WATERBIRD DETERRENCE AT OIL SPILLS AND OTHER HAZARDOUS SITES: POTENTIAL APPLICATIONS OF A RADAR-ACTIVATED ON-DEMAND DETERRENCE SYSTEM

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SUMMARY

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Oil spills can have catastrophic effects on seabirds. Researchers have experimented with various methods of deterring birds from landing in or around oil spills and other hazards, but the effectiveness of these methods frequently declines over time, presumably because birds habituate to deterrent stimuli. New techniques that employ radar to activate deterrents only when birds are approaching a spill offer the potential to deter birds with greater and lasting efficacy. We summarize the findings of three recent studies of radar-activated bird deterrents at contaminated inland ponds and develop hypothetical scenarios for implementing such a system at marine oil spills. In open-water areas and inaccessible coastlines, boats may act as platforms for both radar and cannon deterrents. In coastal areas, networks of land-based radar and floating cannon platforms could be used. We discuss the importance of coupling knowledge on bird distributions and spill risk for effective planning and implementation of deterrents in oil spill response and then address some limitations of the radar-based system for oil spill responses. We conclude by considering the potential application of the technology for deterrence of birds at other hazardous sites such as wind farms and aquaculture facilities.

Key words: Oil spill, radar, deterrence, hazing, seabirds, habituation, wind farm, aquaculture

INTRODUCTION

Oil spills can have catastrophic effects on wildlife, particularly seabirds. Documented estimates of cumulative seabird mortality attributable to oil pollution worldwide between 1937 and 1999 are over 1 million birds (see reviews by Burger 1997, Oka *et al.* 1999; plus additional estimates from Smiddy 1998, Flint *et al.* 1999, Goldsworthy *et al.* 2000, Cadiou *et al.* 2004). The spill from the *Exxon Valdez* alone probably killed hundreds of thousands of birds (Piatt *et al.* 1990) and long-term effects have persisted in some ecosystems for more than a decade (Peterson *et al.* 2004).

Accidents, transportation of petroleum and other routine operations involving vessels may account for an estimated 26%–43% of the oil entering marine systems; the remainder stems from natural seepage, runoff from rivers and coastal facilities, and release of petroleum from consumption-related activities (Burger 1997, Oka *et al.* 1999, NRC 2003). Although the frequency of spills from tanker incidents has decreased in recent decades (Clark 2001), spills off the coasts of France in 1999 and Spain in 2002 had significant impacts on seabirds in those regions (Bohannon *et al.* 2002, Cadiou *et al.* 2004). These spill examples illustrate the persistent threat of large spills and the importance of having adequate response systems in place to prevent seabird casualties (Heubeck *et al.* 2003).

To date, the usual response to an oil spill is to try to remove the oil and rehabilitate any oiled seabirds that can be caught. As discussed below, such measures are intrusive, expensive and not always successful. As an alternative, many researchers have suggested various methods of deterring waterbirds from landing in or near oil spills (Ward 1978, Sharp 1987, Koski *et al.* 1993, Greer & O'Connor 1994, Hounsell & Reilly 1995, Whisson & Takekawa 2000). However, deterrence suffers from the problem of birds habituating to deterrent stimuli, which reduces long-term effectiveness (Bomford & O'Brien 1990). New techniques that employ radar to activate deterrents only when birds are detected offer the potential to deter birds while avoiding habituation. This paper addresses the potential role of radar-activated deterrents at oil spills for deterring flying birds from the area before they land and become contaminated with oil.

POST-SPILL METHODS FOR REDUCING SEABIRD MORTALITY

Most post-spill efforts to reduce seabird mortality can be divided into two approaches: spill cleanup and oiled bird rescue and rehabilitation. A third approach is to deter birds from spill sites before they encounter the spilled oil, but that approach has received limited study and application.

Various techniques for oil spill cleanup are practiced globally and may involve containment with booms and barriers; recovery with skimmers and sorbents; treatment with dispersants, sinking agents, chemical barriers and biological agents; and, finally, shoreline cleanup and restoration (reviewed by Burger 1997). Although post-spill cleanup efforts are legally mandated by most jurisdictions, current cleanup methods often degrade local ecosystems, and the remaining oily residues and their effects can persist with continuing effects on birds (e.g. Peterson *et al.* 2004).

The results of rehabilitation efforts have met with mixed success (Oka 1999). Post release survival has been high for a few species (e.g. Whittington 2003), but poor for most others (e.g. Mead 1997). Rehabilitation of oiled birds may be a valuable conservation tool for endangered or vulnerable species or those that respond well to cleaning, such as penguins (Burger 1997, Oka 1999, Wolfaardt *et al.* 2001). However, the high cost (Heubeck *et al.* 2003) and limited success of rehabilitation efforts with most seabirds make prevention of oiling in the first place a more desirable option.

Prevention of oiling is best achieved by deterring seabirds from landing or swimming in the vicinity of oil pollution. Although deterrence devices have been repeatedly proposed as a strategy to reduce oil spill casualties (Ward 1978, Sharp 1987, Koski *et al.* 1993, Greer & O'Connor 1994, Hounsell & Reilly 1995, Whisson & Takekawa 2000), we do not know of an example in which such devices have been used at an actual spill.

Reasons that deterrence has not been tried at oil spills may reflect the equivocal results from deterrence testing. Although some tests have shown significant responses to deterrents (Boag & Lewin 1980, Martin & Martin 1984, Bomford & O'Brien 1990, Read 1999), most tests in aquatic and marine environments have shown initial deterrence, followed by a pronounced decline in efficacy (Ward 1978, Moerbeek *et al.* 1987, Sharp 1987, Koski *et al.* 1993, Bomford & O'Brien 1990, Gosler *et al.* 1995, Stickley *et al.* 1995, Andelt & Hopper 1996, Andelt *et al.* 1997). The decline is presumably caused by habituation: animals simply cease responding to repeated stimuli that have no adverse associations (Shettleworth 1998).

The rapidity of habituation reported in most of the studies makes constant deterrence an unlikely solution for oil spills, which may persist in an area for extended periods (e.g. Piatt *et al.* 1990). Alternatively, habituation to constant or continuously-activated deterrents might be avoided with manual activation that occurs only when birds approach the oil-affected area. Such a system would allow birds to link their approach behaviour with a specific stimulus, creating the conditions needed for associative learning (Shettleworth 1998, Domjan 2003). However, using on-demand activation of deterrents over the weeks or months of a spill cleanup would be costly and labour-intensive. Moreover, human observers can operate only when visibility is adequate.

As a possible solution to these problems, we suggest using a radar-activated, on-demand systems for deterring birds. Such systems have shown some promise for reducing habituation to deterrents. We review some recent research that tested such systems for deterring birds from contaminated ponds (Johansson *et al.* 1994, Stevens *et al.* 2000, Ronconi & St. Clair 2003). Successful implementation of such systems could reduce seabird mortality at oil spills, which may also alleviate expensive and labour-intensive rehabilitation efforts. We caution, however, that the radar-based, on-demand deterrence strategy proposed here would be effective only for flying birds. The principles may be applicable for deterring swimming birds (e.g. penguins and alcids) near oil spills with other technology that allows detection of approaching birds on or underwater and that uses underwater deterrent stimuli.

RADAR-ACTIVATED DETERRENTS FOR BIRDS

The on-demand radar-activated system described here (BirdAvert: Peregrine Systems, Salt Lake City, Utah, USA) was designed to deter waterbirds from landing on contaminated ponds. This system used a standard marine radar [Furuno 1942 Mark2, 1.2 m antenna, 4 kW output, 9.410 GHz (X-band)] mounted on a mobile trailer [Fig. 1(A)] equipped with a radar monitor linked to a personal computer. The BirdAvert software interprets the radar images in real time to detect bird groups (as echoes) by comparing images in successive radar scans (birds appear as temporary and moving images on the radar). When a group is detected, the computer triggers a radio transmitter that sends a signal to activate deterrents. The system can be customized to a variety of installation conditions.

Although the main strength of a radar-activated deterrent system is to activate deterrents just as birds approach the area of deterrence, the effectiveness of deterrence will hinge on the effectiveness of the stimuli used. When the system was field tested (Ronconi &

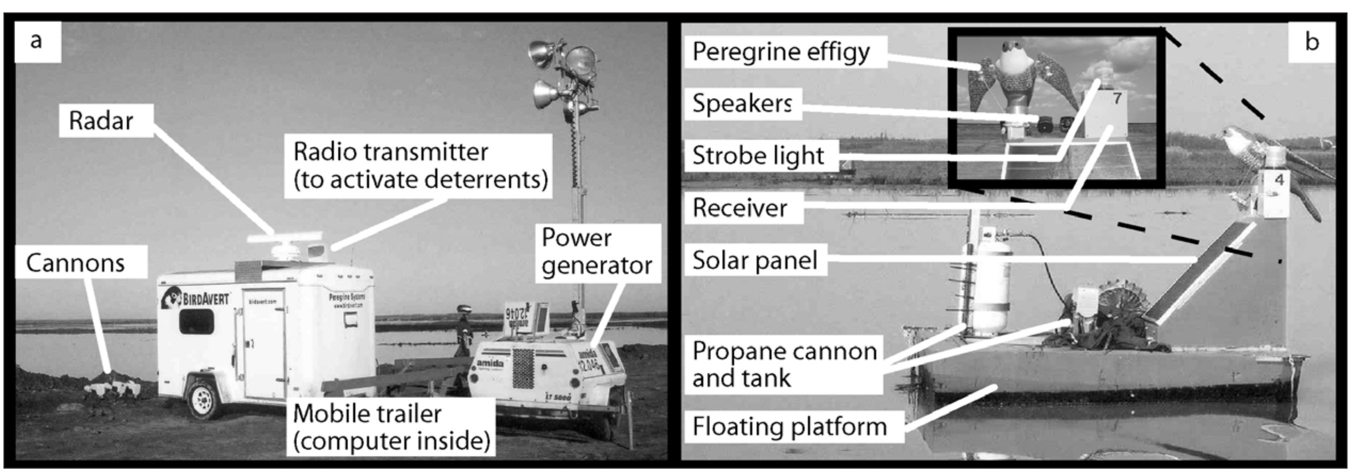

Fig. 1. The BirdAvert (Peregrine Systems, Salt Lake City, Utah, USA) on-demand radar-activated system.

St. Clair 2003), deterrence stimuli included peregrine falcon effigies with flapping wings, speakers broadcasting peregrine calls, strobe lights and propane cannons, all of which were mounted on floating platforms equipped with solar panels and batteries [Fig. 1(B)]. These stimuli were chosen specifically for deterrence of waterbirds at contaminated ponds in northern Alberta.

Koski *et al.* (1993) reviewed potential deterrence stimuli for oil spills and suggested that pyrotechnics (rockets and mortars) and/or propane cannons probably are the most useful stimuli in most marine habitats. Any stimulus, or combination of stimuli, could be linked to radar activation, but some would require higher maintenance rates (e.g. frequent reloading of pyrotechnics) than others (e.g. propane tanks with cannons may last for weeks).

Efficacy of on-demand deterrents

To date, radar-activated on-demand deterrents have been tested at three inland sites, where they were used to deter birds from landing on contaminated ponds (Johansson *et al.* 1994, Stevens *et al.* 2000, Ronconi & St. Clair 2003). At two power plant evaporation pond sites (Johansson *et al.* 1994, Stevens *et al.* 2000) deterrence was necessary because the water contained sodium decahydrate, which can crystallize on the feathers of birds landing in the pond. At the third site [oil sands tailings ponds (Ronconi & St. Clair 2003)], birds had to be deterred because of bitumen (oil) floating on the surface. Pond sizes ranged from 18 ha to 350 ha, various deterrent stimuli were linked to radar activation, and deterrence targeted waterfowl, shorebirds and other waterbirds. Although each of the studies had some limitations (e.g. deterrents tested on few ponds), the results suggest that the system is effective: all three studies showed successful effects of radar-activated deterrents (Table 1). A brief review of each study is presented here.

In 1993, Johansson *et al.* (1994; see also www.birdavert.com) assessed deterrence efficacy in two ways. First, they compared the numbers of birds landing in one pond when deterrents were "on" and when they were "off." From 1440 hours of observation, only 17 birds landed during "on" periods; 125 birds landed during "off" periods. The average number of birds landing was lower with deterrents "on."

TABLE 1
Results of three radar-activated bird deterrence studies at contaminated freshwater ponds

Study	Measure of effectiveness	Test vs. control	Summary of results
1 (Johansson *et al.* 1994; www.birdavert.com)			
Assessment 1	Number of birds landing	Compared deterrent "on" and "off" periods	Reduced landings when deterrents were active: 17 birds landed during "on" periods; 125 birds landed during "off" periods (1440 hours of observation)
Assessment 2	Observed vs. expected landings (expected landings based on pond size	Compared pond with deterrents to 10 ponds without	From 43 964 bird landings observed, only 16 birds landed on the pond with deterrents
2 (Stevens *et al.* 2000)			
Assessment 1	Number of birds flying over and number of birds landing	Compared ponds with deterrents to control pond	Waterfowl were 12.5 times less likely to fly over and 4.2 times less likely to land on the ponds with deterrents; non-waterfowl were 7 times less likely to land on the pond with deterrents
Assessment 2	Number of bird rescues	Compared years pre and post deterrent implementation	Between 685 and 714 rescues occurred in preceding years, 859 rescues in the transition year, and 210 rescues in the first year of full deterrent operation
Assessment 3	Number of birds deaths	Compared years pre and post deterrent implementation	Greater than 77% reduction in mortalities in the first year of full deterrent operation
3 (Ronconi & St. Clair in review)			
Assessment 1	Number of bird groups landing	Compared deterrent "on" and "off" periods with "on" periods separated into continuous and on-demand deterrents	On-demand deterrents reduced landings: birds were 3.3 times more likely to land during the control period. Continuously activated deterrents showed some reduction in landings for ducks but the difference was not statistically significant
Assessment 2	Bird responses in flight	Compared two deterrent types: peregrine effigies and cannons	Cannons and peregrine effigies elicited responses in 40% and 11% of the trials respectively (i.e. cannons were more effective)

In the second phase of the study, when radar-activated deterrents were continuously operated, the authors compared bird landings on the defended pond to bird landings on 10 undefended ponds in the study area. Landings were significantly lower than expected on the defended pond. More than 43 000 birds were observed landing on ponds in the study area, yet only 16 of those landings (2% of the number expected based on pond size) occurred on the defended pond, even though it was one of the largest ponds in the area.

Stevens *et al.* (2000) used a combination of acoustic alarm calls, pyrotechnics and chemical repellants (a bird tear-gas) around two contaminated ponds and compared bird landings on the defended ponds to landings on a third uncontaminated and unprotected (no deterrents) pond. Relative to the unprotected pond, waterfowl were 4.2 times less likely and other birds (mostly shorebirds) 7 times less likely to land on the ponds with deterrents. Once the system was fully operational, the authors compared rescue and death rates of birds before and after deterrent use. Bird rescues per year decreased by more than 400 (>70% fewer rescues) in the first year that deterrents were fully operational. And of the birds rescued, the number of mortalities per year was reduced by more than 77% in the first year of operation relative to each of the three preceding years.

Following those successful trials, Ronconi and St. Clair (in review) tested radar-activated deterrents on waterbirds at oil sands tailings ponds in Alberta, Canada. Deterrent efficacy was assessed by comparing the numbers of bird landings in the study area under three treatments:

- a radar-activated, on-demand deterrent system
- cannons that fired continuously at random intervals
- no deterrent system (experimental control)

The radar-activated deterrents significantly reduced the probability of birds landing relative to controls (by 3.3 times). Under control conditions, 50 of 96 flocks landed (52%); with the radar-activated deterrents, only 40 of 160 flocks landed (20%). A nonsignificant trend was observed for continuously-firing cannons to reduce landings for ducks but not for other birds, which provides circumstantial evidence that birds habituated to the continuously-firing cannons.

A second experiment at the same study site tested the in-flight response of birds to various stimuli with the radar-activated system. Birds in flight responded to cannons in 40% of the trials, but only 11% of the peregrine falcon activations elicited bird responses.
In summary, experiments at the site showed that the radar-activated on-demand system was more effective than continuously-firing cannons for deterrence at oil-polluted ponds, and that propane cannons provide an effective stimulus.

Applications to oil spills

The apparent success of these three recent studies that have employed radar to activate on-demand deterrent systems in large bodies of fresh water (Johansson *et al.* 1994, Stevens *et al.* 2000, Ronconi & St. Clair 2003) suggest some potential for similar systems to offer effective deterrence from oil spills. At oil spills, deterrence might include coastal land-based installations, nearshore installations with moored platforms and floating deterrents tethered to the seafloor, or ship-based installations carrying both radar and deterrents. Accessibility, currents, tides, weather, water depth and movement of oil would dictate where to place the deterrents. Assuming that most oil spill sites would be suitable for one of the foregoing installation types, we describe three hypothetical scenarios to demonstrate how radar-activated on-demand systems might be implemented in coastal and open water regions.

Scenario 1

A tanker is damaged in a storm and begins to leak oil at sea, threatening bird species that forage in open-water areas (e.g. Bohannon *et al.* 2002). Under such conditions, boat-based deterrents may be the only feasible platform for both radar and deterrents. Oil tankers might be equipped with their own initial deterrence equipment. Multiple cannons could be fixed to the outer decks of the ships and a computer could be linked directly to the existing ship's radar system to detect birds in the vicinity of the spill and to activate deterrents. For large spills, multiple ships would be necessary to cover the extent of a spill effectively and to continue moving with a drifting oil slick (Fig. 2).

Scenario 2

A tanker runs aground, causing oil to spill near seabird colonies and foraging areas (e.g. Piatt *et al.* 1990). This scenario, characterized by the *Exxon Valdez* spill, is most likely to threaten seabirds, because it occurs where seabird activity is high, and it may impact breeding birds. Birds traveling between colonies and foraging areas might come in contact with oil while resting en route to foraging areas or while searching for food. Strategic placement

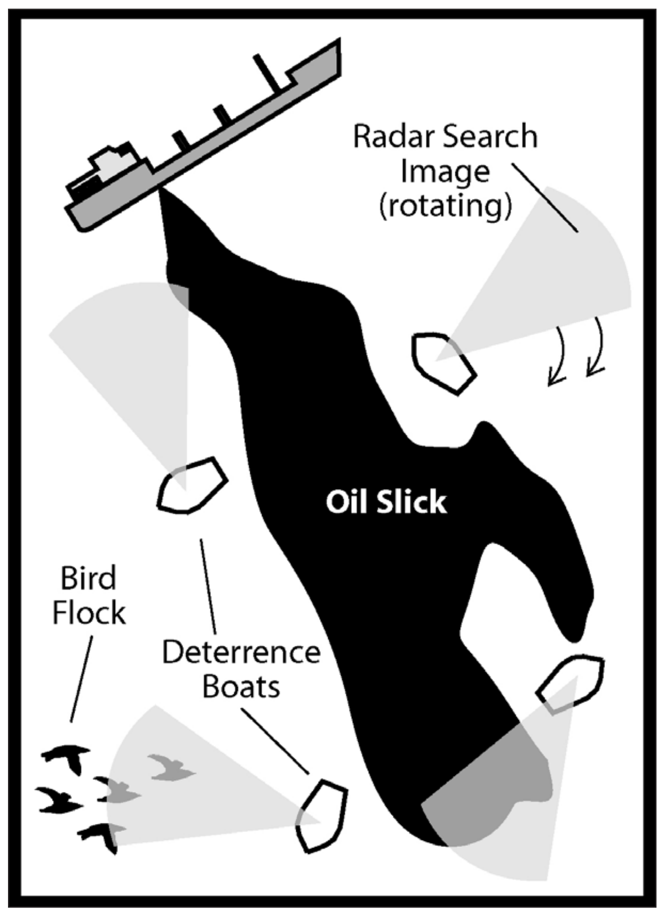

Fig. 2. A radar-activated on-demand system would require multiple ships to cover a large spill effectively and to continue moving with the drifting slick.

of ship-based, shore-based, or moored deterrents could be used to detour birds around the slick and to deter birds from foraging in the affected area. Caution should be observed, however, when deploying deterrents near colonies, because the deterrence measures may cause disruption of nesting or may lead to increased nest predation.

Scenario 3

A large slick drifts ashore and begins to accumulate there. Such a situation would badly affect shorebirds and other wading birds (e.g. Maccarone & Brzorad 2000) in addition to seabirds—such as gulls and terns—that come ashore or loaf near beaches. In this case, a land-based system might be most effective. One or more land-based radar stations and sets of deterrent cannons could be installed along affected coastal areas (Fig. 3) using access by road, helicopter or ocean-going vessel. Longer-term installations might be needed to accommodate the greater longevity of oil under this circumstance.

Implementation of deterrents

Successful implementation of deterrents depends on effective spacing of deterrents and adequate radar detection range. Ronconi and St. Clair (in review) found that floating deterrents were effective when spaced 300 m apart, although other spacing densities were not tested. In other contexts, cannons have been effective up to 400 m (Ward 1978) and 600–1000 m (Sharp 1987). Closer spacing of cannons may be needed to deter landed birds from shore-based platforms (Ronconi & St. Clair 2003).

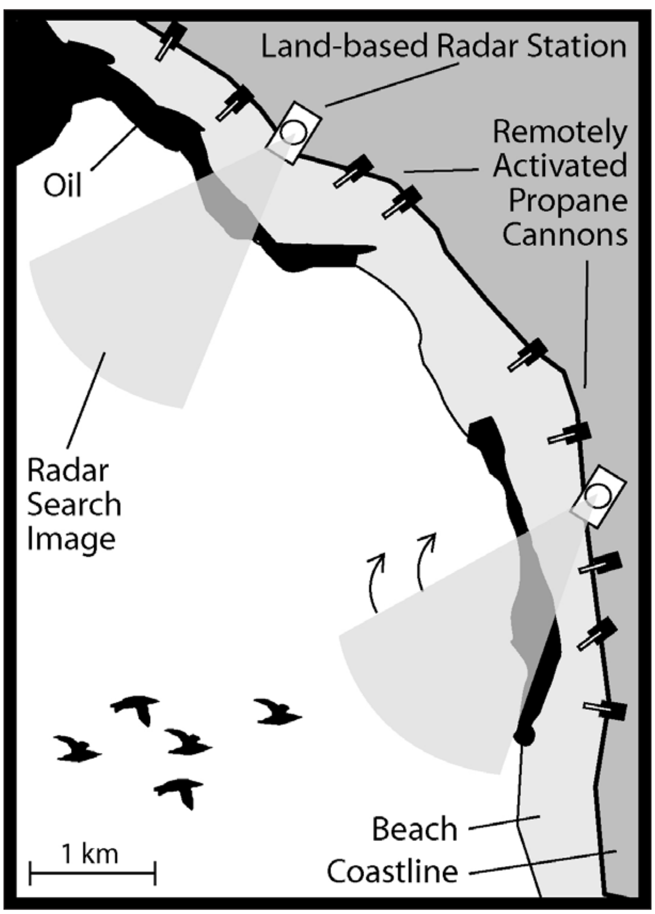

Fig. 3. A land-based system might be most effective when a large slick drifts ashore, affecting shorebirds and other wading birds.

Radar effectiveness will likely limit on-demand deterrence capabilities as well. In the tailings ponds study (Ronconi & St. Clair 2003), flocks of ducks, geese and gulls had a mean maximum detection distance of 1.19 km. Using a more powerful radar (10 kW), Cooper *et al.* (1991) reported maximum detection distances for several species of geese and ducks (4.5–7.4 km) and shorebirds (2.9 km), and one species of gull (5.2 km). Detection ranges of birds at sea will require further testing, although current results are encouraging and suggest reasonable (1–7 km) working distances for small spills. Because radar detection range is much greater than deterrence range, it will typically be necessary to place many deterrents for a single radar unit (Fig. 3).

A rapid response to an oil spill, using a deterrence system such as the one described here, will also be critical for mitigating the effects of an oil spill on seabirds. Making the best use of limited equipment and personnel requires strategic placement of equipment and the development of suitable response protocols. In addition, estimating frequency probabilities of oil spills in various marine areas and predicting seabird distributions at sea are important considerations for preparedness in oil spill response and deterrence.

Seabird mortality is often attributed to ship-source oil pollution in areas where high densities of seabirds and intense shipping activity overlap (Camphuysen & Heubeck 2001, Wiese & Ryan 2003). Identifying "hot spots" where oil spills are likely to contact large numbers of seabirds requires thorough information on ship traffic and seabird distributions during various seasons. Vessels offshore are presumably monitored by port countries and, in the near future, the automatic identification system (AIS), which transmits ship identification and location continuously, will be mandatory [*International Convention for the Safety of Life at Sea* (SOLAS: www.imo.org)]. Also, many countries conduct regular surveys for oil spills in coastal waters with both patrol aircraft and satellites with synthetic aperture radar (Brown & Fingas 1999). Information collected during such patrols may help to identify locations where spills and illegal bilge dumping are most likely to occur. Moreover, seabird distributions have been associated with distinct biologic and physical oceanographic processes (Hunt & Schneider 1987).

Researchers are also now attempting to track those oceanographic processes with remote sensing techniques (e.g. SeaWiFS) and are estimating the temporal–spatial predictability of those processes in association with fixed physical features such as bathymetry (e.g. Yen *et al.* 2004). Coupling seabird distributions (especially for vulnerable species) and annual cycle information with spatial–temporal oil spill probabilities makes it possible to identify high-risk areas. Predicting where oil spills will have the greatest impact on seabird populations is a critical step in designing response programs to mitigate the potential impacts when a spill occurs.

Advantages and limitations of radar-based deterrents

Radar-activated deterrents offer several advantages over traditional deterrents and have particular advantages in the marine environments where oil spills occur:

- a well-designed system will need fewer personnel during operation than a manually-operated system does
- activating deterrents just as birds approach the spill enhances the learning association between deterrents and the threat

- marine radar operates well in marine environments (but, see discussion below on effects of waves and rain)
- radar can detect even small seabirds (e.g. Bertram *et al.* 1999) and is effective at night and in fog
- ship-based deterrence systems could employ radars already installed on vessels, thus reducing costs and increasing availability at the time of a spill.
- deterrence systems can be modified to suit a range of platforms (e.g. shore-based, ship-based, or tethered platforms) permitting them to be customized to particular circumstances of bird vulnerability and access
- mobile systems can be strategically placed to deter birds from foraging areas and moving slicks, all of which may change rapidly and unpredictably

(Although the latter two points may also apply to an observer-based system, we suggest them as strengths for deterrence systems in general.)

Despite the advantages of radar-based systems, some limitations and unresolved issues are also apparent. Perhaps most importantly, the system we have described applies only to flying birds. The concept could be applied to diving or swimming birds if they could be detected and deterred as effectively. For example, underwater sounds have shown some promise of deterrence for diving birds (Frost *et al.* 1975, Jehl *et al.* 1979). Although diving birds can be detected with hydroacoustic sounders (Axelsen *et al.* 2001), detection distances are typically less than 50 m and may be of little application to the detection and deterrence of birds around oil spills.

A second limitation is the severe weather that is common in marine environments, which may reduce radar efficacy. Problems of wave action (i.e. creating noise on the radar screen from the echoes of surrounding waves) may be partially overcome by masking the sea surface with a radar-opaque barrier (e.g. Bertram *et al.* 1999), which allows radar to detect birds in the air, but which masks the reflections from waves. Sea-clutter sensitivity adjustment on radars is another potential solution, but it may also reduce bird detections. This problem of sea clutter from waves is currently one of the biggest challenges for radar use in marine ornithology and will likely require further technological improvements before radar may be used in deterrence at oil spills.

Additionally, rain reduces bird detections by radar. Shorter wavelength radar (X-band) was used in the studies discussed earlier, yet longer wavelength radar (S-band) may offer better detection of at least large seabirds in rain (B. Cooper pers. comm.). Regardless of detection problems in poor weather, radar may still be better at detecting birds under such conditions than human observers are. When rain inhibits bird detection completely, deterrents may be programmed to default settings that activate deterrents constantly, thus offering some continued deterrence in poor weather. In addition to affecting bird detection, weather might also limit the effective range of deterrents through the effects of wind, waves and background noise. Consequently, the number, spacing and type of deterrents need to be matched to particular situations.

Despite the foregoing limitations, we believe that enough similarity exists between the freshwater sites where deterrence systems have been tested so far and some marine oil-spill locations to merit further development and testing of such deterrence systems.

OTHER APPLICATIONS FOR WATERBIRD DETERRENCE

In addition to the oil-spill context that we have emphasized, on-demand deterrence systems have several other potential marine and terrestrial applications. These include deterrence in the vicinity of aquaculture, wind farms, airports, mining developments, agricultural systems, electrical generating stations and landfills.

Some of those industries are associated with extreme bird mortality. For example, 69 000 birds were killed by cyanide poisoning at a single mine site in Australia (Read 1999). Because birds are protected under federal laws and international treaties (e.g. *Migratory Birds Convention Act* in Canada, *Migratory Bird Treaty Act* in the United States), the industries are usually obliged to prevent, or attempt to prevent, impacts of their activities on bird life. Moreover, birds can present significant danger to humans in the context of airstrike at airports (Dolbeer *et al.* 2000). Many industries are, therefore, in need of an effective deterrent system that can prevent bird activity at their installations.

In this section, we briefly review two examples of bird–industry conflicts, identify some of the common pitfalls in existing solutions, and then evaluate the potential for radar-activated on-demand deterrence systems to solve outstanding problems. Although applications to terrestrial contexts are apparent (as described earlier), discussion here is restricted to industries with marine analogs—for example, aquaculture and wind farms.

In both freshwater and marine aquaculture, conflicts with birds stem from competition for fish and from the potential for birds to drown in the nets that are intended to prevent birds from landing or consuming farmed products. In addition to piscivorous birds, seaducks and shorebirds can also be affected by shore-based shellfish industries (e.g. Hilgerloh *et al.* 2001). Freshwater fish-rearing facilities may suffer more prevalent conflicts because freshwater aquaculture tends to be concentrated in the very areas—wetlands—where fishing birds are most likely to occur (Kushlan 1997).

Where permitted, shooting is a common solution to dissuade fish-eating birds from the vicinity of fish farms. More than 9 000 birds are shot annually to protect *Tilapia* farms in Colombia, but without actually preventing fish loss (Bechard & Marquez–Reyes 2003). Netting is another common means of preventing consumption of farm products by piscivorous birds, but it tends to be effective only for small areas (Bomford & Sinclair 2002) and can lead to substantial bird mortality unless particular net types are used (Nemtzov & Olsvig–Whittaker 2003). As an alternative, deterrents have been used (Andelt & Hopper 1996, Andelt *et al.* 1997), and pyrotechnics offer some promise to reduce fish losses to cormorants *Phalacrocorax auritus,* which may otherwise cost the Mississippi catfish industry millions of dollars (Tobin *et al.* 2002). A main limitation of this approach is that it is labour-intensive (and hence expensive) and that repeated stimuli cause habituation. Both problems could be reduced with radar detection of incoming birds and on-demand activation of conflict-specific deterrents.

Wind farms can also cause significant bird mortality (Erickson *et al.* 2001, Johnson *et al.* 2002), and increasingly, coastal regions are being proposed as potential sites for development. Cumulative mortality or avoidance may cause lower densities of upland birds near terrestrial wind farm installations (Leddy *et al.* 1999). Particularly when birds have repeated but infrequent exposure, approaching birds might be detected with radar and deterred with audio stimuli before they reach the turbine area.

Radar has been used to estimate the numbers of migrating birds near wind farms (Johnson *et al.* 2002, Mabee & Cooper 2004) and the movements of Marbled Murrelet *Brachyramphus marmoratus* near a proposed wind farm in British Columbia (Cooper *et al.* 2003). Because site-specific attributes such as topography and habitat suitability combine with seasonal differences in vulnerability (Barrios & Rodriguez 2004), there is potential to use radar-activated on-demand systems sparingly to increase their success and cost-effectiveness. Alternatively, radar alone (without deterrents) could also be used to detect incoming birds and shut down turbine operation when particular bird passage thresholds are exceeded (i.e. during migrations). Reducing bird mortality remains crucial for the successful development of wind-generated power (Krewitt & Nitsch 2003).

CONCLUSIONS AND RECOMMENDATIONS

Although bird deterrence efforts have frequently been proposed to prevent the oiling of birds at spills (Ward 1978, Sharp 1987, Koski *et al.* 1993, Greer & O'Connor 1994, Hounsell & Reilly 1995, Whisson & Takekawa 2000), such techniques have never been tested in that context. Our review of related literature suggests that deterrents may be an effective strategy to minimize impacts of oil spills on seabirds. The use of radar-activated on-demand deterrents should not only increase the effectiveness of deterrent systems but should also reduce cost and person-hours necessary for a system that successfully mitigates oil spill effects on seabird populations. We summarize here, as recommendations, some of the logistics and information that would be needed to test a radar-deterrence system in the context of an actual spill.

Equipment and trained response teams need to be in place and available on demand. The system must be as simple and portable as possible, have self-contained power sources (solar or generators) and have equipment suitable for boats as platforms (for open ocean conditions) and land-based radar equipment for coastal regions. Technological improvements to radar detection systems are also needed to overcome problems of weather (rain and waves) for effective bird detection. Moreover, the current proposed system is applicable only to flying birds and alternative methods are needed to deter swimming and diving birds.

Effective deterrence will be facilitated by knowledge of the overlap between oil-spill risk areas and seabird distribution and abundance. Models capable of predicting the risk, movement and dispersal of oil spills can be important not only in managing a response, but also in determining an appropriate network for centres of response (i.e. preparation before an oil spill actually occurs). Identification of critical habitat (nesting and foraging areas) and vulnerable marine bird species (and populations) will help to prioritize deterrent deployment locations to minimize seabird mortality. Both of these subjects should be areas of ongoing research in oil-spill response preparedness.

Although the initial and operational costs of implementing an oil-spill deterrence system may be high, the long-term gains of reducing the oiling of seabirds may outweigh the economic costs associated with rehabilitation while saving the lives of many birds. The effective development of an oil-spill deterrence system could have important immediate and long-term conservation implications for seabirds if petroleum products persist as a dominant fuel source in the 21st century.

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