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# Two forage fishes as potential conduits for the vertical transfer of microfibres in Northeastern Pacific Ocean food webs☆

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ABSTRACT

We assessed the potential role played by two vital Northeastern Pacific Ocean forage fishes, the Pacific sand lance (*Ammodytes personatus*) and Pacific herring (*Clupea pallasii*), as conduits for the vertical transfer of microfibres in food webs. We quantified the number of microfibres found in the stomachs of 734 sand lance and 205 herring that had been captured by an abundant seabird, the rhinoceros auklet (*Cerorhinca monocerata*). Sampling took place on six widely-dispersed breeding colonies in British Columbia, Canada, and Washington State, USA, over one to eight years. The North Pacific Ocean is a global hotspot for pollution, yet few sand lance (1.5%) or herring (2.0%) had ingested microfibres. In addition, there was no systematic relationship between the prevalence of microplastics in the fish stomachs vs. in waters around three of our study colonies (measured in an earlier study). Sampling at a single site (Protection Island, WA) in a single year (2016) yielded most (sand lance) or all (herring) of the microfibres recovered over the 30 colony-years of sampling involved in this study, yet no microfibres had been recovered there, in either species, in the previous year. We thus found no evidence that sand lance and herring currently act as major food-web conduits for microfibres along British Columbia's outer coast, nor that the local at-sea density of plastic necessarily determines how much plastic enters marine food webs via zooplanktivores. Extensive urban development around the Salish Sea probably explains the elevated microfibre loads in fishes collected on Protection Island, but we cannot account for the between-year variation. Nonetheless, the existence of such marked interannual variation indicates the importance of measuring year-to-year variation in microfibre pollution both at sea and in marine biota.


## 1. Introduction

There is growing awareness that the vast quantities of debris polluting the world's oceans pose a serious threat to a wide range of marine organisms (Law, 2017). The debris gets into the ocean from both marine and terrestrial sources, and in a plethora of forms, colours, shapes and sizes. Once there, physical abrasion and UV irradiation can cause much of the debris to degrade into smaller and smaller fragments (Auta et al., 2017). Microfibres of a variety of types, both natural and manufactured (the latter including microplastics), enter marine food webs when small pieces are ingested by planktivores, detritivores, suspension-feeders and filter-feeders (Goldstein and Goodwin, 2013; Setälä et al., 2014; Hall et al., 2015; Remy et al., 2015; Gusmão et al., 2016). These organisms can, in turn, transfer the microfibres on to their predators (Eriksson and Burton, 2003; Farrell and Nelson, 2013; Tosetto et al., 2017). Once ingested, the microfibres can have both physical (Wright et al.,

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2013) and toxicological (Cole et al., 2011a,b) effects on marine predators, with deleterious effects most evident at organismal and sub-organismal levels (Rochman et al., 2016).

Forage fishes often act as the key trophic links between zooplankton and the broad suite of piscivorous taxa that inhabits the oceans (Smith et al., 2011). Zooplanktivorous fishes can both incidentally take up small particles of debris ingested by or attached to their zooplankton prey (Cole et al., 2011a, b; Desforges et al., 2015), and actively consume larger particles that resemble natural food items (Lusher et al., 2013; Ory et al., 2017). Consequently, forage fishes could act as primary conduits through which microfibres, and any associated contaminants, are transferred vertically into piscivores in marine food webs.

The Pacific sand lance (*Ammodytes personatus*) and the Pacific herring (*Clupea pallasii*) are two abundant, widely-distributed forage fishes that play vital roles in food webs of the Northeastern Pacific Ocean. Diets in both species consist of zooplankton, particularly calanoid copepods (Foy and Norcross, 1999; Hipfner and Galbraith, 2013). Sand lance and herring are themselves consumed by a wide array of predators including many commercially valuable fishes (Brodeur, 1991; Coutre et al., 2015), and many species of marine mammals (Friedlaender et al., 2009; Tollit et al., 2015) and seabirds (Gjerdrum et al., 2003; Gladics et al., 2015). Compared to other marine taxa, the frequency at which microfibres are ingested, and the consequences of their ingestion, are especially well documented for seabirds, a taxonomically and ecologically diverse group that is widely distributed throughout the world's oceans (Wilcox et al., 2015; Provencher et al., 2017).

Here, we quantify spatial and temporal variation in the amount and types of microfibres ingested by sand lance and herring in waters off the coasts of British Columbia, Canada and Washington State, USA. Fishes were collected directly from a widely-distributed and abundant North Pacific seabird, the rhinoceros auklet (*Cerorhinca monocerata*), on six island breeding colonies in July or August in up to eight years, their stomachs were excised, and the contents quantified. The rhinoceros auklet is an ideal forage-fish predator for the purposes of this study for several reasons. First, they are known to ingest microfibres; microplastic was found in the stomachs of four of 68 rhinoceros auklets recovered from various sources in the Northeastern Pacific over recent decades (Day, 1980; Robards et al., 1995, 1997; Blight and Burger, 1997; Avery-Gomm et al., 2013). Second, these birds are central-place foragers while breeding, so they sample prey within a restricted range around their colonies. Based on 63 day-long foraging trips taken by provisioning auklets equipped with GPS tags on islands in British Columbia, maximum linear travel distances away from colonies averaged 59.7 km (3.8 SE), and ranged from 5.8 to 119.4 km (A. Domalik, unpubl. data). Third, these birds dive to catch bill-loads of up to 30 whole fishes at dusk, mainly within the top 10 m of the water column (Kato et al., 2003), which they then deliver intact to their single nestlings (Davoren and Burger, 1999). It is a simple matter to collect the captured fishes when the birds return to the colony *en masse* (Bertram et al., 2002). The stomachs of fishes obtained in this manner contain zooplankton prey ingested within a short period of time prior to collection from within the auklets' foraging range (Hipfner and Galbraith, 2013). Information on the retention time of fibres in the stomachs of sand lance and herring is lacking, but laboratory experiments with goldfish (*Carassius auratus*), a zooplanktivorous fish of similar size, show that microfibres only rarely accumulate in the gut contents over successive meals (Grigorakis et al., 2017).

Our primary objective in undertaking this research was to assess the potential role that these two forage fishes play as conduits for the vertical transfer of microfibres to piscivores in Northeastern Pacific Ocean food webs. In addition, our multi-colony sampling protocol enabled us to test the hypothesis that the local at-sea density of microplastic predicts its prevalence in marine zooplanktivores (Wilcox et al., 2015; Schuyler et al., 2016; Güven et al., 2017). Our test of that hypothesis rested on the results of Desforges et al. (2014), who measured the density of microplastic debris in sub-surface waters at 4.5 m depth across the southern portion of our study area in August and September of 2012.

The North Pacific Ocean is a global hotspot for small debris (van Sebille et al., 2015), but the local at-sea density of debris can vary due to small-scale oceanographic and anthropogenic factors. Desforges et al. (2014) found that microplastic density was 2.5–3 times higher around Pine Island, British Columbia (~8000 $m^{-3}$) than around Triangle Island, BC (~2600 pieces $m^{-3}$) or Protection Island, Washington (~3200 $m^{-3}$). Therefore, we specifically predicted that we would find more microplastic in forage fish stomachs collected from auklets on Pine Island than on Protection or Triangle islands. Those authors attributed the high at-sea density of plastic debris in southern Queen Charlotte Sound, where Pine Island is located, to the convergence of pan-Pacific currents with outflow from Johnstone and then Queen Charlotte Straits, creating a zone of accumulation, combined with the actions of a clockwise gyre that tends to retain seawater, and any entrained plastic, for extended periods of time. They attributed the lower plastic density in the Salish Sea around Protection Island, despite the close proximity of large, land-based sources of plastic, to the short residency time of surface waters due to strong outflow through Johnstone and Queen Charlotte straits to the north, and Juan de Fuca Strait to the west. Low plastic density near Triangle Island, located 45 km offshore, was attributed to the tendency for plastic density to decline with distance from the mainland coast, as it does in other marine systems (Rudduck et al., 2017). At-sea plastic density has not been measured across the northern part of our study region, but there are no obvious oceanographic or anthropogenic forces that would be expected to produce high density around S'G̲ang Gwaay, Moore Island or Lucy Island, all along BC's outer coast.

## 2. Materials and methods

### 2.1. Study sites

Our study took place on six rhinoceros auklet breeding colonies, five of them in British Columbia, Canada: Lucy Island (54°17′ N 130°37′ W) and Moore Island (52°57′ N 129°34′ W) along BC's North Coast; Pine Island (50°35′ N 127°26′ W) along BC's Central Coast; S'G̲ang Gwaay (52°05′ N 131°13′ W) off the southwestern tip of the Haida Gwaii archipelago; and Triangle Island (51°52′ N 129°05′ W), the outermost island in the Scott Islands archipelago. Sampling also occurred at one colony in Washington State, U.S.A.: Protection Island (48°07′ N 122°55′ W), in the protected inner waters of the Salish Sea (Fig. 1).

### 2.2. Field methods

Forage fishes were collected from rhinoceros auklets on 5–7 day visits to breeding colonies in early July to early August of 2009–2016. Auklets returning to the colony to deliver bill-loads of prey to their nestlings were induced to drop their bill-loads using bright lights, or were captured on the ground either by hand or with long-handled nets. The bill-loads were collected and placed in Whirl-Pak bags. For each bill-load, individual prey items were identified and enumerated to species, and whole specimens of sand lance (2009–2016) and herring (2014–2016) were selected for stomach sampling. The stomach contents of the individual fishes present in the same bill-load would not be independent if, as is likely, the fishes were feeding together when captured. Therefore,