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A preliminary spatial assessment of risk: Marine birds and chronic oil pollution on Canada's Pacific coast

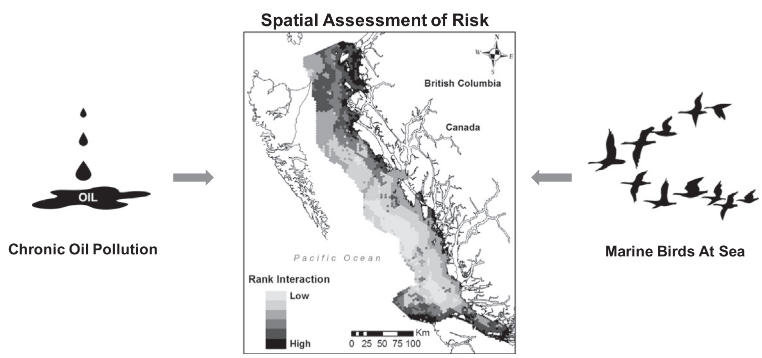
C.H. Fox [a,b,c,*], P.D. O'Hara [b,d], S. Bertazzon [e], K. Morgan [d], F.E. Underwood [e], P.C. Paquet [b,c]

[a] Department of Oceanography, Dalhousie University, Halifax, NS B3H 4R2, Canada
[b] Department of Geography, University of Victoria, Victoria, BC V8W 2Y2, Canada
[c] Raincoast Conservation Foundation, Sidney, BC V8L 3Y3, Canada
[d] Environment and Climate Change Canada, Sidney, BC V8L 4B2, Canada
[e] Department of Geography, University of Calgary, Calgary, AB T2N 1N4, Canada

HIGHLIGHTS

- On Canada's Pacific coast, the effects of chronic oil pollution are poorly known.
- This study evaluates the spatial risk of oil exposure to marine birds.
- Two areas of highest potential risk were identified in the study area.
- Individual marine bird species identified at most risk varied taxonomically.
- Further improvement of marine bird and chronic oil pollution information is needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Chronic oil pollution poses substantial risks to marine birds and other marine wildlife worldwide. On Canada's Pacific coast, the negative ecological consequences to marine birds and marine ecosystems in general remain poorly understood. Using information relating to oil spill probability of occurrence, areas of overall importance to marine birds, and the at-sea distribution and density of 12 marine bird species and seven bird groups, including multiple Species at Risk, we undertook a spatial assessment of risk. Our results identify two main areas important to marine birds potentially at higher risk of exposure to oil. For individual bird species or species groups, those predicted to have elevated bird densities near the mainland and the northeast coast of Vancouver Island were identified as being at higher potential risk of exposure. Our results, however, should be considered preliminary. As with other anthropogenic stressors, in order to better understand and subsequently mitigate the consequences of chronic oil pollution on marine birds, improved information relating to marine birds and the occurrence of oil spills on Canada's Pacific coast is needed.

1. Introduction

The planet's oceans, particularly continental shelf ecosystems, are increasingly subject to a number of anthropogenic stressors (Halpern

* Corresponding author at: Department of Oceanography, Dalhousie University, Halifax, NS B3H 4R2, Canada.
E-mail address: carolinehfox@gmail.com (C.H. Fox).

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et al., 2008). Canada's Pacific coast is no exception, with the entire continental shelf already subjected to a litany of human activities (e.g., Ban et al., 2010), many of which are anticipated to increase (e.g., shipping traffic, Nuka Research, 2013). In addition to driving biodiversity losses (e.g., declines in species richness and population sizes), these human activities influence whole-ecosystem properties, including structure, function, and resilience (Chapin III et al., 2000; Worm et al., 2006).

Although a large number of human activities occur in marine ecosystems, oil pollution is among the more serious threats. Oil enters the world's marine ecosystems by way of natural processes (i.e., natural seeps) and through anthropogenic activities, including land-based run-off, routine marine operations, drilling platforms, and ship and pipeline spills (NRC, 2003; GESAMP, 2007; Morandin and O′Hara, 2016). Anthropogenic releases may be intentional, the result of negligence, or accidental (Bertazzon et al., 2014). Of these, large volume or "catastrophic" oil spills typically result in significant attention (e.g., Bourne et al., 1967; Vermeer and Vermeer, 1975; Piatt et al., 1990) despite estimates that oil pollution resulting from "day to day" activities contributes more oil to marine ecosystems than do shipping accidents (NRC, 2003; GESAMP, 2007). These small-scale oil discharges, also known as chronic oil pollution, almost never trigger a formal response in Canada and elsewhere (i.e., in terms of cleanup and other efforts to mitigate potential impacts), primarily because they are small and occur frequently over extensive and remote areas.

In addition to contributing more oil to marine environments, the cumulative ecological impacts from small-scale discharges may be greater than impacts arising from large-scale catastrophic spills (Camphuysen, 1989; NRC, 2003). Although oil in marine environments is broadly deleterious to marine organisms, marine birds are among the most prominent and abundant taxa injured or killed (Burger and Fry, 1993). Small-scale discharges may result in similar or even greater cumulative bird mortalities than the larger, catastrophic oil spills (e.g., Camphuysen, 1989; Burger 1992, 1993a). And although there is clear evidence that rates are generally declining worldwide (e.g., GESAMP, 2007; Serra-Sogas et al., 2008; O′Hara et al., 2009; Camphuysen, 2010; Lagring et al., 2012), operational oil pollution remains a serious environmental threat (GESAMP, 2007; Vollaard, 2014).

Based on spatial patterns detected in Beached Bird Surveys (BBS - systematic surveys of beaches for documenting rates of oil fouled beach-cast bird carcasses; O′Hara et al., 2009; Camphuysen, 2010) and in aerial surveillance (aircraft borne surveillance for oil pollution; O′Hara et al., 2013), there is evidence that declining rates occur in coastal areas where enforcement activities are concentrated. Furthermore, operational discharges may be displaced to areas or times where enforcement activities are less concentrated (Vollaard, 2014; for a general reference on criminal displacement theory see Weisburd et al., 2006). Indeed, Gullo (2011) detected no change in non-compliance with federal and international oil pollution regulations (i.e., MARPOL 73/78 is the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978) in port-state inspections, despite increased enforcement efforts by US federal agencies, although these rates should be interpreted with caution as it appears the author did not correct for number of inspections each year. The potential displacement of illegal discharges is particularly troubling for much of the isolated coastal regions of Canada and the rest of the world where enforcement efforts are generally low to non-existent.

On Canada's Pacific coast, there is a documented history of marine birds being oiled (e.g., Vermeer and Vermeer, 1975; Burger 1993b; Stephen and Burger, 1994; O′Hara et al., 2009). The ecological consequences, however, have not been quantified, primarily due to limitations associated with interpreting information from BBS (O′Hara and Morgan, 2006). Given the presence of globally significant populations of marine birds on Canada's Pacific coast, including Species at Risk, the co-occurrence of chronic oil pollution with marine bird species warrants investigation.

In general, efforts to understand and mitigate the socio-ecological consequences of human activities typically require knowledge relating to a given human activity and a given ecosystem component. Spatially explicit quantitative risk assessments, by definition, are composed of two core components (often expressed as probabilities): (1) the likelihood of a stressor (e.g., oil spills) occurring in an area; and (2) the socio-ecological consequences or costs, should the specific stressor occur. Where information regarding both components is available, spatial risk assessments are a key approach to examining potential consequences of anthropogenic activities in marine ecosystems.

A spatially-explicit approach that focuses on the consequence component of risk assessment involves the overlay of spatial probability of occurrence of potential stressors with the spatial distributions of response organisms considered sensitive to those stressors (often referred to as "receptors"; see US EPA, 1998 for example). This approach essentially addresses vulnerability of organisms, which is defined here as the likelihood of exposure to the stressor, and assumes that these organisms are negatively affected or sensitive when exposed (sensu Zacharias and Gregr, 2005). Examples include the spatial assessment of ship strike risk to whales using both whale species and marine vessel densities (e.g., Vanderlaans et al., 2008; Williams and O′Hara, 2010), and seabird bycatch in fisheries using information on seabird species distributions and fishing effort (e.g., Fischer et al., 2009). Notably, however, this approach is considered a first step in estimating the potential consequences of exposure, in large part because understanding of the interaction and the potential outcomes of the interaction between organisms and stressors is necessary to fully assess risk on a spatial basis.

In this study, we assess the risk of exposure for marine birds to chronic oil pollution in coastal British Columbia (BC) using a spatially explicit semi-quantitative approach. Our objectives: (1) identify vulnerable areas predicted to experience elevated probabilities of small-scale oil spills co-occurring with elevated marine bird densities for 19 species or species groups and for marine birds on a cumulative or overall basis; and (2) rank marine birds or groups based on their risk of exposure to chronic oil pollution. Here, the probability of marine birds being oiled is the variable of interest although we note that the proximity of small-scale oil discharges to a given marine bird is only one determinant of risk. In this study, risk is therefore approximated by multiplying the predicted probability of a small-scale oil discharge with the predicted probability of occurrence of marine birds in a given area. Herein, we rely on oil spill predictions from a spatial model developed by Bertazzon et al. (2014) based on oil spill data collected by the National Aerial Surveillance Program (Transport Canada) in Canada's Pacific Exclusive Economic Zone (EEZ). Marine bird spatial predictions for 12 marine bird species and seven groups (representing 24 species) were modified from Fox et al. (in review).

2. Methods

The study area, referred to here as the Queen Charlotte Basin, comprises approximately 36,000 km^2 of BC's coastal region. The boundaries were chosen to match mutually shared spatial extents of predicted small oil discharges (modified from Bertazzon et al., 2014) and predicted marine bird densities (Fox et al., in review). The Queen Charlotte Basin includes four major bodies of water: Dixon Entrance, Hecate Strait, Queen Charlotte Sound, and Queen Charlotte Strait (Fig. 1a). The Queen Charlotte Basin and surrounding region hosts numerous seabird colonies, including Triangle Island within the Scott Islands, which is Canada's largest Pacific coast seabird colony (Fig. 1a).

2.1. Marine bird information

Marine bird predictive surfaces were generated from systematic line transect survey information collected in the Queen Charlotte Basin. Marine bird surveys took place in spring (April and May 2007; June 2008), summer (August 2005, 2006, 2008), and fall (October and November