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The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984–1999

Francis K. Wiese^{a,*}, Pierre C. Ryan^b

^a Department of Biology, Atlantic Cooperative Wildlife Ecology Research Network, Memorial University of Newfoundland, St. John's Newfoundland, Canada A1B 3X9

^b Canadian Wildlife Service, Environment Canada, Mount Pearl, NF, Canada A1N 4T3

Abstract

The Grand Banks south of Newfoundland provide year-round feeding habitat for tens of millions of seabirds of numerous species, an abundance and diversity unparalleled in the North Atlantic. Dense ship traffic routes traverse this productive environment as vessels travel the Great Circle Route between Europe and North America. Oiled seabirds have washed up on beaches in Newfoundland for many decades. Most oil on their feathers is heavy fuel oil mixed with lubricants, the mixture found in bilges of large vessels. Beached bird surveys conducted between 1984 and 1999 indicate that chronic oil pollution along the southeast coast of Newfoundland is among the highest in world. Sixty two percent of all dead birds found over the 16-year period had oil on their feathers; 74% during the last five years. Auks, especially Thick-billed Murres (*Uria lomvia*), are the most affected. The mean number of oiled birds per kilometer was 0.77 and thus higher than in other regions of the world during a comparable time period (0.02–0.33). Oiling rates correlated with weather patterns and degree of the regional murre hunt, indicate that illegal dumping of oil may occur year round, and point out that it is critical to assess all possible environmental and anthropogenic factors influencing the number of clean and oiled dead birds found on beaches before inferring trends in oiling rates over time.

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Keywords: Oil pollution; Seabirds; North Atlantic; Beached bird surveys; Murre hunt; Ship traffic; Oil fingerprinting; Oil Vulnerability Index

1. Introduction

Oil enters the marine environment from land runoff, natural seeps, vessels, pipelines and offshore exploration and production platforms (Clark, 1992; Schmidt Etkin, 1999; Wiese et al., 2001). Not including spills under 0.17 tonnes, vessels have contributed 64% of all accidental spills worldwide between 1978 and 1997, either through routine operations or large catastrophic spills, spilling an estimated total of 701,040 tonnes of oil into the marine environment (Schmidt Etkin, 1999). Much of the public concern about oil affecting the marine environment arose following large catastrophic spills such as the *Torrey Canyon*, *Exxon Valdez*, *Braer* and the *Sea Empress* where 30,000–370,000 seabirds were killed (Bourne

et al., 1967; Holme, 1969; Ford et al., 1996; Edwards and White, 1999). Total spillage from such incidents in terms of metric tons of oil, however, is less than that released as illegal discharges due to tank washings, dirty ballast and bilge pumping (Brander-Smith et al., 1990).

Seabirds are the most conspicuous marine organisms and have been used as monitors of the marine environment (Montevecchi, 1993, 2001) and of the incidence of oil pollution for decades (Furness and Camphuysen, 1997). Oil at sea is a threat to seabirds because it forms a thin layer on the ocean surface where many birds spend their time. The hydrophobic nature of oil causes plumage to readily absorb the oil, which decreases the birds' insulation, waterproofing and buoyancy, leading to death due to hypothermia or starvation (Brown, 1990). The many toxic compounds in the oil, when ingested or inhaled, can also lead to debilitating or fatal effects due to their impact on internal organs (Fry and Lowenstine, 1985; Leighton, 1993; Briggs et al., 1997). The amount of oil that is lethal to birds is very small (Levy, 1980; Fry

* Corresponding author. Address: School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA 98195, USA. Tel.: +1-206-221-6768; fax: +1-206-685-7471.

E-mail address: wiesef@u.washington.edu (F.K. Wiese).

and Lowenstine, 1985; Khan and Ryan, 1991; Leighton, 1995).

The extent of chronic oil pollution along a given shoreline is usually assessed by conducting systematic beached bird surveys, and determining the number and percentage of birds found that are oiled. Oiling rates (percentage of birds found that are oiled) are considered to indicate the risk to birds of becoming oiled at sea, and thus to mirror fluctuations in the amount of oil spilled over time and in different regions (Furness and Camphuysen, 1997; Camphuysen and Heubeck, 2001). Chemical analyses of oil samples taken from beaches and from stranded oiled birds in Newfoundland and Germany have shown that 90% are heavy fuel oils mixed with lubricant oils, the type of mixture found in bilges of large ocean-going vessels (A.R. Lock, Canadian Wildlife Service, personal communication; Averbeck et al., 1992). Based on the frequent overlap of shipping activities and seabird distribution, it is not surprising that beached bird surveys around the world have reported dead and live oiled seabirds resulting from chronic spills for decades (Canada East coast: Tuck, 1961; Levy, 1980; Piatt et al., 1985; Montevecchi and Tuck, 1987; Elliot and Ryan, 1988; Lock, 1992; Chardine, 1992, 1995; Chardine and Pelly, 1994; Wiese and Ryan, 1999. Canada West coast: Burger, 1993a; Burger and Fry, 1993. USA West coast: Speich and Wahl, 1986; Bodkin and Jameson, 1991; Nur et al., 1997. USA East coast: Simons, 1985. Argentina: Perkins, 1983; Boersma, 1995. Japan: Ohata et al., 1993. New Zealand: Veitch, 1982. Australia: Raaymakers, 1995. South Africa: Avery, 1989. North Sea: Dahlmann et al., 1994. UK: Cadbury, 1978; Stowe and Underwood, 1984; Heubeck, 1995. Denmark: Joensen and Hansen, 1977. Belgium: Kuyken, 1978. Netherlands: Camphuysen, 1989, 1998. Germany: Averbeck et al., 1992. France: Debout, 1984; Raewel, 1990. Lithuania: Vaitakus et al., 1994; Zydelsis and Dagys, 1997).

It has been suggested that these chronic effects may be as important or more important to long-term seabird population stability than occasional large spills (Hunt, 1987; Burger, 1992). This conclusion is supported by the absence of a strong correlation between the volume of oil spilled and consequent seabird mortality. It is rather the timing and location of the spill that determines the degree of seabird mortality (Burger, 1993b).

The Grand Banks off the east coast of Canada are the most important wintering ground for seabirds in the North Atlantic. Over 40 million pelagic seabirds are estimated to reside or migrate annually through the waters surrounding the island of Newfoundland (Chardine, 1995; Montevecchi, 2000), and they are generally considered one of the most productive marine areas in the world. Illegal discharges of oil have occurred in this region for decades (Tuck, 1961; Montevecchi and Tuck, 1987). Although spilled oil undoubtedly affects

the entire marine ecosystem (Kennish, 1997), it is most visible in the ongoing presence of oiled birds on beaches.

This paper presents the results of beached bird surveys conducted in Newfoundland during October to April of 1984–2000. We investigate species-specific mortalities and vulnerabilities, trends and patterns in oiling rates, and discuss the impacts of weather, ship traffic, and the local murre hunt on these trends. Finally, we assess the value of beached bird surveys and oiling rates as indicators of chronic oil pollution in the region, as well as its wider implications and applications.

2. Methods

2.1. Study area

The island of Newfoundland is located at the easternmost extremity of North America and lies near major shipping routes with Europe, many of which converge off Cape Race, the southeastern tip of the island (Fig. 1). Because most oil found on birds comes from large trans-Atlantic vessels travelling through this area (A.R. Lock personal communication), and because their routes overlap with large concentrations of seabirds vulnerable to oil pollution (Chardine, 1990), the south coast of Newfoundland and other regions in Atlantic Canada, similar to areas in the North Sea (Skov et al., 1995), were identified as an extremely high oiling risk zone for seabirds by Environment Canada in 1994 (Lock et al., 1994).

2.2. Oiling rates

Beached bird surveys in Newfoundland are coordinated and systematically carried out by the Canadian Wildlife Service of Environment Canada in St. John's,

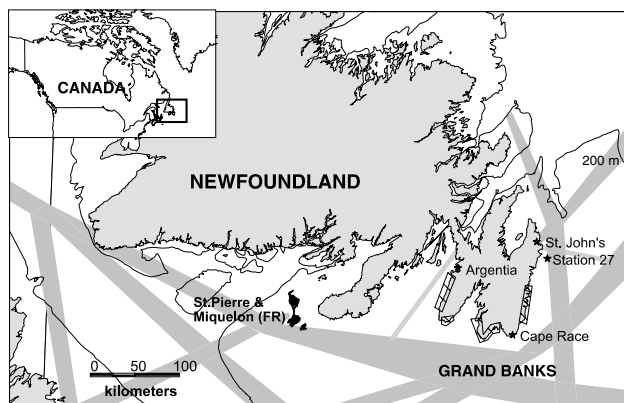


Fig. 1. Location of winter (October–March) beached bird surveys in southeastern Newfoundland, Canada. Beached bird survey sections are shown as hatched areas, weather stations and place names are shown as stars and major shipping routes are greyed bars. FR = France.

Newfoundland since 1984. Monthly surveys are conducted on a small section of the southeast coast of the island during the winter months (October–April) by one to three observers (Fig. 1). Beached bird surveys were conducted on foot, walking the upper and lower high tide line, recording and describing all corpses and parts of corpses encountered. Details on the age, sex, species, rate of decomposition, presence and amount of oil, survey effort and environmental and beach conditions at the time of the survey were recorded whenever possible, using international beached bird surveys protocol (Camphuysen and Heubeck, 2001). Counted corpses were either collected or marked to avoid recounting later.

Species-specific oiling rates and temporal trends of the proportion of birds found that were oiled were calculated, using only corpses complete enough to assure the presence or absence of oil (i.e. >75% of body present), and using information only from those 13 beaches in southeastern Newfoundland that were consistently surveyed each month during the winters of 1984/1985 to 1999/2000. All records related to known oil spill incidents or wrecks were eliminated from the database before the trend analysis was performed (Camphuysen and van Franeker, 1992). Winters were treated as six months periods designated by the year in which they began, e.g. 1984 refers to the period of mid-October 1984 until mid-April 1985 inclusive. Because beached bird surveys were conducted during the last or first days of the month, months were coded to start and end on the 15th day in order to avoid bias to one specific month. For example, for the purpose of this analysis, the month of October refers to the period of 15 October–15 November.

2.3. Analysis

Trend analyses were performed using logistic regression models (SAS, 1990), where the proportion of birds found that were oiled $p(\text{oiled})$ was analyzed with a General Linear Model where the response was treated as binary and using a logit link function. First, a general model was built to investigate annual trends. Subsequently the influence of explanatory variables on $p(\text{oiled})$ were included, and finally a full model where

$$p(\text{oiled}) = \beta_0 + \beta_1 \text{weather} + \beta_2 \text{hunt} + \beta_3 \text{ships}$$

was assessed, where weather is a composite index based on wind speed and direction and air temperature, hunt is the number of murres killed in the winter murre hunt in Newfoundland, and ships is the number of container, cargo and tanker vessels in coastal Newfoundland waters (see relevant sections below). Where trends in oiling rates over time were found to be significant ($P < 0.05$), analyses were performed using ANOVA/ANCOVA designs to determine whether changes in the number of clean or oiled birds were driving the change in the

proportion of birds found that were oiled. Furthermore, the influence of weather, hunting and ship traffic on these two components (oil and unoiled), as well as changes of each covariate over time, were investigated using standard correlation analysis. Where the model did not converge due to insufficient data, some covariates were dropped from the analysis and investigated separately if possible.

Chi-square values are presented instead of the usual F for ANOVA/ANCOVA designs, as a General Linear Model framework was used for all analysis. Correlation coefficients (r), obtained from Pearson's correlations are also presented for ANOVA/ANCOVA type analysis. All means are presented as ± 1 S.E., and all tests are 2-tailed.

2.4. Weather

Environmental conditions such as wind speed and direction, surface current variability, ambient air temperature and sea surface temperature can influence the number of oiled and clean birds found during beached bird surveys. If oiled and clean birds do not respond equally, fluctuations in these environmental parameters will affect the proportion of birds found that are oiled and its trends over time. Therefore, hourly weather information (wind speed and direction, ambient air temperature) from weather stations at Argentia and Cape Race (Fig. 1) were obtained from the Environment Canada Atlantic Climate Center in Fredericton, New Brunswick, Canada for the period between 1984 and 2000. Daily means, minima and maxima were calculated for each weather parameter for each month, and the following summary and ratio parameters were derived from these means in order to give more weight to colder and windier days (adapted from Camphuysen, 1989).

1. Temperature code, where the higher the code the colder the temperature. Days with temperatures greater than 0 °C get one point, days with temperatures less or equal than 0 °C but greater or equal to -5 °C get two points, days with temperatures less than -5 °C but greater or equal to -10 °C get three points, days with temperatures less than -10 °C get four points, and then all points are summed.
2. Onshore wind ratio, defined as the number of days with onshore days (dependent on individual beach orientations and defined as any wind parallel or at a direct angle towards the beach) relative to all days.
3. Extreme wind velocity code was calculated by assigning the number of days with gales (28 kts \leq wind speed < 47 kts) one point, and the number of days with storms (wind speed \geq 47 kts) two points, and adding them over the month.

Temperature codes, onshore wind ratios and extreme wind velocity codes were chosen because they appeared

to represent the data well, reflected most relevant weather patterns for seabirds, and accounted for missing data in a reasonable way. In order to avoid the use of correlated variables, a correlation and subsequent principal component analysis of these weather parameters was carried out. All weather indices were significantly correlated and combined into one 'weather' index. The first principal component described 63% of variation in the weather, where high values indicated cold ambient air temperatures (eigenvector loading = 0.616), strong winds (eigenvector loading = 0.638), and high proportion of onshore winds (eigenvector loading = 0.463).

In addition, representative daily sea surface temperatures (SST) were obtained for Station 27 (Fig. 1) from <http://oceanography.nwafc.nf.ca:81/testpoint/english/stn27/index.html>. SST had a significant negative correlation with the ambient air temperature code ($n = 88$, $\chi_1^2 = 61.8$, $P < 0.0001$, $r = 0.71$) and was therefore not included in the analysis, as more detailed ambient temperatures could be obtained.

2.5. Murre hunt

Thick-billed Murres (*Uria lomvia*) and Common Murres (*Uria aalge*) are hunted in a traditional fall and winter murre hunt along the coasts of Newfoundland and Labrador (Montevecchi and Tuck, 1987; Elliot, 1991; Chardine et al., 1999). Hunting effort can influence the number of crippled or non-retrieved murres which would be found as clean dead birds. Because this influences the oiling rate, it needs to be accounted for. Data on the hunt were from the Canadian Wildlife Service for seven of the 16 years (1985–1987, 1990, 1995–1997). For the oiling rate analysis, the data were split into the period before and after the implementation of hunting restriction in 1993, and the influence of the murre hunt on oiling rates was analyzed together and separately for each period.

2.6. Ship traffic

Oil found on seabirds in Atlantic Canada originates from the illegal pumping of waste oil and oil-water mixtures of bilges from large trans-Atlantic tankers and cargo/container vessels. In order to include ship traffic volume of these types of vessels in the oiling rate analysis, we obtained all available container, cargo and tanker traffic information for Atlantic Canada from the Department of Fisheries and Oceans Atlantic Mapping Project in Dartmouth, Nova Scotia. Data were available between 1990 and 2000. This database includes all vessels reported to the Eastern Canada Vessel Traffic Services Zone Regulations (ECAREG), i.e. those destined or originating from Canadian ports. It does not include ships travelling through the area under 'innocent pas-

sage', i.e. those destined to foreign ports while keeping outside the 12 nm territorial water limit. Ship traffic volume was determined along the south coast of Newfoundland out to and including the major shipping lanes (Fig. 1), and its relationship to oiling rates was investigated.

2.7. Oil Vulnerability Index

Winter Oil Vulnerability Indices (WOVI) were calculated for species commonly found on beached bird surveys in this area throughout the winter months (October–March). These indices are based on the criteria outlined by King and Sanger (1979) and adapted by Camphuysen (1998), and take into account the birds' distribution, behaviour and exposure to oil. In general, birds with high WOVI are those that roost on the sea, forage by swimming, escape by diving, have small wintering areas and overlap with areas of ship traffic throughout most of the year. WOVI were compared to observed oiling rates using Pearson correlation coefficients.

3. Results

3.1. Patterns of covariates

3.1.1. Weather

Analysis of weather parameters during winter showed a significant warming trend of ambient air temperature between 1984 and 2000, most strongly expressed by an increase in minimum ambient air temperature ($\chi_1^2 = 10.35$, $P < 0.005$, Fig. 2a). This trend was mirrored by increases of winter sea surface temperatures at Station 27 over the same time period ($\chi_1^2 = 7.51$, $P < 0.01$, Fig. 2b), and a decrease in the proportion of onshore winds from 1990 to present ($\chi_1^2 = 4.98$, $P < 0.05$, Fig. 2c).

3.1.2. Murre hunt

The number of murres harvested showed a significant overall decrease over time ($n = 42$, $\chi_1^2 = 9.3$, $P < 0.005$, $r = 0.45$), due primarily to a bag limit and geographic and seasonal hunting restriction first implemented by the Canadian Wildlife Service in the winter of 1993–1994 (Chardine et al., 1999). No trends were apparent within the periods before and after the restriction, largely due to limited data.

3.1.3. Ship traffic

Ship traffic volume in winter along the south coast of Newfoundland increased significantly from 1990 to 2000 ($\chi_1^2 = 9.3$, $P < 0.05$, $r = 0.32$). In addition, ship traffic records of individual vessels tracks coming in and out of Atlantic Canada showed that containers and tankers do

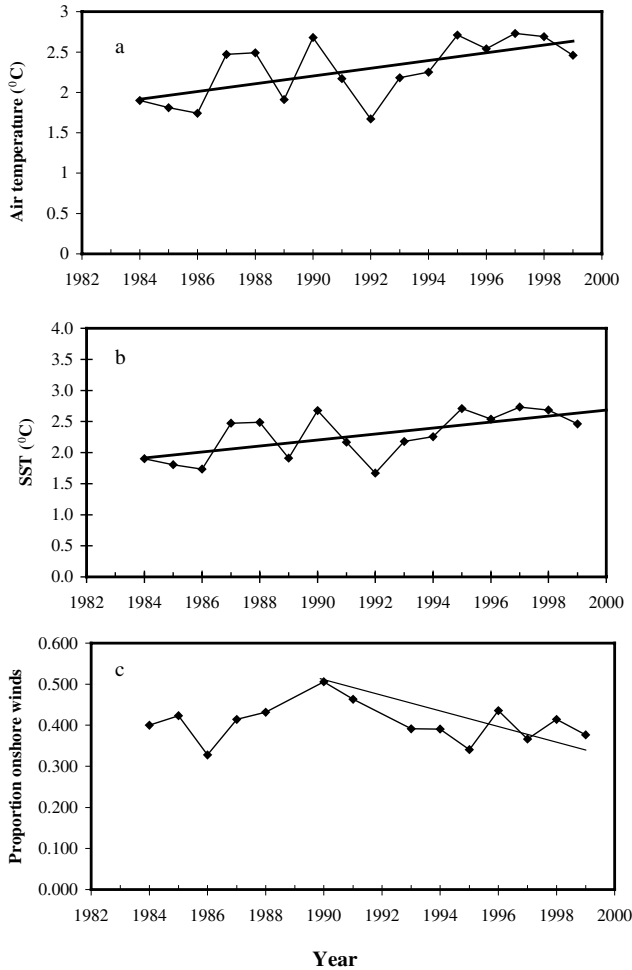


Fig. 2. Changes in (a) minimum ambient air temperatures, (b) sea surface temperatures (SST), and (c) proportion of onshore winds, during winters (October–March) 1984/1985–1999/2000 in southern Newfoundland, Canada. Linear correlation are shown, correlation of onshore winds with time was only performed from 1990 onwards (see results for details).

not adhere strictly to defined shipping lanes and can be found throughout the area (Fig. 3 compared to Fig. 1).

3.1.4. Winter Oil Vulnerability Index

WOVI were determined for the 11 species of birds most commonly found on Newfoundland beaches (Appendix A). Murres (*Uria* spp.), Dovekies (*Alle alle*) and Common Eiders (*Somateria mollissima*) all scored high (above 30 out of a maximum score of 40), Herring and Great Black-backed Gulls (*Larus argentatus* and *Larus marinus*) scored low (below 20), the others being intermediate (between 20 and 30). Predicted WOVI were significantly correlated with observed oiling rates ($n = 11$, $\chi^2_1 = 9.9$, $P < 0.005$, Fig. 4, $r = 0.77$).

3.1.5. Oiling rates

1676 birds were found on systematically surveyed beached during the winters 1984–1999 (Table 1), after

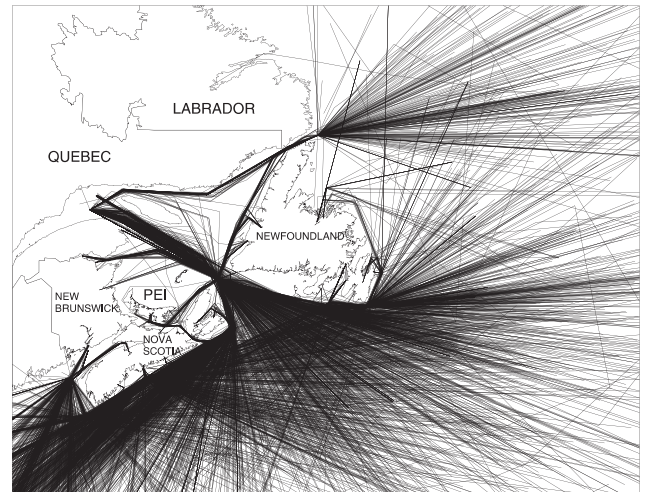


Fig. 3. Typical annual ship track pattern of container, cargo and tanker vessels travelling to or through Atlantic Canada destined to Canadian ports in 1995. Patterns were similar in 1990–2000 (adapted from ECAREG).

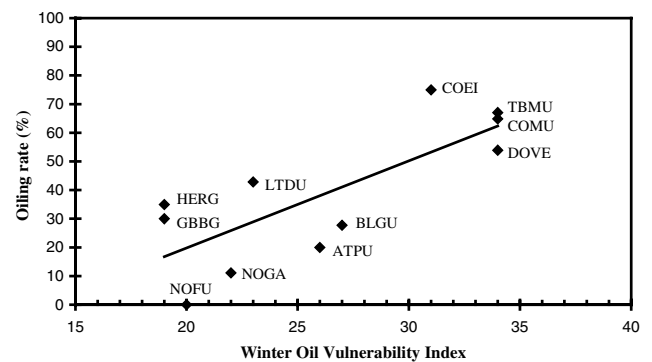


Fig. 4. Winter Oil Vulnerability Index (Appendix A) in relation to observed oiling rates during winter (October–March) 1984–1999, $r = 0.77$. HERG = Herring Gull; GBBG = Great Black-backed Gull; NOGA = Northern Gannet; NOFU = Northern Fulmar; LTDU = Long-tailed Duck; ATPU = Atlantic Puffin; BLGU = Black Guillemot; COEI = Common Eider; TBMU = Thick-billed Murre; DOVE = Dovekie and COMU = Common Murre. WOVI adapted and derived from King and Sanger (1979) and Camphuysen (1998).

those apparently resulting from known oil-spill incidents were removed from the sample. In 708 (42.2%) cases, more than 75% of the carcass remained allowing an accurate coding for oil (Table 1). The overall oiling rate of those birds was 62.0%, the mean number of oiled birds per km was 0.77, and the total number of corpses per km was 2.25. 75.6% of all oiled birds had oil on less than 25% of their bodies and most oiled birds were highly emaciated (absence of body and muscle fat, reduced pectoral muscles).

3.2. Annual trends

Oiling rates increased significantly from 1984 to 1999 at an average rate of 1.4% per annum ($\chi^2_1 = 12.38$,

Table 1
Corrected total number of birds found, number of birds coded for oil (>75% of body present) and oiling rate detected during monthly winter (October–March) beached bird surveys along the Avalon Peninsula, Newfoundland, Canada, 1984–1999

Winter	Total no. of birds found	No. birds coded for oil	Oiling rate (%)
1984	160	55	63.6
1985	106	54	42.6
1986	122	51	47.1
1987	179	68	70.6
1988	102	35	31.4
1990	106	68	48.4
1991	140	116	79.3
1993	73	58	41.4
1994	148	36	72.2
1995	33	20	85.0
1996	308	17	76.5
1997	49	35	80.0
1998	46	40	77.5
1999	104	55	61.8
Total	1676	708	62.0

$P < 0.005$, Fig. 5) while survey effort (number of beach surveys per month) showed no significant change over time ($\chi^2_1 = 1.74$, $P > 0.1$). The overall increasing trend in the proportion of birds found that were oiled was only apparent in November and December, and was due to decreasing trends in the number of clean birds found per km in those months ($\chi^2_1 = 4.15$, $P < 0.05$). Factors related to the number of clean birds were ambient temperatures ($\chi^2_1 = 5.08$, $P < 0.05$) and for the murres, which made up 65.1% of all birds reported (Table 2), the size of the murre hunt ($\chi^2_1 = 16.91$, $P < 0.0001$, Fig. 6). Overall the number of oiled birds was positively correlated to the weather index ($\chi^2_1 = 4.89$, $P < 0.05$), but no association with ship traffic volume was found ($\chi^2_1 = 0.18$, $P > 0.5$).

3.3. Monthly patterns

Monthly oiling rates differed from each other ($\chi^2_5 = 75.83$, $P < 0.0001$). The proportion of birds found that were oiled peaked in December (Fig. 7), a pattern likely related to significant fluctuations in the monthly number of oiled birds per km ($\chi^2_1 = 18.15$, $P < 0.005$), as the monthly number of clean birds per km did not change significantly ($\chi^2_1 = 9.61$, $P > 0.05$). As above, monthly occurrence of oiled birds was found to be significantly influenced only by weather, with high incidence of oiled birds corresponding directly to periods of cold ambient air temperatures, high winds and periods of increased onshore winds ($\chi^2_5 = 18.15$, $P < 0.0005$, Fig. 8, $r = 0.81$). No association with ship traffic volume was found ($\chi^2_5 = 0.21$, $P > 0.5$).

3.4. Species

The two species most affected in terms of numbers and oiling rates were murres (Common and Thick-billed Murres), for which a combined oiling rate of over 70% was recorded (Table 2). Overall, the oiling rate for murres increased between 1984 and 1999 by an average of 0.9% annually ($\chi^2_1 = 4.16$, $P < 0.05$), and showed less variability among years than all species combined. When the two species of murres were considered separately, this increase was only evident for Thick-billed Murres. Inclement weather was a significant predictor of the number of oiled murres found on beaches ($\chi^2_1 = 5.21$, $P < 0.05$). Of the variability examined, the murre harvest explained the most variation in the proportion of murres found that were oiled ($\chi^2_1 = 15.02$, $P < 0.0001$) because the decrease in harvest over the years was significantly correlated to a decrease in the number of clean murres found on beaches ($\chi^2_1 = 17.29$,

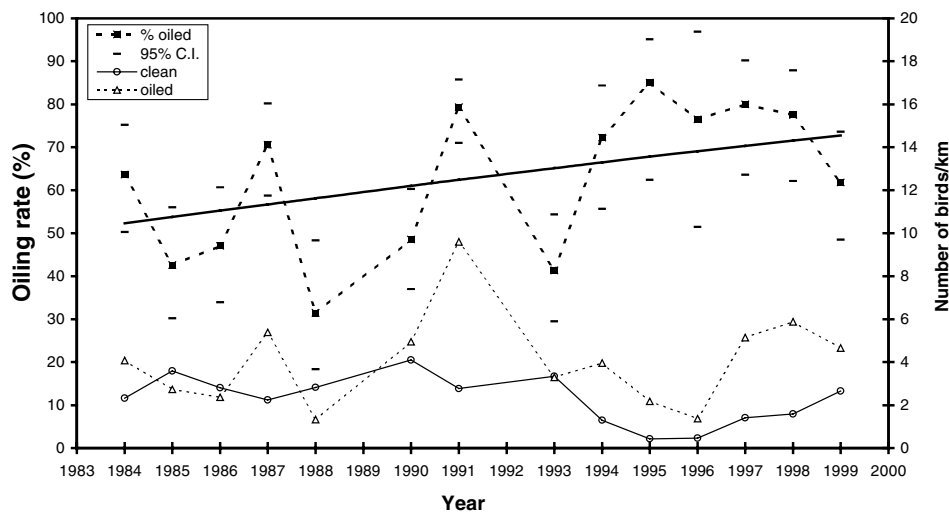


Fig. 5. Inter-annual change in the proportion of birds found oiled (oiling rate), and the density of clean and oiled birds per km found on southeastern Newfoundland, Canada beaches during winter (October–March) 1984–1999.

Table 2

Frequency of the corrected total number of birds coded for oil, and oiling rates of species found on beached bird surveys in Newfoundland, Canada, 1984–1999

Species	Number	Frequency (%)	Oiling rate (%)
Murres (<i>Uria</i> spp.)	461	65.1	70.5
Thick-billed Murres (<i>Uria lomvia</i>)	164	23.2	67.1
Common Murres (<i>Uria aalge</i>)	111	15.7	64.9
Unidentified Murres (<i>Uria</i> spp.)	186	26.3	76.9
Dovekies (<i>Alle alle</i>)	115	16.3	53.9
Herring Gulls (<i>Larus argentatus</i>)	20	2.8	35.0
Black Guillemot (<i>Cepphus grylle</i>)	18	2.5	27.8
Common Eider (<i>Somateria mollissima</i>)	16	2.3	75.0
Great Black-backed Gull (<i>Larus marinus</i>)	10	1.4	30.0
Atlantic Puffin (<i>Fratercula arctica</i>)	10	1.4	20.0
Northern Gannet (<i>Sula bassana</i>)	9	1.3	11.1
Northern Fulmar (<i>Fulmarus glacialis</i>)	8	1.1	0.0
Long-tailed Duck (<i>Clangula hyemalis</i>)	7	1.0	42.9

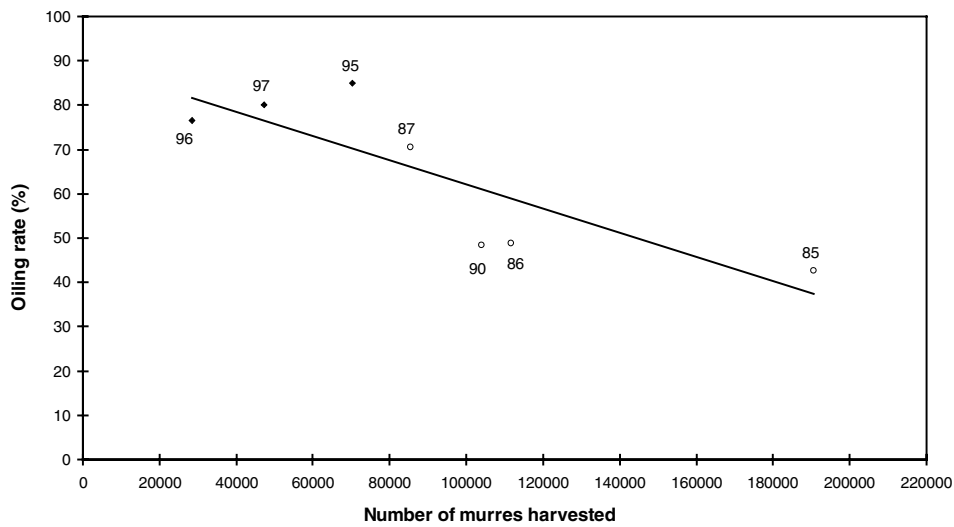


Fig. 6. Relationship between the number of murres harvested on the south coast of Newfoundland, Canada and the proportion of birds found oiled (oiling rate) during winter (October–March), $r = 0.83$. Years are shown, circles represent years before hunting restrictions and diamonds after restrictions.

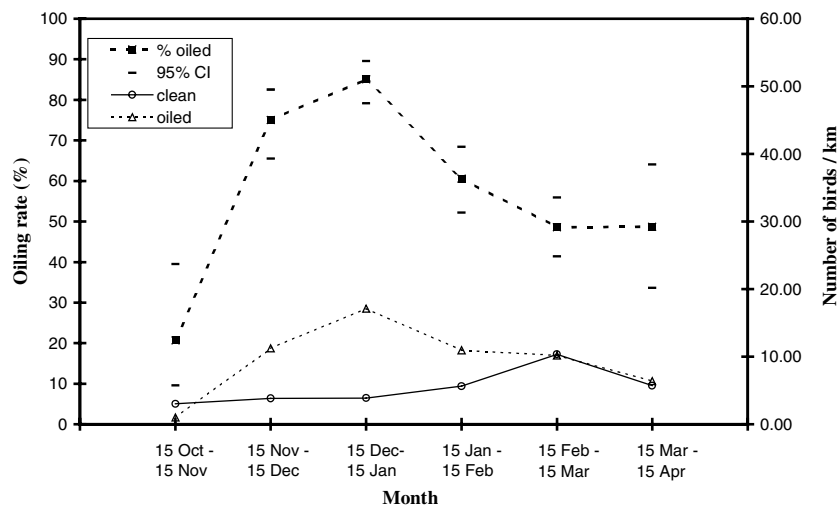


Fig. 7. Monthly changes in oiling rates, and the total number of clean and oiled birds found per km on beaches in southeastern Newfoundland, Canada between mid-October and mid-April, 1984–1999.

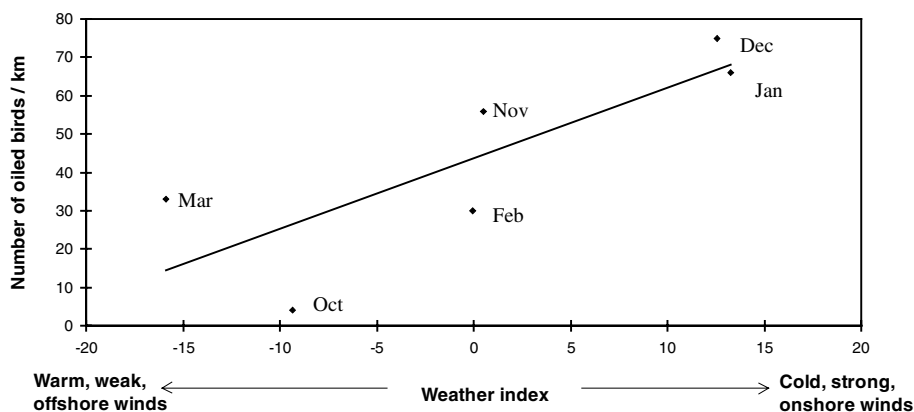


Fig. 8. Relationship between the total number of oiled birds per km found during winter (October–March) on beaches on southeast coast of Newfoundland, Canada and the sum of the weather index for each winter month (1984–1999 pooled), $r = 0.81$.

$P < 0.0001$). When annual changes in the murre harvest were accounted for, the oiling rate for all murres combined, as well as for Thick-billed Murres alone, remained unchanged over time ($\chi^2_1 = 1.29$, $P > 0.05$).

4. Discussion

Newfoundland's overall oiling rate of 62% is among the highest documented in the world (Burger, 1993a; Vaitakus et al., 1994; Heubeck, 1995; Nur et al., 1997; Zydalis and Dagys, 1997; Camphuysen, 1998; Camphuysen and Heubeck, 2001). In addition, the linear density of oiled birds on studied beaches (0.77/km) is also markedly higher than in other regions of the world during a comparable time period (0.02–0.33, Burger, 1993a; Vaitakus et al., 1994; Heubeck, 1995), and has remained at these high levels for the last 16 years.

Birds found in more northern latitudes or colder oceans can be expected to have higher oiling rates, because oil on water persists longer in cold temperatures, and because the thermal stress of birds is increased after oiling (Hartung, 1967; Jenssen et al., 1985; Culik et al., 1991; Doerffer, 1992). The much higher number of murres compared to all other species certainly reflects their high abundance during the winter months, but the overall oiling rate for murres of 70.5%, and of 80.4% during the last 5 years surveyed, also ranks among the highest in the world (3–82%, Camphuysen, 1998). High oiling rates are of special concern for the conservation of murres and other auks. Owing to their low-fecundity and high-survival life histories, even slightly increased sustained adult mortality can have appreciable population impacts and could threaten long-term population stability (Nur et al., 1997; Wiese et al., in press).

WOVI were a good predictor of observed oiling rates. As in studies elsewhere, auks and diving ducks are the avian groups most affected by oiling, likely because they spend most of their time on, or under, water (Cam-

phuysen, 1998). Auks and sea ducks are known to dive as an escape response, a behaviour that makes them more vulnerable to oil at sea than species more likely to evade a slick by taking flight. Coastal species such as gulls and Black Guillemots, and highly aerial species such as fulmars and gannets, were less affected by oil. Larger gulls and birds of prey may be contaminated when they prey on or scavenge, injured and oiled birds. However, gulls and auks have been observed to successfully preen themselves clean of oil and survive, although perhaps with lower reproductive success (Corkhill, 1973; Esler et al., 2000).

Oiling mortality is underestimated by excluding birds whose carcasses lacked external oil but that died due to internal contamination (Leighton, 1995; Briggs et al., 1997). Vauk (1984) suggested that this could be the cause of death for as many as 20% of clean birds found, but as few corpses were autopsied, this percentage could not be determined for our study. Alternatively, oiling rates may be overestimated by including birds oiled post-mortem (Kuyken, 1978; Camphuysen and van Franeker, 1992). However, recent drift block experiments around the Newfoundland coast suggest that post-mortem oiling in this region is negligible, and that sinking rates of oiled and unoled birds are comparable (Wiese, 2002a). Additionally, as there is no difference in the persistence time of oil and unoled birds on beaches (Wiese, 2002a), observed oiling rates in Newfoundland appear to be a reasonable representation of a bird's risk of dying from spilled oil.

4.1. Annual trends

Observed oiling rates in our study indicate an increase in the proportion of birds found that were oiled of 1.4% per annum. Declining oiling rates of seabirds in parts of the North Sea over the last 20 years were interpreted as a decline in overall chronic oil pollution, and attributed to more extensive aerial surveillance and

decisions to clean-up oil slicks rather than wait for natural dissipation (Camphuysen, 1998; Camphuysen and Heubeck, 2001). While changes in oiling rates in North Sea appear to reflect changes in the risk to birds of being oiled, this may not apply in the Newfoundland region. Detailed investigation of the data showed that increasing trends in oiling rates were mainly due to a reduction in the numbers of clean birds found on beaches, and this was related to increasingly warmer winter ambient air temperatures. Increasing oiling rates of murre harvest leading to fewer deaths due to crippling, and improving weather during winter (including higher proportions of onshore winds) causing a likely reduction in natural mortality. Such a relationship supports the observation that processes on the winter grounds seem to determine Thick-billed Murre population dynamics (Gaston, in press).

4.2. Ship traffic

Ship traffic volume was not related to overall oiling rates when changes in weather and the murre harvest were taken into account. Given the known origin of the oil found on birds, this result is rather surprising and perhaps an artifact of the limited data that do not include ships travelling under innocent passage. Alternatively, the seabird–oil matrix may be “saturated” and major reductions in spilled oil are needed before a relationship is apparent. A more detailed analysis of ship traffic volume in Atlantic Canada is needed. Results did show that container and tanker vessels can be found throughout the area, suggesting that seabird oiling risks may occur in more areas in Atlantic Canada than previously defined (Environment Canada, 1998).

If true, the lack of a relationship between oiling rates and shipping volume, given the increase in ship traffic and the constant number of oiled birds found, would suggest that it is a relatively constant number of ship operators illegally discharging their oily bilge into the ocean, rather than a consistent proportion of ships passing through the area. Such a result would send an encouraging message to local enforcement agencies because it implies that stricter control of chronic polluters, increased fines for multiple offenders, and increased aerial surveillance, have a high probability of reducing the number of birds killed (Camphuysen, 1998).

4.3. Monthly patterns

While decreases in the number of clean birds recorded seem to explain annual trends of oiling rates since 1984, fluctuations in the number of oiled birds most closely explain monthly oiling rate patterns. Like annual trends elsewhere in the world, oiling rates during the winter months may accurately represent the risk for birds to die

due to oil. The occurrence of oiled birds throughout the winter was highest during periods of cold ambient air temperatures, high wind speeds and frequent onshore winds. This is consistent with earlier findings (Kuyken, 1978). High winds and cold ambient air temperatures may increase seabird mortality due to oil indirectly because it influences the amount of time oil remains on the surface of the water, and directly because of increased thermal and metabolic stress due to the lack of insulation and buoyancy. The relatively high numbers of oiled birds during months with frequent onshore winds indicates that oiled birds float ashore with wind-driven currents or fly ashore aided by the wind (Camphuysen, 1989). In addition, observations indicate that most birds have depleted fat reserves after bad weather periods, suggesting that it is hard to feed during such environmental conditions (R.D. Elliot, Canadian Wildlife Service, personal communication).

As in the North Sea (Camphuysen and Heubeck, 2001), oiling rates are significantly higher in winter than summer (Wiese and Ryan, 1999). Certainly, ships have more need to discharge bilges in winter because they accumulate more waste fluids during storms and high seas, and ship operators have more opportunity to illegally discharge oil at sea in winter because they are less likely to be detected during the long periods of darkness or bad weather. However, it is doubtful that chronic oil pollution only occurs in the winter. Rather, lower oiling rates in the summer may reflect (1) reduced abundance of highly vulnerable birds such as murrelets and eiders, (2) reduced overlap of nesting common murrelets with shipping lanes (Lock et al., 1994), (3) reduced susceptibility of seabirds to oil in warmer ambient and sea surface temperatures, (4) faster dispersion of refined oils at higher sea surface temperatures, and (5) faster loss of volatile and soluble toxic components of crude oils components and faster reduction of these oils to biologically inert solids such as tar balls at higher sea surface temperatures (Bourne and Bibby, 1975; Kenish, 1997). Observations of body condition and the degree of oiling of beached birds further strengthens this interpretation. Small quantities of oil on a carcass, combined with high emaciation, indicates that the bird lived for a period of time after contacting the oil before it perished, likely from hypothermia and starvation during harsh weather conditions (Camphuysen and van Franeker, 1992).

5. Conclusions

Data collected during beached bird surveys in southeastern Newfoundland were useful to determine trends in chronic oil pollution. However, the underlying patterns influencing oiling rates such as weather, ship traffic volume and, in Newfoundland, the murre harvest,

must be investigated thoroughly to fully understand observed trends. Although weather parameters can explain variation in oiling rates, hunting plays a significant role for some species, and the influence of shipping needs to be further investigated. All these factors need to be compiled and considered for future analysis. To discern whether the data presented here are typical for the entire coastline, or for all of Atlantic Canada, it is necessary that beached bird surveys be expanded geographically.

The Grand Banks provide suitable year-round feeding habitat for tens of millions of seabirds of many species, an abundance and diversity unparalleled in the North Atlantic (Nettleship and Birkhead, 1985; Montevecchi and Tuck, 1987). It is disturbing that oil continues to be a big threat to many seabird species in this region. Our results indicate that chronic oil pollution off the coast of Newfoundland is among the highest recorded in the world, and has remained high for the last 16 years. The damage caused to seabirds and the entire marine ecosystem through the continuing illegal flushing of oily bilge water from large container and tanker vessels along this coast is a significant and continuing problem, and has decreased population growth rates of Thick-billed Murres in the eastern Canadian Arctic (Wiese et al., in press).

To help reduce and hopefully eliminate this worldwide chronic problem, ship operators must be aware of a strong year-round enforcement presence in Atlantic Canada and elsewhere. The adopted polluter-pay principle must be fully applied and not succumb to political and economic pressure from large shipping companies. Clearly, as proven effective elsewhere, enforcement needs to increase, awareness and imposed fines (including minimum fines) need to be raised substantially,

and accessible and convenient oil disposal facilities need to be established in Atlantic Canada to help reduce the illegal dumping of oil at sea (Averbeck et al., 1992; Camphuysen, 1998; Wells, 2001; Wiese, 2002b).

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Appendix A. Winter Oil Vulnerability Indices

Winter Oil Vulnerability Indices (WOVI) for the species most commonly found on winter (October–March) beached bird surveys in southeastern Newfoundland, Canada, 1984–1999. Following methods suggested by King and Sanger (1979) and adapted from Camphuysen (1998). Maximum score per criteria is 5, overall maxima is 40.

AOU species codes	Behaviour				Range				WOVI
	Roosting	Foraging	Escape	Flocking	Exposure	Migration	Wintering	Marine orientation	
GBBG	3	3	3	3	2	1	1	3	19
HEGU	3	3	3	3	2	1	1	3	19
NOFU	5	3	1	3	1	1	1	5	20
NOGA	5	3	3	3	1	1	1	5	22
LTDU	3	5	1	5	2	3	3	1	23
ATPU	5	5	5	3	1	1	1	5	26
BLGI	5	5	5	3	2	1	3	3	27
COEI	5	5	1	5	4	3	3	5	31
COMU	5	5	5	3	5	5	1	5	34
DOVE	5	5	5	3	5	5	1	5	34
MUSP	5	5	5	3	5	5	1	5	34
TBMU	5	5	5	3	5	5	1	5	34

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