Marine Pollution Bulletin 69 (2013) 157–164

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Estimating discharge rates of oily wastes and deterrence based on aerial surveillance data collected in western Canadian marine waters

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ARTICLE INFO

Keywords:
Aerial surveillance
Chronic oil spills
Marine pollution
Deterrence
Detection
Monitoring effort

ABSTRACT

Illegal discharge of waste oil from ships is a major source of mortality for seabirds globally. Using linear and log-linear regression, we explored the relationship between detection rates of marine oily discharges and surveillance effort at different time scales, based on data collected in the Canadian Pacific Ocean by the National Aerial Surveillance Program (NASP) from 1997 to 2006. We introduce an approach for quantifying reductions in discharge rates with increased surveillance while controlling appropriately for surveillance effort, as standard linear correction for effort can introduce considerable bias. Despite low probabilities of detection (0.088–1.1%), we found evidence for reduced discharge rates with increasing surveillance effort for data summarized monthly and bimonthly in region A, which is closest to the NASP base airport. Using residuals derived from the best-fit log-linear models, we found detected discharge rates declined annually (−[0.070 spills/month] × year).

1. Introduction

Illegal discharges of oily wastes from maritime activities including marine vessel operations (often termed "chronic" oil pollution) are considered an important source of mortality for seabirds worldwide (Camphuysen and Heubeck, 2001; Wells, 2001; Wiese and Ryan, 2003). Assessing and managing this issue is difficult because marine territorial waters where ships and seabirds co-occur can be an extremely large area. Defining and understanding the spatio-temporal patterns of high risk area is essential for estimating the scope of ship-source marine oil pollution, and for effectively directing management and conservation efforts dedicated to reducing impacts to marine birds. Aerial and satellite-based surveillance programs can be important components for the management of oil pollution (Armstrong and Derouin, 2004; Brekke and Solberg, 2005; Carpenter, 2007), but they are typically costly to operate. Defining hotspots of elevated oil pollution intensity relative to surrounding areas would be useful for informing surveillance and enforcement efforts, and for increasing their efficiency and capacity for reducing ecosystem impacts from oily discharges.

Understanding spatial patterns and temporal trends based on surveillance data is difficult for two principal reasons: (i) data collection during surveillance typically is not standardized with a randomized design (i.e., random stratified sampling), resulting in statistical biases and insufficient coverage of some areas; and (ii), behaviour of the individuals or groups under surveillance is affected by, and often adapts to, the surveillance activity itself. For example, the effect of deterrence (i.e., reduced rates of malicious activity with increased surveillance/enforcement effort) is difficult to measure because surveillance effort and deterrence are often tightly coupled (Cohen, 2000). The general expectation is that detection rates decline per unit effort of surveillance, particularly if surveillance is obvious. The relationship between surveillance and deterrence probably is not a simple linear one, and it is important to understand the relation between detecting discharges and monitoring in order to estimate a deterrent effect of the monitoring (Grau and Groves, 1997). In this study, it was necessary to understand how detection rates scale with surveillance effort, as a first step for defining spatial and temporal patterns in discharge rates. Defining the relationship between detection rates and effort allows for appropriate control for effort when analyzing spatio-temporal patterns of incidence and can lead to the estimation of the effect of the surveillance program itself on the occurrence rates of the activity that is being monitored (i.e., deterrence).

Reducing the impacts to marine ecosystems, human health, and cultural resources is the ultimate goal for aerial surveillance programs dedicated to monitoring oily discharges. Such reductions may occur if ship operators and crew are aware that they are being monitored and if they are aware of punitive actions that have re-

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http://dx.doi.org/10.1016/j.marpolbul.2013.01.034

sulted from oil pollution events documented by a surveillance program. Some programs may enhance this deterrence intentionally. For example, the Canadian National Aerial Surveillance Program (NASP) operates using aircraft painted bright red that is labeled with "Surveillance" in large white letters. In addition, NASP personnel often contact the crew while overflying a marine vessel, specifically reminding them that discharging oily wastes is illegal. Intuitively deterrence should be related to surveillance presence, and measuring the effect of deterrence on incident rates requires an understanding of how these rates scale with effort. It is important to note that for the purposes of this discussion, we define deterrence as a spatially explicit reduction in discharge rates resulting from increased surveillance effort. The distinction is that individuals may not be reducing their discharge rates, and are instead changing their behaviours to avoid detection by discharging in areas where surveillance effort is lower, or discharging when conditions reduce the likelihood of detection (i.e., during either or both inclement weather and reduced visibility).

In this study, we explore the relationship between NASP effort and rates of detection of illegal oily discharges in the marine Exclusive Economic Zone (EEZ) off Canada's Pacific Coast. We expected detection rates of oily discharge per unit time to increase with surveillance effort with a decreasing slope until a maximum detection rate is reached (i.e., see Fig. 1: asymptote labeled as "Discharge rates per unit time"). Ideally, the maximum detection rate would equal the rate of occurrence per unit time, if surveillance coverage were complete (i.e., total area covered all the time) and detection probability was 100%. However, complete coverage is both prohibitively expensive, and logistically impossible. In addition, oily discharges are likely detected with less than 100% probability, as detection relies on visual observations and/or sensors that may be affected by a number of environmental factors such as light levels, angle of the sun, position of aircraft relative to sun and oil spill, cloud cover, wind speed and direction, and precipitation.

We divided our study area into three regions (Fig. 2) that differed in terms of surveillance effort (Fig. 3), and we modeled the relationship between detection rates of oily discharges per unit area of NASP surveillance effort at three time scales (month, bimonth, and annual quarter) in each region. We compared the performances of linear versus log-linear regression techniques for modeling this relationship. Using log-linear regression, we tested for the deterrence effect of NASP presence on the number of detected oily discharges per unit of time, by comparing the shape of the functional relationship between surveillance effort and detections rates per unit of time. We also tested for declines in detection rates with year, while controlling for variation in detection rates with surveillance effort using residuals from both the linear and log-linear best-fit regressions.

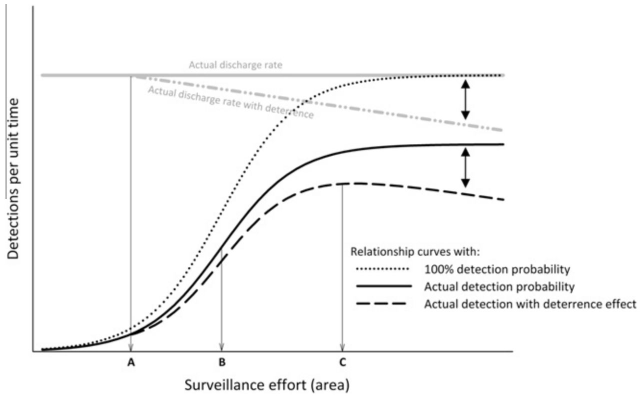

Fig. 1. Heuristic models describing expected relationships between oily discharges detections and surveillance effort per unit time (month, bimonth, or quarter). Relationships are shown with 100% detection probability, actual detection probability (i.e., spatial and temporal coverage of surveillance is not absolute), and actual detection probability with deterrence (i.e., effect of surveillance/enforcement efforts on actual spill rates). Although the actual discharge rates ("Discharges per unit time") would likely vary depending on the time unit used, we assume a fixed rate for the purposes of demonstration. A, B, and C along the x-axis, denote important surveillance effort thresholds defining the relationship between detection rates and effort: "A" = deterrence effect onset, "B" = inflection point, and "C" = detection rates begin to decrease with increasing surveillance effort (see Section 2). Double ended arrows are equal in length, as these represent the difference between actual discharge rate and actual discharge rate with deterence and the difference between actual detection rates and actual detection rates with deterrence; differences which are equal.

2. Materials and methods

2.1. Data collection and study area

Our data were collected by the National Aerial Surveillance Program (NASP) for the Pacific Region, operated by Transport Canada and based in Richmond, British Columbia (Fig. 2). We built our Geographic Information System (GIS) database with 271 oily discharge records and 786 NASP surveillance flights that were conducted from 1997 to 2006. We use the term oily discharge because not all observations were verified as a hydrocarbon (i.e., petrogenic oil), and we did not differentiate between intentional and accidental discharges. None of the discharges were self-reported. We used a grid overlay with 5 km by 5 km cells to summarize oily discharges and surveillance effort per cell. Surveillance effort was estimated by converting each flight path from polylines to polygons using a 2 km buffer, which is an estimate of the visual coverage from the plane by pilots and crew (i.e., "visual swath"). We calculated the cumulative total area of flight coverage per cell as an index of surveillance effort for each cell (Fig. 2). For the analyses below, we summed the number of oil spills and totaled surveillance flight area per region per month, bimonth, and annual quarter (January–March, April–June, July–September, and October–December). For a more detailed description of the database, please see Serra Sogas et al. (2008).

2.2. Surveillance effort and detectability of oily discharges

The study area was divided into three areas we refer to as "regions" (Fig. 2: regions A, B and C) because of the uneven and limited coverage of the principal surveillance aircraft (de Havilland DHC-6 Twin Otter) and the location of its base station (see Fig. 2). Total area covered by NASP was defined spatially by the largest extent of the flights within each region (grid cells were included if they were visited by NASP at least once); grid cells in each of the regions that were never overflown were excluded from our analyses. The three regions differed considerably with the smallest total area covered by NASP in region A (16,100 km^2), the largest in region B (52,600 km^2) and region C (32,100 km^2) in between. Region A lies adjacent to the NASP base in Richmond, BC, and must be traversed to survey either region B or C.

We estimated the maximum probability of detecting an oily discharge based on spatial and temporal coverage of NASP for each of the study regions, as detection depends on the likelihood that NASP is in the right spot at the right time (assuming that a given oily discharge is 100% detectable unaided visually from the aircraft). For the spatial coverage part of the probability of detection, we used the proportional NASP spatial coverage per flight relative to the entire area covered per region to estimate that NASP would be in the right place to detect a given oily discharge in each of the regions. We used proportional daily coverage (i.e., number of days NASP visited a region per total days in a year) to estimate the prob-