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A zero percent plastic ingestion rate by silver hake (*Merluccius bilinearis*) from the south coast of Newfoundland, Canada

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ABSTRACT

Silver hake, (*Merluccius bilinearis*), contributes significant biomass to Northwest Atlantic ecosystems. The incidence of plastic ingestion for 134 individuals collected from Newfoundland, Canada was examined through visual examination of gastrointestinal contents and Raman spectrometry. We found a frequency of occurrence of ingestion of 0%. Through a comprehensive literature review of globally published fish ingestion studies, we found our value to be consistent with 41% (n = 100) of all reported fish ingestion rates. We could not statistically compare silver hake results to other species due to low sample sizes in other studies (less than n = 20) and a lack of standardized sampling methods. We recommend that further studies should 1) continue to report 0% plastic ingestion rates and 2) should describe location and species-specific traits that may contribute to 0% ingestion rates, particularly in locations where fish consumption has cultural and economic significance.

1. Introduction

The province of Newfoundland and Labrador, Canada plays a critical role in the nation's fishing industry. Despite the collapse of the Atlantic cod (*Gadus morhua*) stock and the province's subsequent moratorium on Atlantic cod in 1992, the fishing industry still contributes 3.1 billion dollars in revenue and employment of over 17,000 individuals in the remote province (Bavington, 2010; Campling et al., 2012; Government of Newfoundland and Labrador, 2016). One of the ways the Newfoundland fishery has survived the cod collapse is by diversifying what is fished (Bavington, 2010). Although the slender schooling fish, silver hake (*Merluccius bilinearis*), makes up a significant biomass of the Northwest Atlantic ecosystem (where biomass is a measurement used by the fisheries to describe the total mass of organisms in a given area), there is no established silver hake fishery in Newfoundland (Bayse and He, 2017; Garrison and Link, 2000), making it a potential species through which to further diversify the fishery in the province. Silver hake have a broad geographic distribution in the Atlantic Ocean ranging from South Carolina, U.S.A. to Newfoundland, Canada (Bayse et al., 2016; Bigelow and Schroeder, 1953). Since the 1950s, there have been commercial fisheries in North America for various species of hake (Helser and Alade, 2012; Pitcher and Alheit, 1995), and the Canadian and American silver hake fishery produces approximately 8–9000 metric tons/yr and 6–7000 metric tons/yr, respectively (DFO, 2015; NMFS, 2017). Despite the size of the silver hake fishery in the North Atlantic, Canada only became involved in the fishery in 2004, and Canadian fleets fish exclusively in the Scotian shelf south of Newfoundland (DFO, 2015). The catch from the American fleets mainly comes from the New England fishery fished in the Gulf of Maine and Georges Banks region, where the populations are relatively stable with no scientific evidence of past overfishing (Bayse and He, 2017; Morse et al., 1999; New England Fisheries Management Council, 2012). Silver hake is an economically important fish species as its flesh has been found to be an alternative fish product for the manufacture of surimi, a seafood analog (e.g. imitation crab meat), that is consumed worldwide (Lanier, 1984).

Fragmented or manufactured plastics are ubiquitous in marine environments. Plastics that are small in size (< 5 mm) are known as microplastics, a size class which accounts for > 90% of all marine plastic particles (Eriksen et al., 2014). The abundance and small size of marine microplastics makes them highly bioavailable for ingestion by marine animals. It has been reported that plankton - some of the smallest marine animals which form the base of the marine food web - can successfully ingest microplastics (Cole et al., 2014). This is especially

Terms: Frequency of occurrence, the number of individual fish within a sample population that have ingested plastics, regardless of how many plastics they ingested (%FO)

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concerning given that plastics contain contaminants enmeshed during manufacture such as plasticizers, colourants, and flame retardants (Colton et al., 1974; Lithner et al., 2012) as well contaminants that accumulate on plastics from the surrounding seawater, such as flame retardants like polychlorinated biphenyls (PCBs) and insecticides such as dichlorodiphenyltrichloroethane (DDT), among many other chemicals (Mato et al., 2001; Newman et al., 2015). There is potential for these toxicants to bioaccumulate in marine animals that ingest plastics (Rochman, 2013). The biomagnification of these contaminants into higher trophic levels of the food web (including human consumers), while of great concern, is not fully understood and is an increasing area of study (Bakir et al., 2016; Engler, 2012). Most plastic ingestion studies, particularly in Canada, have focused on seabirds (Bond, 2016; Bond et al., 2012; Bond and Lavers, 2013; Holland et al., 2016; Provencher et al., 2014), while fewer have focused on fish, and only a handful have studied fish destined for human consumption (Choy and Drazen, 2013; Liboiron et al., 2016; Rochman et al., 2015).

The vulnerability of marine animals to the ingestion of plastics will depend on their ecological niche. For example, given that plastics exist at various depths but accumulate in pelagic and benthic environments, fish that occupy bathymetric ranges that correspond to high marine plastic abundance may be more susceptible to plastic ingestion. For instance, Neves et al. (2015) found that pelagic species consumed more plastic particles when compared to the sampled benthic species from off the Portuguese coast. This is consistent with reports of high concentrations of marine plastics in the ocean's surface layer (Cózar et al., 2014; Eriksen et al., 2014). To date, the relationship between fish species' bathymetric depth range and plastic ingestion have not been regularly or systematically examined within or across published studies.

Silver hake are a species of fish we hypothesize are likely to ingest plastics. They are a demersal species, found in depths ranging from 55 to 914 m (Lloris and Matallanas, 2005), where they feed from both surface and benthic environments. Because they are predators, silver hake are assumed to be a species likely to ingest food that contains plastics (via secondary ingestion) in environments that contain plastics (particularly surface waters where plastics accumulate) (Andrady, 2003; Eriksson and Burton, 2003; Romeo et al., 2015). Between the ages of 1–3 years, silver hake opportunistically feed on invertebrates, transitioning to a more piscivorous diet at maturity (Vinogradov, 1984; Waldron, 1992), potentially increasing the size of plastics they may ingest via secondary ingestion. In fact, individual silver hake > 40 cm typically feed exclusively on fish (Durbin et al., 1983; Langton, 1982), and as adults commonly exhibit cannibalistic behavior (e.g. diets consist of ∼10% frequency of occurrence of juvenile conspecifics) (Bowman, 1983; Bowman, 1975). Variation from this piscivorous diet can arise as a result of seasonality, combined with the opportunistic nature of predation (Waldron, 1992). For instance, during the spring adults mostly consume fish, while diverse prey items like crustaceans and molluscs may also be preyed upon during the summer (Waldron, 1992). Generally, however, silver hake feed primarily on pelagic species that in turn feed from the surface of the water where plastics tend to accumulate. In relation to other fish species in the region (e.g. cod and haddock), silver hake are more selective in their feeding habits and the species of prey consumed are less diverse (Bowman, 1975). Although the feeding ecology of this fish has been well-studied, a search of published English-language scientific literature has returned no research examining plastic ingestion by silver hake, despite feeding habits that position them to do so.

The silver hake in this study were collected from an area of suspected high plastic pollution, off the south coast of Newfoundland, both within the Gulf of St. Lawrence and just outside of it, along the southwestern Grand Banks (Fig. 1). This sample area is expected to have a higher representation of plastic pollution compared to more northern Newfoundland waters fed by the Labrador current (Liboiron et al., 2016). The Gulf of St. Lawrence is surrounded and enclosed by five Canadian provinces, is home to intense fishing (especially in the case of the Grand Banks) and shipping activity, and sits at the mouth of a river draining a large portion of mainland Canada and the United States (Fisheries and Oceans Statistical Services, 2016; The St. Lawrence Seaway Management Corporation, 2016). The numerous pathways of introduction for marine plastics in the Gulf of St. Lawrence and the high fishing intensity on the Grand Banks makes this sample site ideal for the investigation of plastic ingestion. Regardless of the effect that the feeding behavior of silver hake may have on their ingestion of plastic, silver hake of this region are expected to be at a higher risk of plastic ingestion than in other regions around Newfoundland. If %FO of plastic remains low despite environmental plastic concentrations that are expected to be high, silver hake may represent a safe new fishery option within the context of plastics in fish in the face of increasing plastic loads in the future.

2. Methods

2.1. Collection of silver hake

Individual silver hake were collected by trawling from the RV Celtic Explorer research ship, from April 27 to May 6, 2016 by Fisheries and Oceans Canada and the Fisheries and Marine Institute of Memorial University of Newfoundland (Table 1; Fig. 1). Of the 175 silver hake collected off of the south coast of Newfoundland, 41 individuals were eliminated from analysis due to compromised gastrointestinal tracts (inverted, split or detached stomachs occurring during the course of trawling or initial processing), resulting in a total of 134 fish for this study. Body length and sex of each individual was recorded, and entire gastrointestinal (GI) tracts were removed, individually bagged and tagged, and frozen aboard the RV Celtic Explorer for later transport to the laboratory.

2.2. Laboratory procedures

2.2.1. Visual analysis

We undertook precautions to avoid cross-contamination of plastics, which included: rinsing or wiping down all tools with water and Kimwipes, including the microscope lens and plate, Petri dishes, and sieves before use; hands were washed; cotton lab coats worn; and hair was tied back. After each dissection, we closely examined our hands and tools for any microplastics that may have adhered. We kept a control dish to collect microplastics, specifically microfibers, that originated within the lab, the contents of which were then used to compare to any microfibers found in the fish for exclusion purposes. However, microfiber contamination precautions were not taken during the collection period onboard the ship.

This study followed methods used by Liboiron et al. (2016) (which were in turn adapted from van Franeker et al. (2011) and Avery-Gomm et al. (2016)) to allow for comparability across studies done in the region of Newfoundland. The bagged GI tracts were thawed in cold water for approximately 30 min prior to dissection. A double sieve method was used by placing a 4.75 mm (#4) mesh stainless steel sieve directly above a 1 mm (#18) mesh stainless steel sieve. The 4.75 mm sieve served to separate mesoplastics and larger GI contents from microplastics and smaller items. The lower threshold of 1 mm was selected as anything smaller cannot be reliably identified with the naked eye (Song et al., 2015). GI tracts were placed in the 4.75 mm sieve and an incision was made using fine scissors, running from the esophagus, to the stomach, through the intestines, then to the anus. The contents of the GI tract were gently rinsed with tap water into the sieve to remove contents. The GI lining was closely examined for any embedded plastics and the contents of the sieves were visually inspected. Any identifiable food was recorded, and suspected anthropogenic debris was removed with tweezers and transferred to a Petri dish for later observation under a microscope. Stomach contents were described as containing either no