



Ectoparasitism on deep-sea fishes in the western North Atlantic: In situ observations from ROV surveys



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ABSTRACT

A complete understanding of how parasites influence marine ecosystem functioning requires characterizing a broad range of parasite–host interactions while determining the effects of parasitism in a variety of habitats. In deep-sea fishes, the prevalence of parasitism remains poorly understood. Knowledge of ectoparasitism, in particular, is limited because collection methods often cause dislodgment of ectoparasites from their hosts. High-definition video collected during 43 remotely operated vehicle surveys (2013–2014) provided the opportunity to examine ectoparasitism on fishes across habitats (open slope, canyon, seamount, cold seep) and depths (494–4689 m) off the northeastern U.S., while providing high-resolution images and valuable observations of fish behavior. Only 9% ($n = 125$ individuals) of all observed fishes (25 species) were confirmed with ectoparasites, but higher percentages (~33%) were observed for some of the most abundant fish species (e.g., *Antimora rostrata*). Ectoparasites included two copepod families (Lernaepodidae, Sphyrriidae) that infected four host species, two isopod families (Cymothoidae, Aegidae) that infected three host species, and one isopod family (Gnathiidae) that infected 19 host species. Hyperparasitism was also observed. As host diversity declined with depth, ectoparasite diversity declined; only gnathiids were observed at depths down to 3260 m. Thus, gnathiids appear to be the most successful group to infect a diversity of fishes across a broad depth range in the deep sea. For three dominant fishes (*A. rostrata*, *Nezumia bairdii*, *Synaphobranchus* spp.), the abundance and intensity of ectoparasitism peaked in different depths and habitats depending on the host species examined. Notably, gnathiid infections were most intense on *A. rostrata*, particularly in submarine canyons, suggesting that these habitats may increase ectoparasite infections. Although ectoparasitism is often overlooked in deep-sea benthic communities, our results demonstrate that it occurs widely across a variety of habitats, depths, and locations and is a significant component of deep-sea biodiversity.

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1. Introduction

The importance of parasites in shaping community structure and influencing ecosystem functioning in the marine environment has gained considerable recognition over the past few decades (Dobson and Hudson, 1986; Poulin, 1999; Poulin et al., 2016). Parasites have complex roles in community ecology by influencing population sizes and shifting patterns in both biodiversity and community structure. Parasites can also alter the outcome of competitive interactions, either by enabling rare species to coexist

with dominant ones or by helping to eliminate competitors. Additionally, parasites have become increasingly recognized as important components of trophic pathways (see Demopoulos and Sikkell, 2015). The inclusion of parasites in food webs has revealed higher connections among species (Amundsen et al., 2009) and higher trophic efficiency (Arias-González and Morand, 2006). Although the importance of parasites in marine ecosystems is clear, there is still much to be learned regarding the multiple effects that parasites have in different ecosystems throughout the marine realm.

A recent review regarding the synergy of marine ecology and parasitology highlighted seven key areas to further increase our understanding of the importance of parasites in marine ecosystem functioning (Poulin et al., 2016). Poulin et al. (2016) emphasized the need to discover and identify key parasite species that play pivotal

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roles in ecosystems, while adding new model systems to broaden perspectives on marine parasitism. Because the majority of marine parasitology studies have been conducted in coastal and coral reef ecosystems, it was also suggested that research should be expanded to additional marine habitats. Focusing on a narrow range of habitats can constrain generalizations regarding parasitism in the marine environment (Poulin et al., 2016).

The deep sea is one such understudied ecosystem in which data on parasitism remains limited. For fishes inhabiting the deep sea, knowledge of parasitism is limited to <10% (Klimpel et al., 2006). The few studies on parasitism in deep-sea fishes have focused mainly on the prevalence of endoparasitism (Noble, 1973; Campbell et al., 1980; Klimpel et al., 2006; Palm and Klimpel, 2008), revealing the importance of temperature, depth, and habitat (such as submarine canyons) in influencing the prevalence of endoparasite infections in the deep sea (Manter, 1934; Campbell et al., 1980; Gartner and Zwermer, 1989; Marcogliese, 2002; Klimpel et al., 2006). However, deep-sea fishes are also hosts to ectoparasites, which can adversely affect fishes by causing anemia (Adlard and Lester, 1995; Lester et al., 1995), tissue damage (Adlard and Lester, 1995; Lester et al., 1995), scarring (Ross et al., 2001), and behavioral changes (e.g. Welicky and Sikkel, 2014; Artim et al., 2015), while transmitting other diseases [e.g., blood parasites, (Davies and Smit, 2001), viruses (Lawler et al., 1974)]. Ectoparasitism may thus influence population dynamics of deep-sea fishes and may be important in trophic ecology through direct consumption by other organisms (Johnson et al., 2010; Demopoulos and Sikkel, 2015). Yet, ectoparasitism remains understudied, partly because prior data have been obtained opportunistically from trawling and dredging efforts. These types of gear can dislodge ectoparasites from their hosts during collection (Ross et al., 2001).

To investigate ectoparasitism in the deep sea, direct observations using remotely operated vehicles (ROVs) provide an alternative method to trawling. Visual based surveys have provided a considerable amount of information on ectoparasite-host interactions in shallow waters, while revealing effects of parasitism on fish behavior (e.g., swimming behavior, site fidelity, Barber et al., 2000; Sikkel et al., 2004). Trophic connections have also been determined from *in situ* observations (i.e., cleaner stations on coral reefs, Sikkel et al., 2004). Thus, the value of visual analysis in parasite studies, from shallow waters to the deep-sea, is clear.

Recent expeditions to survey various seafloor features along the continental margin of the northeastern United States (NEUS) provided an opportunity to increase knowledge of ectoparasites infecting demersal fishes in the deep sea. Visual observations from ROV surveys were used in the present study to identify ectoparasites and their hosts and examine whether ectoparasite diversity declines with increasing depth. We also examined whether ectoparasite-host interactions and intensity of infections differ among depths and habitats in each of three common fish species [*Antimora rostrata* (family Moridae), *Nezumia bairdii* (family Macrouridae), and *Synphobranchus* (family Synphobranchidae)]. The high-definition video obtained from these expeditions enabled *in situ* observations of host-parasite interactions while providing unparalleled, high-resolution images of ectoparasites infecting fishes in the deep sea.

2. Material and methods

Forty-three remotely operated vehicle (ROV) dives were conducted with the ROV *Deep Discoverer* (D2) along the NEUS continental margin and New England Seamount Chain during two expeditions (9 July to 16 Aug 2013 and 19 Sep to 6 Oct 2014) aboard the NOAA Ship *Okeanos Explorer* (Fig. 1). These expeditions were

telepresence-enabled, with live video feeds transmitted back to shore in real time (<http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream.html>), allowing scientists on shore and on the ship to interact during the dives via an Internet chat room and satellite teleconference line.

The ROV D2 was equipped with two high-definition cameras and 16,600 lumens of hydraulically positioned LED lights. A Seabird 911+ conductivity-temperature-depth (CTD) logger with a dissolved oxygen (DO) sensor was also attached to the ROV. Paired lasers (10 cm apart) were positioned on the ROV to approximate field of view and sizes of fishes and ectoparasites. The *Okeanos Explorer* followed the vehicles using dynamic positioning and tracked vehicle position with an ultra-short baseline tracking system.

Each ROV dive traversed one broad-scale habitat feature at depths ranging from 494 to 4689 m (Fig. 1). These habitat features included: submarine canyons (25 dives), cold seeps (three dives), open slope/intercanyon areas (seven dives), and seamounts (eight dives). No fishes were observed during one dive at the deepest seamount surveyed (un-named Seamount, 4552–4689 m). As the ROV traversed a habitat feature (~0.1–0.2 knots, 1 knot = 0.514 m s⁻¹), the cameras were generally set on wide-angle view, but zooms were frequently conducted to obtain detailed imagery of each previously undocumented species encountered during a given dive survey. The over-ground distance covered by the ROV [measured in ArcGIS v9 (ESRI)] varied across dives (300–2200 m), but the observation time on bottom was approximately the same (5–7 h per dive).

During each dive, video clips (103–191 clips) from the high-definition camera mounted on the ROV D2 were contiguously acquired as part of the mission of the expeditions. These video clips ranged in length from approximately 30 s to 5 min. Frame grabs (112–351 per dive) were subsequently taken from video clips. Sixty-nine demersal fish taxa and three mesopelagic taxa were identified using both frame grab and video observations (see Quattrini et al., 2015). Ectoparasites were identified to the lowest taxonomic level on fishes from all available frame grabs. Ectoparasite type, placement, number and size also ensured that individuals were counted only once. Because we restricted this analysis to using frame grabs only, we calculated frequency of ectoparasite-host interactions to examine general patterns across the region.

Three species of fishes (*Antimora rostrata*, *N. bairdii* and *Synphobranchus* spp.) that were dominant in the region and had ectoparasites were further enumerated using all video clips. The average intensity of infection (number per one side) was estimated for these species using individuals imaged during times when the camera was positioned to permit accurate counts. Although gnathiid parasites were common, these could not be consistently identified on all individuals due to the wide camera view. Thus, estimates provided herein for this taxonomic group are conservative and many parasites labeled as “unknown” may in fact be gnathiids.

For each dominant fish species, abundances of ectoparasite-host interactions were estimated by taking the total number of hosts observed with at least one ectoparasite during a dive and dividing by the product of the total over the ground distance covered by the ROV and the estimated field of view (4.3 m). Abundances were also calculated within particular depth zones per dive. Depth zones were binned into 300 m depth intervals from 500 to 3200 m, except the last depth zone ranged from 2900 to 3262 m. A single dive may have traversed across two depth zones, but only across one broad-scale habitat feature. A Kruskal-Wallis (K-W) test was used to determine if hosts or ectoparasite-host interactions were significantly more abundant within a particular depth range or habitat.

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