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Research Paper, part of a Special Feature on Quantifying Human-related Mortality of Birds in Canada

Mortality of Migratory Birds from Marine Commercial Fisheries and Offshore Oil and Gas Production in Canada

Mortalité d'oiseaux migrateurs attribuable à la pêche commerciale et à la production de pétrole et de gaz au large des côtes

Joanne I. Ellis [1], *Sabina I. Wilhelm* [2], *April Hedd* [3], *Gail S. Fraser* [4], *Gregory J. Robertson* [5], *Jean-François Rail* [2], *Mark Fowler* [6] and *Ken H. Morgan* [2]

ABSTRACT. There is an imminent need for conservation and best-practice management efforts in marine ecosystems where global-scale declines in the biodiversity and biomass of large vertebrate predators are increasing and marine communities are being altered. We examine two marine-based industries that incidentally take migratory birds in Canada: (1) commercial fisheries, through bycatch, and (2) offshore oil and gas exploration, development, and production. We summarize information from the scientific literature and technical reports and also present new information from recently analyzed data to assess the magnitude and scope of mortality. Fisheries bycatch was responsible for the highest levels of incidental take of migratory bird species; estimated combined take in the longline, gillnet, and bottom otter trawl fisheries within the Atlantic, including the Gulf of St. Lawrence, and Pacific regions was 2679 to 45,586 birds per year. For the offshore oil and gas sector, mortality estimates ranged from 188 to 4494 deaths per year due to the discharge of produced waters resulting in oil sheens and collisions with platforms and vessels; however these estimates for the oil and gas sector are based on many untested assumptions. In spite of the uncertainties, we feel levels of mortality from these two industries are unlikely to affect the marine bird community in Canada, but some effects on local populations from bycatch are likely. Further research and monitoring will be required to: (1) better estimate fisheries-related mortality for vulnerable species and populations that may be impacted by local fisheries, (2) determine the effects of oil sheens from produced waters, and attraction to platforms and associated mortality from collisions, sheens, and flaring, so that better estimates of mortality from the offshore oil and gas sector can be obtained, and (3) determine impacts associated with accidental spills, which are not included in our current assessment. With a better understanding of the direct mortality of marine birds from industry, appropriate mitigation and management actions can be implemented. Cooperation from industry for data collection, research to fill knowledge gaps, and implementation of mitigation approaches will all be needed to conserve marine birds in Canada.

RÉSUMÉ. Dans les écosystèmes marins, le déclin de la biodiversité et de la biomasse des grands prédateurs vertébrés s'accentue à l'échelle globale et les communautés marines subissent de plus en plus de perturbations. Étant donné la situation, il est important de faire des efforts de conservation et de pratiques exemplaires de gestion pour ces écosystèmes. Nous avons examiné deux industries du milieu marin qui entraînent des prises accessoires d'oiseaux migrateurs au Canada : 1) la pêche commerciale; et 2) l'exploration, le développement et l'exploitation du pétrole et du gaz au large des côtes. Afin d'évaluer l'ampleur et les sources de mortalité, nous avons compilé l'information issue de la littérature scientifique, y compris de rapports techniques, et présentons les résultats d'analyses récentes. La pêche commerciale était responsable du plus grand nombre de prises accessoires d'oiseaux migrateurs : les prises accessoires combinées de la pêche à la palangre, aux filets maillants et aux chaluts de fond à panneaux dans les régions de l'Atlantique (y compris le golfe du Saint-Laurent) et du Pacifique, s'échelonnaient de 7 579 à 38 798 oiseaux par année. En ce qui concerne l'industrie pétrolière et gazière extracôtière, les estimations se situaient entre 188 et 4 494 oiseaux morts par année, en raison de la décharge d'eau souillée qui forme un film d'hydrocarbures, et des collisions avec les plateformes et les navires. Cependant, ces estimations pour le secteur pétrolier et gazier marin sont fondées sur de nombreuses prémisses non vérifiées. En dépit de ces incertitudes, nous pensons que la mortalité causée par ces deux industries n'affectera vraisemblablement pas les communautés d'oiseaux marins au Canada, mais que la pêche commerciale est susceptible de causer certains effets sur les populations locales. De plus amples recherches et suivis seront nécessaires pour : 1) obtenir de meilleures estimations de la mortalité causée par la pêche pour les espèces vulnérables et les populations pouvant être affectées à l'échelle locale; 2) déterminer

[1]Coastal & Freshwater Group, Cawthron Institute, [2]Canadian Wildlife Service, Environment Canada, [3]Cognitive and Behavioural Ecology, Memorial University of Newfoundland, [4]Faculty of Environmental Studies, York University, [5]Wildlife Research Division, Environment Canada, [6]Population Ecology Division, Bedford Institute of Oceanography, Department Fisheries & Oceans

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l'effet des films d'hydrocarbures issus des rejets d'eau souillée, de même que l'attraction des plateformes et la mortalité qui y est associée (collisions, lumière et brûlures par torchères), afin d'obtenir de meilleures estimations de la mortalité causée par l'industrie pétrolière et gazière extracôtière; et 3) déterminer les impacts associés aux déversements accidentels, qui ne sont pas pris en compte dans notre analyse. Grâce à une compréhension accrue de la mortalité directe des oiseaux marins par l'industrie, des mesures d'atténuation et de gestion appropriées pourront être instaurées. Afin de conserver les oiseaux marins au Canada, il sera nécessaire d'obtenir la coopération de l'industrie pour la collecte des données, la poursuite des recherches destinées à pallier le manque de connaissance et la mise en place de mesures d'atténuation.

Key Words: *gillnet fishery; longline fishery; marine birds; oil sheens; platform attraction; seabirds*

INTRODUCTION

Human pressure on marine ecosystems has increased enormously over the last several decades (Halpern et al. 2008) with concurrent global-scale declines in the biodiversity and biomass of large vertebrate predators (Lewison et al. 2005). For seabirds, threats include unregulated harvest, fisheries overharvesting, introduced predators, contaminants, marine oil pollution and litter, climate change, ecotourism, disease and aquaculture activities (Camphuysen and Heubeck 2001, Carter 2003, Burger and Gochfeld 2004, Newman et al. 2007, Votier et al. 2008, Croxall et al. 2012). These activities are directly responsible for the deaths of hundreds of thousands of marine predators worldwide each year (González-Solís and Shaffer 2009). Apex predators are particularly sensitive to these impacts and may show nonlinear responses in the form of sharp unexpected collapses (González-Solís and Shaffer 2009). Seabirds are particularly vulnerable to additional sources of adult mortality because many have life-history strategies that involve naturally high adult survival, low reproductive success, delayed recruitment, and overall slow population growth (Weimerskirch 2001). Because there are many impacts operating in a marine context that increase adult mortality, seabirds, particularly pelagic species, have become threatened at a faster rate globally than other groups of birds (González-Solís and Shaffer 2009, Croxall et al. 2012). Oro et al. (2004) estimated about 30% of pelagic species are threatened with unsustainable population declines.

In Canada, several marine based industries incidentally take, kill, or affect birds during normal operations. We focus on two sectors that have the potential to have important impacts: fishing and offshore oil and gas activities. The incidental catch, or bycatch, of seabirds and other nontarget species, e.g., marine mammals and sea turtles, raises a complex set of scientific, economic, political, and ethical issues (Hall et al. 2000) and is one of the most prominent concerns facing fishery managers and harvesters worldwide (Alverson et al. 1994). Fisheries also have indirect effects on seabird populations including competition for forage prey and creating changes in trophic structure (Tasker et al. 2000). Mortality of migratory birds from offshore oil and gas operations is poorly understood and lingering issues remain related to the potential attraction of birds to the platforms and hydrocarbons released in produced water (Burke et al. 2012). Generally, marine oil pollution is a persistent source of increased mortality and decreased fecundity for marine birds (Ford et al. 1982, Butler et al. 1988). Oil at sea in cold ocean systems that surround Canada is a particular threat to marine birds because they quickly succumb to hypothermia after contacting oil (Wiese and Ryan 2003).

Quantitative assessment of the numbers of migratory birds taken in Canada is needed to actively manage affected populations and ensure that Canada is fulfilling its obligations under federal legislation (Migratory Bird Convention Act 1994, Canada Wildlife Act, Species at Risk Act [SARA]). We summarize information from the scientific literature and technical reports and present new data analyzed to assess the magnitude and scope of mortality. Where possible, we assess the impact of the estimated levels of incidental take on marine bird populations (see also Calvert et al. 2013).

Within this review, we provide mortality estimates for large-scale longline, gillnet, and bottom otter trawl fisheries operating in marine waters within Atlantic and Pacific Canada. We did not include the Arctic because large-scale commercial fisheries are currently limited (DFO-CWS 2003). Similarly, the review does not include an overview of incidental take from freshwater fisheries that may result in bycatch of various species (see Calvert et al. 2013 for more details). This review is also limited to assessing mortality associated with these two industries and does not include assessment of wider cumulative take in the marine environment such as shipping collisions or oiling of migratory birds from chronic oil pollution associated with maritime transportation.

Impacts of commercial fisheries on migratory birds

Seabird bycatch in commercial fisheries has been the focus of research and conservation concern since the late 1980s (Brothers 1991, Tasker et al. 2000, Lewison and Crowder 2003). Common fishing methods and gear classes include: dredges, bottom gillnets, midwater gillnets, hook and line, bottom longlines, pelagic longlines, pots and traps, purse seines, bottom trawls, and midwater trawls. Almost all seabird bycatch occurs in longline (pelagic and demersal), gillnet, and bottom otter trawl fisheries (Chuenpagdee et al. 2003, Sullivan et al. 2006, Zydelis et al. 2009, Anderson et al. 2011, Croxall et al. 2012). Seabird mortality related to bottom otter trawls is a more recent concern (Sullivan et al. 2006). Attracted to baited hooks on deployed lines, seabirds forage while gear is being set and are susceptible to becoming caught on hooks for longline fisheries (Brothers et al. 1999, Tasker et al. 2000, Lewison and Crowder 2003). Once entangled, the bird is pulled down with the line and drowned (Brothers 1991). Gillnets have been associated with high entanglement rates. Seabird mortality with bottom otter trawls usually occurs from interactions with the cables running from the vessel to the net and from entanglement in the net itself (Dietrich and Melvin 2004). Bycatch events can be highly episodic (Piatt et al. 1984, Vader et al. 1990) because of the overlap of aggregations of birds and fishing effort at certain times of year in specific areas (Tasker et al. 2000).

Longline fisheries in Canadian waters

Demersal and pelagic longline fisheries in Atlantic Canada target a variety of species, including: Greenland halibut (*Reinhardtius hippoglossoides*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*), various tunas (*Thunnus* spp.), swordfish (*Xiphias gladius*), and porbeagle shark (*Lamna nasus*). Fishing effort has changed over time, particularly for Atlantic cod following the 1992 groundfish fishery closure (Hutchings and Myers 1995, Sinclair and Murawski 1997). Tuna, swordfish, and Atlantic halibut fisheries have been consistently exploited over the last 30 years, whereas fishing for Greenland halibut off northern Labrador has been reduced since the mid-1980s (DFO-CWS 2003, DFO 2007). Preliminary estimates of seabird bycatch in longline fisheries for the period 1986-1999 were made by Cooper et al. (2000); information up to 2001 has been summarized within Canada's National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (DFO 2007) and updated with data up to 2009 in the 2012 progress report on the Plan (DFO 2012*a*). Clark et al. (2010) provide updated estimates for the Maritime region from 2002-2006 while we provide new information of seabirds incidentally caught in the longline fishery for the Gulf of St. Lawrence region from 2001-2008 (see also DFO 2012*a*).

Demersal longlining occurs on the Pacific coast of Canada with most effort directed at Pacific halibut (*Hippoglossus stenolepis*), spiny dogfish (*Squalus acanthias*), rockfish (*Sebastes* spp.), and sablefish (*Anoplopoma fimbria*; McElderry 1998, DFO 2007). Seabird bycatch in demersal fisheries on the Pacific Coast were noted by Cooper et al. (2000), with quantitative estimates provided by Smith and Morgan (2005) from 1999-2002. Since then almost all vessels in the commercial hook and line groundfish fishery off the Pacific coast of Canada have switched to using electronic video monitoring, rather than having observers on board. A review of fishing effort, reported bycatch (in logbooks), and bycatch events observed during audits of the video is currently under way; in this paper we report some preliminary findings.

Although seabird bycatch is known to occur within the eastern Canadian Arctic in longline and gillnet fisheries targeting Greenland halibut (Mallory et al. 2006), overall estimates of incidental take were not available.

Gillnet and bottom otter trawl fisheries in Canadian waters

The gillnet fishery in the Atlantic targets a variety of species including: Atlantic cod, Greenland halibut, winter flounder (*Pseudopleuronectes americanus*), lumpfish (*Cyclopterus lumpus*), monkfish (*Lophius americanus*), pollock (*Pollachius virens*), and white hake (*Urophycis tenuis*). The problem of incidental mortality of seabirds in the Newfoundland and Labrador gillnet fisheries is well documented (Piatt and Nettleship 1987, Brothers et al. 1999, Cooper et al. 2000, DFO-CWS 2003, Davoren 2007, Benjamins et al. 2008). For the Maritimes, Clark et al. (2010) summarize bycatch estimates from 2002-2006. Here, we provide first estimates of seabirds incidentally caught in the gillnet fishery for the Gulf of St. Lawrence region from 2001-2008 (see also DFO 2012*a*).

In the Pacific region, a reduction in salmon (*Oncorhynchus* spp.) abundance and resultant increase in fishery closures has led to a decline in salmon fishing effort (Smith and Morgan 2005). Quantitative estimates of seabird mortality in these fisheries are provided by Smith and Morgan (2005) for the period 1995-2001.

Bottom otter trawl fisheries target both ground fish, e.g., halibut, and semipelagic species such as cod and rockfish. Seabird mortality due to bottom otter trawling has not been previously quantified for Canadian waters. We present mortality estimates of birds caught in this gear type for the Maritimes and Gulf of St. Lawrence regions from 2001-2008. There are currently no estimates available for British Columbia, Newfoundland and Labrador, or the Arctic regions.

Impacts of oil and gas activities on migratory birds

Impacts associated with oil and gas activities include hydrocarbon pollution, both from operational discharges and spills, and attraction to structures (see Wiese et al. 2001). We focus on mortality associated with operational discharges and attraction to structures. Additional mortality from accidental spills from production platforms or drilling rigs or illegal bilge water discharges from general shipping (see Wiese and Robertson 2004, Wilhelm et al. 2009) and tanker spills (e.g., Wiens 1996) are not explicitly addressed because these activities are not part of normal operations of the offshore oil and gas industry.

Operational discharges: produced water

Produced water is formation water from the oil-bearing substrata brought to the surface with the oil and gas (Patin 1999) and represents most of the waste discharged from offshore oil extraction production facilities (Patin 1999, Veil et al. 2004). Currently, offshore oil and gas exploration, development, and production are relatively limited and concentrated in Atlantic Canada because of the moratorium on oil and gas exploration in British Columbia. The release of hydrocarbons and the presence of oil sheens, through legal discharges of produced water, is the main concern (Fraser et al. 2006, O'Hara and Morandin 2010) because of the potential to compromise thermoregulatory capabilities of diving birds (e.g., Jenssen et al. 1985, Wiese and Ryan 2003). Fraser et al. (2006) provide estimates of auk mortality associated with oil sheens in Newfoundland, but no estimates are available for the gas producing platforms in Nova Scotia.

Platform attraction

Seabirds are attracted to large offshore structures such as drilling and production platforms. Causes for this attraction might include simple attraction to a foreign structure (Tasker et al. 1986, Baird 1990), food concentrations (Tasker et al. 1986), and lights and flares (Montevecchi 2006). Mortality may occur by striking the structure or incineration in the flare, or from oil sheens from produced water or other discharges.

Increased bird densities around offshore platforms and structures are known to occur in Newfoundland. Seabird concentrations around offshore platforms on the Grand Banks Canada were higher than on survey transects leading to the platforms (Wiese et al. 2001, Burke et al. 2012) and large numbers of Black-legged Kittiwakes (*Rissa tridactyla*) and shearwaters (*Puffinus* and *Calonectris* spp.) are noted by observers on platforms (Baillie et al. 2005).

Offshore shelf areas have been shown to be important habitat for many marine species (Fifield et al. 2009), and detailed tracking studies confirm the importance of the Grand Bank shelf area for murres (*Uria aalge* and *U. lomvia*; Hedd et. al 2011, McFarlane Tranquilla et al. 2013) and kittiwakes (Frederiksen et al. 2012). Oiled murres and Dovekies (*Alle alle*), the species most susceptible to oil pollution, have been recorded in small numbers at offshore oil platforms (Burke et al. 2012). We were unable to identify published studies that document seabird mortality due to attraction to platforms and marine vessels for Canadian waters and this has been identified as a significant data gap by Burke et al. (2012) and Fraser (2013).

METHODS

Impacts of commercial fisheries on migratory birds

In the Atlantic, the Department of Fisheries and Oceans (DFO) Fisheries Observer Program data were examined from 1998-2008 for midwater and bull trawls, various seines (except purse), handlines, troll lines, mechanized squid jigging, traps and pots, and dredges and no birds were observed bycaught in those fisheries. In Newfoundland only, trivial numbers of birds were recorded bycaught in shrimp trawls (16 observed sets had bird bycatch) and purse seines (2 observed sets had bird bycatch) and were not examined further. Over 400,000 sets were observed in the Atlantic from 1998-2008.

For Newfoundland, estimates of seabird bycatch in longline fisheries were based on data summarized in DFO (2007). The annual take was derived from the total number of birds caught and the proportion of observed fishing sets during the period 1989-2001 (estimated at 5-10%; DFO 2007). Benjamins et al. (2008) provide estimates of total numbers of incidentally caught seabirds for gillnet fisheries in nearshore and offshore Newfoundland waters from 2001-2003. Incidental catch rates for Newfoundland were derived using incidental catch estimates and net-days as measures of effort from two data sources: DFO's Fishery Observer Program (Newfoundland and Labrador) and Bycatch Collectors, an existing network of selected commercial fishers fishing primarily inshore (DFO, Newfoundland and Labrador Region).

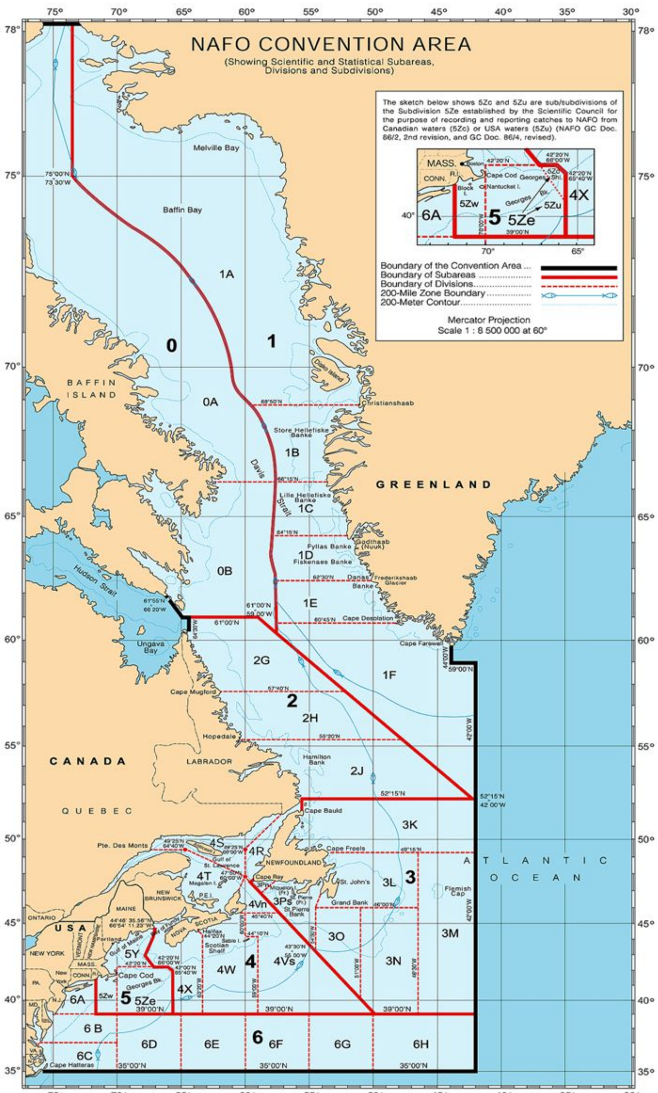
For the Maritimes region, estimates of incidental take of marine birds in longline and gillnet fisheries between 2002 and 2006 were based on analyses made by DFO (Clark et al. 2010). Total weights of discarded birds and mammals were estimated from DFO's Fishery Observer Program for three Northwest Atlantic Fisheries Organization (NAFO) areas (4VW, 4X5Y, 5Z; Fig. 1) considered to be reflective of species assemblages, sectors, and fisheries (Clark et al. 2010). Total discards (metric tons, mt) by fishery and NAFO area were estimated as follows: the total weight of all species landed was multiplied by the ratio of birds to total species landed in the observed portion of each fishery. Species landings (mt) were obtained from DFO, while bird (and other discard) weights were estimated from volume and derived from DFO's fisheries observer database. Clark et al. (2010) reported on the total weight of "birds" discarded and we extended their analysis using their reported observer coverage and the fisheries observer data to identify the species and numbers of birds involved. Many of the birds were counted; however, when weights were provided by observers, numbers were estimated using average bird weights. Clark et al.'s (2010) approach did not include small inshore gillnet fisheries because these fisheries would not be represented in the Fisheries Observer Program.

First estimates of seabird bycatch in bottom otter trawl fisheries for Maritimes region were derived using data from DFO's Fisheries Observer Program for the period 2001-2008. For each year, the total number of birds taken by each gear type in NAFO subdivisions (Fig. 1) reporting bycatch was extrapolated by dividing the number of birds observed caught by the percent observer coverage. Observer coverage was estimated by summing the total weight of the catch for all observed fishing sets, for a particular gear type, and dividing these by the total landings for a gear type within a particular NAFO subdivision and year.

Updated estimates of bycatch in the longline fishery for the Gulf of St. Lawrence (which includes NAFO divisions 4S, 4T and 4R; Fig. 1) and first estimates of bycatch in the gillnet and bottom otter trawl fisheries were derived from data collected by DFO's Fisheries Observers Program for the period

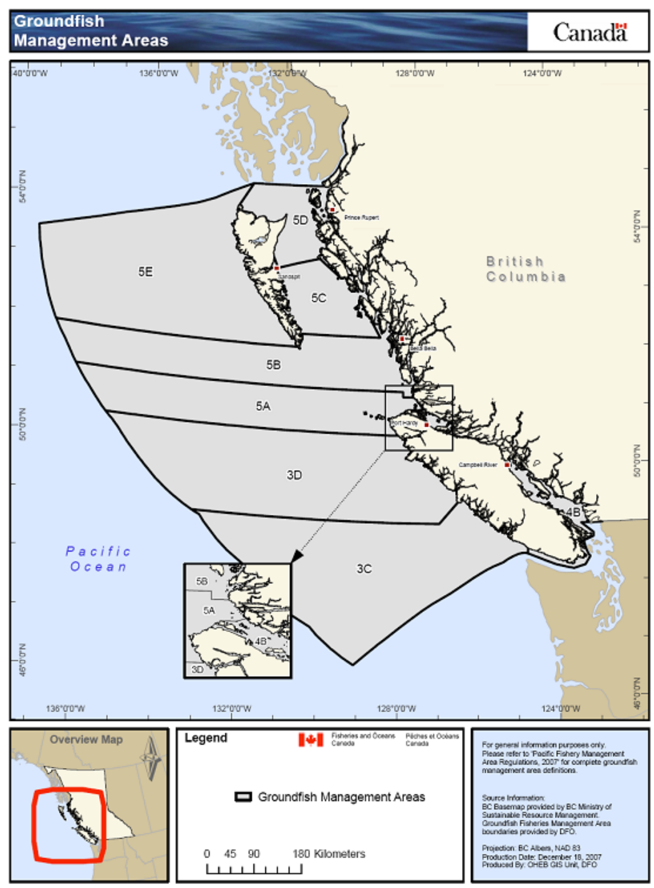
2001-2008 using methods outlined above for the Maritimes region. Similarly, these estimates would not include small inshore gillnet fisheries.

Fig. 1. Geographic delineations of the Northwest Atlantic Fisheries Organization (NAFO) Convention Area. Taken from: http://www.nafo.int/about/frames/area.html



Estimates of bycatch in commercial hook and line groundfish fisheries, occurring off the west coast of British Columbia (primarily over the continental shelf in management areas 3C, 3D, 5A-E; Fig. 2), were derived from seabird mortalities detected during audits of videos captured by the Electronic Monitoring (EM) system. Within the British Columbia groundfish fisheries, virtually all vessels are equipped with the EM system in which each time the gear is hauled, a video recording is made by the system. Upon returning to port, each video is randomly audited, covering approximately 10% of the imagery, and all seabird mortalities are noted, along with other pertinent information, i.e., vessel identification number, gear type, date, set number, etc. Utilizing data, collected and housed by DFO, on fishing effort, i.e., number of sets fished, gear type, date, etc., and the percentage of sets audited by gear type and date, the total predicted annual seabird bycatch for 2006 through 2009 was extrapolated by dividing the number of seabird mortalities observed in the audits by the annual percentage of sets audited. For 2010 and 2011, we extrapolated by dividing the total annual number of seabird bycatch events detected from the audits in 2010 and 2011 by the average annual percentage of sets audited in 2008 and 2009; the predicted total seabird bycatch for 2010 and 2011 should be considered preliminary at this point.

Fig. 2. Commercial groundfish management area map (Source: DFO 2012*b*).



Impacts of oil and gas activities on migratory birds

Information on the impact of oil and gas activities on migratory birds is limited for Canada. The industry has generally adopted a stranded bird-handling program, which allows the operators to possess, under permit, migratory birds that have pitched on

Table 1. Extrapolated estimates of total numbers of birds incidentally caught in longline (pelagic and demersal) and gillnet fisheries in the Maritimes region based on observer coverage information from Clark et al. (2010) and data collected through the Maritimes Fisheries Observer Program (2002-2006). NAFO = Northwest Atlantic Fisheries Organization.

Species	NAFO subdivisions	2002	2003	2004	2005	2006	Total	% of Total
Pelagic longline								
Great Black-backed Gull (*Larus marinus*)	4V4W	193		80			273	36.2
Great Shearwater (*Puffinus gravis*)	4V4W, 4X5Y, 5Z	22	14	40		50	126	16.7
Herring Gull (*Larus argentatus*)	4V4W	14					14	1.8
Northern Fulmar (*Fulmarus glacialis*)	4V4W			20			20	2.6
Northern Gannet (*Morus bassanus*)	4V4W	321					321	42.5
Total		550	14	140		50	754	
Demersal longline								
Great Black-backed Gull	4V4W, 4X5Y, 5Z			300	150	500	950	17.0
Great Shearwater	4V4W, 4X5Y, 5Z	510	240	200	500	500	1950	34.9
Herring Gull	4V4W, 4X5Y	1,020					1020	18.3
Northern Fulmar	4V4W, 4X5Y, 5Z	600		500	25		1125	20.2
Northern Gannet	4X5Y			200		333	533	9.6
Total		2130	240	1200	675	1333	5578	
Gillnet								
Common Eider (*Somateria mollissima*)	4X5Y				400		400	29.1
Double-crested Cormorant (*Phalacrocorax auritus*)	4X5Y				150		150	10.9
Great Shearwater	4X5Y, 5Z	125		700			825	60.0
Total		125		700	550		1375	

a platform or vessel and are disoriented. These birds are handled under approved protocols and held long enough to be safely released, usually the following morning. The activities under this stranded bird program provide some minimal indication of mortalities associated with attraction and striking the platforms. Data from the stranded bird program from 1998-2002 are presented in Baillie et al. (2005) and updated with information from 2003-2006 data from permit reports. The data from 2003-2006 includes all three platforms producing oil at that time. Incidental take estimates from produced water are based on information gathered from published studies.

RESULTS

Longline fisheries in Canadian waters

Atlantic Canada

A previous assessment of seabird bycatch in longline fisheries in Newfoundland waters found that the total number of birds caught during observed trips between 1989 and 2001 was 120 for Canadian vessels (DFO-CWS 2003, DFO 2007). The majority of birds caught were Northern Fulmars (*Fulmarus glacialis*), followed by shearwaters (Great *Puffinus gravis* and Sooty *P. griseus*). General observer coverage was estimated at 5-10% within the Newfoundland region, but the majority of birds (115) were caught in the Canadian demersal longline fishery where a higher proportion of the fishing effort was observed (DFO 2007). Based on the number of observed birds caught and estimated observer coverage, it is estimated that 1200- 2400 birds were caught during the longline fisheries between 1989 and 2001, with an annual rate of 92-185 birds. Observer data have been collected in the region since 2001, but have not been fully analyzed to date.

Using the aggregation scale and observer coverage in Clark et al. (2010), we estimated that a total of 6332 birds were caught by Canadian longline vessels in the Maritimes between 2002 and 2006, at an annual average of 1266 birds/year (range = 234-2680). Observer coverage ranged from 0.2-25% (mean = 7%) for pelagic, and 0.2-10% (mean = 4%) for demersal longline fisheries (Clark et al. 2010). Great Shearwaters dominated the bycatch (33%), followed by Great Black-backed Gulls (*Larus marinus*; 19%), Northern Fulmars (18%), Herring Gulls (*Larus argentatus*; 16%) and Northern Gannets (*Morus bassanus*; 13%; Table 1).

In the Gulf of St. Lawrence, Canadian demersal longline vessels targeting Atlantic cod, Atlantic halibut, and Greenland halibut were estimated to have taken a total of 701 seabirds in NAFO subdivisions 4R, 4S, and 4T between 2001 and 2008

Table 2. Extrapolated estimates of birds incidentally caught in demersal longline and gillnet fisheries, based on data collected through the Gulf Fisheries Observer Program (2001-2008) and total landings data provided by Department of Fisheries and Oceans. NAFO = Northwest Atlantic Fisheries Organization.

Species	NAFO Subdivisions	2001	2002	2003	2004	2005	2006	2007	2008	Total	% of Total
Demersal longline											
Great Black-backed Gull (*Larus marinus*)	4R, 4T				19				4	23	3.3
Great Shearwater (*Puffinus gravis*)	4T						2			2	0.3
Herring Gull (*Larus argentatus*)	4R, 4S	27								27	3.9
Northern Gannet (*Morus bassanus*)	4T			6		3		15	129	153	21.8
Northern Fulmar (*Fulmarus glacialis*)	4S					64				64	9.1
Great Skua (*Stercorarius skua*)	4T			12						12	1.3
Unidentified gull	4R, 4S, 4T	136	6	12		53	12		35	254	36.2
Unidentified bird species	4R					166				166	23.7
Total		163	6	30	19	286	14	15	168	701	
Gillnet											
Black-legged Kittiwake (*Rissa tridactyla*)	4T							31		31	1.1
Common Murre (*Uria aalge*)	4S, 4T	1,744	40						180	1964	67.0
Northern Fulmar	4S								20	20	0.7
Northern Gannet	4S, 4T								90	90	3.1
Unidentified alcid	4R							151		151	5.1
Unidentified cormorant	4T						400			400	13.6
Unidentified gull	4S, 4T	43		11						54	1.8
Unidentified murre	4T				223					223	7.6
Total		1787	40	11	223		400	182	290	2933	

with, on average, 88 birds being killed per year (range = 6-286; Table 1). The percentage of sets observed by independent fisheries observers in subdivisions reporting bycatch ranged from 1-51% (mean = 33%). Herring and Great Black-backed Gulls and unidentified *Larus* species were the most prevalent in the bycatch (43% Table 2).

Pacific Canada

Based strictly upon extrapolated numbers from the proportion of the electronic monitoring video audited, a total of 3037 seabirds were estimated to be taken on hook and line gear in the commercial longline fisheries between 2006 and 2011, at an annual rate of 506 birds (162-907 annually; Table 3). The category 'unidentified birds' accounted for the greatest number of birds (40%), followed by gulls (29%), which included unidentified, Glaucous-winged (*Larus glaucescens*), and Sabine's (*Xema sabini*) Gulls, and Black-legged Kittiwake; albatrosses (*Phoebastria* spp.) were the third most numerous birds taken in this fishery (23%; Table 3). Although many albatrosses were listed simply as 'unidentified,' Black-footed Albatross (*Phoebastria nigripes*) were frequently noted. With the exception of a single Laysan Albatross (*Phoebastria immutabilis*) reported killed in 2012, to date all identified albatrosses caught on hook and line gear in British Columbia, have been Black-footed Albatrosses (K. Morgan, *unpublished data*). Thus, assuming that all of the unidentified albatrosses in Table 3 were Black-footed Albatrosses, the average bycatch of this species increases to 117 birds per year (range 0-248). Other species taken in these fisheries included Northern Fulmar, Sooty Shearwater, and unidentified cormorants (*Phalacrocorax* spp.). Many of the birds detected during the video audits were not listed in the vessel logbooks; consequently, the estimated bycatch numbers presented in Table 3 should be considered conservative.

Gillnet fisheries in Canadian waters

Atlantic Canada

In the Newfoundland and Labrador region, gillnet fisheries for Atlantic cod, lumpfish, monkfish, white hake, and Greenland halibut were responsible for most incidental catch of seabirds (Benjamins et al. 2008). Even so, much of the bycatch originated from the nearshore gillnet fishery for Atlantic cod (Benjamins et al. 2008). The most commonly captured seabirds were murres and shearwaters. More than 5000 murres, over 2000 shearwaters, and tens to hundreds of

Table 3. Reported bycatch from vessel logbooks for all commercial hook and line groundfish longline fisheries in British Columbia (2006-2011) and extrapolated bycatch estimates based upon numbers of birds detected during audits of approximately 10% of the total number of sets fished. Note: the extrapolated values (for 2010 and 2011) were derived using the average percent of sets audited in 2008 and 2009.

Species	2006	2007	2008	2009	2010	2011	Annual Mean
From vessel logbooks							
Black-footed Albatross (*Phoebastria nigripes*)	1	0	0	0	0	0	< 1
Unidentified albatross	33	18	10	2	5	6	12
Northern Fulmar (*Fulmarus glacialis*)	0	0	1	0	0	0	< 1
Unidentified ‘tubenosed’ spp.	0	1	0	0	0	0	< 1
Herring Gull (*Larus argentatus*)	0	0	0	1	0	1	< 1
Unidentified gull	5	99	40	14	28	36	37
Unidentified bird	8	22	6	25	18	38	20
Total	47	140	57	42	51	81	70
From video audits (extrapolated)							
Black-footed Albatross	27	0	21	47	139	228	77
Unidentified albatross	95	0	42	84	0	20	40
Northern Fulmar	0	0	0	0	0	10	2
Sooty Shearwater (*Puffinus griseus*)	0	0	0	0	0	10	2
Unidentified shearwater	0	0	0	0	0	10	2
Glaucous-winged Gull (*Larus glaucescens*)	0	0	0	0	40	159	33
Black-legged Kittiwake (*Rissa tridactyla*)	0	0	11	0	0	0	2
Sabine’s Gull (*Xema sabini*)	0	0	0	9	0	0	2
Unidentified gull	14	306	116	28	79	109	109
Unidentified cormorant	0	193	0	19	0	0	35
Unidentified bird	27	408	201	298	248	40	204
Total	162	907	392	485	506	585	506

Northern Fulmars, Northern Gannets, Double-crested Cormorants (*Phalacrocorax auritus*), loons (*Gavia* spp.), Common Eiders (*Somateria mollissima*), Razorbills (*Alca torda*), Atlantic Puffins (*Fratercula arctica*), and Black Guillemots (*Cepphus grylle*) were captured annually in the area during 2001-2003 (Benjamins et al. 2008; Table 4). In total, it is estimated that 7885 (95% CL: 3811-12,146) seabirds were killed annually in the gillnet fishery in Newfoundland waters.

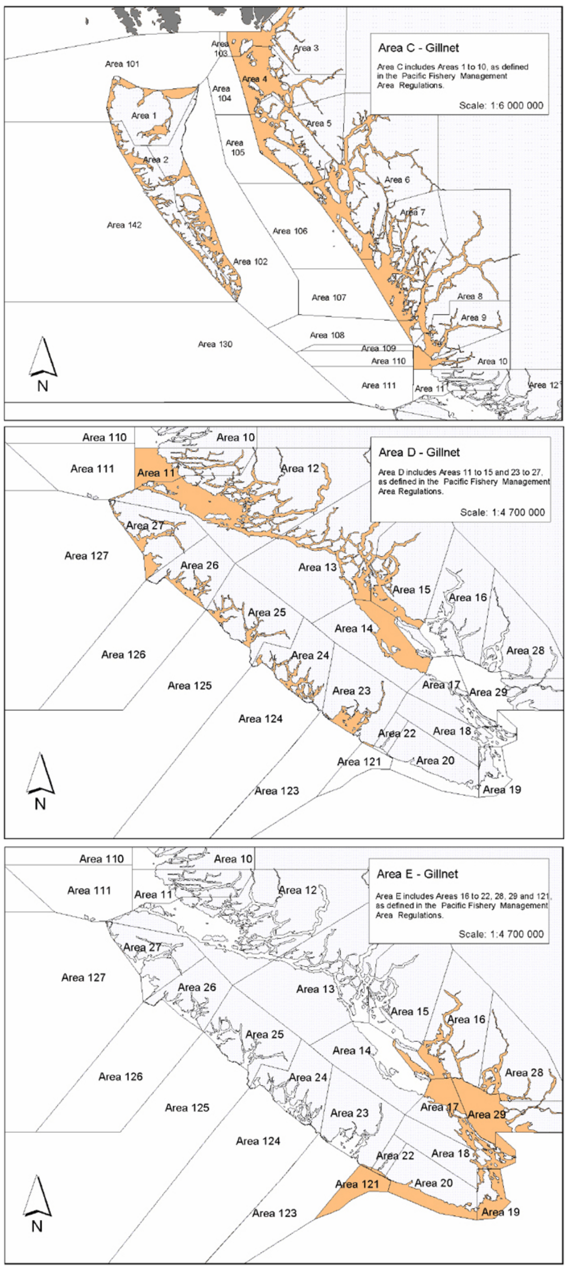
In the Maritimes region, using the aggregation scale and observer coverage in Clark et al. (2010), estimates of the total number of birds taken in gillnets from 2002-2005 were 1375 birds, with an average rate of 275 birds/year (range = 0-700; Table 1). Observer coverage in gillnet fisheries reporting seabird bycatch ranged from 0.03-17% (mean = 6%) between 2002 and 2006. Birds were incidentally taken in the winter flounder and pollock fisheries (Clark et al. 2010), and were restricted to NAFO subdivisions 4X, 5Y, and 5Z (Table 1). Great Shearwaters dominated the species taken (60%) in this region (Table 1) followed by Common Eiders.

In the Gulf of St. Lawrence between 2001 and 2008, it was estimated that 2933 birds were incidentally taken in gillnet fisheries targeting Atlantic cod, Greenland halibut, and winter flounder with an estimated annual take of 367 birds (range = 11-1787; Table 2). Observer coverage in gillnet fisheries reporting seabird bycatch ranged from 2-9% (mean = 5%). Alcids dominated the bycatch (80%; Table 2).

Pacific Canada

The salmon gillnet fishery in British Columbia occurs in DFO’s Pacific Fishery Management Areas C, D, and E (Fig. 3). However, the majority of fisheries occur in areas C3 (mouth of Nass River), C4 (mouth of Skeena River), D12/13 (Johnstone Strait), D23 (west coast Vancouver Island), and E29 (mouth of Fraser River; Fig. 3; L. Wilson, *personal communication*). Based on the total hours fished (all British Columbia commercial salmon gillnets, 2001 through 2004), the average annual fishing effort was 167,206 (± 7369) set-hours (Smith and Morgan 2005). Using bycatch data, Smith and Morgan (2005) derived an average annual bycatch rate of 0.0723 (± 0.0652) seabirds caught/hour of fishing. Utilizing the average and range of fishing effort and the range (average ± SD) of bycatch rates, extrapolations to the entire gillnet fleet were made. This resulted in a predicted average annual bycatch of 12,085 seabirds (range = 1129-24,002; Table 4). The most frequently captured bird (69%) was the Common Murre (*Uria aalge*; range 782-16,636 birds/year) followed by the Rhinoceros Auklet (*Cerorhinca monocerata*; 23%, range 263-5585 birds/year). Marbled Murrelets (*Brachyramphus marmoratus*) made up 2% of the total bycatch in British Columbia's gillnet fishery (range 26-552 birds/year; Smith and Morgan 2005).

Fig. 3. Maps of commercial salmon licence areas (C, D, and E) in British Columbia (Source: DFO 2008).



Bottom otter trawl fisheries in the Maritimes and Gulf of St. Lawrence regions

It was estimated that 59-132 birds were incidentally caught in bottom otter trawl gear in the Maritimes between 2002 and 2008, with an annual rate of 8-19 birds. Great Shearwaters were predominant, followed by Sooty Shearwaters and Northern Gannets. Seven percent of birds were not identified. Birds were caught in NAFO subdivisions 4W, 4X, and 5Ze during the silver hake (*Merluccius bilinearis*), pollock, haddock, and Atlantic cod fisheries. Observer coverage ranged from 3-38% (mean = 15%). For the Gulf of St. Lawrence region, 73 Double-crested Cormorants were caught between 2001 and 2008, yielding an annual estimate of 9 birds. Observer coverage ranged from 18-26% and all birds were caught in NAFO subdivision 4T during the Atlantic cod fishery.

Oil and gas activities

Produced water discharges

Fraser et al. (2006) specifically consider the impacts of oil sheens from daily operational discharges of produced waters on auk populations in Atlantic Canada using dilution models generated from the environmental assessment process for the White Rose platform (Husky Oil Ltd 2000). Assuming a worse-case scenario of sheens occurring 210 days/year and assuming mortality with exposure they estimate that between 52 and 1444 auks could be oiled in the 1 km^2 range surrounding one platform. For three operating platforms in Atlantic Canadian waters that discharge similar volumes of produced water the estimate was 156 to 4332 auks oiled annually because of oil sheens.

More recently O'Hara and Morandin (2010) used an experimental approach to quantify the effect of exposure to oil sheens on seabird feather structure. Microstructure impacts for Common Murre and Dovekie feathers exposed to thin sheens of crude oil and synthetic drilling fluids were tested. The study demonstrated that feather damage can occur with small quantities of oil absorption. The authors conclude that seabirds may be affected by thin, barely visible sheens that form around offshore production facilities from produced water that contains currently admissible concentrations of hydrocarbons (O'Hara and Morandin 2010).

Platform attraction

Baillie et al. (2005) report that 469 birds, mostly Leach's Storm-Petrel (*Oceanodroma leucorhoa*) were stranded on various offshore oil and gas platforms, i.e., various dredge ships, mobile offshore drilling units (MODU), and drill ships, from 1998-2002. Most relevant are the results from a platform that was in place year round that reported that of the 314 birds encountered, 213 were released alive, and 9 died; the fate of the remaining 92 birds is unknown. Over the three years of study, 129, 128, and 49 storm-petrels were recovered annually (2000-2002) and all in the fall and peaking in October. More

Table 4. Extrapolated seabird bycatch for gillnet fishery in Newfoundland and Labrador (2001-2003; derived from Benjamins et al. 2008, mean with 95% CI in parentheses) and British Columbia (1995-2001; from Smith and Morgan 2005, mean with range in parentheses).

Species	Extrapolated Annual Bycatch
Newfoundland and Labrador	
Common Murre (*Uria aalge*)	4822 (2085 – 6921)
Great Shearwater (*Puffinus gravis*)	1752 (1525 – 2149)
Sooty Shearwater (*Puffinus griseus*)	349 (51 – 923)
Atlantic Puffin (*Fratercula arctica*)	216 (32 – 453)
Cory's Shearwater (*Calonectris diomedea*)	156 (0 – 296)
Unknown shearwater	134 (6 – 367)
Black Guillemot (*Cepphus grylle*)	123 (16 – 281)
Northern Gannet (*Morus bassanus*)	118 (83 – 174)
Northern Fulmar (*Fulmarus glacialis*)	98 (0 – 278)
Double-crested Cormorant (*Phalacrocorax auritus*)	46 (0 – 132)
Loons (*Gavia* spp.)	38 (4 – 96)
Razorbill (*Alca torda*)	25 (9 – 50)
Common Eider(*Somateria mollissima*)	9 (0 – 26)
Total	7885 (3811 – 12146)
British Columbia	
Common Murre	8367 (782 – 16,636)
Rhinoceros Auklet (*Cerorhinca monocerata*)	2812 (263 – 5585)
Marbled Murrelet (*Brachyramphus marmoratus*)	278 (26 – 552)
Sooty Shearwater	185 (17 – 367)
Pelagic Cormorant (*Phalacrocorax pelagicus*)	185 (17 – 367)
Pigeon Guillemot (*Cepphus columba*)	123 (12 – 245)
Common Loon (*Gavia immer*)	31 (3 – 62)
Pacific Loon (*Gavia pacifica*)	31 (3 – 62)
Brandt's Cormorant (*Phalacrocorax penicillatus*)	31 (3 – 62)
Cassin's Auklet (*Ptychoramphus aleuticus*)	31 (3 – 62)
Total	12,085 (1129 – 24,002)

recent information from 2003-2006 for the three production platforms on the Grand Banks indicate similar numbers (8-27 [median 12] dead birds and 20-674 [median 75] live birds recovered annually on each platform). Seismic vessels recovered between 0 and 27 dead birds from 2003-2006. In recent years, there are usually four platforms operating on the Grand Banks, which would amount to 32-108 (median 48) birds found dead annually. Similarly, there are generally two seismic vessels operating on the Grand Banks, which would amount to 0 to 54 (median 14) birds killed annually.

DISCUSSION

Effects of commercial fisheries on migratory birds

Gillnet fisheries were responsible for the bulk of seabird bycatch within Canadian waters followed by longline fisheries and bottom otter trawling. We highlight possible population level effects, interactions with Species at Risk and data gaps for these three fisheries. In general, seabird populations in Canada number in the hundreds of thousands to millions (Milko et al. 2003), so the mortality of hundreds of individuals of common species are not expected to pose a threat to the population. The majority of reported catches in the gillnet fisheries involve Common Murres on both the Atlantic and Pacific coasts. Catches vary considerably from year to year within the same region, and even among fishers within a region. In the Atlantic, schools of capelin (*Mallotus villosus*), an important prey species of both murres and cod, are patchily distributed, leading to clustering of murres in areas of high capelin density (Davoren et al. 2003, Davoren 2007). Such areas may be targeted by fishers fishing for cod, which could increase the likelihood of many murres being captured at once in relatively few gillnets (Piatt and Nettleship 1987, Robertson et al. 2004). The occasional capture of large numbers of murres in only a few sets can strongly influence the final estimate. Associated confidence intervals are often large, indicating high levels of variability. However, even with these large variances it can be concluded that seabird mortality associated with the gillnet fisheries continues to occur despite limited fishing effort (Davoren 2007, Benjamins et al. 2008).

Even at these relatively lower numbers, there is concern that this source of mortality may be having an impact on certain Common Murre colonies or populations in Canada. Recent information indicates murre populations in Newfoundland are increasing (Robertson et al. 2004), so in spite of some bycatch, with the population numbering well over one million adults, it appears able to withstand current levels of bycatch. In British

Columbia, murres are showing signs of decline, with bycatch mortality a contributing factor (Smith and Morgan 2005). Declines in Common Murre populations in Washington State between 1979 and 1995 have been attributed to several factors including: bycatch, oiling, predation, and harassment by Bald Eagles (*Haliaeetus leucocephalus*), and El Niño events (Carter et al. 2001, Parrish et al. 2001). Hipfner (2005) confirmed numbers of Common Murres breeding at Triangle Island, the larger of the two colonies in British Columbia, were about 27% lower in 2003 than in 1989, although it is not clear whether this change is a true population decline versus a redistribution that may reflect changes in raptor populations.

In addition to murres, other species may be significantly affected by the gillnet fishery on both coasts. Gillnet bycatch in the Maritimes suggest that high numbers of Common Eiders in NAFO division 4X, which encompasses the inshore waters along Nova Scotia's southwest coast (Fig. 1), may be taken in the winter flounder gillnet fishery. The estimated incidental take of that area may represent 7% of the entire Nova Scotia breeding eider population (Lock et al. 1994, Calvert et al. 2013) and this local population is currently showing signs of decline (S. Gilliland, CWS, *personal communication*).

In British Columbia, it is estimated that several thousand Rhinoceros Auklets are taken every year on the Pacific coast and populations may be affected if fishing efforts increase near large colonies (Smith and Morgan 2005). Although an order of magnitude lower than the bycatch of Rhinoceros Auklets, several hundred Marbled Murrelets are estimated to drown each year in gillnets. Incidental take of Marbled Murrelets, listed as Threatened in SARA (Schedule 1) and Endangered by the International Union for Conservation of Nature (http://www.iucnredlist.org/details/106003309/0), in gillnet fisheries may represent up to 12% of the annual production (Smith and Morgan 2005).

The longline fishery in Canada has the potential to have regional species-specific impacts as well as incidentally taking Species of Concern as listed by SARA. The Canadian domestic longline fisheries operating off the Atlantic coast incidentally take shearwaters, gulls, Northern Fulmar, and Northern Gannets, which, depending on the region and season, all have populations numbering in the hundreds of thousands or millions. Although the overall take is relatively low in global terms (Anderson et al. 2011), the southwest slope of the Grand Bank and the outer slope of the Scotian Shelf have seasonally high bycatch rates that may be cause for concern. A reassessment of overall longline take in the Newfoundland and Labrador region is warranted, to include information collected since 2001.

In Pacific Canada, approximately 500 birds are incidentally taken annually in the longline fishery, with the Black-footed Albatross, listed as a Species of Concern by SARA (Schedule 1), representing up to 23% of all birds caught. These mortalities have been shown to have a cumulative and significant effect on Black-footed Albatross populations when combined with longline bycatch occurring on the high seas and within the exclusive economic zones of other countries bordering the Pacific, i.e., the United States, Japan, and Chinese Taipei. DFO (2007) predicts that if bycatch mortality from these countries were eliminated, then the potential population growth rate of the Black-footed Albatross would increase by 3.9%.

Very few birds were reported as bycatch in the bottom otter trawl fisheries operating within the Gulf of St. Lawrence and Maritimes regions. The true magnitude of this bycatch in Canadian waters, however, is thought to be largely unknown both as a result of regional data gaps and because unlike other gear types with which birds are hauled onboard the fishing vessel after they become entangled, carcasses of birds killed following collision or entanglement with trawl warp cables are often lost at sea before the gear is retracted (Sullivan et al. 2006). In other parts of the world, trawl warp or cable strikes are a major source of mortality for large-winged, gliding seabirds such as albatrosses and large petrels (Sullivan et al. 2006, Croxall 2008, Watkins et al. 2008). The threat this source of mortality poses for the suite of seabird species inhabiting Canadian waters needs to be robustly assessed.

The episodic nature of seabird bycatch implies that accurate bycatch levels can only be obtained with high levels of observer coverage. Observer coverage on Canadian vessels remains low and commercial fisheries occurring in eastern Arctic have not been quantitatively assessed, although seabird bycatch is known to occur (Mallory et al. 2006). Currently there is also a data gap for the inshore/coastal gillnet fisheries in the Gulf of St. Lawrence and the Maritimes, the portion of the fleet that has been shown to be responsible for the majority of gillnet bycatch in Newfoundland (Benjamins et al. 2008). Therefore, bycatch estimates generated in this paper, especially for gillnets, should be considered as minima. Further, for species-specific bycatch rates to be accurately determined, observer coverage needs to be expanded in a manner that reflects both the spatio-temporal variation in fishing effort and the variability in the distribution and abundance of the seabird species being affected (Smith and Morgan 2005). On both coasts, observer coverage varied greatly, anywhere from 0 to 100%, between fisheries and years. Benjamins (et al. 2008) also suggested that for some fisheries, increased observer coverage would help strengthen the estimates of mortality. Across regions, research combining data on fishing effort with seabird distributional and oceanographic information would provide an understanding of the factors that generate bycatch hotspots.

Overall, gillnets are taking the largest numbers of marine birds in Canada, a situation typical for northern countries (Bakken and Falk 1998). Some of these gill-net fisheries may be having local impacts on specific marine bird populations, but are not currently at levels that would cause wide-spread population declines. At present levels, the impact of longline, otter trawls, and other gear types on migratory bird populations in Atlantic Canada is likely low, however a number of estimation issues have been identified that should be considered. Longlining in British Columbia continues to take the listed Black-footed Albatross.

Impacts of oil and gas activities on migratory birds

Estimates of incidental take from the operational discharge of produced water are weak at best because of the lack of data (see Fraser and Ellis 2008). Although the estimated range of 150-4000 birds potentially oiled annually from produced waters at all three current production sites off the coast of Newfoundland likely does not pose a significant threat to seabird populations, Fraser et al. (2006) mention several limitations to their study, including: lack of oil sheen data available to the public, assuming produced water caused a 1 km^2 sheen every day outside of the summer, assuming all birds in the 1 km^2 area are oiled and killed, limited seabird density data, and unknown extent from which birds may be attracted to the platforms and hence come into contact with oil sheens. Furthermore, these estimates do not include mortality due to other substances discharged from drilling activities, e.g., synthetic-based drilling fluids, which are now known to have similar fouling effects on feather microstructure (O'Hara and Morandin 2010). Sublethal effects of oil contamination can include changes in food web structures (see Olsgard and Gray 1995) and a reduction in the probability of breeding and reduced breeding success for deoiled/rehabilitated birds (Giese et al. 2000, Wolfaardt et al. 2008, 2009), which are also not considered. One data gap identified by Fraser et al. (2006) has been addressed; a much richer data set on seabird densities in the vicinity of the platforms is now available (Fifield et al. 2009). These recent estimates are corrected for detectability; from 2006-2009 an average of 6.65 murres/km^2 and 7.44 dovekies/km^2 were present in the vicinity of the Newfoundland production area in winter. Using these numbers would effectively double the maximum estimate produced by Fraser et al. (2006); they used 6.9 birds/km^2 as a mean of the maximum values in Burke et al. (2005). Clearly, more research is needed to accurately quantify the magnitude of seabird mortality due to produced water and other routine operational discharges in Newfoundland and Labrador.

Stranded bird reports indicate that the number of birds found on deck by operators is in the low hundreds and that only a small proportion of these are dead. However, these data cannot directly assess the mortality caused by strikes and flaring because it is unknown how many birds are killed and not recovered. More work is required to relate the numbers of birds found on vessels and platforms to the total number of birds dying from collisions and flaring.

Although strictly not incidental take, accidental releases of oil are consistently identified as the largest risk to marine birds from the offshore oil and gas industry (Fraser and Ellis 2008). Between 1997 and 2009, Newfoundland has had 417 accidental spills totaling some 434,993 liters of hydrocarbons and synthetic based drilling fluids (Canada-Newfoundland and Labrador Offshore Petroleum Board 2012). Wilhelm et al. (2007) estimated 10,000 murres and Dovekies were oiled and killed in the largest accidental spill that occurred in 2004 that involved a release of about 1000 barrels (158,987 liters) of crude oil from the Terra Nova Floating Production, Storage and Offloading.

Between 1999 and 2010, there were 174 spills of varying substances from offshore oil and gas activities in Nova Scotia totaling approximately 3324 barrels (Canada-Nova Scotia Offshore Petroleum Board 2013). These summary statistics do not include the Cohasset Panuke project. We were unable to identify published studies or technical reports that provide estimates of seabird mortalities associated with these spills.

The general lack of information available on seabird mortality estimates for the offshore oil and gas sector makes assessing the actual levels of mortality very difficult. Further research to quantify seabird mortality estimates associated with collisions, flaring, sheens, and accidental spills, and to address the general issue of attraction to platforms are all required.

CONCLUSION

The management and conservation of the world's oceans require synthesis of spatial data on the distribution and intensity of human activities and the overlap of their impacts on marine ecosystems (Benjamins et al. 2008). It may also be used to assess whether or how human activities can be managed to reduce their negative impacts on ecosystems.

We assess industrial activities currently operating in Canadian waters that have the potential to incidentally take seabirds including some species at risk. The spatial coverage was broad, Canadian waters of the Pacific and Atlantic Oceans (no data from the Arctic), and thus refined scales of incidental take were not considered. Future work will require the development of models for mapping resource overlap between seabirds and marine industries that could be used to identify 'hotspots' of highest potential for conflict (e.g., Karpouzi et al. 2007, Montevecchi et al. 2012). The study of the spatial ecology of seabirds is therefore crucial for understanding impacts of marine based industries and will provide opportunities for developing marine protected areas, conservation action plans and species management (González-Solís and Shaffer 2009, Lewison et al. 2012).

Although we provide incidental take data for two marine-based industries, there are also significant gaps in these estimates. Further research and monitoring will be required to: (1) better estimate overall fisheries-related mortality, particularly for the Arctic and Newfoundland and Labrador regions, (2) determine the impacts of oil sheens from produced water, and attraction to platforms and associated mortality from collisions, sheens, and flaring, and (3) determine impacts associated with accidental spills. The incidental take estimates for both fisheries bycatch and the oil and gas sector presented in this paper should be considered underestimates.

Overall estimates of cumulative mortality will need to also assess other activities. For example, in Newfoundland there is mortality associated with hunting (Montevecchi et al. 2007) and illegal discharge of oily bilge water from ships (Wiese and Robertson 2004). Overall, cumulative direct mortality estimates will still likely underestimate overall effects because of indirect sources such as competition for forage prey, changes in trophic structure from fishing activities (see Tasker et al. 2000), and potential sublethal impacts from hydrocarbon exposure. Incidental take estimates provide opportunities to implement approaches to mitigate seabird mortality. For some fisheries, effective mitigation is already identified (Løkkeborg 2011), but still remains an important issue to be resolved (Lewison et al. 2012). Cooperation from industry for data collection, research to fill knowledge gaps and implementation of mitigation approaches will all be needed to conserve marine birds in Canada.

Responses to this article can be read online at:
http://www.ace-eco.org/issues/responses.php/589

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