FIORELLO ET AL., OPHTHALMIC EFFECTS OF DISPERSANTS ON MURRES

OPHTHALMIC EFFECTS OF PETROLEUM DISPERSANT EXPOSURE ON COMMON
MURRES (*URIA AALGE*): AN EXPERIMENTAL STUDY

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1 FIORELLO ET AL., OPHTHALMIC EFFECTS OF DISPERSANTS ON MURRES

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8 ABSTRACT
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10 The safety of chemical dispersants used during oil spill responses is largely unknown in birds.
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12 We captured common murres in Monterey Bay, CA and exposed them to Corexit EC9500a,
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14 crude oil, or a combination in artificial seawater. We performed ophthalmic examinations and
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16 measured intraocular pressures and tear production before and after exposure. Loglinear analysis
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18 found that exposure to oil or dispersant was related to the development of conjunctivitis and
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20 corneal ulcers. Odds ratios for birds exposed to oil or dispersant were positive and significant for
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22 the development of conjunctivitis, while odds ratios for the development of corneal ulcers were
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24 positive and significant only for birds exposed to a high concentration of oil. Ocular exposure to
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26 dispersants and petroleum in seabirds may cause conjunctivitis and may play a role in the
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28 development of corneal ulcers. These results have implications for policymakers who develop
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30 protocols for the use of dispersants during marine oil spills.
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41 Key Words: chemical dispersants, COREXIT EC9500A, corneal ulcers, oil spills, tear
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43 production, seabirds
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1 INTRODUCTION

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1 The use of chemical dispersants for oil spill response is highly controversial (Addassi et al. 2005;
2 Duprat et al. 2012; Kleindienst et al. 2015a). During the Deepwater Horizon spill in the Gulf of
3 Mexico in 2010, dispersants, including Corexit EC9500a and 9527, were used in greater
4 quantities than ever before (Wise and Wise 2011). The rationale for using dispersants is to
5 emulsify the petroleum compounds so that they remain suspended in the water column rather
6 than resting on the surface at the air-water interface, where air-breathing marine wildlife
7 typically become exposed (NRC 2005). By maintaining the petroleum in small droplets
8 dispersed throughout the water column, surface area is increased, so natural decomposition
9 occurs more rapidly, thereby reducing the duration that marine life are exposed to harmful
10 hydrocarbons.

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1 The controversy of dispersant application is largely focused on the safety of these compounds to
2 animals, plants, and the marine ecosystem as a whole (Le Floch et al. 2014), although their
3 efficacy has also been called into question (Kleindienst et al. 2015a). Chemical dispersants such
4 as Corexit EC9500a are comprised of a proprietary mixture of surfactants, solvents, and
5 petroleum distillates; given their composition, it is reasonable to predict that they are not
6 innocuous. Previous studies have found varying levels of toxicity to marine invertebrates and
7 fish, but evaluation of toxicity to birds and mammals are lacking (Ramachandran et al. 2004;
8 Wise and Wise 2011; Agamy 2013; Hansen et al. 2014). Recent studies have shown that some
9 mammalian cells suffer acute toxicity when exposed to Corexit EC9500a and other dispersants
10 (Wang et al. 2012; Shi et al. 2013; Wise et al. 2014; Zheng et al. 2014). A theoretical concern is
11 the finding that smaller droplet sizes may be more disruptive to feather structure than larger
12 droplets (Duprat et al. 2012); while not a toxic effect, this has the potential for serious negative

1 impacts on seabirds. Finally, researchers have found that dispersants may actually suppress
2 microbial degradation of oil, thus delaying the breakdown of oil after spills (Kleindienst et al.
3 2015b).

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5 Experimental exposures of dispersants to vertebrates have largely been performed using pure
6 compounds and *in vitro* cell culture (Ramachandran et al 2004; Wang et al 2012; Zheng et al
7 2014). While important for determining mechanisms of injury and compound-specific causality,
8 they are not necessarily reflective of *in vivo* effects. Some researchers have looked at the effects
9 of exposure on live rats (Krajnak et al. 2011; Sriram et al. 2011; Roberts et al. 2011), but marine
10 avian species—those most likely to be exposed during actual use of dispersants—have not been
11 evaluated. In the field, animals are more likely to be exposed to mixtures of dispersant,
12 petroleum, and seawater. More realistic studies on the safety of dispersants are urgently needed
13 to provide policymakers with data needed to develop risk assessments for the use of dispersants
14 during oil spills (Newman et al. 2005; NRC 2005).

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16 Although Corexit EC9500a was used both underwater and on the surface during the Deepwater
17 Horizon spill, dispersants are more commonly sprayed onto the surface of the water. If used in
18 this manner, it is likely that in some cases marine birds, which often rest on the water’s surface,
19 will be exposed to relatively high concentrations of dispersant. Given its toxicity to epithelial
20 cells (Shi et al. 2013; Wise et al. 2014), we hypothesized that Corexit EC9500a would result in
21 adverse effects to avian ocular structures. Eye lesions may not only impair vision, they may
22 cause pain and they may indicate a systemic inflammatory process (Schmidt et al. 2003). Most
23 marine birds are visual predators (Machovsky-Capuska et al. 2012); therefore eye lesions may
24 seriously decrease their survival. To test this hypothesis, we captured free-ranging common

1 murre (Uria aalga) in Monterey Bay, California, USA and subjected them to ocular
2 examinations before and after exposure to various concentrations of Corexit EC9500a (COR),
3 Prudhoe Bay crude oil (PBCO), and mixtures of the two in saltwater.

4 MATERIALS AND METHODS

6 *Capture and husbandry*

7 Forty common murre were captured in Monterey Bay, California over six nights (days 1-6)
8 using an on-water night-lighting technique described by Whitworth et al. (1997). A subset of 29
9 of these birds was included in the present study. Within two hours of capture, birds received a
10 brief veterinary examination, were identified with a temporary leg band, and were implanted
11 with a uniquely numbered, temperature-sensitive 12 mm PIT tag (Biomark, Boise, ID) in the
12 right pectoral muscle. All birds were in good to excellent body condition and appeared healthy.
13 They were housed overnight in pet carriers with net-bottoms and then transported to a pool
14 facility where they were maintained in three pools of freshwater. Itraconazole (Sporanox Oral
15 Suspension, Amerisource Bergan, Chesterbrook, PA) was administered orally at a dose of 20
16 mg/kg once daily for aspergillosis prophylaxis. Vitamin supplements (Seatabs, Pacific Research
17 Laboratories, Inc., San Diego, CA) and sodium chloride tablets (Consolidated Midland
18 Corporation, Brewster, NY) were administered orally every other day. Birds received an *ad*
19 *libitum* diet of whole, frozen-thawed night smelt (*Spirinchus starski*) provided in dishes or
20 tossed into the pool. Birds were weighed daily, and force fed night smelt once or twice a day if
21 they were losing weight.

23 *Ophthalmic examinations*

On day 7 (6 days prior to exposure), a veterinary ophthalmologist (KF) evaluated 29 birds using phenol red thread tear tests (PRTT), fluorescein staining, slit lamp biomicroscopy, and rebound tonometry (Tonovet, dog setting). First, slit lamp biomicroscopy was performed to allow for detailed, magnified examination of the periocular regions, adnexa (eyelids, lacrimal system, etc.), and each eye. Then, the PRTT was administered for 15 seconds in each eye as described by Holt et al. 2009 to evaluate tear production. One drop of fluorescein stain was applied to each eye and, if needed, excess stain was flushed with sterile ophthalmic saline solution; the corneas were then examined for loss of epithelial integrity. Finally, rebound tonometry was performed to determine intraocular pressure (IOP). Fundoscopy was performed on selected birds, but the small size of the eyes and lack of pupil dilation led to an incomplete view of the fundus and therefore to minimize further stress associated with restraint and examination, this was not performed in all birds. Birds with corneal ulcers severe enough to progress further to significantly threaten vision if left untreated were prescribed topical ofloxacin solution and systemic (oral) meloxicam for pain. These birds were removed from post-exposure ulcer analyses. On day 14 (one day after exposure), the ophthalmologic exam was repeated. All ophthalmic lesions were recorded, including adnexal abnormalities such as blepharodema (swollen eyelids), conjunctival hyperemia (redness) and chemosis (edema of the conjunctiva); corneal lesions such as edema, fibrosis, vascularization, and ulceration; intraocular diseases such as anterior uveitis and cataract; as well as age-related conditions such as iris atrophy and lenticular sclerosis. For birds with pre-existing ulcers, only additional ulcers that developed after exposure were included in analyses.

Exposure

Exposure occurred on day 13. Each bird was assigned to a control group or one of seven treatment groups using a random number chart. Treatments consisted of low, medium, or high

1 concentrations of Corexit EC9500a and/or low or medium concentrations of Prudhoe Bay crude
2 oil (PBCO) in artificial seawater at 3.5% salinity (Instant Ocean Aquarium Sea Salt Mixture,
3 Blacksburg, VA) (Table 1). Three birds were assigned to the control group. Ten birds were
4 exposed to Corexit EC9500a only, six birds were exposed to PBCO only, and seven birds were
5 exposed to a mixture of the Corexit and PBCO.

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7 To prepare pools for each exposure event, water was circulated using a 57 L/hour aquarium
8 pump with water uptake and return via vertical PVC pipes with holes at 2-inch intervals. The
9 premeasured oil and/or dispersant for each treatment was added to the pool using a one-way
10 valve and allowed to circulate throughout the water column for 90 seconds, at which time a
11 water sample was collected for concentration analysis. After each exposure event, the pools were
12 first cleaned with detergent and then thoroughly rinsed with water.

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14 Treatment groups were split into two cohorts for exposure in two separate pools. Birds from both
15 cohorts were placed in exposure pools simultaneously and induced to dive by manual hazing
16 from the water surface. At 90 seconds, all the birds were removed from the exposure pool and
17 immediately placed in a freshwater rinse pool, where they remained for 60 minutes or as long as
18 they could maintain buoyancy. After their time in the rinse pool, birds were placed into net-
19 bottom pens by treatment group. Birds with severe eye lesions noted on initial ophthalmic exam
20 (i.e., prior to exposure) had the affected eye(s) flushed with sterile ophthalmic saline solution
21 before they were returned to the net-bottom pen; this was done to avoid progression of lesions to
22 melting ulcers which could lead to corneal perforation.

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24 *Cleaning and release*

On day 16 (three days after exposure), birds were transferred to the San Francisco Bay Oiled Wildlife Care and Education Center, Fairfield, CA, where they were washed and housed until ready for release. Birds were cleaned, rinsed, and dried using standard protocols (OWCN 2014), and housed in soft-sided pens overnight. Conditioning of birds for release was initiated two days after cleaning, using standard protocols. At this time, medical issues—including ocular lesions—were treated as indicated and no attempt was made to standardize treatments for the sake of the study. Birds were released into Monterey Bay upon meeting Oiled Wildlife Care Network release criteria (OWCN 2014).

Statistical analysis

Statistical analyses were performed in SPSS 22.0 (IBM Corp, Armonk, NY); significance was set at p-values < 0.05. For most analyses, values for right and left eyes were averaged for each bird after confirming that there were no significant differences between them. Paired t-tests were used to evaluate differences between pre and post-exposure values. Because small sample sizes of individual treatment groups resulted in low statistical power, data were pooled for analysis. Categories, termed “ANYOIL,” “ANYDISP,” and “MEDOIL,” were created to describe, respectively, all birds that were exposed to any concentration of PBCO either alone or in combination with dispersant, all birds that were exposed to dispersant either alone or in combination with any PBCO, and all birds exposed to the medium concentration of PBCO either alone or in combination with dispersant. These groupings allowed for 95% power to detect differences in paired t-tests at the 0.05 level. Ophthalmic diagnoses were grouped into three categories for analysis: 1) corneal ulceration, 2) conjunctivitis, and 3) anterior uveitis (defined as eyes with visible flare indicating increased protein in the anterior chamber of the eye and/or IOP<15 mmHg). Loglinear analysis was used to determine whether oil or dispersant was related

1 to development of conjunctivitis or corneal ulcers. Note that the final model of a loglinear
analysis is considered to be a good fit for the data if p-values > 0.05. Odds ratios were calculated
to determine the relative likelihood of developing ulcers or conjunctivitis. Due to low sample
sizes (4 birds and 6 eyes), only odds ratios were calculated for anterior uveitis, and this was done
by eye, not by bird.

Data were also separated by eye, although it is important to recognize that the values are not
independent, since some eyes belonged to the same bird and multiple values for the same eyes
(representing pre- and post-exposure) were included. However, this permitted the use of t-tests to
explore the relationship of IOP and PRTT in individual eyes with and without the presence of
ulcers, conjunctivitis, and flare. Odds ratios were calculated to compare the occurrence of
anterior uveitis with ulcers or conjunctivitis in individual eyes.

All procedures were conducted under the University of California Davis Institutional Animal
Care and Use Committee Protocol No. 17350. Bird collection and release were conducted under
United States Fish and Wildlife Service Scientific Collecting Permit MB-101637-0 and in
collaboration with the California Department of Fish and Wildlife.

RESULTS

Three of 29 birds were excluded from the exposure study due to medical conditions. The
remaining 26 birds had both a pre- and post-exposure ophthalmic exam. Twelve birds had active
lesions (conjunctivitis n=5, ulcers n=8, and/or anterior uveitis n=3) noted at the time of their pre-
exposure exams; most of these were minor and resolved rapidly prior to exposure. Four birds had
severe ulcers and were treated as described above. These birds were in treatment groups 1 (n=2),

2 (n=1), and 6 (n=1). The source of the lesions is unknown, and may be multifactorial. Capture trauma, handling stress, injury due to the captive environment (nets, pen & pool sides, etc.), housing in freshwater, or pre-existing injuries are all possibilities.

Tear production decreased after exposure in all birds, but the decrease was not statistically significant and it did not vary by treatment group (Table 2). There was no difference in pre-exposure tear production between birds that did and did not subsequently develop ulcers (one-way ANOVA, $p=0.616$) or conjunctivitis (one-way ANOVA, $p=0.214$) post-exposure. When examined by individual eye, PRTT was significantly lower for eyes with conjunctivitis (17.1 ± 4.6 (n=50) vs. 19.8 ± 3.7 (n=49), $p=0.002$) and anterior uveitis (16.2 ± 3.5 (n=12) vs. 18.7 ± 4.3 (n=91), $p=0.033$), but not for eyes with ulcers.

Like tear production, IOP tended to decrease after exposure, but this decrease was small and significant only in birds exposed to the medium concentration of oil (Table 3). Birds with conjunctivitis did not have lower IOP compared to birds without conjunctivitis (21.6 ± 3.3 (n=16) vs. 21.6 ± 1.6 (n=6) mmHg, $p=0.977$), nor did birds that developed ulcers have lower IOP than birds that did not (20.5 ± 5.0 (n=9) vs. 21.6 ± 2.0 (n=17) mmHg, $p=0.431$). However, individual eyes with ulcers, whether pre-existing or newly developed post-exposure, did have lower IOP than eyes without ulcers (Table 4), as one might expect due to a potential reflex uveitis secondary to corneal ulceration. Individual eyes with flare had significantly lower IOP compared with those that did not, as would be expected.

Loglinear analysis evaluating the relationship between oil or dispersant exposure and conjunctivitis resulted in a model with a likelihood ratio of 6.528 (df=9, $p=0.686$) and included

1 first and second-order effects, with MEDOIL*ANYOIL, ANYOIL*conjunctivitis, and
2 ANYDISP as significant. Odds ratios are reported in Table 5. One of the three control, and two
3 of 18 treatment birds had pre-existing conjunctivitis, and so were excluded from the calculations.
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5 In a loglinear analysis to determine whether oil or dispersant exposure was related to
6 development of ulcers, the best model retained all first and second-order effects, with MEDOIL,
7 MEDOIL*ANYOIL, MEDOIL*ulcer, ANYDISP*ulcer, and MEDOIL*ANYDISP as significant
8 effects (likelihood ratio =1.123, df=7, p=0.993). Odds ratios are reported in Table 5; only birds
9 exposed to medium oil had significantly higher risk for ulcer development. Birds with pre-
10 existing ulcers noted prior to exposure were included only if a new ulcer developed. Two of
11 these birds, in treatment groups 2 and 6, were being treated for severe ulcers prior to exposure,
12 and nonetheless developed additional ulcers.
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14 Eyes with ulcers were 112.1 times more likely to have anterior uveitis than eyes without ulcers,
15 while eyes with conjunctivitis were only 35.7 more likely to have anterior uveitis than eyes
16 without conjunctival inflammation (Table 5). Although conjunctivitis was usually present in eyes
17 with ulcers, conjunctivitis was also frequently seen in the absence of ulcers; 26 of 30 (87%) eyes
18 with ulcers had clinically evident conjunctivitis, while only 26 of 50 (52%) eyes with
19 conjunctivitis had ulcers.

20 21 22 DISCUSSION

23 The argument for broader use of chemical dispersants in marine oil spills is likely to increase in
24 the future due to their successful removal of oil from the water surface during the Deepwater
25 Horizon oil spill. Therefore, a better understanding of potential toxic effects of these chemicals is

1 essential for policy development, response strategies (using net environmental benefits analysis),
2 and post-spill impact assessment. Our results suggest that exposure to dispersant alone can cause
3 conjunctivitis in seabirds. Additionally, we found that exposure to dispersant may potentiate the
4 development of corneal ulcers in birds also exposed to high concentrations of oil. The presence
5 of either conjunctivitis or corneal ulcers was associated with anterior uveitis, which if left
6 untreated can cause pain, cataract formation, and lead to more serious ocular sequela such as
7 glaucoma. While we did not observe these negative outcomes in the birds of this report, our
8 study subjects experienced a limited 90-second exposure and were treated for eye problems after
9 data collection was complete. In the wild, birds would likely be exposed for longer periods of
10 time, and would not have the benefit of medical intervention.

12 There was significantly lower tear production in birds with conjunctivitis, which is not surprising
13 as conjunctival swelling can lead to temporary occlusion of the lacrimal ductules that release the
14 lacrimal gland secretions and presumably may also partly occlude the Harderian gland
15 secretions. Reduced tear film render the eyes more vulnerable to insults such as abrasion,
16 infection, and chemical irritation. While we did not find a direct link between dispersant
17 exposure and lower tear production, the conjunctivitis caused by dispersant exposure could
18 potentially reduce tear production. Additionally, the experimental design of a 90-second
19 exposure may not reflect the reality of dispersant use during a spill response. For example, birds
20 may be exposed to oil, dispersant, or both during a spill, and if their feathers are sufficiently
21 fouled, they may be rendered flightless and/or unable to dive. These birds would then be unable
22 to escape the dispersant and could suffer prolonged exposure. The relationship between duration
23 of exposure and tear production is unknown, but it is possible that the trend of decreased tear
24 production would have continued with increased duration of contact with dispersant.

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6 2 Abnormally low intraocular pressures can be due to anterior uveitis, which can be secondary to
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9 3 systemic disease, primary intraocular disease, or reflex anterior uveitis (which may be seen with
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11 4 corneal disease such as ulceration). Normal intraocular pressure ranges in birds vary by species
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14 5 as well as by the method of intraocular pressure measurement. A recent study in raptors found
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16 6 that IOP varied by species, with the highest mean at 19.8 mmHg (TonoVet) in red-tailed hawks
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18 7 (*Buteo jamaicensis*) and the lowest mean at 6.3 mmHg (TonoVet) in Eastern screech owls
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20 8 (*Megascops asio*) (Labelle et al 2012). Higher pressures were found in penguins, with means of
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22 9 28 (left eye) and 30 (right eye) mmHg (Mercado 2010). Based on wild and captive animals, we
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24 10 have determined the mean IOP for common murres to be 23 mmHg +/- 2.6 mmHg (Freeman et
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26 11 al., unpublished data), which is clinically indistinguishable from the mean IOP of 23 +/- 2.4
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28 12 mmHg for this study's wild birds. The range of IOP for birds in this study without ulcers or flare
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30 13 was 18-29 mmHg; however, the range for captive murres without ulcers or flare was 15-26
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32 14 mmHg (Freeman et al., unpublished data). The slight difference in this range is likely due to
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34 15 stress, which is known to elevate IOP; undoubtedly the wild birds were under greater stress than
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36 16 captive birds. We therefore considered an IOP of 15 mmHg to be the lower limit of the normal
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38 17 range for these wild murres.
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48 19 In this study, we saw a significantly lower IOP in birds with evidence of flare, which is not
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50 20 surprising since both of these are indicators of anterior uveitis. We did not see a consistent trend
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52 21 of decreased mean IOP in birds with corneal ulceration. When eyes were examined individually,
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54 22 however, those with ulceration did have significantly lower IOP than those that did not, and most
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56 23 of these eyes with the lower IOP also had flare (Table 4). This indicates a probable reflex uveitis
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58 24 secondary to corneal ulceration.
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6 2 The intention of the study was to evaluate the effects of dispersant, and oil-exposed birds were
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9 3 included to distinguish effects from dispersant from those of oil; however, the data revealed that
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11 4 the birds exposed to the higher concentration of PBCO – regardless of the presence of dispersant
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14 5 – were a discrete group with respect to exposure effects. The IOP of the MEDOIL birds
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16 6 decreased significantly, despite small sample size and associated low power. The MEDOIL term
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19 7 also was significant in models describing the development of both conjunctivitis and ulcers.
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21 8 These results highlight how damaging exposure to petroleum is to seabirds.
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26 10 Exposure to both oil and dispersant, alone and combined, was associated with the development
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29 11 of conjunctivitis (Table 5). This is not surprising as both products are known eye irritants. Given
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31 12 that three birds had conjunctivitis at their pre-exposure exams, it is possible that housing in
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33 13 freshwater may have predisposed these birds to conjunctival inflammation; freshwater is thought
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36 14 to be a contributing factor in the development of corneal lesions in captive pinnipeds (Colitz et
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38 15 al. 2010). Our study lacked power to determine if a dose-dependent effect of dispersant or
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41 16 petroleum exposure on conjunctivitis was evident.
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45 18 Although birds exposed to dispersant did not have significantly greater odds of developing new
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48 19 ulcers, the loglinear analysis found the ANYDISP*ulcer and ANYDISP*MEDOIL terms had
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51 20 significant effects on the fit of the model. This suggests that exposure to dispersant may have a
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53 21 role in corneal ulcer development, especially in the presence of oil. If this is the case, it is
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55 22 somewhat concerning, as birds exposed to dispersant in the field are likely to be exposed to oil as
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58 23 well. Corneal ulcers are a serious concern for seabirds, most of which are visual predators.
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1 Untreated ulcers may progress and cause permanent damage and partial or complete loss of
2 vision, a consequence that is likely to impair foraging ability and thus survival.

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4 Dispersants are intended to be sprayed directly onto an oil slick. According to the California
5 Dispersant Use Plan (Faurot-Daniels and Addassi 2008), caution should be used to avoid
6 spraying over marine mammals and sea turtles, and wildlife observers are required on aircraft to
7 spot these animals and direct the sprayers to avoid them. Seabirds, however, are not mentioned.
8 In other words, seabirds within an oil slick may well be sprayed with dispersant, putting them at
9 risk of exposure to dispersant alone as well as dispersed oil. If, as our results suggest, dispersant
10 or dispersed oil exposure does facilitate the development of corneal ulcers in seabirds, this policy
11 should be reconsidered.

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Treatment group	Concentration PBCO (oil) (mg/L)	Concentration COR (dispersant) (mg/L)	N	Classification in ANYOIL	Classification in ANYDISP	Classification in MEDOIL
1 Control	1.5	<RL	3	no	no	no
2 Low dispersant	<RL	8.9	4	no	yes	no
3 Medium dispersant	<RL	85.5	4	no	yes	no
4 High dispersant	<RL	944.5	2	no	yes	no
5 Low PBCO	116.5	<RL	3	yes	no	no
6 Medium PBCO	1066.0	<RL	3	yes	no	yes
7 Low dispersant + low PBCO	93.5	7.4	5	yes	yes	no
8 Medium dispersant + medium PBCO	1128.0	78	2	yes	yes	yes
Total			26	13	17	5

Table 1. Treatment groups with concentrations of Prudhoe Bay crude oil (PBCO), Corexit EC9500a dispersant, sample size, and group classification for common murres evaluated in a dispersant exposure study. Concentrations of oil and Corexit were measured from samples taken from the water columns of the two exposure pools immediately prior to exposure of the birds, and represent the average of the two pools. RL=reportable limit of detection.

Treatment	Pre-exposure (mean $\pm$ SD) PRTT (mm)	Post-exposure (mean $\pm$ SD) PRTT (mm)	N	p-value
All birds	19.08 $\pm$ 3.5	17.86 $\pm$ 4.5	25	0.159
ANYOIL	19.88 $\pm$ 2.4	17.92 $\pm$ 3.1	12	0.106
No oil exposure	21.38 $\pm$ 4.2	17.81 $\pm$ 5.5	13	0.676
ANYDISP	19.44 $\pm$ 3.6	18.47 $\pm$ 4.8	16	0.394
No dispersant exposure	18.44 $\pm$ 3.3	16.78 $\pm$ 3.9	9	0.247
MEDOIL	19.4 $\pm$ 3.2	18.7 $\pm$ 3.2	5	0.707

Table 3. Pre- and post-exposure values for phenol red thread test (PRTT) in mm of tear production for wild common murre in an experimental study of petroleum and dispersant exposure. See text and Table 1 for treatment group explanations.

Treatment group (s)	Pre-exposure (mean $\pm$ SD) IOP mmHg	Post-exposure (mean $\pm$ SD) IOP mmHg	N	p-value
All birds	21.7 $\pm$ 3.2	21.21 $\pm$ 3.3	26	0.340
1 control	19.3 $\pm$ 5.8	21.5 $\pm$ 2.6	3	0.397
2 low dispersant	22.2 $\pm$ 1.9	20.5 $\pm$ 4.0	4	0.284
3 medium dispersant	23.8 $\pm$ 2.1	22.5 $\pm$ 2.4	4	0.548
4 high dispersant	22.3 $\pm$ 1.1	23.0 $\pm$ 2.1	2	0.500
5 low oil	21.3 $\pm$ 2.0	20.3 $\pm$ 0.3	3	0.510
6 medium oil	20.2 $\pm$ 5.8	16.7 $\pm$ 3.6	3	0.109
7 low oil + dispersant	21.8 $\pm$ 1.6	22.2 $\pm$ 2.4	5	0.789
8 med oil + dispersant	25.0 $\pm$ 5.3	23.5 $\pm$ 6.4	2	0.344
ANYOIL exposure	21.77 $\pm$ 3.4	20.69 $\pm$ 3.7	13	0.177
No oil exposure	21.88 $\pm$ 3.2	21.73 $\pm$ 2.8	13	0.846
ANYDISP exposure	22.64 $\pm$ 2.2	22.11 $\pm$ 3.1	17	0.382
No dispersant exposure	20.28 $\pm$ 4.3	19.5 $\pm$ 3.1	9	0.511
MEDOIL exposure	22.0 $\pm$ 5.5	19.4 $\pm$ 5.5	5	0.047*

Table 2. Mean $\pm$ SD of pre- and post-exposure values for intraocular pressure (IOP) measured by rebound tonometry for wild common murres evaluated in an experimental study of petroleum (Prudhoe Bay crude oil) and dispersant (COREXIT EC9500a) exposure. See text and Table 1 for treatment group explanations. Significant values are marked with an *.

Condition	IOP (mmHg)	N	p-value
Ulcer present	19.2 ± 4.0	30	0.002*
No ulcer	22.0 ± 4.1	75	
Conjunctivitis	20.6 ± 3.9	50	0.259
No conjunctivitis	21.6 ± 5.0	50	
Flare present	16.5 ± 5.2	9	0.001*
No flare	21.6 ± 4.1	95	

Table 4. Mean ± SD of intraocular pressure (IOP) measured by rebound tonometry for wild common murre based on pathology noted on physical exam. Values are for individual eyes and include findings from pre- and post-exposure examinations. Significant values are marked with an *.

Treatment or diagnosis	Odds ratio for conjunctivitis	95% CI	p=value	N
ANYOIL	10.0	0.9 to 110.3	0.0431*	21
ANYDISP	12.0	1.1 to 136.8	0.0318*	19
MEDOIL	4.7	0.2 to 101.0	0.3247	18
Odds ratio for new corneal ulcers				
ANYOIL	2.9	0.5 to 15.5	0.2232	26
ANYDISP	2.5	0.4 to 15.5	0.2903	26
MEDOIL	12.8	1.1 to 142.6	0.0382*	26
Odds ratio for anterior uveitis				
Eyes with conjunctivitis	35.7	2.0 to 621.2	0.0142*	102
Eyes with corneal ulcers	112.1	6.3 to 1985.5	0.0013*	107

Table 5. Odds ratios and 95% confidence intervals for development of conjunctivitis, corneal ulcers, or anterior uveitis in wild common murres in an experimental study of petroleum and dispersant exposure in artificial seawater. See text and Table 1 for treatment group explanations. Birds with pre-existing conjunctivitis were excluded from analyses. Significant values are marked with an *.