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Observations of deep-sea sharks and associated species at a large food fall on the continental margin off South Carolina, USA (NW Atlantic)

PETER J. AUSTER [1, 2]

KASEY CANTWELL [3]

R. DEAN GRUBBS [4]

SHANNON HOY [3,5]

[1]Mystic Aquarium, Mystic, Connecticut 06355, USA
corresponding author: peter.auster@uconn.edu, ORCID #0000-0002-6023-2829
[2]University of Connecticut, Department of Marine Sciences, Groton, Connecticut 06340, USA
[3]National Oceanic and Atmospheric Administration, Office of Ocean Exploration and Research, Silver Spring, Maryland 20910 USA
[4]Florida State University, Coastal and Marine Laboratory, St. Teresa, Florida 32358, USA
[5] Cherokee Nation Strategic Programs, Arlington, Virginia 22202, USA

Abstract

Observations of deep-sea dogfishes (family Squalidae) were made opportunistically via a remotely operated vehicle at a large food fall, a recently dead Atlantic Swordfish, *Xiphius gladius*, on a topographic rise at 453 m depth off South Carolina, USA (NW Atlantic). Genie's Dogfish, *Squalus clarkae* (formerly *S. mitsukurii*), and Roughskin Dogfish, *Cirrhigaleus asper,* were the principal scavengers. Additional scavengers included crabs (Callinectidae) and a cutthroat eel (*Synaphobranchus* sp.). At least two Wreckfish, *Polyprion americanus*, were attracted to the carcass, and one was observed to prey directly upon a small dogfish. The aggregation of highly vagile scavengers to food falls, sources of organic carbon transfer to the deep sea, is generally assumed to be based on odor plumes, but acoustic cues from large and active scavengers can also account for rapid attraction of other scavengers and predators.

Key words: ichthyology, marine biology, scavengers, NOAA, ROV, elasmobranchs, dogfish, *Polyprion*

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Introduction

The transfer of organic carbon, from productive outer continental shelf and epipelagic waters to the deep sea, occurs across a gradient of particle size from the rain of phytodetritus (Hecker 1990, Gibson et al. 2002) and products of digestion from higher trophic level consumers (Youngbluth 1989) to the bodies of whole animals, (i.e. food falls) including elasmobranchs, teleost fishes, and cetaceans (Smith & Baco 2003, Higgs et al. 2014). The fate of such transfers has been the subject of both observational and experimental studies (Bailey et al. 2007, Higgs et al. 2014). While much effort at continental-shelf depths has focused on the trophic transfer of carbon from fisheries discards and associated mortality due to fishing gear (Ramsay et al. 1997), studies at deeper bathyal and abyssal depths have typically focused on basic questions of energy flow across a range of potential food resources and in different ecological settings (Trueman et al. 2014). Here we report on a food fall and its associated scavengers and predators encountered during a video transit at 453 m depth. The location was a short topographic rise in the upper bathyal of the northwest Atlantic Ocean, along the continental margin off the coast of South Carolina, USA.

Materials and Methods

Direct underwater observations were made during dive 7 of the remotely operated vehicle *Deep Discoverer* (ROV D2) on 28 June 2019, during a cruise of the NOAA Ship *Okeanos Explorer* (EX1903 Leg 2, Windows to the Deep 2019 Expedition, 20 June–12 July 2019; see Cantwell et al. [2019] for details). The dive site (Fig. 1) was approximately 100 nm off the southeast coast of the United States (ca. 31.595°, -079.102°) at a topographic

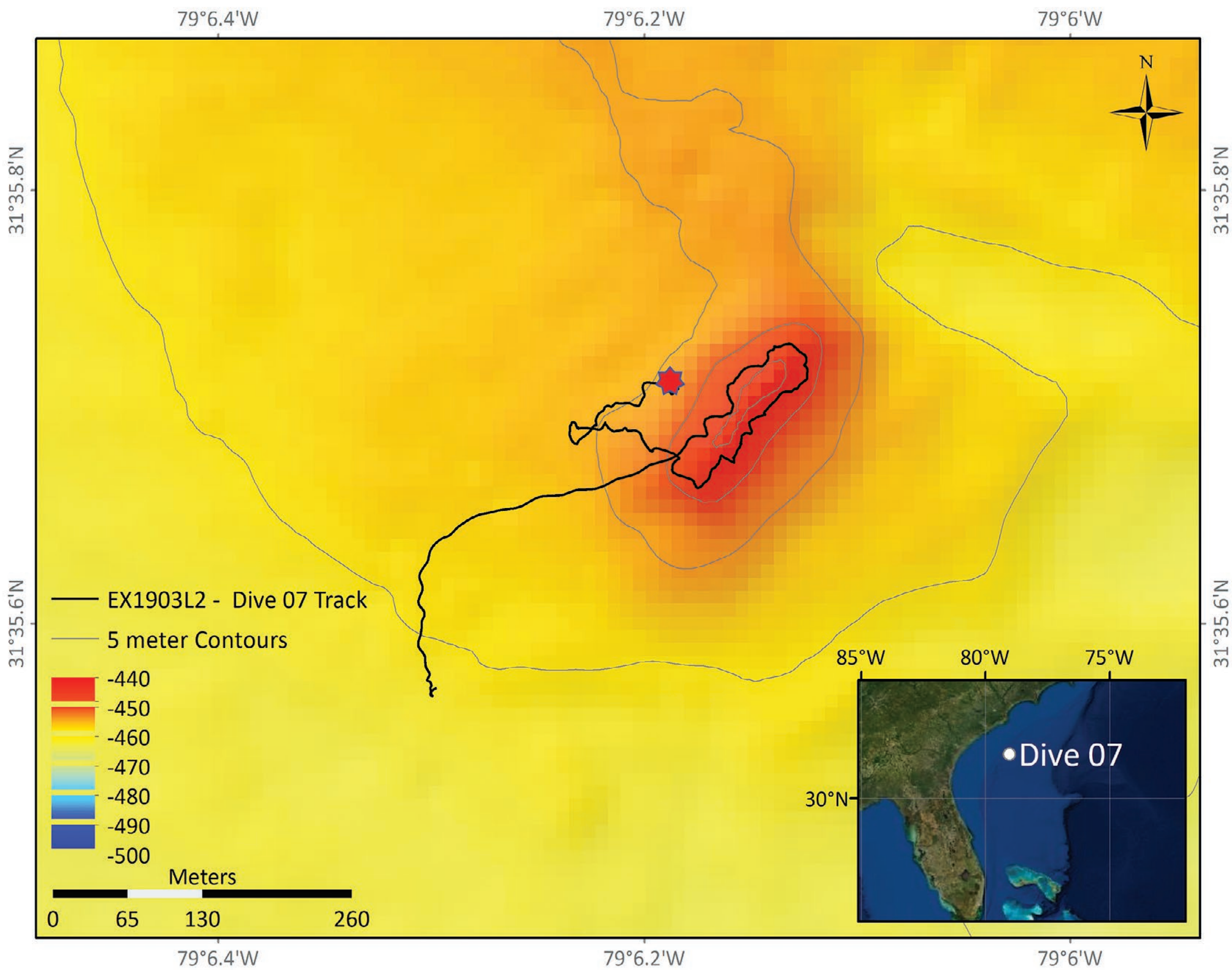

Figure 1. Multibeam bathymetry data with overlay of the track of dive 7 from EX1903L2. The northern terminus of the track (star) indicates where the food fall and shark feeding was observed along the western base of the topographic rise. The inset map shows the relative position of the dive to the US east coast. Figure created from data collected on EX1806 and EX1903 (NOAA, 2018; NOAA, 2019).

high relative to the surrounding landscape, within the Stetson Miami Terrace Deep Water Coral Habitat Area of Particular Concern, an area designated to minimize effects of fishing on deep-water coral habitats (SAFMC 2013).

The ROV system operates in a 6,000 m-rated dual-body configuration, including ROV D2 and ROV *Seirios*, the latter a camera and lighting platform that serves as a depressor. ROV *Seirios* was tethered to the ship with an armored fiber-optic cable with the highly maneuverable ROV D2 linked to *Seirios* by a neutrally buoyant tether, isolating the D2 from the motion of the surface ship. The ROVs carried multiple video cameras to facilitate operations, but both had high-resolution video cameras (five on D2 and one on Serios) that were principally used for scientific observations. Multiple LED lamps for illumination (approx. 270,000 lumens total) were carried by both vehicles. In addition to fixed lighting, D2 had 8 lamps mounted on 4 moveable hydraulic booms for variable positioning. High-definition video from D2 and *Serios* was recorded in PRORES 1080i format. Still images were captured directly from the full-resolution video signal. An integrated navigation system calculated the geographic location of the vehicles over the seafloor, in real time, via GPS for the ship with slant-range and bearing of the vehicles based on acoustic tracking. A Sea-Bird 911+ conductivity-temperature-depth (CTD) system with dissolved oxygen (DO) sensors was carried by the ROV to document local conditions during dives. D2 traversed the seafloor at a speed of about 5–15 cm s^{-1} (0.1–0.3 knots) during regular survey transects, stopping to examine objects or organisms. The ship and *Seirios* generally followed approximately 10 m above and behind D2, providing background lighting to visualize features. Additional details of the ROV and ship systems that facilitate observations can be found in Quattrini et al. (2015) and Kennedy et al. (2019).

Results and Discussion

An aggregation of higher-trophic-level predators (principally dogfish in the family Squalidae) was encountered at a carcass of an Atlantic Swordfish, *Xiphius gladius*, observed on the seafloor near the base of a small topographic rise (Fig. 1). The ecological setting in the area of this food fall consisted of manganese-encrusted rocks with attached structure-forming invertebrate fauna, including coral and sponges. Several small shelter-seeking fishes were observed in crevices (e.g. scorpaenids, *Urophycis* sp.) along the transect and separate encounters with small squalid sharks occurred prior to what appeared to be a feeding frenzy of a group of sharks at the edge of vehicle lighting.

Upon closer approach, the carcass was identified as a dead swordfish, about 2.3–2.4 m length (from tip of rostrum to fork of tail), lying on the seafloor, and with at least 11 sharks circling and feeding on the skin and muscle tissue (Fig. 2). Our length estimate is based on comparison with the known length of the ROV and viewed from the camera sled flown above D2, as well as parallel-scaling lasers set at 10 cm on D2. These observations were made at 31.595119°, -079.10315° (position at 19:40:45 UTC during the dive) at a depth of 453.4 m with bottom seawater temperature of 10.05° C, salinity of 35.25 ppt, and dissolved oxygen of 4.117 mg/l. We first encountered the food fall at 19:26:48 UTC and ended at the time of vehicle ascent at 20:18:44 UTC. Observations at the seafloor began after touchdown at 13:11:37 UTC and the first squalid shark was encountered at 19:19:27, then another at 19:20:03, and three additional sharks at 19:23-19:24 before our reaching the food fall.

We inferred the swordfish was recently dead, for perhaps only hours, given the condition of the body, the presence of only a few individuals of smaller slow-moving scavengers (such as two *Bathynectes* crustaceans), and the body relatively intact in the face of rapid consumption of tissue by the abundant and highly motile scavenging sharks. The cause of death of this swordfish is uncertain and could be senescence, disease, effects of a fishing-related or other injury. There was no visible hook, or trail of fishing line, suggesting a lost catch, or any obvious markings suggesting hook damage, entanglement or interaction with lines, or a ship strike. However, an injury may have been masked by the substantial damage caused by shark feeding underway at the time of discovery.

The sharks observed scavenging on the body represent two species of deep-sea dogfish from the family Squalidae, identified based on external morphology. The smaller and more numerous fish, at least 9 individuals, are Genie's dogfish, *Squalus clarkae* (formerly *S. mitsukurii*), a species described in 2018 and named in honor of the famous elasmobranch biologist Dr. Eugenie Clark– the "Shark Lady" of the University of Maryland and Mote Marine Laboratory (Pfleger et al 2018). Two larger dogfish, with characteristically tall first-dorsal spines, are Roughskin Dogfish, *Cirrhigaleus asper*. Both shark species occur in deep waters along the continental margin

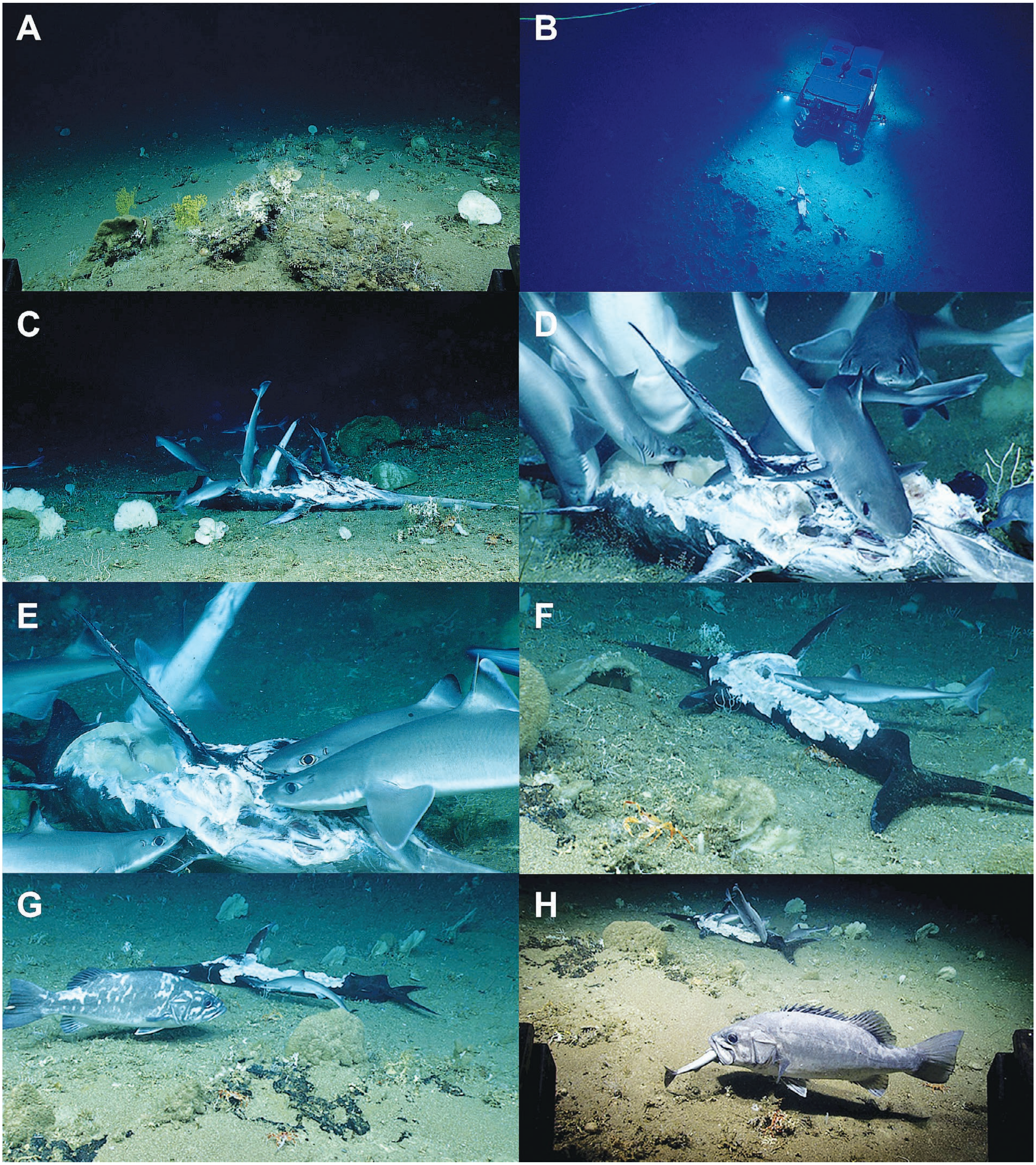

Figure 1. Examples of seafloor habitat and species interactions at the food fall location (left to right from top): A. Manganese encrusted rock with corals, sponges, and other sessile fauna characteristic of the dive site; crevices and undercut ledge outcrops were occupied by small fishes and crustacea; B. Carcass of the Atlantic Swordfish and ROV D2; C. Multiple squalid sharks feeding on the carcass; D. Variable orientation of feeding; E. Characteristic dorsal spine of the Roughskin Dogfish (right foreground) with Genie's Dogfish immediately behind; F. Irregular pattern of feeding demonstrated by complex pattern of bites; G. Wreckfish maneuvering around the swordfish carcass and the actively feeding sharks; H. Wreckfish consuming a small Genie's Dogfish (Images from EX1903L2 dive 7, NOAA Office of Ocean Exploration and Research).

from about 240–720 m depth. Two teleost species were also attracted to and loitered in the vicinity of the carcass: two Wreckfish, *Polyprion americanus*, and a cutthroat eel, *Synaphobranchus* sp., both typically found in bathyal regions

Clearly, scavengers and predators aggregated from some distance to feed on the swordfish or other species attracted to the food fall. Wreckfish consume smaller fishes or chunks by swallowing them whole and we did not observe any contact with the swordfish body. However, the larger Wreckfish did ambush and swallow a small Genie's Dogfish swimming around the carcass. While it used the ROV skids for cover during the ambush, the event does demonstrate that the hunting tactics of a large predatory fish, with a diet of smaller fishes and cephalopods (Goldman & Sedberry 2010), will extend to smaller elasmobranchs. Noteworthy is the wide size range of shark vertebrae found in the stomachs of Wreckfish, suggesting they feed on fisheries discards (George Sedberry, pers comm). Our observations show that at least some of the vertebrae are the result of direct predation. The cutthroat eel was not observed feeding, although it approached and retreated from the carcass several times.

Bailey & Priede (2002) proposed a conceptual model to explain variability in abundance and behavior of fish species around baits and natural food falls based on scavenger density, flow conditions, and swimming velocities, and character and dynamics of the odor plume from the food fall. Based on our observations, we posit an acoustic signal generated by large scavengers with active movement patterns, such as those we observed with sharks feeding, such as rapid tail beats and mechanically removing muscle tissue and bone with jaws and teeth. Those sounds would serve as an acoustic cue to rapidly attract other active predators and scavengers. The spatial envelope of the sound will be different from that based on odor, and dependent on local physical setting and masking sounds by other animals and oceanographic processes (Myrberg 2001). In any case, both types of attractants are likely at play.

Normally deep-sea shark species are observed as solitary unless there is some nearby patch of food. As relatively small-bodied, upper-trophic-level predators, squalid sharks must make a significant investment of time and energy searching for prey. Previous submersible dives in the region indicate encounter rates for squalid sharks are generally low (Ross & Quatrini 2007). When a large food fall occurs, like the ca. 200+ kg swordfish reported here (based length-weight relationships from Hanke et al. [2018]), then the ability to detect and locate the food is critical to maximize food intake. How deep-water sharks and associated species detect large food falls across space and time in order to maximize benefits from such occurrences is an enduring question relevant to basic ecology of the deep sea, as well as for predicting the effects of human-caused disturbances.

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