AN ASSESSMENT OF THE NUMBER OF SEABIRDS AT RISK DURING THE NOVEMBER 2004 *TERRA NOVA* FPSO OIL SPILL ON THE GRAND BANKS

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Summary

On 21 November 2004, about 1,000 barrels (160,000 litres) of crude oil were released from the *Terra Nova* FPSO (floating production, storage and offloading) vessel onto the Grand Banks, approximately 340 km east-southeast of St. John's, NL. This incident affected an area estimated at 793 km^2 and occurred during a time of year when very large numbers of murres (*Uria* spp.) and dovekies (*Alle alle*) use the area. These seabirds are highly vulnerable to the effects of oil at sea. Following the spill, helicopter and vessel-based surveys aboard the *Burin Sea* were conducted between 25 and 29 November 2004, to estimate seabird densities around the impacted area. These densities were compared to other available data from similar time periods in previous years, namely data collected by: William Montevecchi (November 2002), Petro-Canada from the nearby *Henry Goodrich* semi-submersible drilling rig (November 2000-2002), and PIROP (Programme Intégré des Recherches sur les Oiseaux Pélagiques; November-December 1970-1983). The number of birds at risk was estimated based on the densities of seabirds observed aboard the *Burin Sea* and the total area covered by the slick. A mean density of 3.46 murres/km^2 and 1.07 dovekies/km^2 on the sea surface was recorded; when birds in flight were included the mean density increased to 6.90 murres/km^2 and 13.43 dovekies/km^2. These density estimates are comparable to those previously reported for the area during this time of year. The number of birds at risk was calculated under three different scenarios for the area covered by oil. These scenarios yielded a mean of 9,858 murres and dovekies, with estimates ranging from 3,593 to 16,122 depending on what portion of birds in flight were assumed to be at risk. This estimate was compared to a mortality estimate based on the published empirical relationship between the volume of oil released during an incident and the number of seabirds killed, which yielded estimates in the same order of magnitude. The effect of most model assumptions was to underestimate the numbers of birds at risk. Given that previously published models include seabirds on water and in flight to estimate total mortality, we estimate that between 10,000 and 16,000 alcids were put at risk by the *Terra Nova* spill.

Résumé

Le 21 novembre 2004, un millier de barils (160 000 litres) de pétrole brut ont été rejetés à partir du navire de production, de stockage et de déchargement (NPSD) *Terra Nova* sur les bancs de Terre-Neuve, à environ 340 km à l'est-sud-est de Saint-Jean (Terre-Neuve-et-Labrador). Cet incident a touché une région estimée à 793 km^2 et s'est produit à une période où un très grand nombre de guillemots (*Uria* spp.) et de mergules nains (*Alle alle*) fréquentent la région. Ces oiseaux de mer sont très vulnérables aux effets du pétrole en mer. Le nombre d'individus en péril a été estimé à partir des densités observées d'oiseaux de mer et la superficie totale couverte par la nappe de pétrole. Des densités moyennes de 3,46 guillemots /km^2 et de 1,07 mergule nain/km^2 ont été enregistrées à la surface de la mer lors de relevés en bateau les 28 et 29 novembre 2004; lorsque les oiseaux en vol étaient inclus, les densités moyennes passaient à 6,90 guillemots/km^2 et à 13,43 mergules nains/km^2. Ces estimations de la densité sont comparables à celles d'autres sources. Dans le cadre d'un ensemble de trois scénarios, le nombre d'oiseaux à risque a été calculé pour la région touchée par la marée noire. Ces scénarios ont donné une moyenne de 9 858 guillemots et mergules nains, les estimations allant de 3 593 à 16 122 selon la portion d'oiseaux en vol réputés être en péril. On a comparé l'estimation du nombre d'oiseaux potentiellement en péril au cours de l'incident avec une estimation de la mortalité en se fondant sur la relation (établie dans des publications) entre le volume de pétrole rejeté pendant l'incident et le nombre d'oiseaux de mer tués. L'estimation de la mortalité était du même ordre de grandeur que l'estimation du risque. L'effet de la plupart des hypothèses de ces modèles a été de sous-estimer le nombre d'oiseaux en péril. À la lumière du fait que d'autres modèles incluent les oiseaux à la surface ainsi que ceux en vol pour estimer la mortalité totale, nous estimons qu'entre 10 000 et 16 000 Alcidés ont été mis en péril par la marée noire du *Terra Nova*.

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1. Introduction

The Grand Banks of Newfoundland supports a productive marine ecosystem with high numbers and a wide diversity of pelagic seabirds present throughout the year (Lock et al. 1994). Oil was discovered in the eastern portion of the Grand Banks, about 300-350 km offshore, in the late 1970s and early 1980s. Oil production began at the *Hibernia* field in 1997 and first oil was produced at the *Terra Nova* field in 2002. The *White Rose* field first produced oil in late 2005, and other areas on or near the Banks are currently being explored for oil.

Early on 21 November 2004, the *Terra Nova* FPSO reported a release of an estimated 157 barrels of crude oil into the ocean. By the following day, Petro-Canada had revised this estimate, stating that as many as 1,000 barrels may have been discharged into the ocean. On 25 November, a second spill was reported at the same oil field but from the *Henry Goodrich* drilling rig. This spill was estimated at 400 litres, and personnel were able to recover most of the oil within a few hours of the start of the spill. On 27 November, live oiled murres and dovekies were reported on beaches over 300 km to the west, in the south-eastern part of the Newfoundland Avalon Peninsula, primarily in Placentia Bay. In total, 409 birds were recovered from beaches between 27 November and 4 December 2004 (Robertson et al. in press). Oil was analysed from a randomly selected sub-sample of birds collected from nine beaches between 27 November and 1 December, along with oil, debris and tar balls retrieved on 1 December. The analysis revealed that the source was not crude oil from the *Terra Nova* spill, but consistent with bilge or waste oil likely discharged from a single vessel (G. Thomas, Environment Canada-Environmental Protection Branch (EC-EPB), pers. comm.).

At the time, only limited information was available on seabird resources in the vicinity of the *Terra Nova* oil field (Wiese et al. 2001, Burke et al. 2005). Environment Canada-Canadian Wildlife Service (EC-CWS) biologists were deployed to the site to assess the situation and to determine appropriate methods to gather data on seabird numbers. Counts of birds were conducted from helicopters on 25, 27 and 28 November and from vessels on 28 and 29 November.

Previous models assessing seabird mortality from oil at sea have relied on oiled birds found along beaches or shorelines (e.g., Page et al. 1990, Piatt et al. 1990, Heubeck et al. 2003, Wiese and Robertson 2004). However, in the case of the *Terra Nova* oil spill, the offshore location (340 km east-southeast of St. John's, NL) and dominant offshore winds meant that bird carcasses could not drift westward to land and live birds would have had to fly into the wind for more than 300 km to reach land. Drift blocks released during the monitoring of the spill were not recovered and were difficult to re-sight during aerial or vessel-based surveys. Thus, mortality could not be estimated from drift blocks recovered at sea, or from carcasses on beaches. Instead, two independent methods to estimate numbers of seabirds possibly oiled in the *Terra Nova* spill were used. The first approach involved combining information on seabird densities collected at the time of the spill and the total ocean area covered by the slick to estimate the total number of seabirds that were at risk of being oiled during this incident. A total risk estimate was produced by combining estimates of numbers of birds potentially exposed to oil with the probability of these birds actually being oiled and the probability of a bird dying after oiling. The second approach involved predicting seabird mortality based on published observed relationships between the volume of oil spilled and seabird mortality estimates (Burger 1993, Schneider 2002).

The purpose of this report is to estimate the number of seabirds at risk and potentially killed during the November 2004 *Terra Nova* oil spill. The assumptions underlying these estimates are evaluated and assessed for bias.

2. Estimates of birds at risk based on seabird densities and impacted area

2.1 Methods

2.1.1 Surveys at sea from the Burin Sea

Surveys were conducted by P.C. Ryan on board the oil rig tender *Burin Sea*, one week after the first *Terra Nova* oil spill, on 28 and 29 November 2004, within (points E-L) and just outside (A-D and M-P) the affected area, as modeled by André LaFlamme Environment Canada (Fig. 1). Surveys at sea were conducted using standard pelagic survey techniques (Komdeur et al. 1992, Burke et al. 2005), whereby all birds observed in a 90º arc ahead of the vessel and to one side, out to 300 m abeam of the vessel, were counted. They were identified to species or genus when possible, and recorded as flying or on water. Observations were done continuously during most of the daylight period.

It is recognized that counting all flying birds from a moving vessel leads to an overestimation of bird density (reviewed in Tasker et al. 1984). The preferred method of censusing flying birds involves an instantaneous count, or “snapshot”, of flying birds in the area of interest. According to Tasker et al. (1984), the same number of snapshots should be conducted as the vessel’s speed in knots, when observations are being conducted within a 300 m width. A modified version of the recommended method was used on the *Burin Sea* surveys: one snapshot during each 10 minute period. A more conservative estimate of flying birds was calculated based on these intermittent snapshot counts. It was assumed that bird densities within a 10 minute observation period remained relatively constant. The count obtained during the snapshot was multiplied by the speed that the vessel was travelling during the 10 minute period to estimate densities of birds in flight; vessel speed ranged between 9 and 12 knots (17-22 km/hr).

2.1.2 Other data sources

Since only two days of bird observation following the spill (representing 13.2 hours of survey time) were available, the data collected from the *Burin Sea* were compared to data from similar time periods collected in previous years:

1) Data from supply vessel based surveys collected on 26 and 28 November 2002 were provided by W. A. Montevecchi (Burke et al. 2005). The data collected east of 50º W were examined to obtain densities of murres and dovekies. These surveys did not include snapshot counts of flying birds, so comparisons with the *Burin Sea* data were based on estimates not corrected with the snapshot method.

2) Data from the nearby *Henry Goodridge* semi-submersible drilling rig (Fig. 1) were also available for the month of November in 2000, 2001 and 2002 (Baillie et al. 2005). Counts were to be conducted during day-light hours in 20 minute periods, three times per day. Surveys focused on seabirds, although other bird species and marine

mammal sightings were noted. The survey field of view was approximately 180° with an unlimited observation radius from the forward deck on the Mezzanine level. Platform personnel with other regular duties (i.e., weather/ice observers and dynamic positioning operators) performed the surveys, after undergoing a half-day training session regarding seabird identification techniques. All observations were made with the naked eye, although binoculars and spotting scopes were used to verify identification in some cases. Birds sitting on the surface of the sea were not differentiated from birds in flight. Each species was tallied using the maximum number of birds of a given species seen within a 20 minute period per day (DMAX; Tasker et al. 1986). Although precise density estimates cannot be made with an unlimited viewing radius, DMAX values can be quadrupled if one assumes that birds are seen out to 400 m (see Baillie et al. 2005 for details). However, even a 400 m viewing radius likely greatly overestimates the actual observation range of the observers, as Gaston et al. (1987) noted that dovekies were generally detectable to 150 m and murres to 220 m, which would, in turn, result in gross underestimates of density. Standard errors and 95% confidence intervals were based on the number of days where observations were made (n = 52 over the 3 years).

3) Counts of murres and dovekies for November and December were extracted from the PIROP (Programme Intégré des Recherches sur les Oiseaux Pélagiques) database for the Grand Banks (search restricted to 43º-50ºN and 48º-57ºW), and frequency distributions were compared between the PIROP and *Burin Sea* datasets using a Kolmogorov-Smirnov two-sample test. Between 1970 and 1983, 447 observation blocks of 10 minute in length were conducted, representing 74.5 hours of survey time (Fig. 2). In the case of the older PIROP data, observations were done within a 180º arc from the front or to one side of the vessel and all birds seen at an unlimited radius within a 10 minute watch were recorded.

To make the data sources comparable, all data sets were grouped into 10 minute observation blocks, and analyses used these blocks as the sample unit. Ship speed was used to calculate the area covered by the survey and to convert each 10 minute observation into a density of birds/km^2. As older PIROP data were collected without a fixed width from the vessel, bird observations were left as counts per 10 minute unit. Standard errors and 95% confidence intervals were also based on the 10 minute watch being the sample unit.

2.1.3 Aerial surveys of birds at sea

Three helicopter surveys were conducted within the affected area on 25, 27, and 28 November 2004. Each survey had two observers count birds on either side of the aircraft with a transect width of 170 - 259 m per side. The transect width varied due to the altitude at which the survey was conducted and the observer's chosen range of view. Records from both observers were grouped into 5 minute time blocks, and data were analyzed using these blocks as the sample unit. Counts were converted to densities (birds/km^2) based on area surveyed. Flight speed ranged between 130 – 165 km/hr. Length of survey ranged between 36 - 88 min. Bird identification and counts were done by three experienced observers (K. Knox, Jacques Whitford contracted by Eastern Canada Response Corporation (ECRC); G.J. Robertson and P.C. Ryan, EC-CWS).

2.1.4 Estimating birds at risk of being oiled

To estimate the numbers of birds that were at risk of being oiled during this incident, densities of murres and dovekies were calculated, based on the *Burin Sea* surveys collected by P. C. Ryan on 28 and 29 November 2004. Only murres and dovekies were considered, as they are highly vulnerable to oil pollution (Wiese and Ryan 2003). A few auks (n = 36) could not be identified to species or genus, but rather were recorded as "unidentified auks". These records were excluded from density estimates made for murres and dovekies separately, but were included in the final estimate of the numbers of birds at risk. Densities of other pelagic seabird species observed were also calculated, but given uncertainties in their risk of being oiled in this incident, mortality estimates were not calculated.

As there was no quantitative way to estimate whether murres and dovekies flying through the impacted area were at risk of being oiled, estimates of the total numbers of these species at risk were derived under three scenarios:

1) All murres and dovekies sitting on the water would have been at risk of being oiled, while no flying birds would be at risk.

2) All murres and dovekies on the water, and 50% of the flying murres and dovekies, would be at risk. This assumes that half the flying murres and dovekies would have landed in the impacted area at some time.

3) All murres and dovekies on the water and in flight were at risk of being oiled. This assumes that all flying murres and dovekies would have landed in the impacted area at some time.

2.1.5 Estimating the area impacted by oil

The area impacted by oil was estimated at 793 km^2. This estimate was derived from the actual and estimated position of the oil slick over 6 days (21-26 November 2004). By 27 November the slick had largely dissipated (see below). The outer boundary of the affected area was based on information obtained through: 1) aerial surveillance (Canadian Coast Guard (CCG) and Transport Canada), 2) oil trajectory modelling (Environment Canada - Meteorological Service of Canada, EC-MSC), 3) RADARSAT satellite imagery, and 4) a deployable free-floating tracking buoy (ECRC). Visual estimates of size and position of the slick were restricted during the first two days, due to limited personnel in the field (A. Laflamme, EC-EPB, pers. comm.) as a result of poor weather conditions (G. Thomas, EC-EPB, pers. comm.). However, increased aerial surveillance starting 23 November and the acquisition of the satellite image on the same day provided a more detailed account of the slick's position. Daily estimates of the quantity of oil remaining on the sea surface were also available through aerial surveillance. Overall, the oil slick travelled south, almost reaching the continental shelf edge, and then travelled back north in response to changes in wind direction. By 27 November, a light sheen remained of the slick, estimated at 6.1 litres and measuring 1,500 m by 100 m (flight report generated by CCG, on behalf of the Canada-Newfoundland and Labrador Offshore Petroleum Board).

2.2 Results

2.2.1 Densities of birds at sea estimated from the Burin Sea

Murre densities calculated from observations from the *Burin Sea* following the *Terra Nova* incident varied between 3-4 birds/km^2 for birds on water and increased to 7 birds/km^2 combining birds on water and in flight (Table 1). There was considerable daily variation in the estimates obtained. Mean densities for both observation days (28 and 29 November 2004) were 3.46 ± 0.49 (SE) birds/km^2 for murres observed on water, and 3.44 ± 1.62 birds/km^2 for murres in flight calculated using the modified snapshot method (Table 1).

Densities of dovekies observed on water from the *Burin Sea* were much lower than murre densities, ranging from 0-2 birds/km^2. However, total densities increased to 43.3 birds/km^2 when including birds in flight (Table 1). Closer examination revealed that this high average density was driven by a large number of flying birds observed in one transect (A-B, Fig. 1). Although the modified snapshot method decreased the estimated densities of dovekies in flight to 12.4 birds/km^2, this value was nonetheless substantially higher than densities reported from other data sources (see below).

The density of murres, dovekies, and unidentified auks, combined was 4.55 ± 0.81 (95% CI: 2.97 - 6.13) birds/km^2 for birds sitting on the sea surface during vessel-based surveys from the *Burin Sea* on 28 and 29 November 2004. The mean density of auks in flight for both days, using the modified snapshot method, was 15.80 ± 7.05 (1.99 - 29.61) birds/km^2.

In addition to the two murre species and dovekies, nine other seabird species were observed from the *Burin Sea* in and adjacent to the impacted area. Black-legged kittiwakes (*Rissa tridactyla*) were the most abundant, followed by northern fulmars (*Fulmarus glacialis*) and great black-backed gulls (*Larus marinus*; Table 2). Also observed during both observation days were 12 Atlantic puffins (*Fratercula arctica*), 3 herring gulls (*Larus argentatus*), 2 glaucous gulls (*Larus hyperboreus*), 3 unidentified gulls (*Larus* spp.), 2 great skuas (*Catharacta skua*), 1 razorbill (*Alca torda*), and 1 sooty shearwater (*Puffinus griseus*).

2.2.2 Comparison of Burin Sea *data with data from other sources*

Murre densities calculated from the *Burin Sea* data were in the lower range of those reported by Burke et al. (2005) in 2002 (Table 3) and from the *Henry Goodrich* platform data in November 2000-2002 (2000: 5.71 ± 2.99 birds/km^2, n = 21 days; 2001: 4.29 ± 3.80 birds/km^2, n = 21 days; 2002: 53.80 ± 50.00 birds/km^2, n = 10 days).

The distribution of murre counts for birds seen on the sea surface within a 10 minute observation block differed significantly between the PIROP dataset (1970 – 1983) and data collected from the *Burin Sea* in November 2004 (Kolmogorov-Smirnov two-sample test: D = 0.49, P < 0.01; Fig. 3). However, this difference was due to fewer instances where no birds were seen during the *Burin Sea* observations (30%) compared to the historical PIROP data (79%). Differences in count distribution were also observed for murres in flight, due to less frequent instances of no birds seen from the *Burin Sea* (49%) compared to historical PIROP surveys (67%; Kolmogorov-Smirnov two-sample test: D = 0.18, P < 0.01; Fig. 3).

Dovekie densities observed from the *Burin Sea* were considerably higher than those reported by Burke et al. (2005; Table 3) and total dovekie densities observed from the *Henry Goodrich* platform (2000: 5.14 ± 3.90 birds/km^2, n = 21 days; 2001: 1.24 ± 0.65 birds/km^2, n = 21 days; 2002: 0.00 birds/km^2, n = 10 days). High densities observed from the *Burin Sea* were a result of a large flock of flying dovekies observed on 29 November. To determine if the occurrence of such a large flock is typical, counts of flying dovekies outside the breeding season (October-March) were extracted from the PIROP database for the Atlantic Canada region (search restricted to 43º-60ºN and 46º-65ºW). Results from this search suggest that it is not unusual to see large numbers of flying dovekies during a short period of time (10 minutes) outside the breeding season, particularly near the shelf edge (Fig. 4).

The frequency distribution of dovekie counts for birds on water did not differ between the *Burin Sea* and the historical PIROP data sets (Kolmogorov-Smirnov two-sample test: D = 0.09, P > 0.05; Fig. 3). However, differences in count distribution were observed for dovekies in flight, influenced by the higher occurrence of 10 minute observation blocks where no flying dovekies were seen during the *Burin Sea* surveys (87%), compared to the PIROP surveys (65%; Kolmogorov-Smirnov two-sample test: D = 0.22, P < 0.01; Fig. 3).

2.2.3 Aerial surveys of birds at sea

Results from the aerial surveys showed overall low densities of auks (0.14 – 0.63 birds/km^2) and higher densities of fulmars and kittiwakes (0.14 – 7.44 birds/km^2; Table 4). Other seabirds observed during the three surveys were 5 greater shearwaters, 4 herring gulls, 3 great black-backed gulls, and 5 unidentified gulls (*Larus* spp.). On 27 November, observers noted over 300 black-legged kittiwakes around the *Henry Goodrich*, as the helicopter approached the platform to land.

2.2.4 Estimates of seabirds at risk

Under a scenario where only auks on the water were assumed to be at risk of oiling within the 793 km^2 area of the slick, the minimum estimate was 3,593 (95% CI: 1,975 – 5,345) birds at risk of being oiled (Table 5). Under this scenario, three quarters of the birds at risk of oiling were murres. Under the next scenario, where half the flying auks were also assumed to be at risk, 9,858 (2,082 – 18,259) birds were estimated to have been at risk (Table 5). The ratio of the species was about equal under this scenario, although the confidence intervals for dovekies were twice as wide. 16,122 (2,189 – 31,173) birds were estimated to be at risk of being oiled under the last scenario where all birds on water or in flight were considered to be at risk (Table 5). In this scenario, dovekies represent two thirds of the birds at risk. Again, dovekies had a very wide confidence interval, reflecting their patchy or aggregated distribution at sea.

2.3 Discussion

2.3.1 Observations at sea

2.3.1.1 Evaluating *Burin Sea* data

Murre densities obtained from the *Burin Sea* fell within the low end of the range of densities observed on other surveys conducted in the vicinity of the affected area in November 2000-2002 (data provided by W. Montevecchi). However, murres were more frequently seen during the recent surveys from the *Burin Sea* compared to surveys conducted in the 1970s and early 1980s on the Grand Banks in November and December, despite less area being covered during a 10 minute observation period due to methodological differences. The higher incidence of murres in recent surveys is consistent with reports that both thick-billed and common murre populations have increased in eastern Canada (Gaston 2002, Robertson et al. 2004). Given that a high proportion of these murres over-winter off Newfoundland and Labrador (Donaldson et al. 1997), the higher murre counts at sea likely reflect larger populations rather than limited or unrepresentative sampling at sea.

The high number of flying dovekies observed from the *Burin Sea* were representative of typical dovekie abundance on the Grand Banks. Dovekies are described as being highly social at sea, both within and outside the breeding season (Montevecchi and Stenhouse 2002), and flocks of thousands are regularly observed off SE Newfoundland during November and December (Audubon Christmas Bird Count). According to the PIROP dataset, high densities occur outside the breeding season, particularly near the shelf edge. Therefore, the high dovekie density observed within a small area on 29 November 2004 appears to be typical, and it is possible that several thousands or more may have been impacted from the *Terra Nova* oil spill during the previous week, as the spill approached the shelf break.

In contrast, densities of dovekies observed on water were low overall (0-2 birds/km^2), for all November surveys at sea conducted between 2000 and 2004. Numbers of dovekies observed on water during PIROP surveys were also low, as shown by the high proportion of 10 minute observation blocks where no dovekies were observed (79%). Because auks have high energetic costs of flight, they are expected to spend a high proportion of their time not flying (Bradstreet and Brown 1985, Pennycuick 1987, Gabrielsen et al. 1991) and therefore the low numbers of dovekies observed on the surface is a phenomena that requires further investigation. Perhaps dovekies have a high foraging rate and spend a high proportion of time underwater. Alternatively, dovekies sitting on the sea surface may have been disturbed by the oncoming vessel and taken flight, inflating the number of birds seen in flight while underestimating those seen on water. Furthermore, due to their small size, dark colour and horizontal posture, dovekies are very difficult to observe while sitting on the water, especially when the sea is not calm. Dovekies are the most abundant auk in the North Atlantic; the Grand Banks have been identified as important wintering grounds (Montevecchi and Stenhouse 2002). The overall low dovekie densities reported in all datasets likely reflect limitations experienced by observers at sea so actual densities are likely higher.

2.3.1.2 Evaluating other data sources

Aerial surveys proved to be unreliable in assessing auk densities, yielding substantially lower densities compared to vessel-based surveys, likely due to the low detection rates of auks from fast-moving aircraft. Furthermore, as observers had difficulties differentiating between auk species, analyses separating murres and dovekies were not possible. The speed of the helicopter also made observations difficult and although not quantified, it was thought that some birds dove or flushed in advance of the helicopter. The lack of reliable communication with the pilot during surveys also provided a logistical challenge that may have influenced detection rates.

Data collected from the fixed platform *Henry Goodridge* are problematic for a variety of reasons. Firstly, since an unlimited radius of observation was used, only a rough, back-corrected estimate of density could be obtained. It is highly likely that observers could not see all murres and especially dovekies out to 400 m, which would lead to an underestimate of density. In contrast, some seabird species are known to be attracted to offshore structures, so densities seen from the platform may be inflated compared to the general ocean area (Baird 1990, Burke et al. 2005). In this case, densities would be overestimated. However, murres and other auks appear either not to respond or to be only slightly more numerous next to drilling rigs (Baird 1990), in contrast to surface-feeders such as gulls. Fixed platform surveys are useful for collecting data on day-to-day variation in seabird numbers at the same location, which is not usually possible with ship-based surveys.

2.3.2 Estimating numbers of seabirds at risk of oiling

Using the estimate of slick area and murre and dovekie densities, we inferred that a minimum of 3,593 and up to 16,122 murres and dovekies were at risk of being oiled during the *Terra Nova* incident. However, these estimates are based on many assumptions, which may underestimate or overestimate the final numbers. These assumptions are discussed below.

2.3.2.1 Assumptions resulting in underestimation of numbers at risk

1) Numbers of birds on water were underestimated due to low detection rates or ship avoidance by auks, especially dovekies

Murres and particularly dovekies, have low detection rates compared to other species, such as fulmars (reviewed in Gaston et al. 1987). These low detection rates are largely due to the birds' dark plumage and their behaviour of spending much of their time sitting on the surface or foraging underwater. These characteristics make it difficult for observers to detect individuals, particularly in rough waters. On those rare occasions when the sea is calm, alcids can be observed at distances greater than 100 m. They can be observed diving as the ship approaches, suggesting that alcid numbers are underestimated due to ship avoidance. This contrasts to the well recognized and more obvious attraction to ships by fulmars, petrels, and gulls.

2) Other species known to be oiled during the incident were not included as being at risk

Estimates of total mortality were restricted to only three auk species (thick-billed and common murres and dovekies), although other auk species such as Atlantic puffins and razorbills are vulnerable to oil and occur in the area at this time, but in lower numbers (Lock et al. 1994; P. C. Ryan, pers. obs.). High densities of black-legged kittiwakes and smaller number of northern fulmars, gulls, shearwaters and storm-petrels are also present in the area at this time of year (Table 2; Lock et al. 1994). These species were not included in estimates of the numbers of birds at risk for a variety of reasons. Most importantly, these aerial species are less vulnerable to oil (Appendix A in Wiese and Ryan 2003). There is also some evidence that fulmars avoid large slicks, although they were attracted to the vessels in the vicinity of a slick (Lorentsen and Anker-Nilssen 1993). However, individuals of these species were oiled in this incident, as oiled greater black-backed gulls were recovered near the spill and brought to rehabilitation facilities in St. John's, and oiled black-legged kittiwakes were observed during surveys (P. C. Ryan, pers. obs.).

3) Model assumes that only birds in the delineated area were at risk

Our assessment of the number of birds at risk does not take into account birds that may have entered the oily area after the slick had originally travelled through. Some species, such as marbled murrelets (*Brachyramphus marmoratus*), may continue to use a contaminated area, even when visible sheens are present (Kuletz 2001). If birds are unable to detect a slick until it is close, then, when an oil slick starts to break up, the effect is that an alcid that dives to avoid an approaching slick has a good chance of surfacing in the middle of another slick. Furthermore, one would expect the number of birds coming in contact with a slick to be amplified by place keeping behaviour, where birds move into the wind to avoid being displaced from feeding grounds.

The slick initially travelled south from its point of origin. However, as a result of changes in wind directions, the slick retraced its path in a northward direction on 26 November, thereby re-covering the impacted area from the day before (A. Laflamme, EC-EPB, pers. comm.). In this instance, the oil slick may have impacted additional birds in the same area on two separate occasions.

4) Some oil may have persisted after 26 November

The mortality estimate assumes that no birds were at risk after 26 November, based on the observation that the oil slick had generally dissipated by that date (A. Laflamme, EC-EPB, pers. comm.). Nonetheless, an oil sheen was still present on 27 November, which may have continued to have an impact on some birds in the area. Furthermore, it was possible that other small areas of the slick may have persisted several more days, which again would increase the total number of birds at risk.

5) The outer boundary of the affected area is a conservative estimate

Weather conditions did not allow for detailed visual assessment of the oiled area until two days after the spill occurred. Consequently, the size and location during the initial spill relies solely on the oil trajectory modelling, which is likely an underestimate of the area (A. Laflamme, and G. Thomas, EC-EPB pers. comm.).

2.3.2.2 Assumptions resulting in overestimation of numbers at risk

1) All birds on water were at risk

The estimate is based on the assumption that all birds which may have been on the surface of the ocean within the impacted area as the slick passed through were at risk. Little is known about how birds react to an oil slick, and it is possible that some birds may have deliberately avoided the substance by leaving the area (see below), or left the area for other reasons.

2) Estimated ocean area was entirely covered by oil at one point in time

The mortality estimate model assumes that the oil slick travelled uniformly through the entire impacted area. However, it is more likely that the edge of the impacted area delineates the outer boundary of where many smaller patches of oil were travelling. The oil slick broke up into many smaller slicks, as a result of strong wave action and high winds. Therefore, birds present in an area traversed by oil, particularly during the later period, may not have come into contact with oil.

2.3.3 Evaluation of estimates of birds at risk and relationship with mortality

The estimate of number of birds at risk within the 793 km^2 affected area was based on typical seabird densities for that area. Three scenarios were considered that varied the proportion of birds in flight potentially impacted (0%, 50%, and 100%), resulting in a range of estimates (3,593 to 16,122 murres and dovekies). This approach was used due to the uncertainty of the proportion of birds in flight actually at risk of being oiled.

All of the abovementioned assumptions that underestimate or overestimate birds at risk affect all three scenarios equally. The only factor varying the estimates is the number of birds in flight that may have come into contact with the affected area. The behaviour of auks in response to oil slicks is largely unknown; they may be attracted or avoid oil slicks at sea. Because we simply do not know how many birds in flight may have come into contact with oil, we propose that the second scenario (i.e., 50% of birds in flight were potentially impacted) is most probable, yielding an estimate of 10,000 birds of vulnerable species potentially at risk of oiling during the *Terra Nova* spill that occurred on 21 November 2004. However, other studies using densities of birds at sea to estimate mortality following a major oil spill did not differentiate between birds on water and birds in flight (Page et al. 1990, Piatt et al. 1990), suggesting that any bird observed within an area will likely be in contact with the water surface, and therefore at risk of oiling. Therefore, the next most probable scenario would include more birds in flight, thereby increasing the proposed number of birds impacted by the *Terra Nova* spill, potentially up to 16,000 birds. The proposed scenario that no birds in flight observed within the impacted area were affected by the *Terra Nova* oil spill is least likely, and therefore the estimate of 4,000 birds should be viewed as a bare minimum.

We assume that all birds at risk of oiling actually became oiled and that oiled birds eventually perished. Even small amounts of oil compromise the integrity of the waterproofing provided by feathers, resulting in hypothermia and eventually death (Leighton 1993). The rough seas and cold water temperatures in November exacerbate this problem for alcids which live on the water. The assumption that birds perish if oiled applies more strongly to alcids than to aerial gliders such as fulmars.

Aerial species, such as gull and kittiwakes may be able to survival longer, perhaps indefinitely, with small amounts of oil, so we chose not to include these species in the estimate of total number of birds at risk. In contrast, once their plumage has been compromised, most birds of species which are forced to dive for food will eventually succumb.

3. Estimate of mortality based on volume of spilled oil

3.1 Methods

An estimate of the number of seabirds killed by the *Terra Nova* incident based on the volume of the spill was calculated from a power law that scales carcass count to spill size, with an assumed linear relation between carcass count and total mortality N_{kill}:

$$N_{kill} = F^{-1} N_{carcass} \qquad [1]$$
$$N_{carcass} = kV^{\beta}$$

where *V* is spill volume, *k* is an empirically estimated constant required for dimensional consistency, and ß is a scaling exponent that is expected to have a value of 2/3 if kill scales with spill area, compared to a value of 1/3 if kill scales with the perimeter or diameter of a spill. In data from 34 incidents tabulated by Burger (1993) the estimate of ß was 0.223 (95% CI: 0.04 – 0.422, Schneider 2002), consistent with scaling according to perimeter rather than according to area. *V* is the spill volume in tonnes (using a conversion factor of 7.3 barrels/tonne for crude oil such as that produced at *Terra Nova*). *F* is the proportion of total carcasses recovered over the total kill as estimated from drift experiments. Literature estimates of *F* are in the order of 0.2, as reviewed in Burger (1993) and Wiese and Jones (2001).

The parameters *k* and ß were estimated by least squares regression after linearizing the equation by taking the logarithm of the response variable $N_{carcass}$ and the explanatory variable *V*. Assumptions of homogeneous and normal errors were checked by examining the residuals as a histogram and as a scatter plot against fitted values. The explanatory variable was measured with error, a situation for which reduced major axis (RMA) regression is often recommended. The suitability of RMA regression for this data set was evaluated by examining the residual plots.

With parameter estimates, the model was:

$$N_{kill} = 0.2^{-1} N_{carcass} \qquad [1]$$
$$\log(N_{carcass}) = 2.508 + 0.224\log(V)$$

3.2 Results

For a spill of 1,000 barrels (137 tonnes), the estimate of N_{kill} was 4,688 birds (95% CI: 1,905–12,480), which was calculated as follows:

$$N_{kill} = 0.2^{-1} \times 313 \times 137^{0.223 \pm 0.199}$$

The residuals were acceptable (normal and homogeneous), meeting the assumptions for computing the 95% confidence limits from a normal distribution. The confidence limits exclude zero and hence the regression is statistically significant against a criterion of 5%. RMA regression produced a far higher estimate of ß (0.597). Examination of the residual versus fit plot revealed an unacceptable downward trend in the residuals with increase in fitted value, a trend that was not present in the residuals from least squares regression. The RMA estimate was rejected as biased toward high value in large spills, low values for small spills.

3.3 Discussion

This model assumes that carcass counts are a constant fraction of kill. An analysis of *F* as a function of spill size and other factors would represent an opportunity for substantial improvement in this model, but it is beyond the scope of this report.

Another assumption is that the 34 published reports in Burger (1993) are representative of oil spill volumes, which were from 17 to 200,000 tonnes, and carcass counts, which ranged from 100 to 31,000. There is no evidence against this assumption, nor is there any reason to expect selective publication of cases of relatively high or low carcass counts. Since Burger's publication, additional experimental work has been done using drift blocks or seabird carcasses (see Wiese and Jones 2001), providing an updated account of systematic variation in carcass counts.

A plot of Burger's data suggests that the relation of $N_{carcass}$ to spill size is driven by large spills, with no relation at spills less than 3,000 tonnes. However, the plot of residuals versus fitted values from the log – log regression provided no evidence of any change (on a log scale) in the relation of carcass count to spill size above 3,000 tonnes, compared to below.

As discussed below, the actual number of birds killed in an oiling event is a function of the amount of oil and birds that overlap in space and time. There are oiling events that can lead to high mortality due to high densities of birds being present. Hence the estimate of mortality for a spill of 137 tonnes ranged from 1,905–12,480 (95% CI) based on the model.

4. General discussion and recommendations

Because the *Terra Nova* oil spill occurred far from land, it was not possible to estimate seabird mortality using data from beached bird surveys. Rather, an estimate of risk was compared to an independently derived estimate of mortality. The mortality estimate was made with no knowledge of the estimate of risk yet yielded estimates in the same order of magnitude. The risk estimates ranged between 4,000 and 16,000 birds based on estimates of seabird densities, the size of the oil slick, and the proportion of flying birds that were assumed to be at risk. Mortality estimates based on published relationships between spill volume and seabird mortality ranged between 2,000 and 12,000 birds. Because the risk model took into account current information related to the abundance and distribution of vulnerable seabirds at the site of the spill, we argue that the estimate provided from this model is more relevant than the estimate provided by the mortality model. However, being able to compare the estimated number of birds at risk to the independent mortality model reassured us that the estimated 10,000-16,000 birds at risk from the *Terra Nova* FPSO spill is realistic, as both estimates were in the same order of magnitude.

Mortality of seabirds from oil pollution is a combined function of timing and location. Therefore, small spills in densely-occupied areas can lead to high bird mortality. As a local example, in February 1970, the *Irving Whale* spilled 67-156 barrels of Bunker C near St. Pierre, France, off the coast of Newfoundland. The minimum estimate of seabird mortality from this spill was 5,500 birds, mostly common eiders (*Somateria mollissima*; Brown et al. 1973). In February 1986, the *Apex Houston* lost 616 barrels of oil off the coast of California, which resulted in an estimated loss of 11,931 birds, mostly murres and auklets (Page et al. 1990). This last estimate was primarily based on numbers of birds found on beaches, but was based, in part, on densities of birds at sea (Page et al. 1990). The incident occurred when high densities of birds were over-wintering along the coast. The slick went through murre densities ranging from 0-27 birds/km^2, averaging 6 birds/km^2 (densities included murres on water and in flight; Page et al. 1990).

In the case of the *Terra Nova* spill, the oil released was almost twice the volume of the *Apex Houston* spill in an area with similar average bird densities. The estimated mortality in this report may thus have been low by a factor of two, consistent with the upper confidence limit on the estimate of about twice the mean. The models used to estimate risk and mortality in this report were based on several assumptions with most tending to underestimate the number of birds at risk of oiling during this incident, including the proportion of birds in flight potentially impacted by the spill. Therefore, the provided estimate of the number of seabirds potentially oiled in this incident is conservative. Given the high numbers of murres and dovekies that over-winter on the Grand Banks (up to 10 million murres and tens of millions of dovekies), thousands or even tens of thousands of birds killed may not be considered a biologically significant mortality event by itself. However, mortality from any one source must be considered in light of the additive cumulative impacts of anthropogenic activities, notably hunting, fisheries bycatch and ship-source chronic oil pollution in the Northwest Atlantic (Wiese et al. 2004).

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Table 1. Estimated densities of murres (thick-billed and common combined) and dovekies observed from the *Burin Sea* during 28 and 29 November 2004, in and adjacent to the area impacted by the *Terra Nova* oil spill. Values reported as mean ± SE (95% CI).

Date	No. of 10 minute watches	Density on water (birds/km^2)	Density in flight[a] (birds/km^2)	Density in flight using modified snapshot method (birds/km^2)
Murres				
28 Nov	38	3.01 ± 0.55 (1.93 – 4.09)	3.92 ± 1.36 (1.26 – 6.58)	3.65 ± 1.99 (0.00 – 7.54)
29 Nov	41	3.88 ± 0.81 (2.30 – 5.46)	3.30 ± 0.81 (1.89 – 4.89)	3.25 ± 2.53 (0.00 – 8.21)
Average		**3.46 ± 0.49 (2.49 – 4.43)**	**3.60 ± 0.77 (2.09 – 5.11)**	**3.44 ± 1.62 (0.27 – 6.61)**
Dovekies				
28 Nov	38	0.08 ± 0.04 (0.00 – 0.17)	0.00 ± 0.00 (0.00)	0.00 ± 0.00 (0.00)
29 Nov	41	1.98 ± 1.21 (0.00 – 4.35)	83.45 ± 61.31 (0.00 – 203.61)	23.51 ± 13.12 (0.00 – 49.21)
Average		**1.07 ± 0.63 (0.00 – 2.31)**	**43.31 ± 31.98 (0.00 – 105.99)**	**12.36 ± 6.94 (0.00 – 25.96)**

[a]Includes all observations of birds in flight

Table 2. Estimated densities of other seabirds observed from the *Burin Sea* in and adjacent to the affected area during 28 and 29 November 2004. Values reported as mean ± SE (95% CI).

Species	Date	Density on water (birds/km^2)	Density in flight[a] (birds/km^2)	Total density (birds/km^2)
Black-legged Kittiwakes	28 Nov	1.34 ± 1.13 (0.00 – 3.56)	0.24 ± 0.24 (0.00 – 0.70)	1.57 ± 1.15 (0.00 – 3.83)
	29 Nov	1.05 ± 0.74 (0.00 – 2.49)	13.52 ± 3.39 (6.87 – 20.17)	14.56 ± 3.60 (7.51 – 21.61)
Northern Fulmar	28 Nov	0.09 ± 0.07 (0.00 – 0.23)	0.30 ± 0.30 (0.00 – 0.88)	0.40 ± 0.37 (0.00 – 1.12)
	29 Nov	0.00 ± 0.00 (0.00)	1.37 ± 0.93 (5.34 – 3.20)	1.37 ± 0.93 (5.34 – 3.20)
Great Black-backed Gull	28 Nov	1.61 ± 1.46 (0.00 – 4.37)	0.00 ± 0.00 (0.00)	1.61 ± 1.46 (0.00 – 4.37)
	29 Nov	0.03 ± 0.03 (0.00 – 0.08)	0.00 ± 0.00 (0.00)	0.03 ± 0.03 (0.00 – 0.08)

[a]Using modified snapshot method (see text for details)

Table 3. Estimated densities of murres (thick-billed and common combined) and dovekies observed near the Grand Banks oil rigs from vessel-based surveys conducted east of 50ºW and south of 48ºN in 2002 (data source: Burke et al. 2005). Values reported as mean ± SE (95% CI).

Date	No. of 10 minute watches	Density on water (birds/km^2)	Density in flight[a] (birds/km^2)
Murres			
26 Nov	17	17.01 ± 3.04 (10.65 – 23.37)	2.38 ± 0.62 (1.09 – 3.67)
28 Nov	15	4.66 ± 0.57 (3.46 – 5.74)	4.52 ± 0.59 (3.34 – 5.71)
Average		**11.72 ± 2.78 (6.26 – 17.18)**	**3.46 ± 1.07 (1.36 – 5.56)**
Dovekies			
26 Nov	17	0.57 ± 0.24 (0.07 – 1.07)	0.67 ± 0.26 (0.13 – 1.21)
28 Nov	15	0.27 ± 0.14 (0.00 – 0.57)	0.69 ± 0.22 (0.22 – 1.15)
Average		**0.42 ± 0.22 (0.00 – 0.85)**	**0.70 ± 0.26 (0.18 – 1.12)**

[a]Includes all observations of birds in flight

Table 4. Estimated seabird densities (birds/km^2) calculated from helicopter surveys in the affected area, late November 2004. Values reported as mean ± SE (95% CI).

Date	No. of 5 minute watches	Speed (km/hr)	Altitude (m)	Estimated transect width (km)	Total area covered (km^2)	Auks	Kittiwakes	Fulmars	Mixed flocks of kittiwakes and fulmars
25 Nov	7	130-148	91	0.51	40.2	0.16 ± 0.16 (0.00 – 0.47)	5.74 ± 5.12 (0.00 – 15.77)	4.55 ± 2.61 (0.00 – 9.66)	7.44 ± 5.29 (0.00 – 17.81)
27 Nov	7	148	61	0.52	86.5	0.14 ± 0.05 (0.03 – 0.25)	0.65 ± 0.50 (0.00 – 1.62)	0.14 ± 0.06 (0.02 – 0.26)	N/O
28 Nov	10	148	61	0.14	17.4	0.63 ± 0.19 (0.25 – 1.01)	0.69 ± 0.23 (0.24 – 1.14)	0.45 ± 0.27 (0.00 – 0.97)	N/O

N/O = none observed

Table 5. Estimated number of murres and dovekies (95% CI) at risk of being oiled within the impacted area (793 km^2) during the *Terra Nova* oil spill, November 2004 (see text for details).

	Birds on water only	Birds on water and 50% of birds in flight	All birds in flight or on water
Murres	2,744 (1,975 – 3,513)	4,108 (2,082 – 6,134)	5,472 (2,189 – 8,755)
Dovekies	849 (0 – 1,832)	5,750 (0 – 12,125)	10,650 (0 – 22,418)
Total	3,593 (1,975 – 5,345)	9,858 (2,082 – 18,259)	16,122 (2,189 – 31,173)

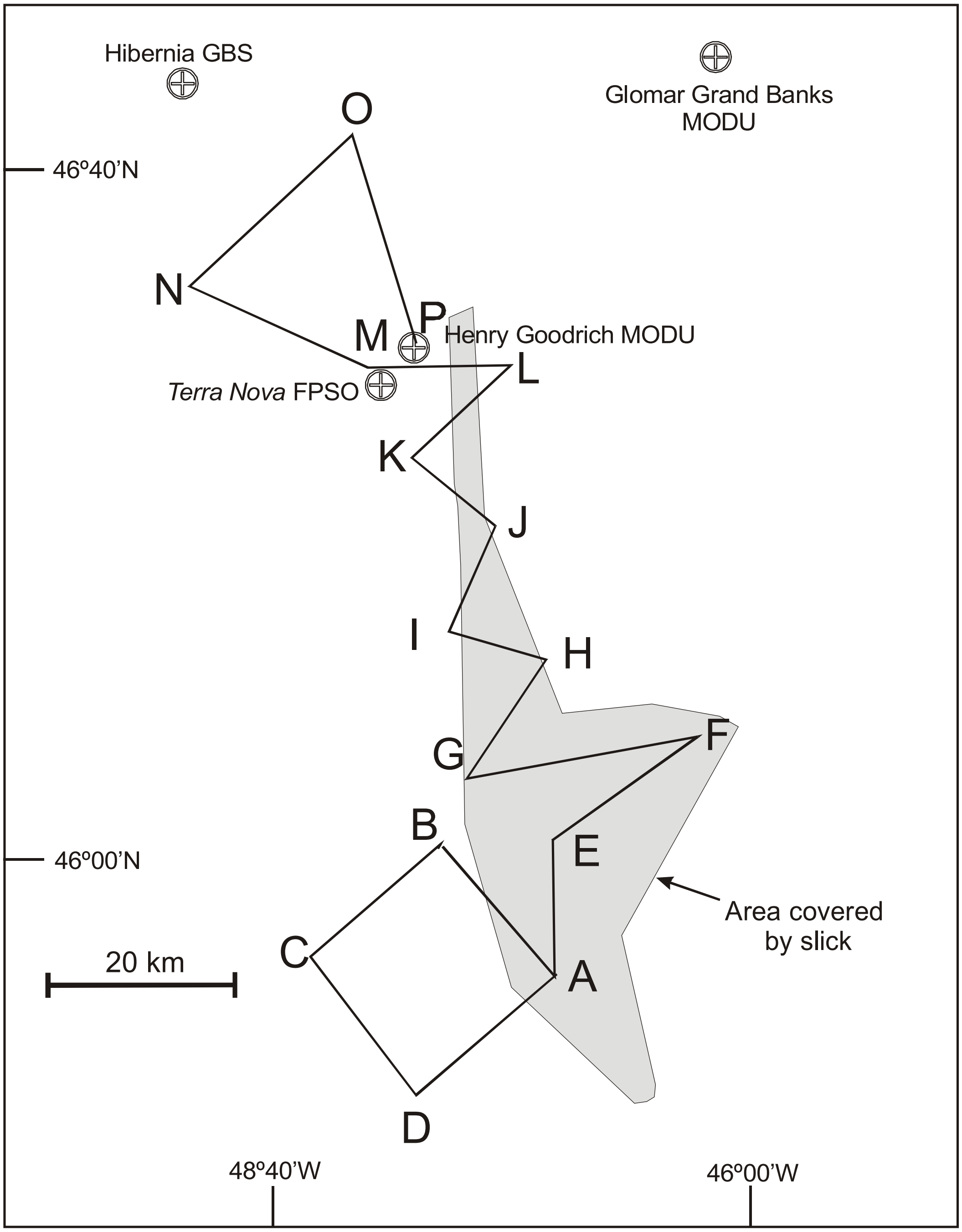

Figure 1. Location of offshore oil installations, area covered by the *Terra* Nova FPSO oil slick (estimated at 793 km^2) and transects covered by the *Burin Sea* on 28 and 29 November 2004 to conduct at sea seabird observations (Points A-P). Map prepared from information provided by ECRC, and oil spill trajectory mapping by A. Laflamme (EC-EPB).

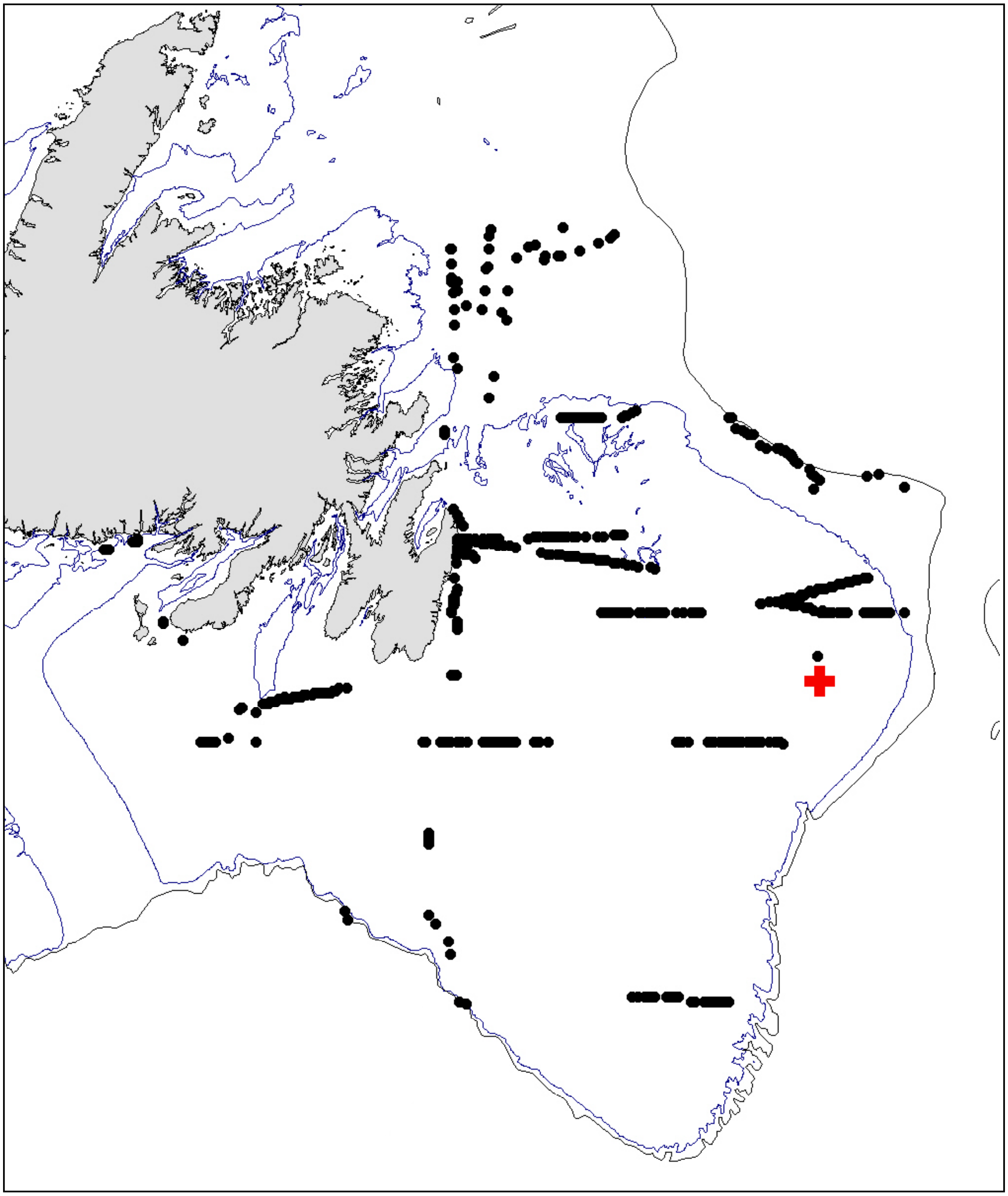

Figure 2. Sampling effort of PIROP data on and adjacent to the Grand Banks in November and December. Each dot represents a 10 minute observation period (n = 447). Contour lines represent 200 m and 500 m isobaths. Cross indicates location of *Terra Nova* spill.

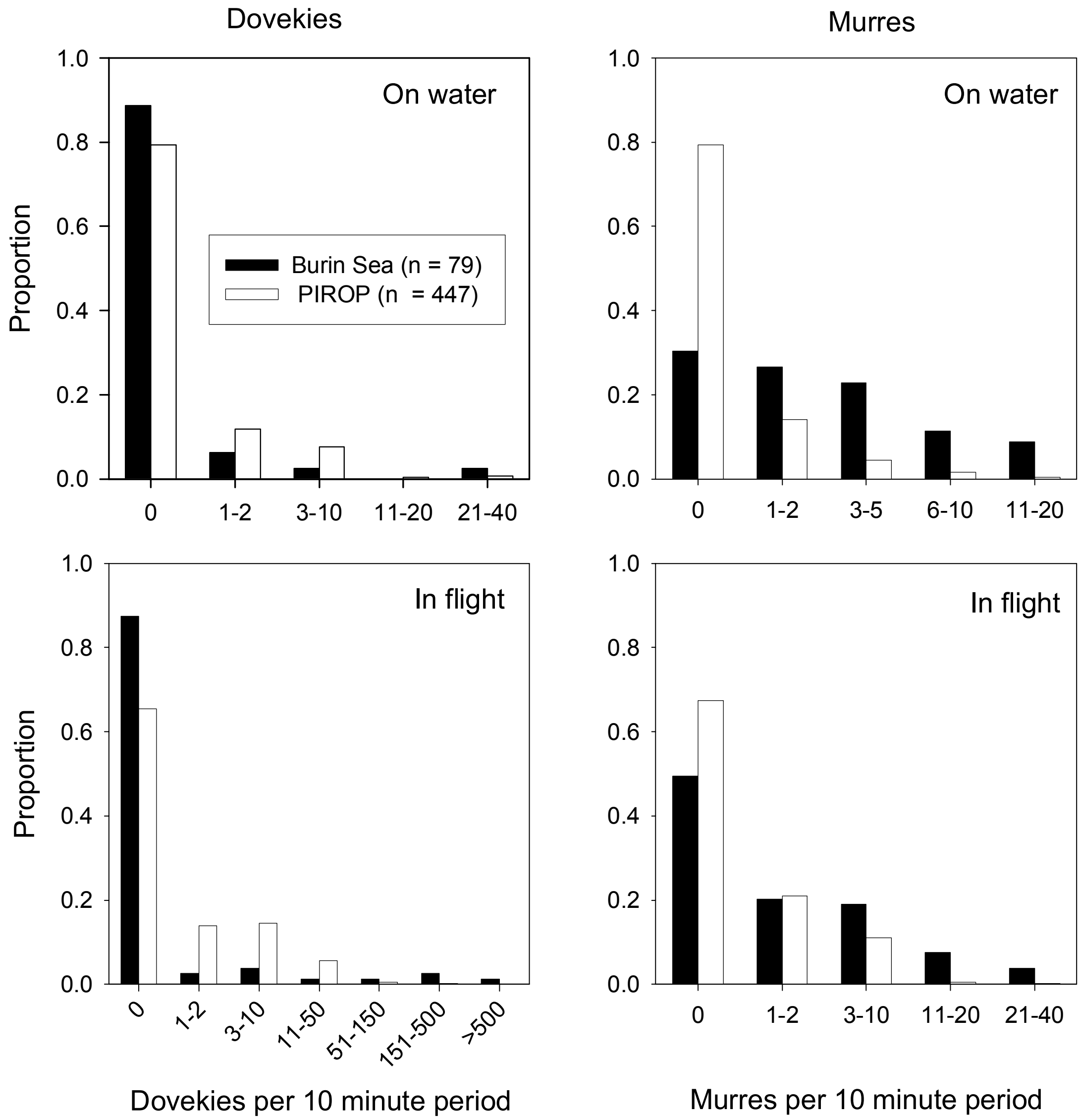

Figure 3. Frequency distribution of dovekies and murres seen on water and in flight per 10 minute observation blocks. Data were obtained from the *Burin Sea* and the PIROP datasets.

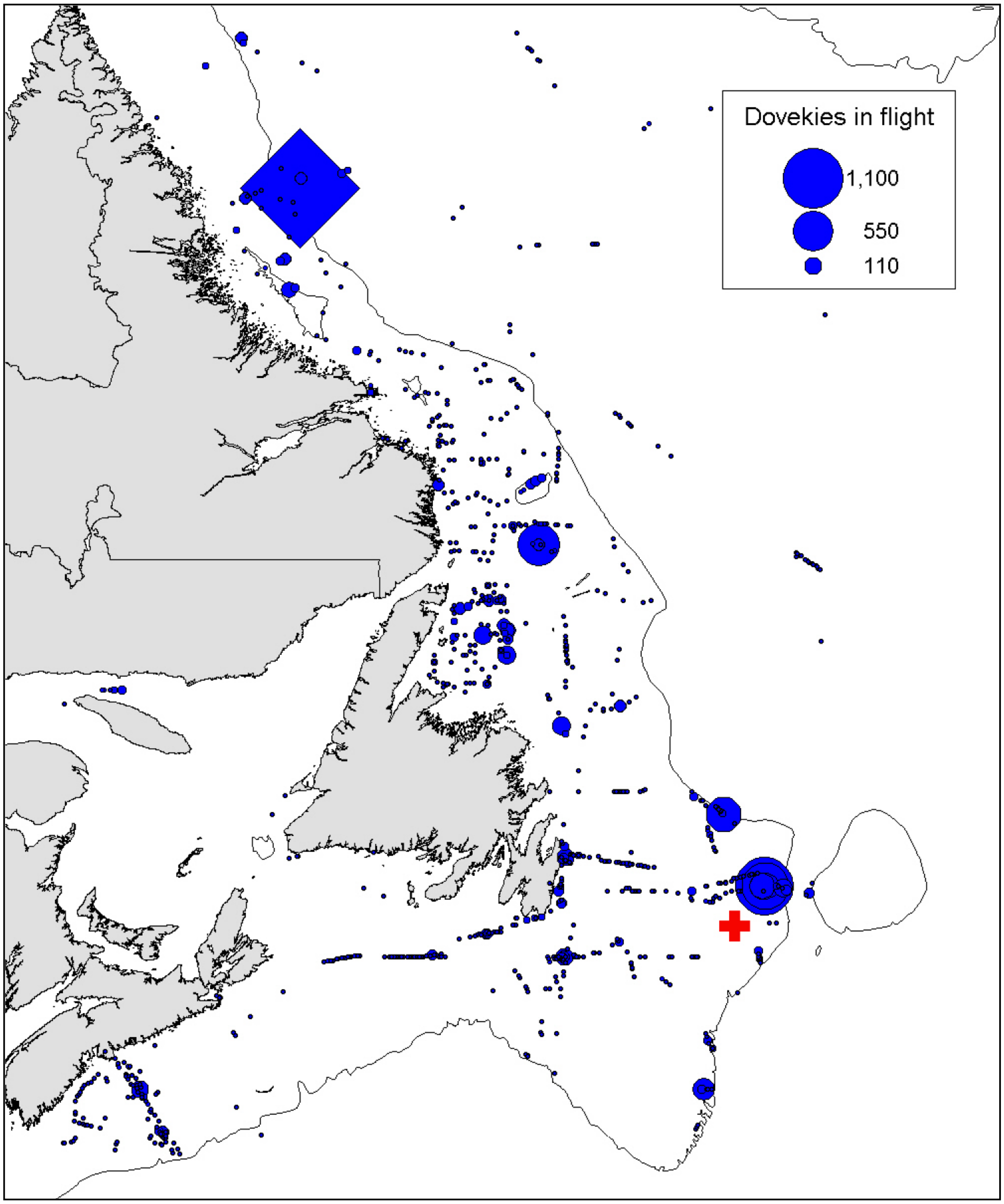

Figure 4. Observations of dovekies in flight (counts/10 minute block) outside of the breeding season (October-March) in Atlantic Canada based on PIROP data (1971-1983). Square represents one 10 minute block where 22,000 dovekies were observed. Cross indicates location of area impacted by *Terra Nova* spill. Contour line represents 500 m isobath.