DEMOGRAPHICS AND GROSS PATHOLOGY OF SCOTERS AND SCAUPS KILLED BY THE *COSCO BUSAN* OIL SPILL IN CALIFORNIA

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ABSTRACT

BECK, J., CARLE, R.D., NEVINS, H., DE LA CRUZ, S.E.W. & DONNELLY-GREENAN, E. 2023. Demographics and gross pathology of scoters and scaups killed by the *Cosco Busan* oil spill in California. *Marine Ornithology* 51: 69–78.

Unusual wildlife mortality events provide a unique opportunity to collect information on demographics, disease, and body condition in affected wildlife, which may be useful for informing oil spill damage assessments and future spill responses. In November 2007, the *Cosco Busan* Oil Spill occurred in San Francisco Bay, California, a globally important wintering area for waterfowl. The spill resulted in the mortality of scoters *Melanitta* spp. and scaups *Aythya* spp., species that have declined significantly over recent decades. We examined the demography (sex and age ratios) and prevalence of grossly apparent disease (acanthocephalan parasite infection and mycotic disease) in 288 Surf Scoters *M. perspicillata*, White-winged Scoters *M. deglandi*, Greater Scaup *A. marila*, and Lesser Scaup *A. affinis* killed in the oil spill. The proportions of females and juveniles in examined Surf Scoters was unexpectedly high (0.98:1, females:males, 0.73:1 juveniles:adults) for this species with normally strong male- and adult-biased populations. This disproportionate mortality of female Surf Scoters could result in a greater population impact on this female-limited species, suggesting a mechanism for steep declines in San Francisco Bay scoter numbers in the years after the *Cosco Busan* oil spill. Significantly greater rates of acanthocephalan infection in juvenile vs. adult Surf Scoters indicated a possible interaction between acanthocephalan parasitism and juvenile-biased mortality in our sample. Birds that died during rehabilitation had significantly greater rates of mycotic disease (10% infected) than birds found dead in the field (3%), indicating that infections began or worsened during rehabilitation. Greater Scaup had proportionally greater rates of infection with mycotic disease (26% of individuals) than other species, indicating that they may be particularly susceptible to the disease. We encourage the documentation of demographics and disease as a regular part of future responses to oil spills, or other mortality events, to gain insight into population impacts and improve rehabilitation efforts of affected populations.

Key words: *Melanitta*, *Aythya*, sea duck, acanthocephalan, mycotic disease, parasite, sex ratio

INTRODUCTION

Unusual wildlife mortality events (e.g., caused by oil spills, harmful algal blooms, disease epidemics, food shortages) provide a unique opportunity to collect information on demographics and disease in affected wildlife (Nevins & Carter 2003, Martinez-Abraín *et al.* 2006, Humple *et al.* 2011). Substantial effort and funding are often put toward damage assessment and restoration for wildlife populations injured in oil spills, with the focus typically on quantification of the number of individuals and composition of species impacted (Piatt *et al.* 1990, Hampton *et al.* 2003, Haney *et al*. 2014). The demographics (e.g., age and sex ratios) of species killed by oil spills are infrequently assessed (but, see Anker-Nilssen *et al.* 1988, Nevins & Carter 2003, Martinez-Abraín *et al.* 2006, Humple *et al.* 2011). However, demographic information is important for understanding population impacts on affected species (Martinez-Abraín *et al.* 2006, Humple *et al.* 2011) and for optimization of restoration actions and future management responses (Wiens *et al*. 1984, Sperduto *et al.* 2003). Likewise, data on disease prevalence in wildlife may be difficult to obtain outside of the context of a mortality event such as an oil spill (Hollmén & Franson 2015), and data from such events can be useful for informing rehabilitation care during future events (Tseng 1999, Mazet *et al.* 2002).

On 07 November 2007, the container ship, Merchant Vessel *Cosco Busan* (hereafter *Cosco*) allided with a bridge tower fender and spilled approximately 58 000 gallons (219 553 L) of oil into San Francisco Bay, California (SFB) and adjacent open coastline (Fig. 1). SFB is a highly urbanized estuary and a globally important wintering area for waterfowl including scoters *Melanitta* spp. and scaup *Aythya* spp. (Accurso 1992, De La Cruz *et al*. 2014, Anderson *et al*. 2020). Bird mortality from the oil spill was modeled based on recovery of live and dead birds, search effort, bird surveys, and beachcast carcass surveys, resulting in an estimate of 6 849 birds killed (Cosco Busan Oil Spill Trustees 2012). Surf Scoter *M. perspicillata* was the most impacted species, with 1 147 individuals killed (Cosco Busan Oil Spill Trustees 2012). An estimated 260 Greater Scaup *A. marila*, 52 Lesser Scaup *A. affinis*, 43 White-winged Scoters *M. deglandi*, and 55 scoter spp. were killed (Cosco Busan Oil Spill Trustees 2012). This unfortunate event provided an opportunity to examine the carcasses of scoters and scaup, and to collect demographic and disease-state information.

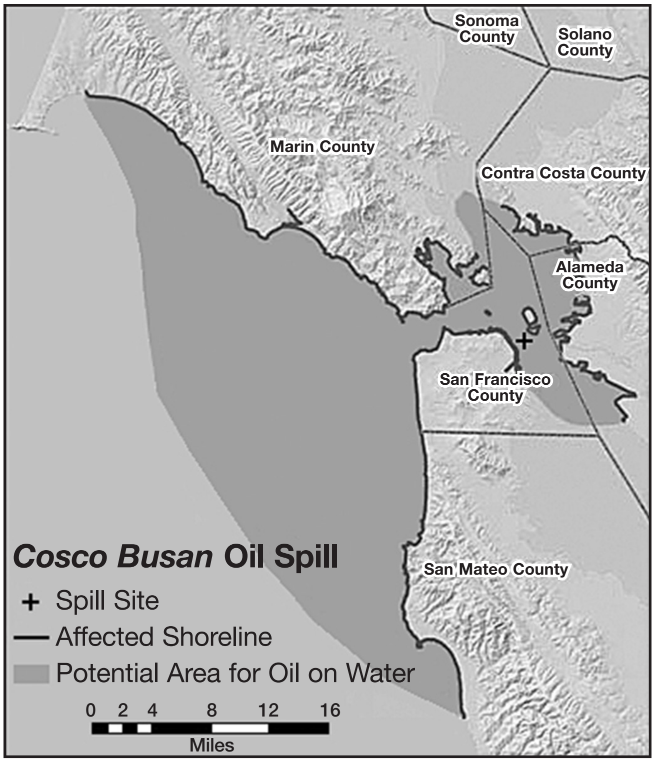

Fig 1. Location of 2007 *Cosco Busan* oil spill (cross) within San Francisco Bay and adjacent water (dark grey) and the shoreline (black line) affected. Image from California Department of Fish and Wildlife, Office of Spill Prevention and Response (OSPR). https://wildlife.ca.gov/OSPR/NRDA/Cosco-Busan

Scoters and scaups breed in high latitude boreal forest and aggregate during winter in coastal and estuarine habitat (Austin *et al.* 2000, Takekawa *et al*. 2011). Scoters and scaups have declined significantly over recent decades (Austin *et al.* 2000, Afton & Anderson 2001, Sea Duck Joint Venture 2007, Anderson *et al*. 2020), especially in North American Pacific coast wintering grounds such as Puget Sound, Washington, and SFB (Richmond *et al*. 2014, Bowman *et al*. 2015, Strong 2018). Causes of these declines are not well understood (Afton & Anderson 2001, Anderson *et al*. 2020). However, one clear threat is the urbanization of critical estuarine habitats (De La Cruz *et al.* 2014, Ramírez-Garofalo 2020), which exposes scoters and scaup to anthropogenic disturbance and pollution (Ohlendorf & Fleming 1988, Ohlendorf *et al*. 1991, Eagles-Smith *et al*. 2009). During October to May, scoters are among the most densely distributed marine birds within 0.5 km the US Pacific coast (Briggs *et al*. 1987, Mason *et al*. 2007), where their habitat overlaps extensively with maritime shipping channels and urbanized estuaries vulnerable to oil spills (Burgherr 2007, De La Cruz *et al*. 2014, Hamilton *et al.* 2022).

We evaluated the demographics of scoters and scaup killed by the Cosco oil spill by quantifying sex- and age-ratios of a sample of carcasses. Male-biased sex ratios typically occur in Surf Scoters (Iverson *et al*. 2004, Rodway *et al*. 2015), Greater Scaup (Alexander 1983), and Lesser Scaup (Anderson *et al*. 1969, Afton & Anderson 2001), whereas more equal or slightly male-biased sex ratios typically occur in White-winged Scoters (Mitchell 1952, Rodway *et al*. 2015). In populations with fewer females relative to males, female-biased mortality events would be expected to have the greatest species-level population impacts (Austin *et al*. 2000, Flint 2015). Scoters typically have adult-biased age ratios (Iverson *et al*. 2004, Rodway *et al*. 2015), whereas reported scaup age ratios are variable, but typically juvenile-biased (Anderson *et al*. 1969, Afton & Anderson 2001). Scoters in particular have high adult survival and low fecundity (Anderson *et al*. 2020), meaning adult-biased mortality would be expected to affect population trends more than juvenile mortality.

To evaluate the disease-state of marine waterfowl killed during the *Cosco* oil spill, we quantified the prevalence of infection with *Acanthocephala* (thorny-headed worm) parasites (hereafter "acanthocephalans" for individual parasites and "acanthocephaliasis" for the state of infection with parasites), and respiratory infection from mycotic disease (often diagnosed as aspergillosis), which is often documented in captive waterfowl (Hillgarth & Kear 1979, Beernaert *et al*. 2010). We evaluated these diseases because they are known to occur in scoters and scaup (Bourgeois & Threlfall 1982, Bush & Holmes 1986, Ching 1989, England *et al*. 2016), are grossly apparent during necropsies, and their prevalence and severity could impact survival during mortality events (Camphuysen *et al*. 2002), or be relevant to oil spill rehabilitation choices (Hillgarth & Kear 1979, Stetter *et al.* 1994). Because of limited resources, we did not investigate other less grossly apparent diseases, or contaminants, which could have interacting impacts on bird survival during an oil spill; however, our aim was not to tease out the impact of disease on mortality but rather to describe the prevalence and severity of these focal diseases. Acanthocephaliasis can cause severe morbidity and mortality across many taxa of wildlife (Cole 1999, Camphuysen *et al*. 2002, Thieltges *et al*. 2006). Acanthocephalans develop cystocanths in intermediate hosts (e.g., Pacific Sand Crabs *Emerita analoga*; Hennessy & Morejohn 1977, Smith 2007), which occur in marine foraging grounds used seasonally by adult scoters and year-round by immature scoters (Savard 1998). Mycotic disease is a major cause of respiratory distress and bird death in rehabilitation centers (Briggs *et al*. 1997, Burco *et al*. 2012), where immunosuppression from handling stress can increase susceptibility to infection (Arné *et al*. 2021). Comparison of mycotic disease prevalence in birds that were found dead and birds that died during rehabilitation provides information on the background prevalence of this disease in wild populations, proportions of individuals becoming infected during rehabilitation, and species-specific susceptibility of infection during rehabilitation (Hillgarth & Kear 1979, Stetter *et al*. 1994).

Our goal was to use demographic and disease-state information collected from carcasses of scoters and scaup killed during the *Cosco* oil spill to better inform rehabilitation during oil spill responses.

We tested the following hypotheses: (1) based on observed ratios from other studies, sex ratios from birds killed in the spill would be male-biased for all species, adult biased for scoters, and juvenile-biased for scaups; (2) based on their year-round exposure to parasites via sand crab ingestion on the Pacific coast, immature scoters would have a greater prevalence and severity of acanthocephaliasis than adults; (3) infection with acanthocephaliasis would be lower in scaup compared to scoters, because scoters more often use open coast habitat where sand crabs are available; and (4) birds that died during rehabilitation would have greater proportions of mycotic disease than those birds that died prior to arrival. The latter would indicate that birds became infected, or infections worsened, during the rehabilitation process.

METHODS

Bird carcasses were recovered in SFB during the 2007 *Cosco* oil spill (Fig. 1). The Wildlife Processing Unit of the Oiled Wildlife Care Network, University of California, Davis, documented all recovered birds, including those found dead on arrival (hereafter, DOA) or that died during rehabilitation but were alive on arrival (hereafter, LOA). Carcasses were frozen at -20 °C until thawed for necropsy in 2013, when they were no longer needed as evidence for litigation.

We necropsied 288 carcasses of Surf Scoter (n = 219; Fig. 2), White-winged Scoter (n = 6), Greater Scaup (n = 57), and Lesser Scaup (n = 6) killed during *Cosco* (Table 1). Our sample represented 25% of Surf Scoters, 14% of White-winged Scoters, 22% of Greater Scaup, and 12% of Lesser Scaup estimated killed in the oil spill (Cosco Busan Oil Spill Trustees 2012), and 40% of Surf Scoter, 22% of White-winged Scoter, 35% of Greater Scaup, and 22% of Lesser Scaup carcasses recovered during the oil spill (Ford *et al*. 2007). Our study sample was composed of all carcasses of the focal species that were collected during the oil spill that were in good enough condition to necropsy. We excluded carcasses that were too heavily oiled, scavenged, or decomposed to necropsy, most of which were DOA birds. Given this constraint, our study sample was weighted toward LOA birds (72% LOA, 27% DOA). A limitation to the sample was that we could only examine recovered birds, though the total estimated mortality from the spill included estimates of birds that were killed and not recovered. Interactions of disease and oiling could affect mortality of birds and therefore whether they were recovered dead, alive, or at all. We identified no obvious reasons why our sampling constraints might affect demography results. It is uncertain whether our sample was truly representative of all the birds affected by the oil spill, but this was the best and only available sample of birds killed in the spill, and we sampled a relatively high proportion of affected individuals.

Fig. 2. Necropsy of a Surf Scoter *Melanitta perspicillata* killed during the 2007 *Cosco Busan* oil spill. This bird was categorized as "emaciated."

Demographics

We conducted gross necropsies on all carcasses (Fig. 2), recording body condition, standard morphometrics, age, sex, and apparent gross lesions related to acanthocephaliasis and mycotic disease. We assessed age classes into "juvenile" (< 12 months old) and "adult" (> 12 months old) categories using plumage characteristics, body morphometrics, and relative size of the bursa of Fabricius and gonads (Broughton 1994, van Franeker 2004). Female Surf Scoters cannot be reliably aged based on plumage (Iverson *et al*. 2003), so we relied on internal metrics of sexual maturity based on gonadal characteristics to sex females (length and width, diameter of largest follicle, and oviduct score), and to age birds by the presence of the bursa of Fabricius as present (juvenile), or absent (adult; Broughton 1994, van Franeker 2004).

We assigned each carcass into one of five body condition classifications by assessing skeletal muscle mass (pectoralis score), fat, and grossly apparent health of five organs (van Franeker 2004). We used this system, rather than body mass, because body mass is an unreliable measure of nutritional condition in heavily oiled carcasses. Following van Franeker (2004), we visually classified the pectoralis-supracoracoideus muscle complex on a scale from "critically emaciated" (muscle significantly below keel-line; Fig. 2) to "excellent" body condition (muscle at or above keel-line), and we scored subcutaneous fat and internal fat from 0 (no fat) to 3 (extensive fat).

We used two-tailed Pearson χ^2 tests to test if sampled birds showed a deviance from a 1:1 ratio for various demographic parameters. We chose to test against a 1:1 ratio because literature values of sex and age ratios were variable, complicating the selection of a single literature-based value to test against for each parameter and species. Instead, we tested against a 1:1 ratio because the result of these tests allowed for interpretation of whether ratios were significantly biased in either direction, and the result could be compared to literature ratios. We tested the following against the

TABLE 1
Demographics of examined Scoters *Melanitta* spp. and Scaup *Aythya* spp. killed during the 2007 *Cosco Busan* Oil Spill, San Francisco Bay, California, USA

Species	Female			Male			Unknown Sex		Female: male ratio	Juvenile: adult ratio	Grand Total
	Adult	Juvenile	Unknown Age	Adult	Juvenile	Unknown Age	Juvenile	Unknown Age			
Greater Scaup	11	9	0	19	7	2	1	8	0.71:1	0.53:1	57
Lesser Scaup	4	2	0	0	0	0	0	0	--	--	6
Surf Scoter	50	50	1	65	33	5	2	13	0.98:1	0.73:1	219
White-winged Scoter	0	4	0	0	1	0	0	1	4:1	--	6
Grand Total	65	56	1	84	34	7	3	22			288

1:1 ratio: (1) female to males in Surf Scoter and Greater Scaup, (2) juveniles to adults for Surf Scoter and Greater Scaup, (3) juveniles to adults and males to females for LOA and DOA Surf Scoters, and (4) juveniles to adults among male and female LOA and DOA Surf Scoters. We included only birds of known sex and age class in this analysis. We did not test sex or age ratios of White-winged Scoters and Lesser Scaup because of insufficient sample sizes.

Documentation of focal diseases

To document acanthocephaliasis, we examined the gastrointestinal tracts of a subsample of Surf Scoter (n = 103) and Greater Scaup (n = 45), and all White-winged Scoter (n = 5) and Lesser Scaup (n = 6) in our sample of necropsied birds. We determined the extent and severity of parasitism by grossly examining the entire intestinal tract for parasites by section (duodenum, jejunum, ileum, cecae, and colon). We measured acanthocephalan abundance by scoring parasite load in the most heavily parasitized 2-cm-segment length of intestine: 0 parasites = none found; 1–10 parasites/2 cm = mild; 11–25 parasites/2 cm = moderate; > 25 parasites/2 cm = heavy (Fig. 3). We identified acanthocephalans to two genera, *Profilicollis* and *Corynosoma* based on size and appearance of the adult stage, and comparison to reference samples collected in California by Mayer *et al*. (2003).

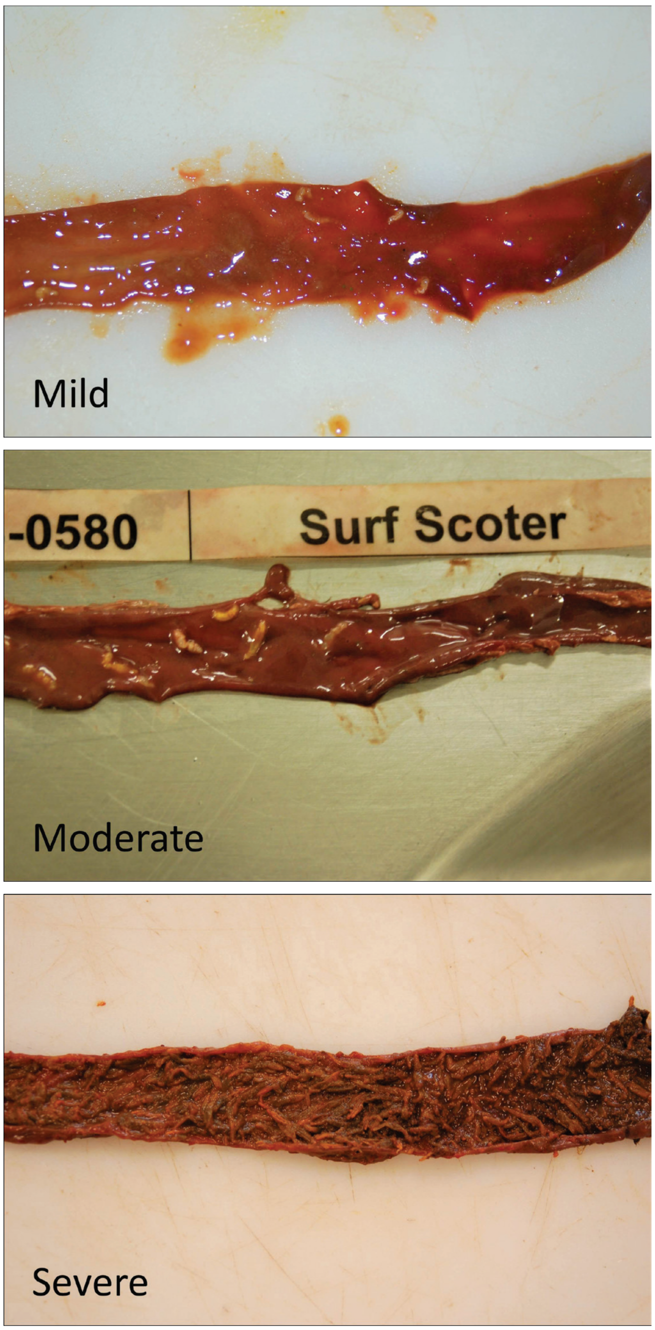

Fig. 3. *Acanthocephalan* parasites in the intestinal tracts of scoters *Melanitta* spp. and scaups *Aythya* spp. characterized as mild (top), moderate (middle), and severe (bottom).

To assess the frequency and severity of mycotic disease, we recorded the number and location of fungal plaques in the lungs and air sacs, and dimensions of the largest plaque present, for all examined carcasses. We identified fungal plaques as mycotic disease, possibly aspergillosis, based on visual assessment of the presence or absence of grossly apparent fungal colonies and/or luxuriant fungal growth in avian respiratory tissue (Hillgarth & Kear 1979, Stetter *et al*. 1994). We did not perform disease identification analyses such as histology, cultures, or genetic sequencing because the carcasses had been frozen for 6 years, making these methods less reliable, and because of lack of resources. Because we performed only visual assessments, we identified infections generally as "mycotic disease," rather than a specific disease such as aspergillosis (Arné *et al*. 2021).

RESULTS

The sex ratio (females:males) of Surf Scoter examined was 0.98:1.0 and did not differ statistically from 1:1 (χ^2 = 0.02, df = 1, n = 204, P = 0.89, Table 1). The distribution of juvenile to adult female Surf Scoter was exactly 1:1 (n = 100), whereas adult male Surf Scoter occurred significantly more frequently than juvenile males (juvenile:adult ratio 0.51:1; χ^2 = 10.45, n = 98 df = 1, P = 0.001; Table 1).

The sex ratio of Greater Scaup was 0.71:1 and did not differ statistically from 1:1 (χ^2 = 1.33, df = 1, n = 48, P = 0.25; Table 1). The six Lesser Scaup examined were all were female, and among White-winged Scoters examined, four were female, one was male, and one was of unknown sex (Table 1). There was a significant bias toward adult males in Greater Scaup (juvenile:adult ratio 0.37:1, χ^2 = 5.54, n = 26, df = 1, P = 0.02), whereas the age distribution of females did not statistically differ from 1:1 (juvenile:adult ratio 0.82:1, χ^2 = 0.20, n = 20, df = 1, P = 0.65; Table 1).

There was no sex bias in Surf Scoters that were LOA vs. DOA (χ^2 = 1.889, df = 1, n = 204, P = 0.17; Table 2). Among DOA Greater Scaup, there were significantly more males than females (χ^2 = 5.19, df = 1, n = 48, P = 0.023; Table 2). Among female Surf Scoters, the ratios of adults and juveniles did not differ significantly for LOA or DOA categories (χ^2 = 2.25, df = 1, n = 100, P = 0.13; Table 2). Among male Surf Scoters, the ratio of DOA adults to juveniles was nearly equal (1.08:1; χ^2 = 0.03, df = 1, n = 27, P = 0.8; Table 2), but there was significant bias towards LOA adult males vs. juveniles (2.55:1; χ^2 = 14.0, df = 1, n = 71, P = 0.0002; Table 2). There were no age biases for Greater Scaup between intake categories (χ^2 = 0.02, df = 1, n = 46, P = 0.89; Table 2). Sample sizes were insufficient to test for biases in age/sex classes for Greater Scaup (Table 2).

TABLE 2
Demographics by intake category of Surf Scoters *Melanitta perspicillata* (*n* = 198) and Greater Scaup *Aythya marila* (*n* = 48) carcasses for which sex could be determined, during the 2007 *Cosco Busan* oil spill

Species	Sex	Age	Dead on Arrival (DOA)[a]	Live on arrival (LOA)[a]	Total	DOA to LOA ratio by sex (all ages)
Surf Scoter	Female	Adult	7	43	50	0.25:1
		Juvenile	13	37	50	
	Male	Adult	14	51	65	0.38:1
		Juvenile	13	20	33	
Greater Scaup	Female	Adult	1	10	11	0.17:1
		Juvenile	2	7	9	
		Unknown	0	0	0	
	Male	Adult	9	10	19	0.87:1
		Juvenile	3	4	7	
		Unknown	1	1	2	

[a] Birds that were found dead in the wild were classified as "dead on arrival" (DOA) and those that were brought in alive to rehabilitation and subsequently died were classified as "live on arrival" (LOA). Birds examined were a sub-set of the total number of birds estimated to be killed by the spill.

Among the four species examined, the majority of individuals were in extremely poor nutritional condition at the time of death; 73% of birds were classified as "critically emaciated" or "emaciated" (Table 3, Fig. 2). Across different species, proportions of birds classified as critically emaciated or emaciated ranged from 66% to 75% by species (Table 3).

Acanthocephaliasis infection was present in 21% of examined birds (33 of 159 birds). Surf Scoters had the highest prevalence of acanthocephaliasis (41%; 30 of 103 birds examined), followed by Greater Scaup (7%; three of 45 birds). Surf Scoters had a significantly greater prevalence of infection than Greater Scaup (χ^2 = 9.12, *n* = 148, *df* = 1, *P* = 0.003). Of 30 Surf Scoters with acanthocephaliasis, 60% had mild parasite loads, 20% had moderate loads, and 20% had heavy loads. Of three Greater Scaup with acanthocephaliasis, one had a moderate parasite load and two had mild loads. No White-winged Scoter or Lesser Scaup were infected with acanthocephaliasis, though we examined a limited sample size of these species (*n* = 5, White-winged Scoter; *n* = 6, Lesser Scaup). We did not test presence of acanthocephaliasis in White-winged Scoters or Lesser Scaup against other species because of limited sample sizes. There was no significant difference in the presence or absence of acanthocephaliasis in DOA (26% with acanthocephaliasis) vs. LOA Surf Scoters (31% with acanthocephaliasis; χ^2 = 0.30, *n* = 103, *df* = 1, *P* = 0.59). Significantly more juvenile male Surf Scoters were infected with acanthocephaliasis than other age/sex classes (χ^2 = 13.38, *df* = 3, *n* = 103, *P* = 0.039). When tested separately, there was no difference in acanthocephaliasis frequency between sexes (χ^2 = 2.58, *n* = 103, *df* = 1, *P* = 0.11) or age classes (χ^2 = 1.290, *df* = 1, *n* = 100, *P* = 0.26).

Acanthocephalan distribution in the intestines was not uniform. Parasites were most densely clustered in the jejunum, often near Meckel's diverticulum. Among infected birds, on average 32% of the length of the jejunum was affected, whereas 11% of the length of the ileum, and 1% of the duodenum, were infected. Acanthocephalans occurred in the colon and in the duodenum in one instance each, and were never found in the cecae. Parasites were < 5 mm long and wrinkled in appearance, leading us to categorize them as a *Profilicollis* spp., except in two birds with parasites > 8 mm long, which likely were *Corynosoma* spp. In severe cases, the *Profilicollis*-like parasites perforated the intestinal walls and could be seen grossly on the outside of the gastrointestinal tract.

TABLE 3
Body condition of carcasses of four species examined from the 2007 *Cosco Busan* oil spill (*n* = 258)

Species	Critically Emaciated	Emaciated	Moderate	Good	Obese	% Critically emaciated or emaciated
Greater Scaup	37	3	6	7	0	75
Lesser Scaup	4	0	0	1	1	66
Surf Scoter	119	22	42	10	0	73
White-winged Scoter	2	2	1	1	0	66
Grand Total	162	27	49	19	1	73

Across all four species, 23 of 278 birds examined (8%) exhibited putative fungal plaques in the air sacs, indicating grossly visible infection with mycotic disease (Table 4). The plaques ranged from one to > 738 mm^2 and often extended throughout the abdominal and thoracic air sacs, and occasionally into the lungs. Across all species, LOA birds had a significantly greater prevalence of mycotic disease than DOA birds (LOA 10% infected vs. DOA 2.5% infected; $\chi^2 = 4.12$, $n = 278$, $df = 1$, $P = 0.043$; Table 4). Within individual species, LOA birds more often had mycotic disease than DOA birds, but differences were not statistically significant (Surf Scoters: LOA 9% infected, DOA 2% infected [$\chi^2 = 2.78$, $n = 215$, $df = 1$, $P = 0.096$]; Greater Scaup: LOA 26% infected, DOA 7% infected [$\chi^2 = 1.85$, $n = 51$, $df = 1$, $P = 0.14$]; Table 4). However, among LOA birds, a significantly greater proportion of Greater Scaup had mycotic disease than Surf Scoters ($\chi^2 = 86.51$, $n = 193$, $df = 1$, $P <$ 0.0001; Table 4). Of all birds examined for both diseases ($n = 159$), five displayed simultaneous infection with acanthocephaliasis and mycotic disease: two Surf Scoters, one Greater Scaup, and two White-winged Scoters. The only other disease process noted was a putative case of *Sarcocystis* spp. skeletal muscle infection, with grossly apparent mature sarcocysts spread throughout the pectoral musculature of a single Greater Scaup. We did not evaluate this case further due to limited resources.

DISCUSSION

Examination of a sample of scoter and scaup carcasses from the *Cosco* oil spill revealed unexpectedly high proportions of female and juvenile Surf Scoters killed, as well as patterns of occurrence of acanthocephaliasis and mycotic disease that related to species, demographics, and whether birds had died during rehabilitation. The disproportionate mortality of female Surf Scoters, if representative of the impact of the entire oil spill, might result in long-term population impacts given the species populations are normally female-limited (Iverson *et al*. 2004, Rodway *et al*. 2015, Flint 2015). Surf Scoter mortality in the spill accounted for approximately 4% of the approximately 30 000 Surf Scoters that historically annually wintered in SFB (Accurso 1992, De la Cruz *et al*. 2014). However, in years following the *Cosco* spill, the population of Surf Scoters using SFB plummeted beyond what would be expected from the direct injury from the oil spill. During 2013–2016, standardized scoter spp. counts in SFB did not exceed 3 600 individuals (Strong 2018) compared with counts of 30 000–70 000 in the 1990s to the early 2000s (Accurso 1992, Richmond *et al*. 2014). Scoter numbers in SFB increased in 2018 (the last year for which data are available) to 14 562 individuals (Strong 2018), still far below historic totals. The disproportionate impact of the *Cosco* oil spill to female Surf Scoters and the subsequent population decline of Surf Scoters in SFB cannot be definitively linked. However, the demographic impacts we identified can be a piece of the puzzle to contribute to better understanding of drivers of Surf Scoter population declines and the long-term impacts of the oil spill.

The unexpectedly high rates of mortality of female Surf Scoters may have resulted in a greater overall impact on the species because sea duck populations are typically male-biased and are thought to be regulated primarily by adult female vital rates (Flint 2015). Conversely, the unexpectedly high ratio of juvenile Surf Scoters in our sample could result in a lesser overall impact on the population because perturbations to adult survivorship are expected to have greater population impacts in long-lived species, such as Surf Scoters (Keevil *et al*. 2018, Anderson *et al*. 2020). Previous studies have found male-biased ratios of 0.32:1 to 0.36:1 female:male (Iverson *et al*. 2004), and from 0.74:1 to 0.47:1 female:male in Surf Scoters in British Columbia (Rodway *et al*. 2015). The only previous data available on sex ratios of Surf Scoters in SFB are from an oil spill there in January 1971, in which the sex ratio was male-biased (0.63:1 female:male, $n = 57$ birds, Smail *et al*. 1972). Compared to these, the ratio from examined Surf Scoters from the *Cosco* oil spill was exceptionally female-biased (0.98:1 female:male). We suggest that either (1) the ratios we observed reflected the population demographics in SFB at the time of the spill, (2) the circumstances of the spill resulted in disproportionate mortality of females within the SFB population present during the oil spill, or (3) the constraints of our sample (greater sampling of LOA birds, sampling only birds that were recovered) biased it toward females.

Wintering and migratory movements of sea ducks are complex, with different sexes and age classes having different timing of movements and/or habitat preferences (Iverson *et al*. 2004, Uher-Koch *et al*. 2014). For example, male scoters do not participate in care of eggs and young, and they depart for molting and wintering areas such as SFB earlier than females (Peterson & Savard 2015). It might, therefore, be expected that more males would have been present than females in SFB in November, during the early part of the wintering period, though we observed the opposite in spill mortality trends. Local-scale sex-specific habitat preference could also have resulted in the unexpectedly high ratio of impacted female Surf Scoters. In British Columbia, female Surf Scoter proportions were greater over rocky than sandy substrates (Vermeer 1981,

TABLE 4
Comparison of ducks from the 2007 *Cosco Busan* oil spill that were dead on arrival (DOA), and those that arrived live to rehabilitation and subsequently died (Live on Arrival; LOA) in prevalence of mycotic disease infection, indicated by putative fungal plaques in air sacs of ducks examined[a]

Species	DOA			LOA		
	No. not infected	No. infected	% infected	No. not infected	No. infected	% infected
Greater Scaup	16	1	6	27	7	26
Lesser Scaup	0	0	0	6	0	0
Surf Scoter	55	1	2	146	13	9
White-winged Scoter	1	0	0	4	1	25

[a] Only carcasses for which aspergillosis infection could be evaluated grossly are included.

Iverson *et al*. 2004); the *Cosco* spill occurred over both soft bottom substrates in SFB and the rocky coastline outside the bay. In SFB, tagged female Surf Scoters had larger home ranges than males during early winter (i.e., December). This suggests a possible, speculative, mechanism for greater spill impacts to females: they used a larger area than males during November 2007 and thus may have interacted more with the spill area.

Despite overall biases toward adults in examined Surf Scoters, the proportion of juveniles to adults was unexpectedly high for males (0.51:1) and exceptionally high for females (1:1) compared with other studies. In British Columbia, juvenile:adult ratios of live flocks were 0.11:1 (males) and 0.23:1 (females; Iverson *et al*. 2004). In another study in British Columbia, male age ratios ranged from 0.064:1 to 0.101:1 juvenile to adult, and female age ratios ranged from 0.141:1 to 0.188:1 over three years and multiple sites (Rodway *et al*. 2015). Disproportionate mortality of first year Surf Scoters could potentially be related to regional differences in demographic composition of flocks in SFB compared to British Columbia, which are not presently understood. Another possibility is that differences in micro-habitat selection influenced mortality at the spatial level of the spill footprint. In British Columbia, first year male Surf Scoters tended to flock together with other first year males, whereas first-year females did not flock together (Iverson *et al*. 2004). Intriguingly, juvenile surf scoters had greater rates of acanthocephaliasis than adults, suggesting a potential, and unproven, link between disease state and mortality in the spill. Further study on the sex-ratios of Surf Scoters in SFB and Pacific-wide, outside of unusual mortality events, would be useful for understanding the drivers behind the higher-than-expected proportions of female and juvenile mortality we observed. For example, understanding what the "normal" demographic composition of the SFB scoter population is, and whether it has changed over time, would be useful for interpreting our results, including evaluation of whether our sample was representative of the scoter population impacted by the spill.

Scaup populations have exhibited a declining trend in SFB counts since around the year 2000, though the decline was less pronounced than for scoter populations (Richmond *et al*. 2014, Strong *et al*. 2018). Some of the lowest counts on record occurred in the years after the *Cosco* oil spill, in 2014 and 2015 (25 556 and 15 207 birds, respectively; Strong *et al*. 2018). However, the *Cosco* spill impacted a much smaller proportion of the overall population of scaup wintering is SFB (i.e., estimated mortality was ≤ 0.5% of the approximately 50 000–100 000 annually recorded 2005–2007; Richmond *et al*. 2014) compared with scoters. Our results do not point to any obvious hypotheses about how the demographic impacts on scaup in the *Cosco* spill might have affected the subsequent population trajectory.

The sex ratio of examined Greater Scaup was slightly male-biased (0.77:1 female:male), but this is difficult to compare with other studies, as Greater and Lesser scaup are frequently grouped together in surveys. The sex ratio of the Greater Scaup that we examined was similar to less male-biased ratios observed in US harvests of scaup in the 1960s and 1970s, and more than male-biased ratios observed in the 1990s (Austin *et al*. 2000, Afton & Anderson 2001). Unlike Surf Scoters, scaup age ratios reported in other studies tend to be juvenile biased rather than adult biased (Afton & Anderson 2001). However, the slight, but non-significant, biases toward adults we observed were consistent with age ratios of Lesser Scaup from US harvests (Afton & Anderson 2001). However, Greater and Lesser Scaup need to be treated as separate species from both ecological and management perspectives (Austin *et al*. 2000, Afton & Anderson 2001), so interpretation of Greater Scaup demography based on comparisons to Lesser Scaup should be taken with caution. There is little information about scaup demography, or patterns of spatial use in SFB or the Pacific Coast region. Future research could focus on these factors to establish baseline information for these species, which would help with understanding population declines and evaluation of demographic impacts observed in *Cosco*, as well as future spills.

Proportionally more Surf Scoters were infected with acanthocephaliasis than other species examined, which was likely due to their ingestion of the Pacific Sand Crab and the Spiny Mole Crab *Blepharipoda occidentalis*. Sand and moles crabs are intermediate host vectors of acanthocephalans (Hennessy & Morejohn 1977, USGS 1999, Mayer *et al*. 2003, Hollmén & Franson 2005) found in nearshore sandy substrate habitat, where Surf Scoters spend a significant part of their annual cycle (Anderson *et al*. 2020). Proportionally greater loads of acanthocephalans among juvenile male Surf Scoters could arise because younger birds may forage on easily-captured prey such as sand crabs in nearshore habitats (Rodway *et al*. 2003), resulting in greater acanthocephalan exposure. Additionally, juveniles may have greater exposure to acanthocephalans because they spend a greater proportion of the year in coastal marine environments compared with adults that return to inland breeding sites (Anderson *et al*. 2020). Immunologically naïve juveniles may also exhibit more severe infections than older birds that have mounted a prior response to a given pathogen (Tolf *et al*. 2013).

The overall prevalence of acanthocephaliasis in Surf Scoters and Greater Scaup examined in this study (6%–29%) was lower than what has been recorded in some other marine waterfowl. For example, acanthocephaliasis rates of Common Eiders *Somateria mollissima* ranged 79%–100% in six studies (reviewed in Camphuysen *et al*. 2002). Acanthocephaliasis rates previously documented in Surf Scoters (Bourgeois & Threlfall 1981, Ching 1989) and scaup (Bush & Holmes 1986, England *et al*. 2016) were lower than the levels we found for Surf Scoters. It is possible that Surf Scoters may live normally with mild to moderate acanthocephaliasis without signs of illness; indeed, "healthy" Common Eiders are thought to virtually always be infected with acanthocephalans (Camphuysen *et al*. 2002). However, acanthocephaliasis has been experimentally shown to be associated with weakened health in Common Eiders (Hollmén 1999). Likewise, acanthocephaliasis has been associated with many waterbird mortality events, though it is usually not implicated as the direct cause of death (Hario *et al.* 1997, Patton *et al*. 2007, Camphuysen *et al*. 2002). Thus, it is possible that the combination of underlying acanthocephaliasis and impacts from the oil spill could have interacted to increase Surf Scoter mortality. This linkage is speculative, but it is notable that Surf Scoters in our study were disproportionately composed of juveniles, and that juvenile Surf Scoters had the greatest rates of acanthocephaliasis. The relatively high prevalence of acanthocephaliasis in Surf Scoter infection in SFB, potentially resulting in greater vulnerability to mortality, can be considered when prioritizing future rehabilitation care.

Scoters and scaup from *Cosco* examined in this study that experienced at least one day of rehabilitation before death exhibited putative fungal plaques, indicating mycotic disease significantly more often than those that were DOA. This indicates that some birds contracted the disease or had underlying conditions worsen during rehabilitation. This result is supported by other studies showing that water birds are, in general, extremely susceptible to mycotic disease infection (Asakura *et al*. 1962, Hillgarth & Kear 1979, Arné *et al*. 2021), especially during the stressful process of oil spill rehabilitation (Horowitz & Haebler 2001, Balseiro *et al*. 2005). The emaciated body condition of the majority of the birds in our study, as well as the prevalence of acanthocephaliasis, indicates that most individuals were under extreme physical stress, and probably immunosuppressed, when they reached rehabilitation centers. In rehabilitation centers, fungal loads of *Aspergillus* spores can be much greater than in natural environments, increasing the chance of contracting the disease (Burco *et al*. 2012). As a group, ducks are particularly susceptible to mycotic disease, and species-specific susceptibility has been shown in other species, including eiders (*Somateri*a and *Polysticta* spp., Hillgarth & Kear 1979, Arné *et al*. 2021). We found that proportionally more LOA Greater Scaup were infected with mycotic disease (26%) than LOA Surf Scoters (9%), suggesting Greater Scaup may be more susceptible to the disease. Controlled studies (e.g., exposing both species to the disease vectors in a controlled environment) would be needed to better understand species-specific vulnerabilities. Regardless, precautions should be taken during rehabilitation to avoid conditions that could lead to mycotic disease in both scoters and scaup (e.g., by following recommendations described in Burco *et al*. 2014), since both species experienced infection during rehabilitation during the *Cosco* oil spill.

Our results show the value of post-oil spill examination of collected carcasses for documentation of the demographic and disease-state information. Findings such as the potential disproportionate impact of the *Cosco* oil spill on female and juvenile Surf Scoters have implications for species recovery (e.g., interpreting the steep decline of scoters in SFB after the spill) and damage assessment (e.g., for calculating lost bird-years and lost reproductive output of individuals killed; Zafante & Hampton 2005). We also showed that useful information on disease prevalence in wild populations can be gathered from examination of birds during mortality events, with potential value in future rehabilitation care. We encourage the documentation of demographics and disease as a regular part of future oil spill and other mortality event responses in order to gain insight into population impacts and improve rehabilitation and preventative care efforts.

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