data by incidence, number of items and mass of items.

Results have been listed in Table 8. An example of the data has been shown in Fig. 7 for the number of items in the 'All plastics' category, with additional data for its two major subcategories of industrial and user plastics. The figure illustrates that the overall number of plastic items per bird stomach has increased over the study period at a moderately significant level. Underlying however, are two highly significant but opposite trends of increasing numbers of user plastics and decreasing numbers industrial plastics. Data in table 8 show that all subcategories of user plastics contribute to the increase in the user category, although significance levels differ somewhat depending on whether incidence, number of items or mass of items is used.

Rubbish subcategories do not show significant trends over the period 1982-2000, but all slopes are positive, suggesting there could have been weak increases in their occurrence in Fulmar stomachs.

Pollutants increased significantly over the study period, mainly due to an increase in the chemical substances which is the major category in terms of incidence and weight.

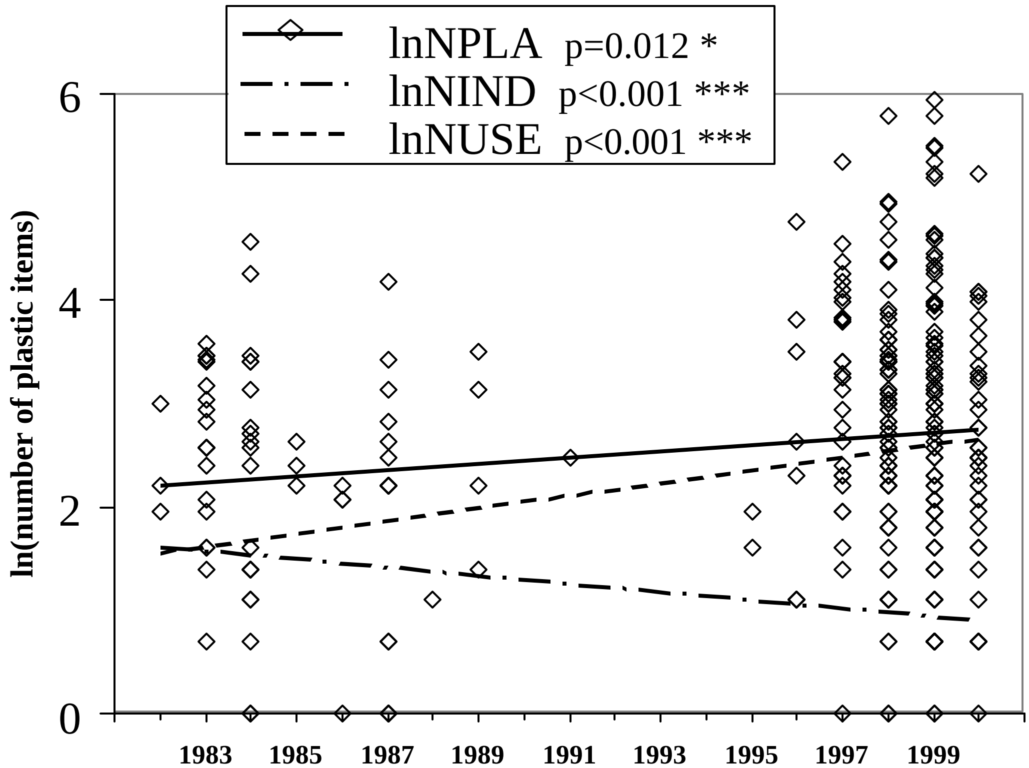


Figure 7 Trends over time in number of plastic items in Fulmar stomachs over the period 1982-2000 based on ln-transformed values for all individual stomachs (all birds n=329). Shown are data for all plastic items (lnNPLA: datapoints + solid regression line) and for the subcategories of industrial (lnNIND) and user (lnNUSE) plastics (regression lines only).

Table 8 Results from regressions for litter in individual bird stomachs against year (all birds 1982-2000: n=329).
*Regressions performed for all litter (sub)categories and for data by incidence, number of items, and mass of litter. Negative values for the estimate (slope) and t–value indicate decrease over the years. Regression line is described by y=Constant+Estimate*x.*

1982-2000 Time trends in INCIDENCE of different litter categories (n=329)

Category	CONST	est	se	t	p
PPLA	-6.7	0.0038	0.0018	2.13	0.034 *
PIND	21.4	-0.0104	0.0045	-2.30	0.022 *
PUSE	-16.0	0.0085	0.0022	3.85	<0.001 ***
PSHE	-24.6	0.0126	0.0047	2.67	0.008 **
PTHR	-9.4	0.0049	0.0048	.1.02	0.307
PFOA	-44.1	0.0224	0.0046	4.84	<0.001 ***
PFRA	-29.3	0.0151	0.0035	4.38	<0.001 ***
PPOT	2.0	-0.0009	0.0041	-0.02	0.830
PRUB	-7.5	0.0038	0.0033	1.17	0.243
PPAP	-2.9	0.0015	0.0026	0.58	0.563
PKIT	-6.0	0.0031	0.0023	1.33	0.186
PRVA	-3.8	0.0019	0.0013	1.47	0.144
PHOO	-0.4	0.0002	0.0005	0.42	0.676
PPOL	-40.9	0.0207	0.0047	4.46	<0.001 ***
PSLA	-20.7	0.0104	0.0030	3.48	<0.001 ***
PTAR	-4.8	0.0024	0.0017	1.46	0.146
PCHE	-26.5	0.0134	0.0041	3.29	0.001 ***
PFEA	-12.5	0.0063	0.0037	1.72	0.087

1982-2000 Time trends in NUMBER of items in litter categories (n=329)

Category	CONST	est	se	t	p
lnNPLA	-55.9	0.0293	0.0116	2.52	0.012 *
lnNIND	79.7	-0.0394	0.0094	-4.18	<0.001 ***
lnNUSE	-120.0	0.0613	0.0116	5.31	<0.001 ***
lnNSHE	-58.0	0.0295	0.0093	3.19	0.002 *
lnNTHR	-20.5	0.0105	0.0062	1.70	0.091
lnNFOA	-92.8	0.0470	0.0103	4.57	<0.001 ***
lnNFRA	-101.8	0.0519	0.0109	4.75	<0.001 ***
lnNPOT	-24.0	0.0122	0.0085	1.44	0.151
lnNRUB	-10.3	0.0053	0.0044	1.20	0.232
lnNPAP	-2.0	0.0010	0.0026	0.40	0.693
lnNKIT	-5.9	0.0030	0.0029	1.05	0.293
lnNRVA	-5.5	0.0028	0.0023	1.21	0.228
lnNHOO	-0.3	0.0002	0.0004	0.42	0.676
lnNPOL	-84.6	0.0427	0.0082	5.24	<0.001 ***
lnNSLA	-21.7	0.0110	0.0036	3.06	0.002 **
lnNTAR	-6.7	0.0034	0.0027	1.27	0.205
lnNCHE	-58.8	0.0296	0.0071	3.84	<0.001 ***
lnNFEA	-15.7	0.0079	0.0035	2.28	0.023 *

1982-2000 Time trends in litter mass for different litter categories (n=329)

Category	CONST	est	se	t	p
lnGPLA	-24.8	0.0114	0.0174	0.66	0.512
lnGIND	149.2	-0.0768	0.0211	-3.63	<0.001 ***
lnGUSE	-128.0	0.0629	0.0183	3.44	<0.001 ***
lnGSHE	-26.0	0.0103	0.0164	0.63	0.530
lnGTHR	-34.3	0.0143	0.0167	0.86	0.391
lnGFOA	-137.1	0.0660	0.0188	3.51	<0.001 ***
lnGFRA	-135.4	0.0662	0.0197	3.36	<0.001 ***
lnGPOT	-2.1	-0.0020	0.0183	-0.11	0.914
lnGRUB	-27.3	0.0105	0.0166	0.63	0.528
lnGPAP	-7.0	0.0002	0.0106	0.01	0.988
lnGKIT	-29.4	0.0114	0.0134	0.86	0.392
lnGRVA	-19.7	0.0064	0.0053	1.21	0.226
lnGHOO	-9.7	0.0014	0.0033	0.42	0.676
lnGPOL	-160.8	0.0782	0.0288	2.71	0.007 **
lnGSLA	-57.6	0.0255	0.0090	2.85	0.005 **
lnGTAR	-27.5	0.0104	0.0092	1.13	0.259
lnGCHE	-101.4	0.0479	0.0232	2.07	0.039 *
lnGFEA	-68.7	0.0315	0.0235	1.34	0.180

In section 3.2 it was concluded that among the potential variables, especially the age of birds in samples could be a confounding factor. Although age composition of samples over subsequent years (Table 7) do not suggest a considerable risk in this respect, its influence on the time related trends observed above was checked by means of separate analysis for adults and non-adults. Figure 8 is an example for the effects of age by showing time trends for plastic loads in our samples for all ages combined and for the subgroups of adults and non-adults. As expected from ealier analyses (Table 6) regression lines for adults are lower than those for the non-adults, but the slopes of the regression lines are sufficiently similar to conclude that age composition, at least in the current data set is not a confounding factor with respect to time related trends. Evidently, significance of regressions is lower because applied on smaller subsets of data from age specific groups.

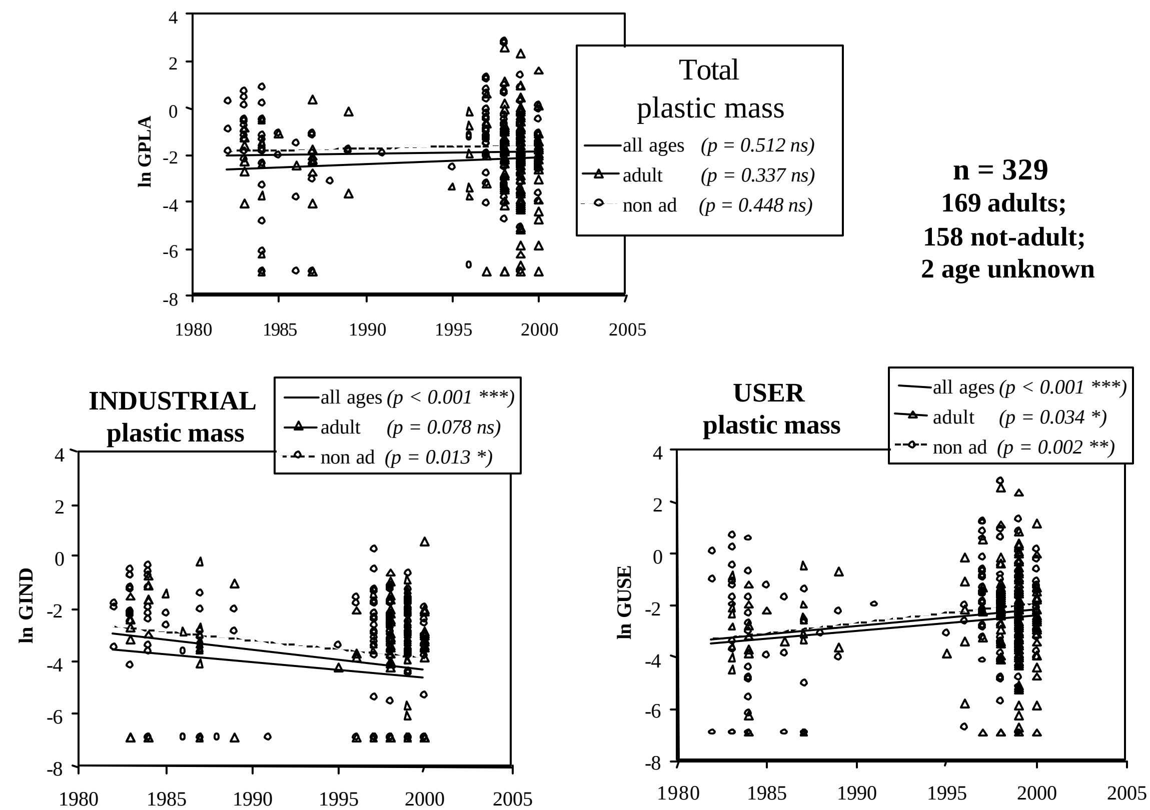


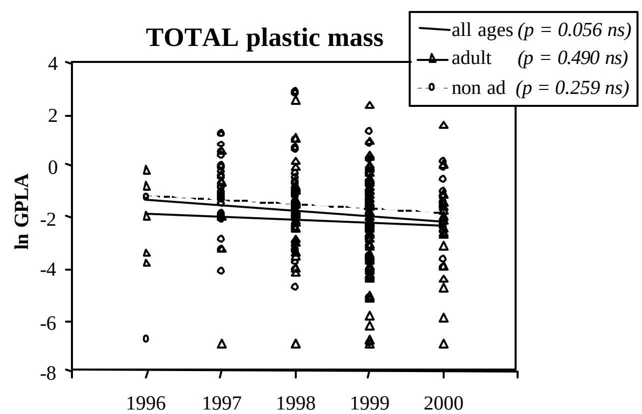
Figure 8. Influence of factor AGE on time trends in loads of total, industrial and user plastics.

In the above we have been looking for long-term trends since the early 1980's. Because more recent trends could be different, the dataset was restricted to samples from 1996 onwards (257 birds in the period 1996-2000). Results are given in Table 9 (mass data only) and illustrated in Fig. 9, a repetition of Fig. 8 for the restricted recent data set. Few trends were significant: the decrease in industrial plastics continues, but no clear trends exist in user plastics. The negative sign of many of the trends could indicate that we are 'over the top' in litter ingestion, but no firm conclusions are possible, and there could be some interference from variable proportions of age groups in recent years.

Table 9. Results from regressions for litter in individual bird stomachs against year for recent years.

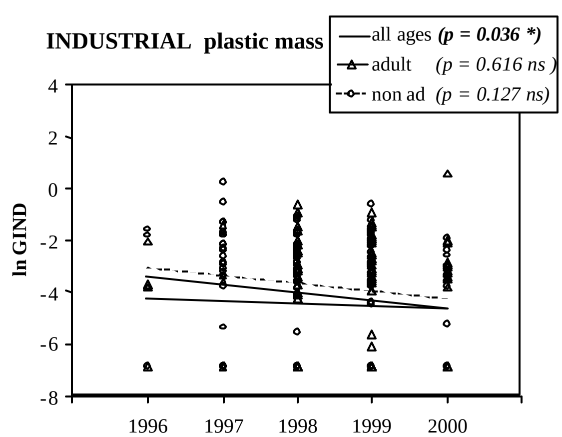
1996-2000 Time trends in litter mass for different categories (n=257)

Category	CONST	est	s.e.	t	p
lnGPLA	419.0	-0.2110	0.1100	-1.92	0.056
lnGIND	579.0	-0.2920	0.1380	-2.11	0.036 *
lnGUSE	326.0	-164.000	0.1550	-1.43	0.153
lnGSHE	400.0	-0.2030	0.1070	-1.90	0.059
lnGTHR	61.0	-0.0330	0.1120	-0.03	0.760
lnGFOA	132.0	-0.0690	0.1280	-0.54	0.591
lnGFRA	562.0	-0.2830	0.1250	-2.26	0.025 *
lnGPOT	211.0	-0.1090	0.1220	-0.89	0.374
lnGRUB	-178.0	0.0860	0.1100	0.78	0.435
lnGPAP	40.0	-0.0231	0.0681	-0.34	0.735
lnGKIT	-281.0	0.1371	0.0892	1.54	0.126
lnGRVA	-83.8	0.0385	0.0394	0.98	0.329
lnGHOO	19.6	-0.0133	0.0248	-0.54	0.593
lnGPOL	477.0	-0.2410	0.1930	-1.24	0.215
lnGSLA	-27.0	0.0105	0.0666	0.16	0.875
lnGTAR	142.0	-0.0745	0.0682	-1.09	0.276
lnGCHE	85.0	-0.0450	0.1600	-0.28	0.776
lnGFEA	339.0	-0.1720	0.1600	-1.08	0.281



SHORT TERM
1996 - 2000

n = 257
139 adult
117 not-adult
1 age unknown



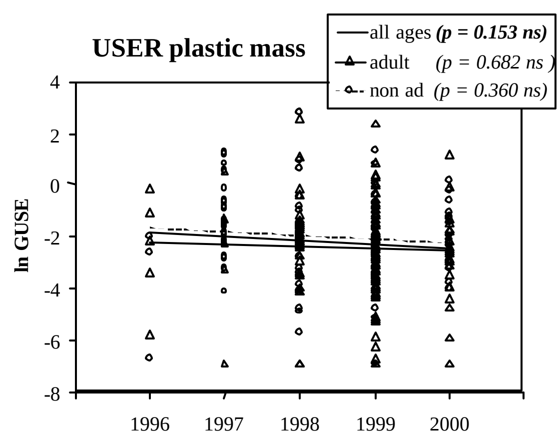


Figure 9 Short-term trends (1996-2000) trends and age influence in loads of plastics.

3.4 Power analysis and sample sizes

For the interpretation of stomach contents of Fulmars as a monitoring tool, the fact that significant regressions are found for some of the potential indicators is not sufficient. Especially when looking at shorter term changes (Table 9 and Fig. 9) one would like to have a better understanding of reliability in interpretation of data. How certain can one be that detected differences are real (Type I Error). Also in cases where no significant regression is found, one wants to know if it can be reliably concluded that indeed no trend is present (in other words, how certain can we be that real differences are indeed detected – Type II Error). Two questions are important here: how many samples are needed to obtain a reliable dataset for a particular point in time ('a year'), and secondly how many samples are needed before one may reliably conclude that change or no change is occurring over time.

The first question may be answered by looking at the annual samples available, which vary in size from one to 107 birds. By looking at variance levels in these annual samples one can assess at which sample size the sample variance becomes 'stable' i.e. the sample size at which one may assume that increased sample size will not really further improve values for averages and standard deviations in litter contents in birds of a particular year. We have chosen to do this analysis on 'real' annual samples, rather than on a series of randomly selected samples of different size. Random samples would only include variability related to birds themselves, and not the variability related to unknown external factors. The analysis of annual samples is shown in Fig. 10 for variances in incidence, number of items and mass of items of overall plastics and its main subcategories of user plastics (ln transformed values). The graphs clearly illustrate very sharp fluctuations in samples smaller than ± 20 birds, indicating that there is a high risk that results from such samples will differ from population means. Variances seem to stabilize between sample sizes of 20 to 40 stomachs. Above ± 40 birds variances stabilize at the levels of the pooled variances of all our 329 samples combined. This means that at a particular point in time (a year) reliable data on plastic ingestion levels are obtained with samples of around 40 birds. At the same time this means that little additional information is gained by analyzing much more than about 40 birds in a particular year. Similar variance patterns were observed in the rubbish and pollutant categories also suggesting that at a particular point in time sample size should be about 40 birds to obtain reliable information.

The second question was how many samples are needed before one may reliably conclude that change or no change is occurring over time. To answer this, Power-analyses were applied to the data for plastics. The analysis uses variances in relation to the mean to calculate sample sizes required for reliable conclusions on change or no change between samples. Results are shown in Figure 11, again for the main plastic categories and different units of measurement. No straightforward conclusions are possible here. When looking at **incidence**, to reliably detect a 25% change from one sample to the other, one would need only 20 to 30 birds for user plastics and overall plastics. However, this is only caused by the very high incidence levels in our current dataset (94% see Table 4). The effects of lower incidences can be seen from the curve for industrial plastics (overall incidence 67%) requiring ± 250 birds in the sample to detect the same level of change. This strong difference persists when considering changes in the **number** of plastic items (roughly 150 birds for a 25% change in user plastics and over 400 for industrial plastics). A remarkable change occurs when looking at plastic **weights**. In industrial plastics, uniform sizes of pellets limit the required sample size (± 150 birds for 25% change), but in user plastic the huge variability in object size lead to higher numbers required in the sample (over 300 birds). It should be noted that in analyses on the basis of weight, the underlying rates of incidence have little impact, which is of importance for future situations which should be suitable to deal with decreasing incidences of litter in bird stomachs.

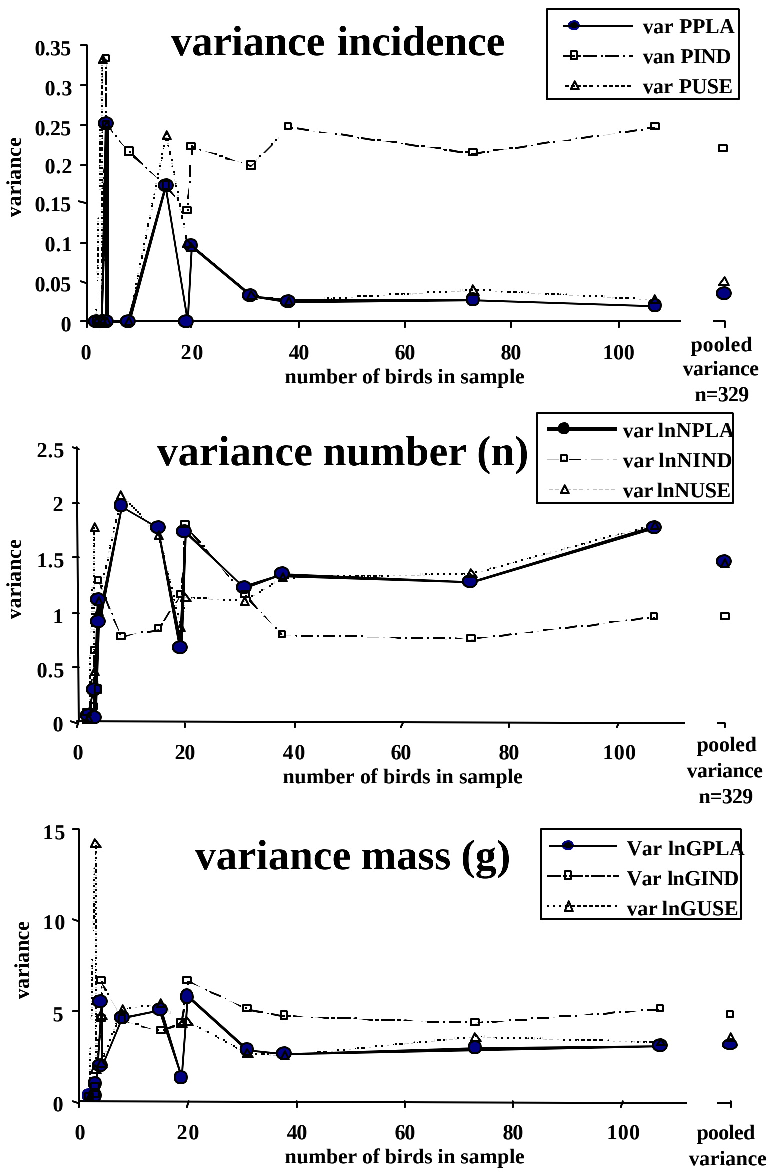


Figure 10. Variance of plastic litter contents in stomachs of Fulmars for differently sized annual samples for the three different units of measurement. At the far right end of each graph the pooled variance for our total dataset of 329 birds from the period 1982-2000 is shown.

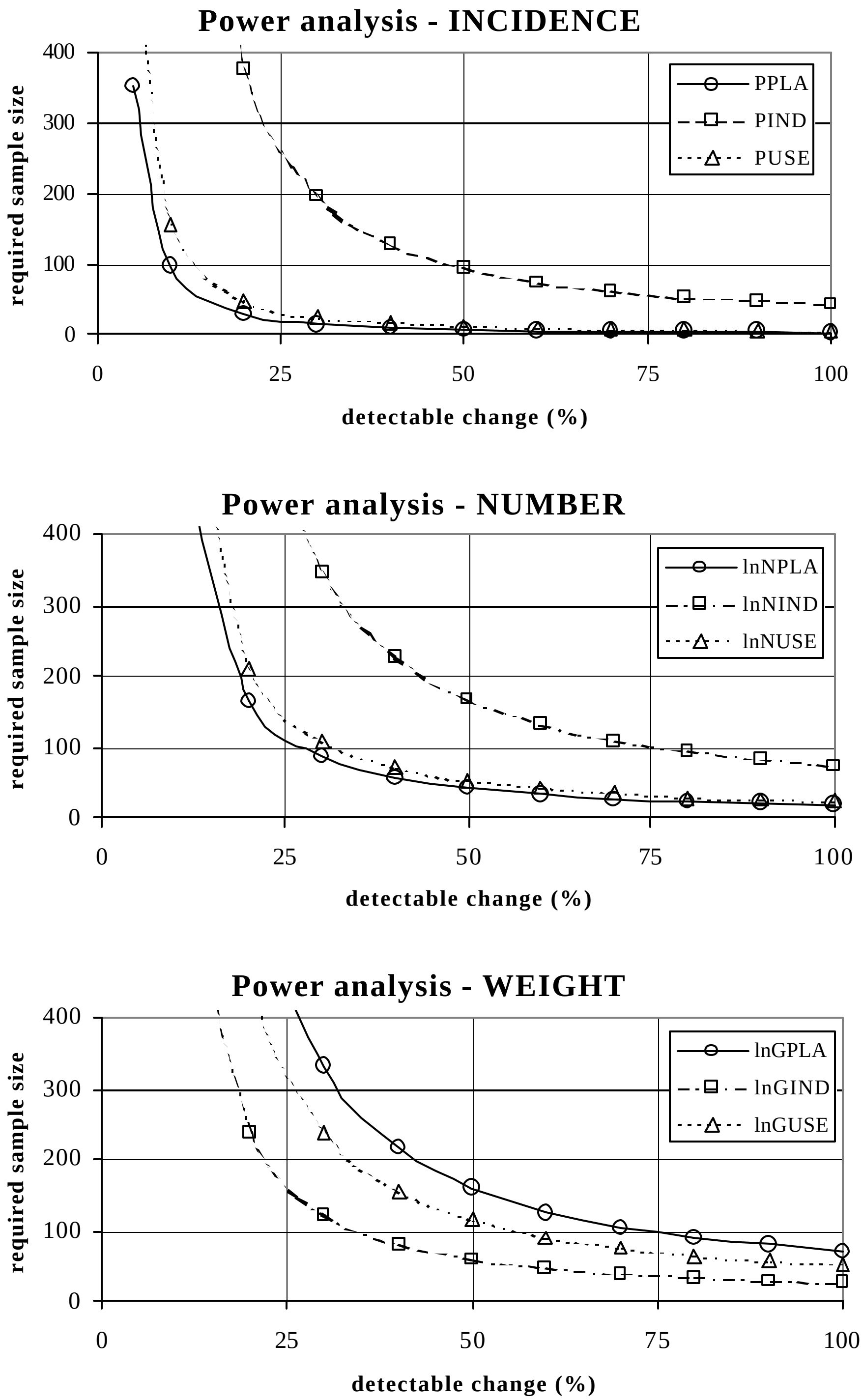


Figure 11. Power analysis to determine sample sizes needed for reliable conclusions on changes in plastic occurrence (overall, industrial and user) in stomachs of Fulmars by different units of measurement.

For a monitoring system aimed at detecting changes over time, both previous issues are relevant. The combination of suitable sample size at a particular point in time (Fig. 10) and bird numbers required to reliably detect change (Fig. 11) determine the time frames over which we can expect that a monitoring system can produce reliable conclusions on whether or not changes are present and in which direction they go. Suitable annual sample size is around 40 birds, and is fairly independent from type of litter or unit of measurement. Generalizing the information from power-analyses samples of between 100 and 400 birds may be needed for reliable conclusions on levels of change in the order of 25%. In units of litter weight per stomach, the required number of samples for plastics ranges from ± 150 for industrial plastics to ± 300 for user plastics. Because it is of little use to sample much more than about 40 birds per year, this implies that one would need to sample such a number annually for about 4 to 8 years (resp. for industrial and user plastic). This suggests for example that the recent short term decrease observed in industrial plastics (257 samples over 1996-2000, $p<0.05$; Fig. 9 and Table 9) is realistic, a conclusion independently supported by the fact that there is also a long term decrease. A similarly significant decrease in user-fragments in the same period (Table 9) should be dealt with cautiously, as power analysis suggests that more samples would be required. From any perspective, it is clear that a number of consecutive annual samples will be needed in a monitoring system. No changes will be detectable in between two consecutive years, because changes would need to be well over 75% to be detected in two consecutive samples of about 40 birds each, and such rates of change are not to be expected.

4 Discussion and conclusions

4.1 The Fulmar as a monitoring tool for marine litter

Northern Fulmars appear to be very indiscriminate feeders. Their stomachs contain an extremely large variety of substances, sizes, shapes and colours of non-food items, which tell us that these birds will consume just about anything that floats on the surface of the sea. The exact mechanism through which this occurs, is obscure. Partially, ingestion may be secondary, litter being ingested earlier by their prey such as fish. Other items however, must have been ingested by the Fulmars directly, maybe because litter was floating in between attractive edible materials. As intentional selection of indigestible litter is unlikely, the rate of litter ingestion is thus probably dictated by the frequency of encounters with litter during normal foraging.
Some ingested materials may be easily digested or broken down whereas others are totally indigestable and very resistant to wear. This means that relative quantities of different litter types found in bird stomachs do not necessarily reflect proportions of these litter types in the marine environment. However, within a particular category of litter, changes over time in stomachs reflect accidental encounter rates at sea and are thus proportional to change in quantities of such litter at sea. For example, suspected chemical material (paraffine-like lumps and softer suspect substances) showed 28% incidence and mean mass of 0.53 g per bird (Table 4) during the 1990's: since these materials are likely to be rapidly processed in the bird stomach, the figures indicate much higher ingestion rates of these substances than of plastic (98% incidence; 0.6 g per bird). However, within each category, a change in occurrence in stomachs will be proportional to a change in its abundance at sea.

Litter ingestion by Fulmars proved not to be affected by a number of variables that might have been expected to affect foraging characteristics of birds, and thus to confound results in a monitoring system. Especially condition of birds was considered a potential risk, as it seems not illogical to expect that birds that gradually starve to death will eat anything at hand, including litter. However, stomach contents of totally emaciated birds were not different from those that had suffered a more or less instantenous death in good body condition. This strengthens the idea that litter ingestion is governed by accidental encounter rates, and is thus proportional to litter quantities at sea.
The only factor found to have some effect on the levels of ingested litter was age, in which adult birds contained somewhat less litter than immature and juvenile birds. This phenomenon has been explained by the fact that adults empty part of their stomachs during chick-feeding and nest-defense (Ryan, 1988) whereas younger birds would accumulate harder litter items until a balance is reached between ingestion and egestion or wear. Adults in our samples from the breeding period indeed show lower plastic quantities (geometric mean 0.02 g per bird compared to 0.09 g adult average), but the sample size from this period is 9 adult birds only and does not allow conclusions. However, lower plastic levels seem present in adult birds throughout the year, and it seems unlikely that this could be caused by stomach emptying during a

single short period of the year. Ryan (1988) suggests different feeding niches for adults in addition to the stomach emptying when feeding chicks. Whatever the background, there is a difference between adults and younger birds. This difference does have some effect on the absolute levels of plastics in bird stomachs, but it was shown that trends over time (slope of regressions) for different age groups were very similar and do not confound a monitoring system based on samples from all ages (Figs. 8 and 9).

Clear changes in ingested litter were demonstrated between the early to mid 1980's and late 1990's (Chapter 3.3). Industrial plastics were found to be reduced by about 50% whereas other types of plastic litter (user plastics) showed significant increases. Increases in non-plastic rubbish could not be shown to be significant, but pollutants were. Presence of suspected chemical substances in about one of every three stomachs in the late 1990's is of considerable concern.
An explanation for opposite trends in industrial plastics and other litter could be that during the late 1970's and 1980's considerable attention has been given to worldwide distribution of large quantities of plastic pellets and their ingestion by marine wildlife. Industrial pellets are a pure raw material with economic value. Measures to reduce losses at shore-based factories and during transport are not too complicated and economically beneficial. In most other litter categories one is facing a waste problem in which economic stimuli for reductions have been lacking.

The availability of a dataset on Fulmars from the early to middle 1980's creates the opportunity to evaluate effectiveness of subsequent policy initiatives to reduce the marine litter problem. Major sources of marine litter are disposal and loss of household garbage and operational waste from ships (commercial and fisheries). As a consequence, major policy initiatives to reduce marine litter have focused on shipping. In 1991, the North Sea was declared a Special Area under MARPOL Annex V. Lack of improvement has stimulated the European Union to issue the Directive on Port reception facilities, which has to be implemented in early 2003. Continuation of Fulmar stomach monitoring will provide not only directly comparative information on litter levels prior and after the North Sea being a Special Area under MARPOL Annex V, but also on the additional effect of the EU Directive.

Monitoring of marine litter by Fulmar stomach contents has considerable additional value to other potential monitoring systems such as by surveys of coastal litter or litter quantities received by port reception facilities:

- Stomach contents of Fulmars reflect levels of marine litter in the ***offshore*** environment of the North Sea,
- The stomach content of each single Fulmar ***integrates*** the actual litter situation at sea over a number of weeks (rather than being an instantaneous spot measurement with risk of sampling errors)
- litter ingestion by Fulmars monitors abundance of ***small litter***, measuring and creating awareness of the fact that environmental problems of litter do not stop when broken down to sizes below the range of perception in other monitoring systems

- ingestion levels by Fulmars are reprentative for similar problems faced by a very wide range of marine living organisms and may be considered to reflect ***ecosystem effects*** of marine littering.
- Directly comparable data are available ***from the early 1980's*** onwards.

The results from this pilot study thus justify the conclusion that stomach contents of beachwashed Northern Fulmars can be a useful monitoring tool for time trends in marine litter abundance and indirectly for the ecological impact of such litter on a wide variety of marine life. A monitoring system based on Fulmar stomach contents covers a range of issues that can not be dealt with by other monitoring programs.

4.2 Choice of units of measurement

Throughout this report, comparative information for different litter categories in Fulmar stomachs has been provided by means of figures for ***incidence*** (proportion of birds affected), ***number of items*** and ***mass.*** Also, information has been dealt with as mean figures for specific periods (years or decades) and as individual measurements throughout. In this pilot study it was considered necessary to provide this variety of datapresentations in order to make a good choice for future work.

In 'beached bird surveys', oil pollution is monitored by the so-called 'oil-rate', that is the proportion of birds in an annual sample that has oil in the plumage. The amount of oil on individual birds is not relevant in this system, similar to the use of incidence for a particular plastic category in our stomachs. In beached bird surveys, the oil approach is logical, because it allows an easily recordable figure that can be obtained from a very large number of samples.

In analyses for trends in marine litter, it would be possible to conform to the 'oil-rate' method using incidence of litter in annual samples (Fig. 6). However, there are disadvantages of such an approach for the purpose of litter monitoring. Firstly, samples of sufficient size to determine annual means for stomach contents are definitely lacking in many previous years, and could also be a problem in occasional years of future sampling. Samples that are too small have to be discarded and mean loss of information. Secondly, usage of annual means masks the potential role of underlying variables such as age, and prevents analyses of these over the full dataset. Thirdly, in our main litter category plastics, incidence during the late 1990's was consistently near 100% (Table 4; Fig. 6). Significant changes in plastic ingestion could remain undetected if we just look at incidence and not quantities of plastic.

So, in litter monitoring, there are good reasons to choose a system in which data of individual birds remain the basic unit for all analyses, because it allows for years of low sampling success and it remains possible to check for individual variables (cf Figs. 8 and 9). Also, there are good reasons to discard incidence as unit of measurement and to look for something that measures quantity.

As indicated in the methods section, volume of litter would be an optimal unit because it relates to the ecological effects on birds. However, volume can not be determined properly without excessive effort. Thus remains the choice between using the number of items per stomach, or the mass of these items. Although usage of number of items requires less effort, there are disadvantages. In industrial plastics, the number of particles is easy to determine and has a fairly constant relation to mass or volume because the granules are fairly uniform. Other plastics however, vary enormously in size, and possibly the variability is not constant over time. In some years during the late 1990's we had several samples with hundreds of minute pieces of plastic sheets and fragments, probably reason why trend analyses 1982-2000 revealed significant increase for number of all plastics but not for mass of plastic litter (Table 8) and why variance in large samples was less constant for numbers than that for mass (Fig. 10). Finally, in some categories of litter it is very difficult to count particles: for example in chemical substances a stomach may have a sticky mud present throughout which can not be distinguished in separate units and can only be estimated by weight.

From the power analyses conducted (Fig. 11) one might conclude that usage of number of items would produce more reliable results at smaller samples: this is true in our present set of data but exists thanks to the fact that nearly all birds have one or more user plastics in their stomach. As seen in industrial plastics, the advantage will disappear as soon as incidence decreases (more birds with zero items). Analysis by mass of litter items suggests more stability in the long run in different situations.

In conclusion, in the long run, the monitoring of time trends of litter in Fulmar stomachs is best conducted by using litter mass values of individual birds.

4.3 Annual or intermittent sampling

For monitoring purposes, it should be considered whether a program needs to be based on continuous sampling (annual) or whether intermittent sampling would be sufficient. In the case of Fulmars for example, every so many years there are incidental situations in which exceptionally high numbers of Fulmars are found on the beaches, and would be relatively easy to collect. Initially the possibility of sampling only a large number birds in such situations, and then wait until the next opportunity, was considered to be an option (e.g. the sampling of 107 birds in 1999 (Fig. 2)).

However, a closer look at variance in data and Power-analysis have made clear that intermittent sampling would not be a good approach. At a particular point in time, it has little use to sample more than about 40 birds, but in order to reliably detect changes (or no change) one needs up to hundreds of stomachs. In an annual sampling program reliable conclusions on trends can be made over time frames probably in the order of 4 to 8 years. Intermittent sampling in for example each fifth year would mean that time frames for reliable conclusions on moderate change-rates (which are likely) would require extremely long periods of time. In order to reach reliable conclusions within reasonable time, monitoring on an annual basis is to be recommended.

4.4 Choice of indicators

Although all litter categories found in fulmar stomachs have potential value as indicators of past and future developments (Tables 2, 8 and 9), the monitoring-tool will benefit from a limited number of well defined indicators consistently used in future data analyses and presentation of trends over time.

Evidently plastics should be used as an indicator because of their abundance, the availability of longer time series, and comparability to data from other parts of the world. Because of their linkage to different sources of pollution and thus policy measures, it is recommended that industrial plastics and user plastics are used as separate indicators.

Identification of substances suspected to be of chemical origin, most likely originating from ship's tankcleaning at sea, is somewhat ambiguous, as is the measurement of weight. Nevertheless, it is chosen as an important indicator. The incidence level (28%) suggests frequent occurrence of this litter type at sea, the ecological impact is potentially high, and and no other monitoring tool is available. Except in extreme incidents (Camphuysen et al., 1999) chemical discharges in the North Sea will tend to remain unnoticed by other observations. Chemical analyses of substances found in bird stomachs is urgently required.

At the moment it does not seem necessary to formalize an indicator status for other litter categories dealt with in this report. Several of the non-plastic rubbish categories are probably well represented by the indicator user plastic. Others could become relevant in future (for example fish hooks) but currently are so infrequent that an indicator status has little informative value. The litter categories 'oil' and 'feather lump (from excessive preening of fouled plumage)' are of importance in terms of effects on birds, but monitoring of the abundance of these pollutants themselves is covered properly in the 'oil-rate' indicator from beached bird surveys.

In bird dissections and stomach analyses, individual bird details and stomach items should be recorded as much as practical, in order to be able to signal any new developments and because such data can be a baseline for potential future indicators.

4.5 Considerations for OSPAR Ecological Quality Objectives for the North Sea.

The task for this pilot study was to analyse the potential of Northern Fulmar stomach contents for usage as a monitoring instrument for marine litter in the Dutch situation and to assign appropriate indicators. Evidently, this work has close linkage to recent developments in Ecological Quality Objectives (EcoQOs) for the North

Sea in an international framework. As advised by the ICES Working Group on Seabird Ecology (ICES-WGSE, 2001), OSPAR-BDC (2001) has recommended that the EcoQO of plastic particles in stomachs of seabirds '*should be given high priority*'. An EcoQO-target has been set in spite of the fact that knowledge is in a '*less advanced stage*' and '*further studies are required*'. The Advisory Committee on Ecosystems (ACE) has proposed that the EcoQO target should be set at a '*maximum of no more than 2% of individuals having ten or more plastic particles within a sample of at least 50 Northern Fulmars*'. This report, which has focused on a local measurement system rather than a target for the North Sea may be the start of such required further work. Some notes to the draft text for the EcoQO in OSPAR-BDC (2001) follow from this report:

1. The draft EcoQO is somewhat ambiguous in translating Fulmar *stomach* to Fulmar *gizzard*. The gizzard, however, is only part of the stomach (see inset in chapter 1.3). In North Sea Fulmars plastics not only accumulate in the gizzard but often 'overflow' in the proventriculus. Wording should make unambiguous that the EcoQO refers to the contents of complete stomach, that is gizzard plus proventriculus.
2. EcoQO draft texts suggest a classification of sampled Fulmars by age group and cause of death. Results from this report show that cause of death, although a useful data record for other purposes, is not required for trend-measurements nor for the EcoQO-target of plastics. Age groups may be combined in trend measurements, but age does have a relation to absolute levels of plastics (Chpt 3.3.; Fig. 8) and thus on the EcoQO-target. Final age group classification used in this report was adult versus non-adult (adult age defined as sexual organs indicating capability of breeding or having bred). An EcoQO-target requires either separate target values for age groups and/or a target value for a standard mix of age groups (roughly 50% of each age group in the Dutch material).
3. EcoQO draft texts make no distinction between industrial and user plastics. As shown in this report these two main categories of plastic show strongly different trends. Their origins, and thus policy-measures attempting to reduce imputs are different. It is recommended that at least records should be kept of the different categories of plastic and specification of the EcoQO-target level into categories may be considered.
4. The proposed EcoQO only refers to plastics. In our study we looked at all sorts of litter and recommend to include an indicator on chemical substances. This indicator suffers problems in accuracy of measurements (due to variability in material from fluid-like to solid materials) and uncertainties on substances involved. However, the total lack of other monitoring options for marine chemical litter plus the likelihood of significant ecological impact convinced us to advise on the inclusion of such an indicator in future Dutch work. OSPAR may wish to consider this at an international level.
5. The proposed EcoQO-target level asks for a sample size of at least 50 Fulmars, but does not specify the period of time nor the location and limits of the sampling area. Analyses in chapter 3.4 of this report show that about 40 birds in a sample are adequate to supply a reliable figure for levels of plastic loads in Fulmars at a particular point in time (a year) and place (the Dutch coast). As explained in Chpt 1.3., strong variability in plastic loads in different areas of the North Sea is not anticipated. However, this is not substantiated by appropriate data. Next step in development of the EcoQO is thus to conduct a 'one-off survey' analyzing for a

few years annual samples of each ± 40 birds from a number of different locations around the North Sea. Only such a background study will make it possible to specify an EcoQO-target for the whole North Sea with specification of an efficient number and location of sampling sites and numbers of birds required to reflect the situation in the whole North Sea. Such a North Sea wide Fulmar study is a component of a marine litter project proposal to the EU Interreg IIIB North Sea programme, in which the 'Keep Sweden Tidy' organisation acts as lead partner.

6. An impression of the current litter situation (in the Dutch North Sea) with regard to the draft EcoQO *('less than 2% of fulmars having 10 or more plastic particles')* may be derived from Fig. 12. The graph is based on all Dutch Fulmars 1982-2000, but the large sample of the late 1990's dominates the results. In this graph all bars except for the three at the left, represent the birds that have 10 or more plastic items in the stomach. Together they represent 58% of the birds in our samples. To meet to EcoQO-target, this percentage has to be reduced to less than 2%. In our overall dataset, the arithmetic means for subgroups of plastics are 4.3 industrial granules and 23.4 user particles per bird. A very rough translation of this ratio to the EcoQO-target means that the objective is that less than 2% of Fulmars should have 2 or more industrial granules and 8 or more user particles. For a potential indicator of chemical substances we think that there is little use in expressing abundance in terms of number of items.
7. The proposed unit of measurement in the EcoQO is the ***number*** of particles per stomach. For reasons explained in chapter 4.2 of this report it is suggested to consider the (additional) use of the mass of plastic contents per stomach rather than (only) the number of items. Translated into terms of mass (based on the above 58% of birds currently not meeting the EcoQO-criterion) the mass limit for the 2% rule would arrive at approximately 0.15g for overall plastic contents (0.03g for industrial; 0.12 for user plastics). No similar procedure is possible to propose a mass limit for a chemical indicator ('only' 24% incidence over the 1982-2000 period). Choosing an arbitrary target of less than 2% of Fulmars having more than 0.1g chemicals in their stomach: in the current situation about 12% of Fulmars would not meet the 0.1g criterion.

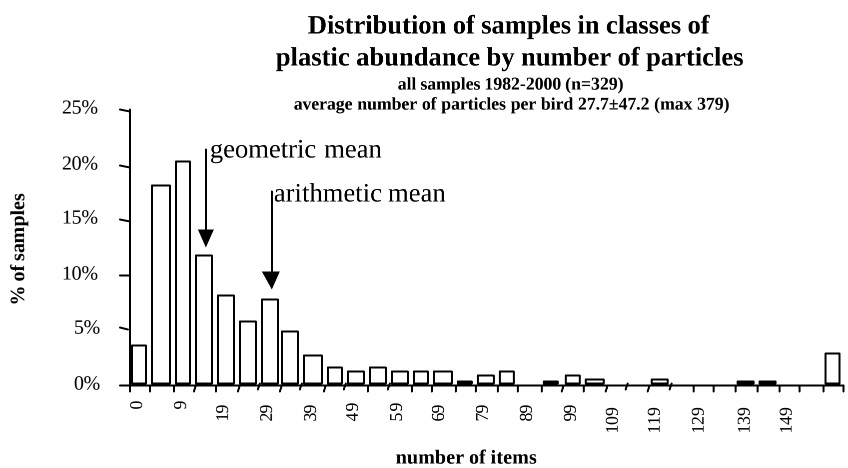


Figure 12. Frequency distribution of the number of plastic particles (industrial and user combined) in stomachs of Fulmars beachwashed in the Netherlands over the period 1982 to 2000 (cf fig. 3A. for similar graph but for plastic mass).

4.6 Conclusions and 'Litter NSV - Report 2000'

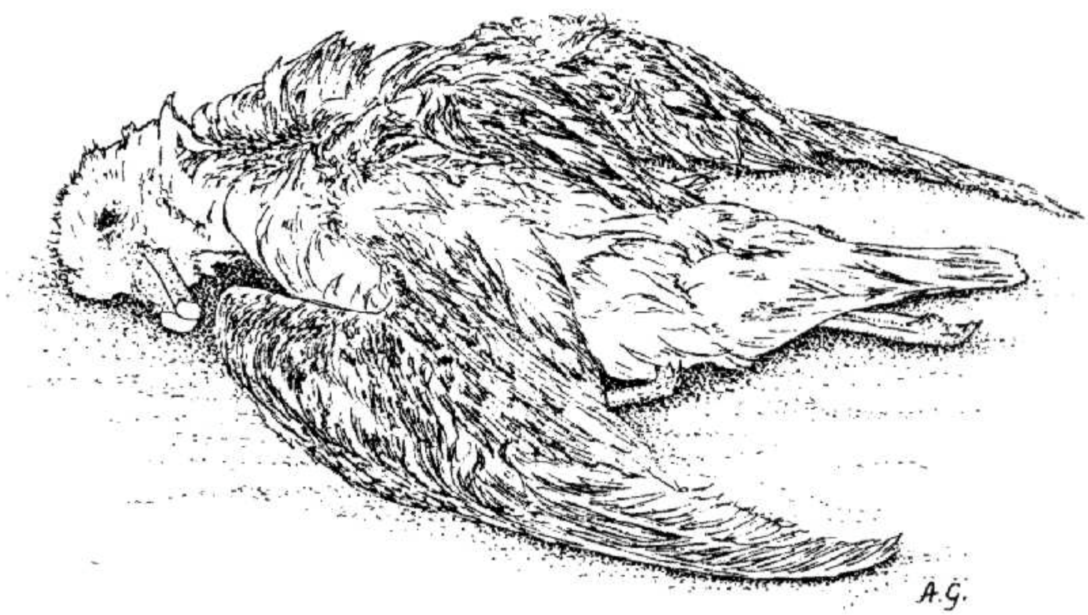
Findings of this pilot study on the Fulmar litter monitoring tool and the three recommended indicators have been summarized below. Data are presented in a format proposed to become the standard lay-out of data presentation of core information in future annual monitoring reports. As such, this chapter can be seen as the 'Litter NSV - Report 2000'.

Information provided is for the Dutch situation, but notes relevant for the wider North Sea and OSPAR's Ecological Quality Objectives have been added *(in italics)*.

MONITORING TOOL MARINE LITTER

Monitoring tool: **stomach contents of Northern Fulmars**
sample size: **per location annually ± 40 (beachwashed) birds recommended** (at dissection at least age of each bird should be determined)

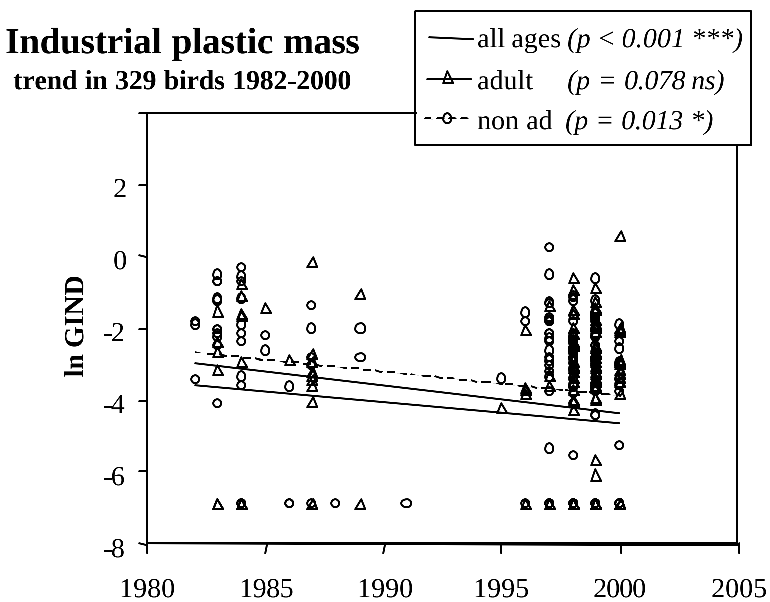
EcoQO notes: *North Sea wide monitoring for OSPAR's Ecological Quality Objectives requires a pilot-study on a number of different North Sea locations to determine an efficient sampling effort (number and position of long-term sampling locations).*



INDICATOR 1

INDUSTRIAL PLASTICS IN FULMAR STOMACHS

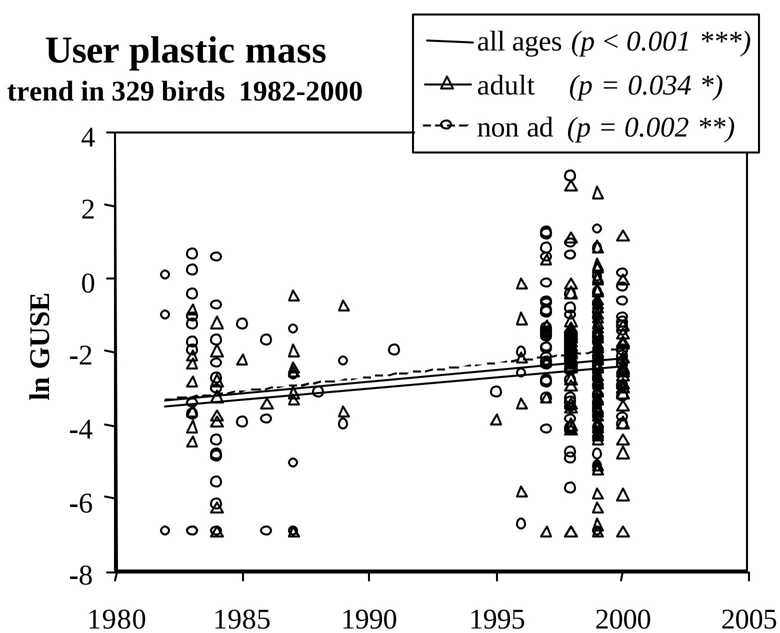
indicator:	Industrial plastics present in proventriculus and gizzard
units	mass per bird (total mass of industrial plastics per bird in grams)
trend calculation	linear regression analysis of ln tranformed mass data fitted on year
litter source	commercial shipping very likely; land-based likely
area:	Southern North Sea, offshore environment
basic data:	1982-2000, mainly early-mid 1980's and 1996-2000
reference:	pre-pollution era: zero industrial plastics
developments	long-term **decrease** 1982-2000 highly significant ($p<0.001$) See graph. Short-term **decrease** 1996-2000 significant ($p<0.05$)
current situation	**0.08 ± 0.16 g/bird** (arithmetic mean mass ± sd; 1996-2000; n=257)(3.6 ± 7.9 granules/bird; incidence 64%)
EcoQO North Sea	*tentative target: averaged over sampling locations less than 2% of Fulmars having more than 0.03 gram or 2 granules of industrial plastic*



INDICATOR 2

USER PLASTICS IN FULMAR STOMACHS

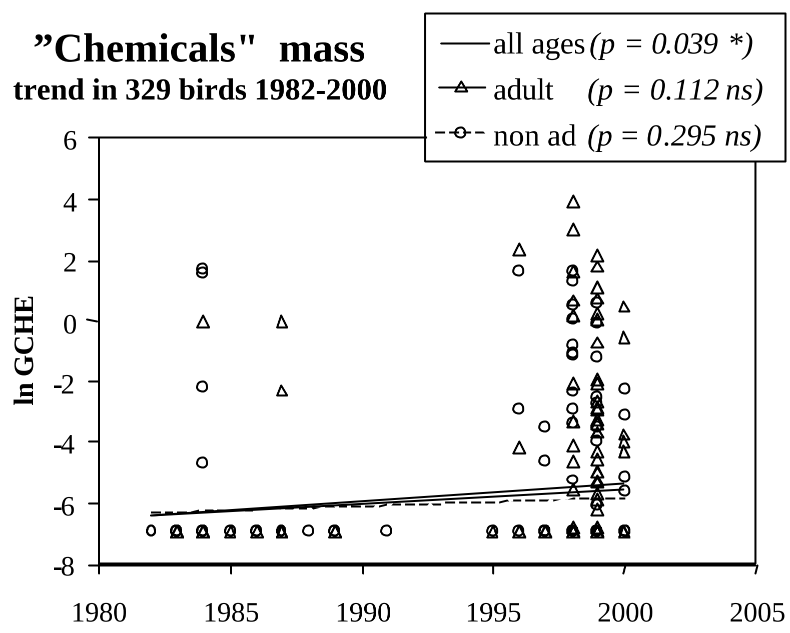
indicator:	all non-industrial plastics present in proventriculus and gizzard
units	mass per bird (total mass of user plastics per bird in grams)
trend calculation	linear regression analysis of ln tranformed mass data fitted on year
litter source	commercial shipping and fisheries very likely; coastal recreation, land-based and offshore industry possible
area:	Southern North Sea, offshore environment
basic data:	1982-2000, mainly early-mid 1980's and 1996-2000
reference:	pre-pollution era: zero user plastics
developments	long-term **increase** 1982-2000 highly significant (p<0.001) See graph short-term **uncertain** 1996-2000 possibly stabilized or declining (not significant)
current situation	**0.53 ± 1.84 g/bird** (arithmetic mean mass ± sd; 1996-2000; n=257) (27.8 ± 48.3 items/bird; incidence 97%)
EcoQO North Sea	*tentative target: averaged over sampling locations less than 2% of Fulmars having more than 0.12 gram or 8 pieces of user plastics*
notes	records for subcategories (sheet, thread, foam, fragment, other) are recommended as they may assist in refining changes in quantitative contributions from different sources



INDICATOR 3

'CHEMICALS' (suspected chemical substances) in Fulmar stomachs

indicator:	chemical-like substances present in proventriculus and gizzard
units	mass per bird (total mass of chemical substance per bird in grams)
trend calculation	linear regression analysis of ln tranformed mass data fitted on year
litter source	commercial shipping most likely (tank washing and possibly fuel residues)
area:	Southern North Sea, offshore environment
basic data:	1982-2000, mainly early-mid 1980's and 1996-2000
reference:	pre-pollution era: zero chemicals
developments	long term **increase** 1982-2000 significant ($p<0.05$) See graph. short term **uncertain** 1996-2000 possibly stabilising or declining (not significant)
current situation	**0.54 ± 3.53 g/bird** (arithmetic mean mass ± sd; 1996-2000; n=257) (2.2 ± 6.6 'items' per bird; incidence 28%)
EcoQO North Sea	*potential use of chemical indicator and target to be considered by OSPAR (see chpt 4.6)*
notes:	chemical analysis of substances encountered highly desirable (no significant differences found between age groups, but shown in graph for consistency with other indicaters)



4.7 Recommendations

Based on the discussions above, the following recommendations can be made:

1. **It is feasible for the Netherlands to start an annual monitoring program of marine litter using stomach contents of beachwashed Northern Fulmars. Such monitoring is recommended because it provides sound information on marine litter abundance in the Southern North Sea and has high additional value as compared to other survey types. The offshore environment, small sized litter, chemical pollution, and the link to ecological effects are not documented by any other type of survey.**
2. **The annual sample size for such a program is ± 40 Northern Fulmars from Dutch beaches. Cooperation will be sought with the Beached Bird Survey program of the Dutch Seabird Group (NZG).**
3. **Considering the continuity with the current dataset and documentation of the effect of the EU Directive on Port Reception Facilities (implementation to be complete by February 2003) it is recommended to immediately start a Dutch Fulmar monitoring program (Fulmar samples of 2001 are kept in freezer storage and are ready for processing).**
4. **Annual reports may be provided to give updates on trends in marine litter indicators for industrial plastics, user plastics and chemical substances, based on mass of such litter in the stomachs of the birds. The core contents of annual reports would be indicator discussions as provided up to the year 2000 in chapter 4.6 of this report. Costs for collections, research and report writing can be estimated at ± 20.000 Euro per year.**
5. **It is recommended that funds be made available for chemical analyses of suspected chemical pollutants found in Fulmar stomachs. Only such analyses can identify substances involved and their potential hazard to marine wildlife, and may pinpoint their sources.**
6. **It is recommended to bring this report to the attention of international organizations such as the EU (in relation to the EU Directive on Port Reception Facilities) and ICES/OSPAR (in relation to the development of Ecological Quality Ojectives for the North Sea.**
7. **Concerning the Ecological Quality Objectives for the North Sea it is recommended to support initiatives for a North Sea wide study of Fulmar stomach contents. This can be a 'one-off survey' running for a limited number of years in different countries bordering the North Sea. Such an integrated international effort is essential for the setup of an efficient international monitoring system in relation to EcoQO-targets. To this end, a partnership is sought in the planning of the Interreg IIIb proposal 'Save the North Sea', which focuses on marine litter and is coordinated by the Keep Sweden Tidy Foundation.**

5 Acknowledgements

We are grateful to all persons and organizations that assisted in collecting the beached birds used in this study. With apologies for unintended omissions, we acknowledge the assistance of P. de Boer, B. van den Boogaart, C. Braat, S. Brasseur, R. Brouwer, H. Brugge, K. Camphuysen, R. Costers, J. van Dijk, K. van Dijk, G. van Duin, Dutch Seabird Group (NZG), H.M. van Eck, A. van den Ende, F. van den Ende, K. de Graaf, A. Gronert, R. Gronert, H. de Groot, S. Hart, E. van Hijum. P. van Horssen, M. de Jong, R. Kats, G. Keijl, S. Kipp, B. Kuiken, D. Kuiken, M. Leopold, F.J. Maas, Nature Organization 'De Windbreker', J. den Ouden, T. Pieters, W. Pompert, T. Prins, Rehabilitation Centers of Bergen, Haarlem, Zandvoort and Ecomare Texel, C. Roselaar, H. Schekkerman, D. Schermer, S. Smit, K. Swennen, M. van Veen, J. van Velzen, B. Winter, Zoological Museum of the University of Amsterdam, and P. Zumkehr. N.W. van den Brink kindly assisted with correspondence analyses. We thank H. Offringa (North Sea Directorate) and T. Janssen (Transport Safety Directorate) for taking the initiative for this pilot study and guidance during the project. Useful comments to improve the draft report were given by L. Enserink (RIKZ). A. Gronert kindly allowed reproduction of his line-drawing of a beachwashed Fulmar.

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