Birds of a feather

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Robertson, Fifield and a flock of others describe how recent advances in technology are helping to advance our understanding of the abundance, distribution and behaviour of seabirds.

Who should read this paper?

Anyone interested in environmental assessment and/or impact of marine activities on seabirds – this could include regulators, industrial environmental officers, consultants, researchers, environmental non-governmental organizations, and technologists and engineers with an interest in miniaturization, instrumentation or telemetry.

Why is it important?

For decades, research on seabirds was constrained to observations at breeding colonies. Once the birds left the colonies they became the ultimate mariners – what they did and where they went was largely a mystery. As a consequence, the data available to assess potential risks to birds on, in and above the open ocean was very limited. In particular, the impact that a hydrocarbon release in a particular area might have on seabirds was a major knowledge gap. This paper describes how various recent advances in technology are giving researchers insights into both the movements and ecology of seabirds. In particular, miniaturized data 'tags' that combine satellite telemetry with GPS and other sensors (such as temperature, pressure and ambient light) are yielding detailed data about the behaviour of individual birds, as well as their surrounding environs. In concert, video combined with new voice activated software is improving the ability of observers on board ships or reconnaissance aircraft to gather quantitative data on aggregations of birds. This flood of new data is being fed into increasingly sophisticated computer simulations and models that reveal previously unknown daily and seasonal patterns. This information can be used to evaluate the risk to seabirds of a hydrocarbon release, and in so doing to improve environmental impact assessments and response planning. While technology is leading to a myriad of new findings, improvements are needed. For example, further miniaturization of electronic tagging devices and addition of remote data downloading capabilities will help researchers to uncover more information on how a wider variety of seabirds use the open ocean.

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MINIATURIZED DATA LOGGERS AND COMPUTER PROGRAMMING IMPROVE SEABIRD RISK AND DAMAGE ASSESSMENTS FOR MARINE OIL SPILLS IN ATLANTIC CANADA

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ABSTRACT

Obtaining useful information on marine birds that can aid in oil spill (and other hydrocarbon release) risk and damage assessments in offshore environments is challenging. Technological innovations in miniaturization have allowed archival data loggers to be deployed successfully on marine birds vulnerable to hydrocarbons on water. A number of species, including murres (both Common, *Uria aalge*, and Thick-billed, *U. lomvia*) have been tracked using geolocation devices in eastern Canada, increasing our knowledge of the seasonality and colony-specific nature of their susceptibility to oil on water in offshore hydrocarbon production areas and major shipping lanes. Archival data tags are starting to resolve questions around behaviour of vulnerable seabirds at small spatial scales relevant to oil spill impact modelling, specifically to determine the duration and frequency at which birds fly at sea. Advances in data capture methods using voice activated software have eased the burden on seabird observers who are collecting increasingly more detailed information on seabirds during ship-board and aerial transects. Computer programs that integrate seabird density and bird behaviour have been constructed, all with a goal of creating more credible seabird oil spill risk and damage assessments. In this paper, we discuss how each of these technological and computing innovations can help define critical inputs into seabird risk and damage assessments, and when combined, can provide a more realistic understanding of the impacts to seabirds from any hydrocarbon release.

KEY WORDS

Seabirds; Offshore; Oil spills; Risk assessment; Damage assessment; Bird-borne archival data loggers; Geolocation

INTRODUCTION

Marine birds are among animals most at risk from a release of oil on water [Heubeck et al., 2003]. The main impacts of oil on marine birds are well documented [Leighton, 1993] and the most prevalent cause of death is the physical fouling of feathers and the subsequent breakdown of insulative properties of the plumage leading to debilitation, starvation, dehydration and/or hypothermia. In cold waters, these impacts are exacerbated, as only a small part of the plumage needs to be oiled and compromised to lead to hypothermia [O'Hara and Morandin, 2010]. Ingestion of oil can have important effects on individual birds, while long-term exposure to even relatively small amounts of hydrocarbons can have negative impacts on reproduction [Leighton, 1993; Khan and Ryan, 1996], or have a variety of adverse effects mediated through food webs [e.g., Olsgard and Gray, 1995].

Assessments of the risk of an oil release to marine birds are often carried out via standard bird survey techniques; either ground or air based depending on the species, location and timing of the discharge event [Komdeur et al., 1992; Smith, 1995]. Damage assessments are usually based on counts of live, oiled birds and dead carcasses recovered. It is well known that carcass counts underestimate total bird mortality [Ford et al., 1987; Wiese and Jones, 2001; Munilla et al., 2011], so carcass persistence and buoyancy studies, along with drift blocks and/or marked carcass releases can be used to improve estimates of total number of birds impacted [Hlady and Burger, 1993; Wiese and Robertson, 2004; Castège at al., 2007]. Spill trajectory modelling has also been used to improve assessments of the total kill of birds [Page et al., 1990].

These methods for risk and damage assessment are not well-suited to remote areas where there are risks of hydrocarbon discharges. In offshore environments (and even inshore environments where prevailing winds and currents are offshore [O'Hara and Morgan, 2006]), carcasses are not likely to be retrieved onshore. At greater distances from shore, standard bird survey techniques become logistically challenging or are simply not possible (out of range of most aircraft suitable for making observations). New technologies and techniques are needed for making credible assessments of risk and damage to marine birds in the offshore environment.

Here we describe advances in various technologies and software that are leading to improved assessments of risk and damage to marine birds at risk from hydrocarbons released in offshore environments. For the purposes of this paper, we broadly use the terms risk assessment to indicate the various assessments that occur before (and during) an actual discharge (e.g., environmental assessments, mitigation planning, oil spill response planning and directing response efforts during a release). Damage assessment we define as the process of evaluating how many birds were actually impacted so that potential damages can be assigned and to understand the consequences of the impact on marine bird populations.

BIRD DENSITIES AT SEA

Almost any assessment of marine bird risk or damage from a hydrocarbon release requires a robust assessment of bird density in the impacted area. Unlike breeding colonies, where a large and stable portion of the population congregates and can be relatively easily counted, estimating densities of seabirds on the open ocean is fraught with challenges. Until recently, the only viable means of collecting data on seabird densities at sea was through the use of ship-or aerial-based surveys. The earliest efforts relied on using standardized protocols for observers on vessels, but suffered from a range of issues, one of the most important being an unlimited transect width which precluded density calculation [Brown, 1986]. These issues were resolved in later protocols by establishing a fixed width observation transect [Tasker et al., 1984; Gjerdrum et al., 2011], but the issue of whether all birds could be seen within the transect remained. Many birds will be missed on a given survey, and the missed proportion will vary with changing environmental conditions such as weather and sea state, across types of vessels, among different observers and even among species of seabird [Buckland et al., 2001; Barbraud and Thiebot, 2009; Ronconi and Burger, 2009].

A major advance in the robust estimation of seabird densities at sea emerged with distance sampling [Buckland et al., 2001], which requires observers to record the distance to observed birds. The expectation is that birds further from the observer are less likely to be detected, which is almost always the case for ship- and aerial-based observations. A stand-alone software program called DISTANCE allows users to model detectability [Thomas et al., 2010], which can be allowed to vary across a wide-range of covariates, thus correcting for many factors known to affect bird detectability and allowing the use of all available data in one analysis. While distance sampling has greatly improved the reliability of density estimates for pelagic birds, the method still requires an assumption of 100% detection along the transect line itself (i.e., at 0 m distance); an assumption that has been rarely tested for seabirds [Bächler and Liechti, 2007; Ronconi and Burger, 2009], and might be expected to be problematic for species that spend a significant fraction of their time underwater or in conditions, such as heavy seas, that impair visibility.

Many jurisdictions now use protocols that rely on distance sampling to estimate seabird densities, including eastern Canada [Fifield et al., 2009a; Gjerdrum et al., 2011]. There is, however, a cost in terms of the demands on the seabird observer; not only does each bird need to be correctly identified, but the distance to each individual or group needs to be accurately estimated, and the behaviour of the birds along with all the ancillary data associated with the sighting has to be recorded [Gjerdrum et al., 2011]. To ease these burdens on observers (and analysts), Fifield et al. [2009a] developed a voice activated data entry system (using Microsoft Access) that allows the observer to concentrate on the bird sighting, while the software records all of the data related to the observation, including the ship's (or plane's) position, speed and heading via an integrated GPS. These capabilities greatly reduce post-observation data-processing time and eliminate the need for data transcription, essentially removing the chances of data recording and transcription errors.

These advances have taken pelagic seabird observation exercises from simply recording bird observations in a notebook to a sophisticated data collection and analytical exercise, with clear advantages. Densities of many species were underestimated by more than half using older methods; and data from different observers, vessels and collected under different conditions can now be integrated with confidence. Additionally, statistically rigorous estimates of error can now be calculated and propagated throughout risk and damage assessment exercises, recognizing that these densities are only estimates and that the absolute density at any given place and time can never be known.

SEASONALITY AND TIMING OF BIRD MOVEMENTS

A second critical piece of information for risk-assessment is the timing of birds' arrival to, and departure from, areas potentially affected by hydrocarbon releases. On the open ocean, marine birds move readily and quickly, following migratory schedules at larger scales and prey aggregations at smaller scales. This means that any area of ocean could have large densities of a given species one day, and can be all but devoid of birds the next. As well, careful spatial and seasonal assessments are needed around identified areas of persistent occupation and biodiversity aggregation [Worm et al., 2005; Hedd et al., 2011; Montevecchi et al., 2012; McFarlane Tranquilla et al., 2013]. Ship-board and aerial surveys are necessarily a snapshot in space and time of the numbers and species of birds in an area of ocean. Bird movements mean that analysts must be careful when choosing which survey data to include as representative of the seabird assemblage at a given place and time.

Seabird-at-sea surveys can inform when significant influxes or exoduses of birds usually occur from certain areas. However, large datasets are needed, and since sampling is necessarily opportunistic in terms of timing and routing, extrapolations to other areas are somewhat tenuous. In recent decades, our understanding of seabirds throughout the annual cycle has been revolutionized by miniaturized archival data loggers and satellite transmitting tags [Wilson and Vandenabeele, 2012]. Satellite telemetry is now a common method of tracking larger seabird species. Due to power requirements, satellite transmitters have been necessarily large (> 20 g and heavier) and potentially cumbersome for all but the larger species [Weimerskirch and Wilson, 2000; Mehl et al., 2004; Croxall et al., 2005; Shaffer et al., 2005; Gill et al., 2009; Strandberg et al., 2009; Hatch et al., 2010; Montevecchi et al., 2011; Sittler et al., 2011]. For smaller seabirds or those that forage by diving these larger devices have not been widely used [Meyers et al., 1998].

In comparison, some archival data loggers have more modest power requirements, and can be exceptionally small (some less than 1g). Smaller seabirds and diving species do not appear to be greatly impacted by having one of these devices attached to a leg band (Figure 1) [Igual et al., 2008; but see Elliott et al., 2012]. These devices can collect a wide range of information, but in terms of improving our understanding of the timing of movements and areas of occupancy outside of the breeding season, solar geolocation devices have furnished the greatest advances. These tags use a simple light level sensor coupled with a chronometer and allow for a twice-daily estimate of position, based on time of sunrise and sunset [Hill, 1994; Wilson et al., 1992]. Device limitations yield positions that are far less accurate (on the order of ± 100-200 km) than those from Argos satellites or GPS, and do not allow for an estimate of latitude for several weeks on either side of the spring and fall equinoxes. Their performance, however, has proven sufficient for generalizations about timing of migration, large-scale movements

Figure 1: Thick-billed Murre *(Uria lomvia)* on the Gannet Islands equipped with a geolocation archival tag.

DAVID A. FIFIELD

and fall, winter and spring areas of occupancy. Improved accuracy (and location approximations during the equinoxes) can be attained by incorporating sea-surface temperature (SST) data recorded by the data loggers [Teo et al., 2004].

Murres (both Common, *Uria aalge*, and Thick-billed, *U. lomvia*) are two of the most vulnerable seabird species to oil pollution in the Northwest Atlantic [Wiese and Ryan, 2003]. Much effort has been devoted to understanding the movements of these species in relation to offshore hydrocarbon developments. Hedd et al. [2011] tracked breeding adult Common Murres from the species' largest North American colony on Funk Island, off the northeast

Newfoundland coast, and showed that birds moved to areas around current oil production by November and remained in the vicinity throughout much of the winter. Interestingly, they found evidence that males, which accompany the chick to sea and raise them for months after colony departure, remain further offshore than females and may have a higher risk to releases from offshore operations [Hedd et al., 2011]. Satellite tracking of parental males from Funk Island also showed male murres moving through the current oil production area in early fall and continuing south to the major shipping lanes [Montevecchi et al., 2012].

Gaston et al. [2011] tracked breeding Thick-billed Murres from two Canadian Arctic colonies, one in Hudson Bay and the other on the east coast of Baffin Island. Birds from these colonies showed vastly different migration patterns, and only birds from the colony on eastern Baffin Island moved into waters over the eastern Grand Bank, an area of current offshore oil production and heavy shipping traffic (birds from the other colony remained further north in the Labrador Sea). These results show that risks from discharge from the currently operating platforms are clearly colony-specific. McFarlane Tranquilla et al. [2013] integrated the various studies tracking murres in the Northwest Atlantic, corroborating and refining the findings to date. With the larger data set, they could begin to see more general patterns, such as the previously underappreciated use of areas north of the Grand Bank (notably the Orphan Basin, northeast of the Grand Bank) by murres from many colonies (Figure 2). The Orphan Basin is also a prime area of interest for oil and gas exploration in eastern Canada, so these results will inform future environmental assessments in this region as exploration continues and if development and production proceeds. To date, there have been no seabird observers present during exploratory drilling activities, again emphasizing the importance of employing bird-borne micro-technology to gain information about seabirds and hydrocarbon industry interactions.

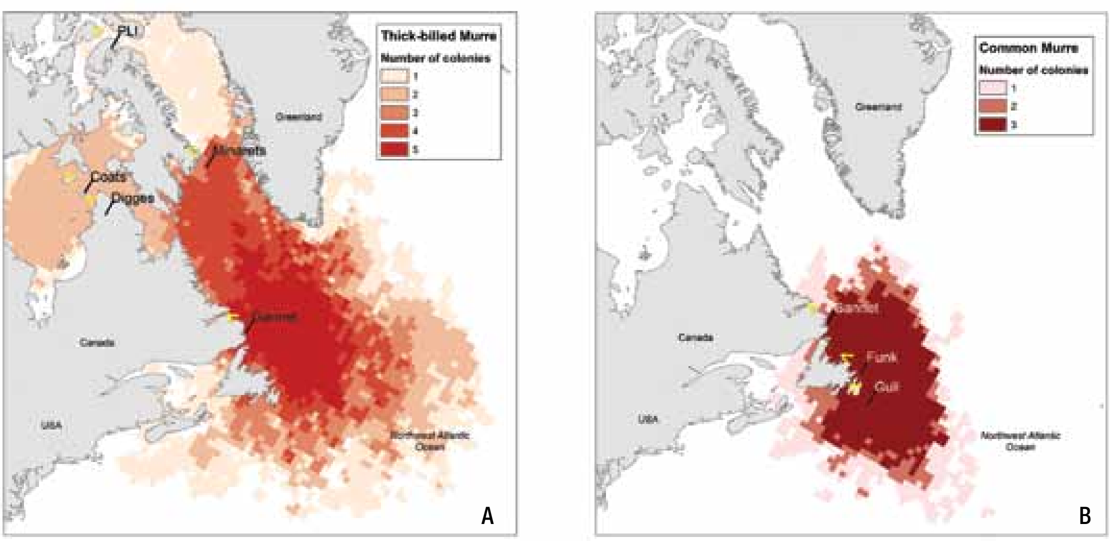


Figure 2: Important areas of use common to colonies of each species: A) Thick-billed Murre and B) Common Murre. Increasing colour intensity indicates increasing representation of study colonies in each grid square (50 x 50 km).

Tracking studies of seabirds in areas of oil development have not been restricted to highly vulnerable species, nor to species that breed in the Northern Hemisphere. Being a more aerial species, individual Black-legged Kittiwakes (*Rissa tridactyla*) are probably not as likely to encounter oil on water compared to a species like murres; but they are found in high concentrations around offshore oil and gas platforms [Baillie et al., 2005; Burke et al., 2005; 2012], increasing their risk. Frederiksen et al. [2012] showed that kittiwakes from most major breeding areas in the North Atlantic use the waters of the eastern Grand Banks during the winter season, peaking in December with return migration to European colonies beginning as early as January. Sooty Shearwaters (*Puffinus griseus*) are an abundant summer visitor to eastern Canadian and northeastern United States waters [Fifield et al., 2009a]. Geolocation studies of birds breeding on the Falkland Islands have confirmed this movement on to the eastern Grand Banks during the boreal summer [Hedd et al., 2012]. Northern Gannets (*Morus bassanus*) are not a species commonly seen near offshore oil operations in Newfoundland, yet geolocation and satellite tracking studies greatly improved the understanding of risk to Northern Gannets from the *Deepwater Horizon* release in the Gulf of Mexico by showing that about 25% of the North American population wintered in the Gulf and concentrated off the coast of Louisiana, a much higher proportion than expected based on decades of banding data [Montevecchi et al., 2011; 2012].

These examples demonstrate how risk assessments of hydrocarbon releases can be much more precise and specific with a better understanding of the seasonal movements and residency patterns of key species.

BIRD BEHAVIOUR ON THE OPEN OCEAN – BIRDS DO NOT ENCOUNTER OIL WHILE FLYING

A third critical piece of information in order to assess the risks faced by seabirds is their general behaviour at sea. Birds on the water will have some probability of encountering a slick, while birds flying over it will not. In addition to the actual amount of oil on water, the probability of encountering oil depends on the proportion of time spent on the water (i.e., versus flying) and the frequency and duration of flights.

Archival data loggers have proven exceptionally useful in helping to answer these questions. Beyond light levels, these devices can also record SST, and some have the capability to detect whether the device is immersed in water (bird swimming or diving) or not (i.e., flying). Fifield et al. [2009b] used immersion data to assess the behaviour of murres wintering on the Grand Bank to improve previous assumptions about the behaviour of birds in the vicinity of an oil spill. Data from 20 data loggers provided information on 13,255 flight times, offering a substantial data set with which to simulate flight behaviour [Fifield et al., 2009b]. However, a surprising result was noted in the data, which was a preponderance of long dry times at night. Murres are relatively poor flyers, and it had been assumed that this species did not fly at night. Further investigation of the data from the devices revealed that these long dry times at night were probably caused by the murres simply tucking one of their legs up into their dry plumage as they roosted on the water. This behaviour has been observed in murres and was also noted in Atlantic Puffins (*Fratercula artica*) [Harris et al., 2010], but it was not

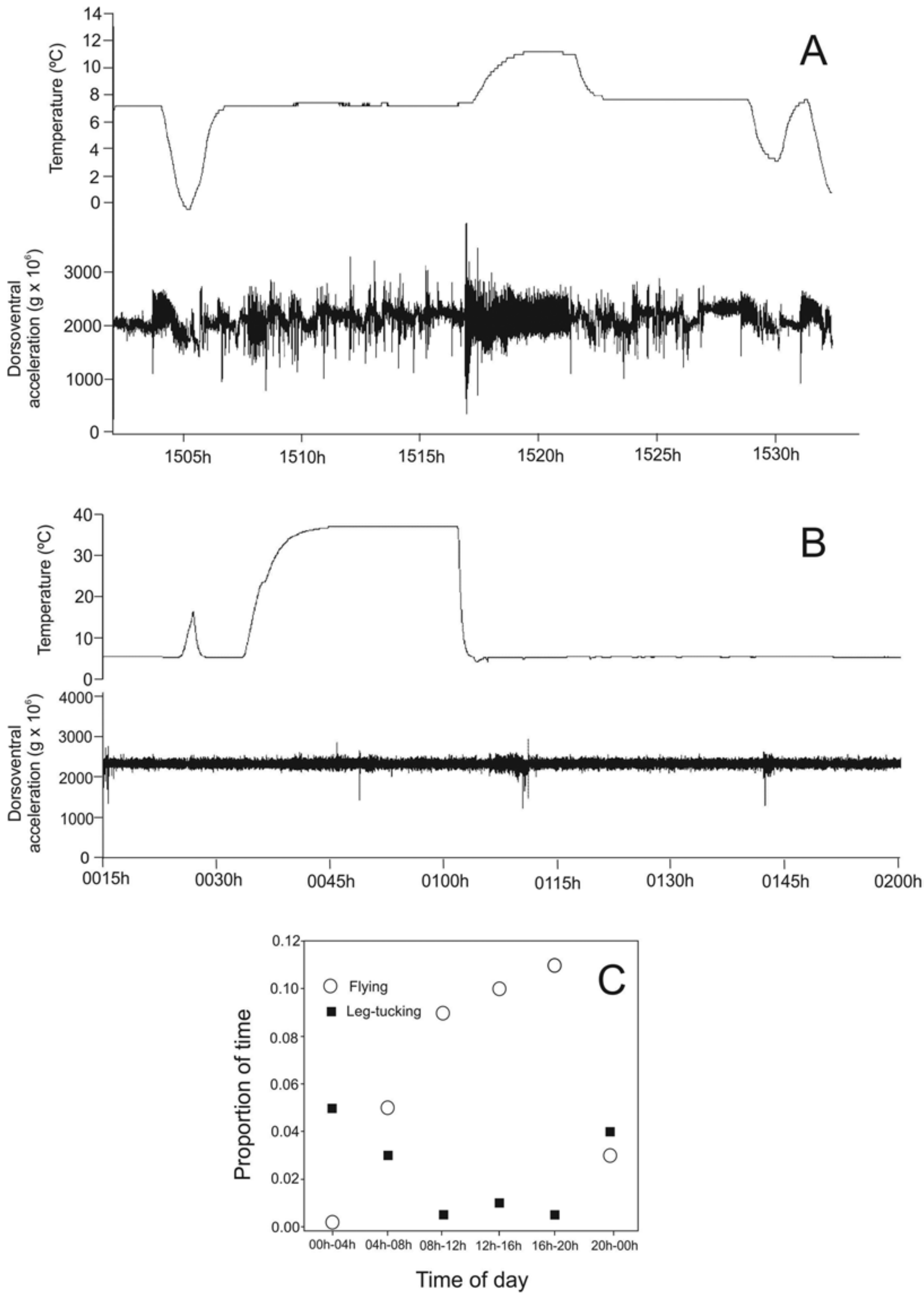


Figure 3: Representative acceleration and temperature data from a validation study where 20 incubating or chick-rearing murres were equipped with both accelerometers (on the back) and temperature loggers (on the leg). A. Flying bird showing a high wing beat frequency from the accelerometer and a leg temperature higher than the water at that time of year (also note that three dives are indicated in this trace). B. Bird resting on the water and tucking its leg showing low dynamic acceleration and high temperature. C. Distribution of leg tucks and flight times shows that birds rarely fly at night but tuck their legs extensively as they rest at the water surface at night.

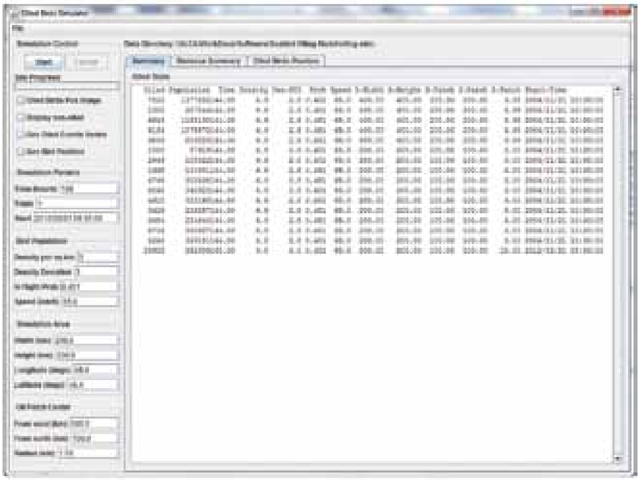
expected to be so common. To address this problem, Fifield et al. [2009b] developed algorithms to separate these suspected leg-tucking events from actual flights. Another possibility is to place a device on both legs, as auks do not tuck both legs at the same time, and so flights are only recorded when both legs are dry. For instance, when 20 murres were equipped with time-depth-temperature loggers on both legs (as part of the experiments described in Elliott and Gaston [2009]), no bird tucked both legs simultaneously.

Another device offering measurements of seabirds' behaviour are time-depth-temperature-recorders (TDTRs) that can collect information on temperature, depth and salt-water immersion. Commercially-available loggers allow for depth and temperature to be recorded at 2-s intervals for extended periods, under the variety of thermal regimes the birds encounter [Tremblay et al., 2003; Elliott et al., 2008; Hedd et al., 2009; Regular et al., 2010]. These devices can also provide data for on-water and off-water times, based on the profile and pattern of the temperature data (TDTRs collect temperature data at a much higher frequency than geolocators). To effectively use temperature as a proxy for time flying, it is important that the loggers record at a high enough rate (<15 s intervals) to capture the temperature transition between swimming and flying and with enough precision (12-bit recording, equivalent to 0.1°C precision) to be able to determine slight variations in temperature between swimming and flying. These devices have a greater ability to distinguish flying from "leg-tucking" than simple wet-dry switches [Fifield et al., 2009b] and have confirmed that murres do not fly at night (Figure 3). In particular, a simple computer script can discriminate between the two activities since leg tucks are typified by a rapid rise to a stable and higher temperature than air (>25°C; Figure 3B), whereas flights are characterized by a slower rise to a variable temperature approaching air temperature (generally <20°C immediately above northern waters; Figure 3A). In that case, a temperature log coupled with a wet-dry switch, or a temperature log that samples at high precision and frequency, could be used to determine flight time with 5-10 s accuracy (dependent on the response time of the thermistor).

Another possibility is offered by accelerometers. Flying murres beat their wings at a characteristic 6.5-8 Hz (depending on wind speed), and it is easy to determine when a murre is flying from accelerometer traces obtained at 16 Hz (the Nyquist sampling rate) or above [Sato et al., 2007]. If those devices were modified to process the accelerometer data in a manner allowing identification and recording of flight events at 1-s intervals, and attached to the leg bands, they would also provide highly accurate flight information, and confirm that murres do not fly at night (Figure 3). Likewise, heart-rate data loggers can record flight times for a year or more, but require surgical implantation [Guillemette and Butler, 2012].

MODELLING BIRDS AND OIL TO ASSESS DAMAGE

Technological advances are providing previously unattainable data on the location and behaviour of seabirds at sea. These data must however be integrated to assess risk and, especially, damage when considering a specific hydrocarbon release. Previous assessments of damage for an offshore spill considered a very simple model that multiplied an estimated density of birds by



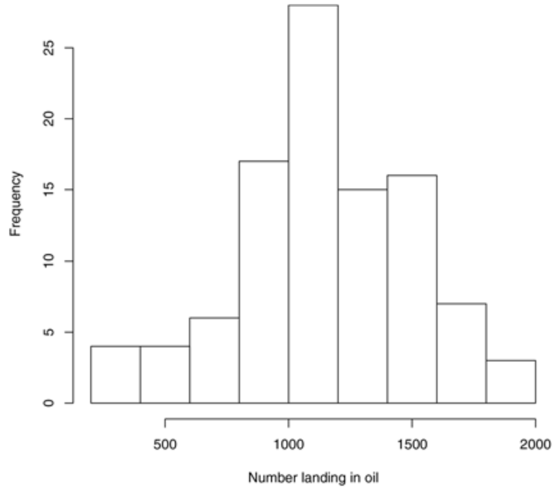


Figure 4 (left): Screenshot showing the seabird oiling simulation software. Figure 5 (right): Histogram showing the number of birds landing in the slick (1156 ± 358) for 100 stimulations of a 10 km^2 spill in a 400 x 400 km area for seven days containing simulated murres at a density of 3 ± 1 birds/km^2.

the spatial extent of the spill to estimate the population at risk [Wilhelm et al., 2006; 2007]. To assess actual damage in terms of birds encountering oil, Wilhelm et al. [2006; 2007] considered a number of scenarios related to swim and flight behaviour, but because behavioural data were not available, the final assessment of damage had a wide range. Fifield et al. [2009b] developed a simulation model to integrate bird behaviour and bird density information in order to improve assessments of potential damage. This model, written in Java (so that it could be run on multiple platforms – Figure 4), allows the user to input information on oil spill size, duration of the spill, bird density with associated standard error, average flight speed of the species, and a distribution of flight durations. The model creates a randomly drawn population of birds based on the densities provided, and overlays a slick of the specified size. The model then proceeds through time steps (for the length of time the slick persisted), and allows each bird to move by making random draws from the flight duration distribution (direction of flight is assumed to be random). The model currently restricts flight to daylight hours (since it was constructed specifically for murres) but other flight schedules are easily accommodated. Any bird encountering the slick is removed from the simulation and tallied. Typically, 1,000 or more runs of the simulation are conducted to obtain a distribution of the number of birds encountering the slick (Figure 5).

This model is a marked improvement over previous approaches, as bird behaviour is explicitly modelled and integrated into the final estimate, along with its variance, of risk/damage. There is a need for more realistic modelling of an oil spill scenario, such as allowing the slick to move and change shape – the current model considers the slick to be stationary. Integrating the oiled bird model with oil spill trajectory models could be an ideal solution.

CONCLUSIONS

Archival data loggers are addressing long-standing questions regarding the movements and behaviour of seabirds away from their breeding areas. These bird-borne devices improve assessments of risk and damage from any anthropogenic impact, including oil spills. Computing power and interfaces are also allowing for the construction of complicated simulation models of bird movements and behaviour, making the most of data in hand. Although much has been learned in recent years, critical gaps remain. Many species winter on the Grand Banks, though data are currently available to describe behaviour for only a few. A concerted effort was made through the 2000s to survey seabirds at sea in eastern Canadian waters, yet despite that effort, important gaps remain [Fifield et al., 2009a; Burke et al., 2012]. In other parts of the world even less is known about the densities and movements of seabirds. Knowledge of other aspects of behaviour, such as whether birds avoid landing within slicks, whether they are attracted to other birds in or near slicks or whether the presence of oil modifies their behaviour in other ways would be useful additional information for risk and damage assessment [Wilhelm et al., 2006; 2007]; but empirical information on how birds move around at these very small scales, and in particular in response to oil, is limited. As a start, different bird behaviours (e.g., attraction, repulsion) near oil slicks could be modelled to see how sensitive model outputs are to different behavioural responses.

Technological advances will continue to enable us to gather more detailed information about the behaviour and movements of pelagic seabirds [Wilson and Vandenabeele, 2012], which will lead to better hydrocarbon release risk and damage assessments for birds in offshore locations. One important current constraint is that archival loggers must be physically retrieved from birds to download the data. For species with high survival rates and a predisposition to nest in the same place every year, this is not a major issue, but for other species this is a significant problem. Remote downloading of data from loggers will provide a major advance when suitable technologies become available for seabirds. Indeed, solar geolocation-based methods of obtaining positional data may be out of date in the near future, as GPS-based technologies become more commonplace and further miniaturized. For counting birds at-sea, human observers have been replaced with video for some applications and this trend is certain to continue [Buckland et al., 2012; Stenhouse and Williams, 2012]. Model-based analytical techniques, which analyse oceanographic or biological information to understand key features that predict concentrations of seabirds, also allow extrapolations of seabird densities to poorly-surveyed areas. These models have the potential to maximize the utility of the data that has been collected to date [Nur et al., 2011; Humphries et al., 2012; Oppel et al., 2012]. Radar technology has been used to assess seabird movements and densities [Burger, 2001; Ronconi et al., 2004; Mateos et al., 2010] and is currently planned for use at offshore platforms. As more and more information is collected from increasingly sophisticated devices, probably the greatest future challenge will be to create robust and tractable methods of integrating these varied data sets into realistic models of risk and damage to seabirds from hydrocarbon releases. A first step will be developing methods to integrate seabird tracking data with the at-sea surveys to allow for the improved extrapolation of bird density data to the vast areas of the ocean that have not been surveyed [Louzao et al., 2009]. Ultimately, better information and integration will lead to more realistic assessments.

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