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Note

Biological characterization of a whale-fall near Vancouver Island, British Columbia, Canada

Lonny Lundsten [a,*], Charles K. Paull [a], Kyra L. Schlining [a], Mary McGann [b], William Ussler III[a]

[a] Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039, USA
[b] United States Geological Survey, 345 Middlefield Road MS 999 Menlo Park, CA 94025, USA

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ABSTRACT

Video analysis of a whale-fall discovered in the northeast Pacific Ocean, off Vancouver Island at a depth of 1288 m during ROV diving operations has identified 26 taxa of deep-sea benthic organisms inhabiting the seafloor immediately surrounding remnants of the whale skeleton. A photo-mosaic derived from high-definition video provides a quantitative visual record of the present condition of the site, the species richness, and substrate preference. Only the skull and caudal vertebrae remains of this large whale skeleton are estimated to have been approximately 16.5 m in length. Most organisms identified near the whale-fall are common benthic deep-sea fauna, typical of this water depth and seafloor composition. Much of this species richness comes from sessile suspension feeding cnidarians attached to the numerous glacial dropstones found throughout the area rather than the presence of the whale skeleton. Seep and bone specialists are rare (4 taxa) and may be, in part, a remnant population from a sulphophilic stage of whale-fall decomposition. Evidence of past colonization by *Osedax* sp. is visible on the remaining bones and we conclude that rapid degradation of the missing bones has occurred at this site as has been observed at whale-falls off central California in Monterey Canyon.

1. Introduction

Most of the existing observations of whale-falls are the result of fortuitous encounters during exploration of the seafloor using seafloor-imaging equipment. In this note, the presence of a whale-fall, discovered during a recent Monterey Bay Aquarium Research Institute (MBARI) expedition using a ROV (Remotely Operated Vehicle), and the surrounding fauna is documented. This discovery was made while exploring the seafloor northeast of Bullseye Vent (Riedel et al., 2006). This site is near a node on the scientific research cable that has been installed by the Canadian Neptune Project (http://neptunecanada.ca/infrastructure/cabled-ocean-observatory) that will be regularly serviced by ROVs, thus making future observations possible.

Dead whales arriving at the deep seafloor provide an enormous pulse of food to the region immediately surrounding the fall. A single 40 ton whale carcass may be equivalent to 100–200 times the typical levels of organic carbon sinking annually to a hectare of seafloor (Smith et al., 2002; Smith and Baco, 2003; Schuller et al., 2004; Smith, 2006). This pulse of nutrients, in turn, has been shown to support abundant and diverse communities of organisms (Smith, 2006).

Studies of the communities that colonize whale-falls indicate a common association with cold seep and hydrothermal vent organisms (Bennett et al., 1994; Deming et al., 1997; Feldman et al., 1998; Smith et al., 2002) and some whale-fall specialists (Smith and Baco, 2003; Smith, 2006), including species of the unique annelid (Siboglinidae) genus, *Osedax* (Rouse et al., 2004; Glover et al., 2005; Fujikura et al., 2006; Rouse et al., 2009; Vrijenhoek et al., 2009). However, most species richness appears to come from common taxa from the surrounding deep seafloor (Goffredi et al., 2004; Braby et al., 2007; Lundsten et al., in preparation). Recent studies have shown that depth also plays a significant role in determining the constituents of whale-fall faunas (Fujiwara et al., 2007; Braby et al., 2007; Lundsten et al., 2010).

A four-stage model of succession has been proposed for whale-falls, which includes (1) a "mobile-scavenger" stage, where mobile scavengers remove flesh from the whale carcass, (2) an "enrichment opportunist" stage, characterized by aggregations of polychaetes and crustaceans attracted to the enriched sediments, (3) a "sulphophilic" stage, composed of a chemoautotrophic bacterial assemblage and organisms fed by these chemoautotrophs, and (4) a "reef" stage, inhabited by suspension feeders exploiting the remaining nutrient-depleted hard substrate (Smith and Baco, 1998). Some have suggested that these whale-fall communities might persist for decades (Smith et al., 2002; Fujiwara et al., 2007). More recent work has shown that all stages may not occur at all

* Corresponding author. Tel.: +1 831 775 1762; fax: +1 831 775 1620.
E-mail address: lonny@mbari.org (L. Lundsten).

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whale-falls, that some stages may overlap (Smith et al., 2002; Goffredi et al., 2004; Braby et al., 2007) and that the ultimate decomposition of the whale carcass can be very quick (Braby et al., 2007; Lundsten et al., in preparation).

2. Methods

This whale-fall was discovered on August 7, 2009, during ROV Doc Ricketts Dive 62 and further surveyed on August 8, 2009, on Dive 64. The skeleton is located 80 km southwest of Vancouver Island, British Columbia, Canada, at 48° 40′ 31.58″ N, 126° 50′ 23.64″ W at a depth of 1288 m (Fig. 1). A studio-quality Ikegami HDL-40 1920 × 1080i video camera was used to survey the whale-fall and these observations were recorded to D-5 digital video tape. Video recordings were annotated in detail using MBARI's Video Annotation and Reference System (VARS; Schlining and Jacobsen Stout, 2006). All benthic and demersal organisms were identified to the lowest possible taxon. For organisms that were not identified to any species level, a 'tag' name was applied within the VARS database (e.g. *Buccinidae* sp. 1). Taxa were classified by habitat affinity including background, bone specialist, seep-wood specialist, or unknown in an effort to determine the impact of the whale-fall on total species richness (Lundsten et al., in preparation).

Still image mosaics of the whale skeleton were created using Photo-Mosaic (Pizarro and Singh, 2003; Singh et al., 2004). The mosaic image was created using high-definition video frame grabs (1920 × 1080) that were collected by carefully "flying" the ROV oriented perpendicular to the whale carcass along a parallel path to the carcass while using the obliquely-oriented Ikegami camera. Images were gathered such that each had 50% overlap with the next image in line, and stitched and blended using Photo-Mosaic in Matlab. Two parallel red laser beams (640 nm), positioned 29 cm apart, provide a scale.

3. Results

The whale-fall occurs within a gully ~2 km NE of Bullseye Vent. The seafloor within this gully is composed of unconsolidated

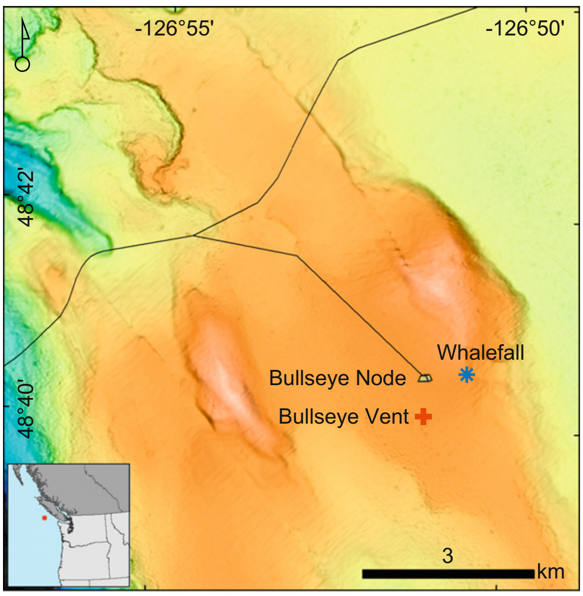

Fig. 1. Map of the study area, including the location of the whale-fall site, Bullseye Vent, and the Neptune Canada Cable Route. Bathymetry courtesy of D. Kelly and J. Delaney.

silty clays with scattered glacial dropstones, on which sessile invertebrates, including cup corals (*Caryophylliidae*), black corals (*Bathypathes* sp.), and anemones are attached. Drift kelp and sea grass (*Phyllospadix scouleri*) are also present on the surrounding seafloor.

The length of the intact whale skeleton is estimated to be 16.5 m (Fig. 2a). Twenty-five vertebrae are visible and these appear to be caudal vertebrae only. The lumbar, sacral, and thoracic vertebrae appear to be missing because the skull is in line with the caudal vertebrae and a large gap, estimated to be 3.8 m in length, exists between the vertebrae and the skull. There is no remnant of bone in or around the gap, so we conclude that the missing section has completely degraded. The total length of the whale-fall and the number of caudal vertebrae suggest this skeleton is from either a blue or fin whale (J. Harvey personal communication, 2009).

A total of 26 taxa were identified, twenty-two of which were located either directly upon or in close proximity (<1 m) to the whale skeleton (Table 1, Fig. 3A–G); four additional taxa were identified slightly further afield within the ROV video survey (~3 m). Most of the observed species are taxa categorized (after Lundsten et al., in preparation) as having background deep-sea affinities (73%, $N=19$), whereas, seep-wood (11.5%, $N=3$) and unknown (11.5%, $N=3$) taxa were observed less frequently, and bone specialists (4%, $N=1$) were rare (Fig. 2a). Cnidarians (27%, $N=7$) accounted for much of the observed species richness, as well as molluscs (19.3%, $N=5$) and arthropods (19.3%, $N=5$). Bony fishes (11.5%, $N=3$), annelids (11.5%, $N=3$), and echinoderms (11.5%, $N=3$) accounted for the remaining observed richness (Fig. 2b). A thin filamentous bacterial mat was also covering at least a small portion of each vertebrae as well as the skull and jaws. The bacterial mat was not visible on the surrounding seafloor.

Taxa of note include a cluster of the annelid *Lamellibrachia* cf. *barhami* of approximately 30 individuals located in sediment directly adjacent to a jaw bone (Fig. 3A and B), patches of yellow *Osedax* sp. on caudal vertebrae, a single *Calyptogena kilmeri* clam partially buried in the sediment between two vertebrae (Fig. 3C), a species of polynoid polychaete seen commonly on Monterey Canyon whale-falls (Lundsten et al., in preparation), clusters of *Idas* sp. mussels, an aeolidiid nudibranch, a few gastropods (*Provannidae* sp.), and many large white munnopsid isopods. Lithodid crabs (*Paralomis multispina*, Fig. 3D) and pandalid shrimp (*Pandalopsis ampla*) were abundant on and around the skull. Several bony fishes were observed, including *Coryphaenoides acrolepis* (Fig. 3E) and *Sebastolobus* sp. (Fig. 3F). Suspension feeding actiniarians (*Stomphia* sp.) and pennatulaceans (*Halipteris californica*) were also observed (Fig. 3G).

4. Discussion

Species richness immediately surrounding the whale-fall was primarily composed of common background deep-sea species (22 taxa). Similar richness has been found at six whale-falls in Monterey Canyon (Lundsten et al., in preparation) and most of the taxa observed at this whale-fall have also been observed at the Monterey Canyon whale-falls.

There is evidence for overlapping of successional stages at this whale-fall. Remnant taxa of a sulphophilic stage (Smith and Baco, 1998) comprise *Lamellibrachia* cf. *barhami*, a single living *Calyptogena kilmeri*, and the presence of numerous *Calyptogena kilmeri* shells and shell fragments immediately surrounding the whale-fall. Opportunists are present and the majority of these are background deep-sea taxa. Numerous suspension feeding cnidarians are also present; however, most of these appear to be

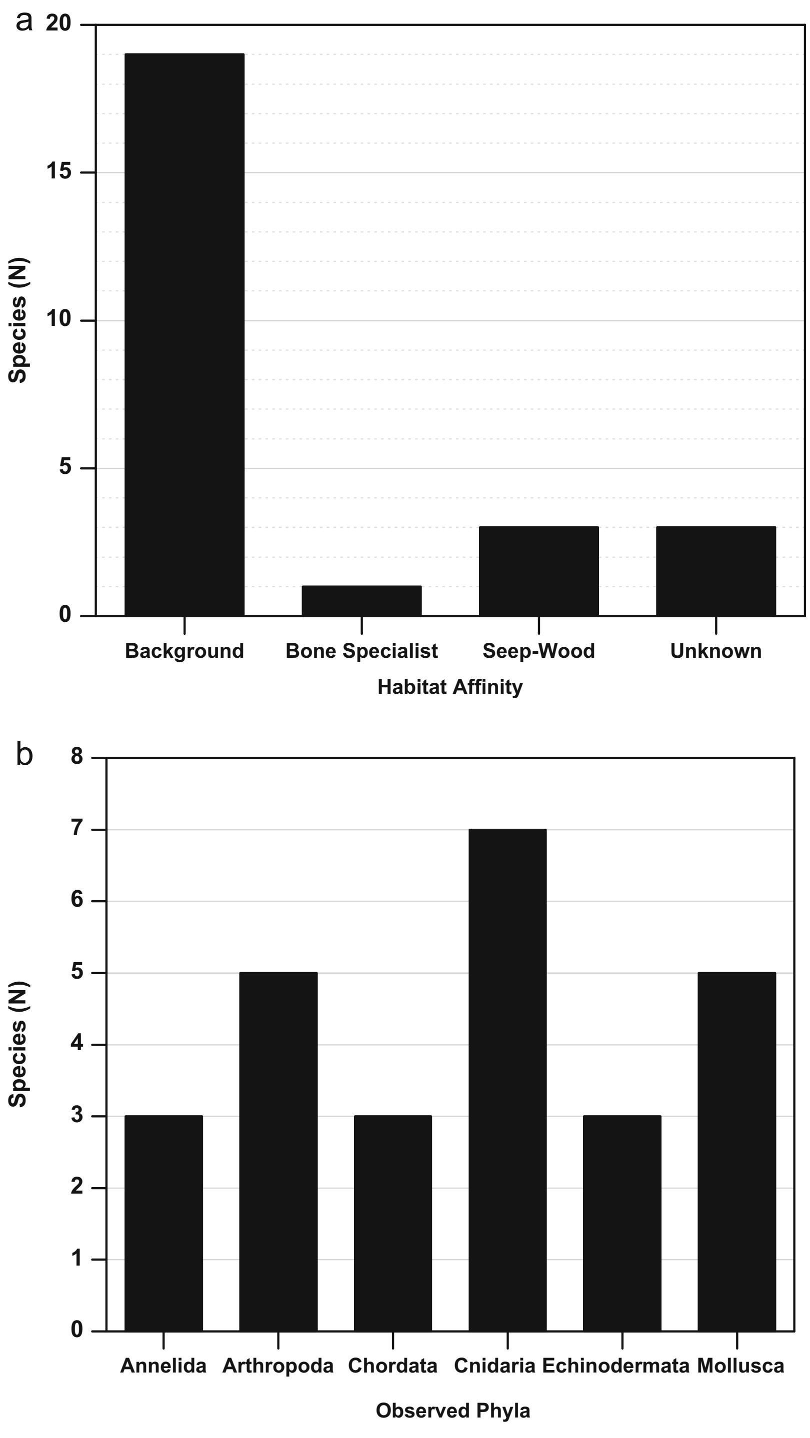

Fig. 2. (a) Whale-fall taxa categorized by habitat affinity (background, bone specialists, seep-wood, and unknown) versus the number of species identified (*N*) and (b) number of taxa (*N*) for each phyla observed at this whale-fall.

attached to the cobbles and boulders beneath and adjacent to the whale skeleton or they are soft-sediment inhabitants (i.e. *Halipteris californica*).

Whale carcass soft tissue was absent and most bones were visibly degraded. The missing bones may have decomposed completely. Time-series studies of whale-falls in Monterey Canyon (Whales 1820 and 2892, Goffredi et al., 2004; Braby et al., 2007; Lundsten et al., in preparation) show that whale carcasses have degraded similarly such that the only bones remaining in later stages of decomposition were fragments of vertebrae and the skull. Populations of *Osedax* sp. can rapidly degrade the lipid-rich bones with their root-like structures, which facilitate consumption of bone marrow by heterotrophic bacterial endosymbionts (Rouse et al., 2004). Dense live populations of *Osedax* were not observed at this whale-fall, however, small borings (<1 mm) on the surface of the bone suggest that an abundance of *Osedax* had been present in the past (Vrijenhoek, personal communication, 2009). A few small clusters of *Osedax* sp. palps are still present on the caudal vertebrae. Vrijenhoek et al. (2009) notes a succession of life stages of *Osedax* sp. at Monterey Canyon whale-falls, and the *Osedax* sp. observed on this whale-fall may be a late successional species. Unfortunately no specimens

Table 1
Observed taxa on R/V Doc Ricketts Dive 64 whale-fall survey.

Phylum	Class	Order	Family	Genus and species or "Tag" Name	Habitat affinity
Annelida	Polychaeta	Phyllodocida	Polynoidae	*Polynoidae* sp.	Unknown
Annelida	Polychaeta	Sabellida	Sibobglinidae	*Lamellibrachia* cf. *barhami*	Seep-wood
Annelida	Polychaeta	Sabellida	Sibobglinidae	*Osedax* sp.	Bone specialist
Arthropoda	Malacostraca	Decapoda	Lithodidae	*Paralomis multispina*	Background
Arthropoda	Malacostraca	Isopoda	Munnopsidae	Munnopsidae sp.	Background
Arthropoda	Malacostraca	Amphipoda	n/a	Amphipoda sp.	Unknown
Arthropoda	Malacostraca	Mysida	n/a	Mysida sp.	Background
Arthropoda	Malacostraca	Decapoda	Pandalidae	*Pandalopsis ampla*	Background
Chordata	Actinopterygii	Gadiformes	Macrouridae	*Coryphaenoides acrolepis*	Background
Chordata	Actinopterygii	Gadiformes	Moridae	*Antimora microlepis*	Background
Chordata	Actinopterygii	Scorpaeniformes	Scorpaenidae	*Sebastolobus* sp.	Background
Cnidaria	Alcyonaria	Pennatulacea	Halipteridae	*Halipteris californicus*	Background
Cnidaria	Alcyonaria	Gorgonacea	Primnoidae	*Primnoidae* sp.	Background
Cnidaria	Anthozoa	Actinaria	Actinostolidae	*Stomphia* sp.	Background
Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	Caryophylliidae sp.	Background
Cnidaria	Anthozoa	Actinaria	Cerianthidae	Cerianthidae sp.	Background
Cnidaria	Hydrozoa	n/a	n/a	Hydroidea	Background
Cnidaria	Zoantharia	Antipatharia	Schizopathidae	*Bathypathes* sp.	Background
Echinodermata	Asteroidea	Forcipulatida	Zoroasteridae	Zoroasteridae sp.	Background
Echinodermata	Ophiuroidea	n/a	Asteronychidae	*Asteronyx* sp.	Background
Echinodermata	Ophiuroidea	n/a	n/a	Ophiuroidea sp.	Background
Mollusca	Bivalva	Veneroida	Vesicomyidae	*Calyptogena kilmeri*	Seep-wood
Mollusca	Bivalvia	Mytiloida	Mytilidae	*Idas* sp.	Seep-wood
Mollusca	Gastropoda	Nudibranchia	Aeolidiidae	Aeolidiidae sp.	Background
Mollusca	Gastropoda	Caenogastropoda	Buccinidae	Buccinidae sp.	Background
Mollusca	Gastropoda	Caenogastropoda	Provannidae	Provannidae sp.	Unknown

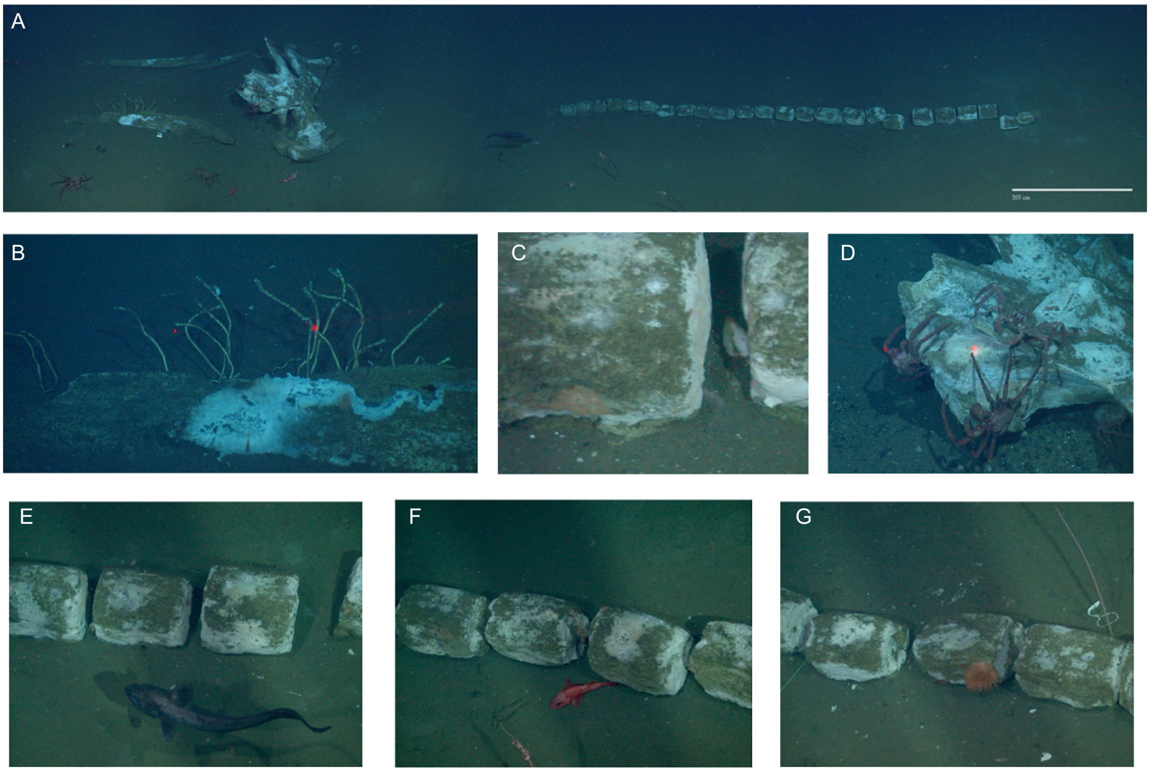

Fig. 3. (A) Mosaic image of whale-fall. Scale bar is 203 cm; (B) *Lamellibrachia* cf. *barhami* near whale jaw; (C) *Paralomis multispina* on skull; (D) *Calyptogena kilmeri* between vertebrae; (E) *Coryphaenoides acrolepis*; (F) *Sebastolobus sp.* and *Halipteris californica*; (G) *Stomphia* sp., *Halipteris californica*, and numerous shell fragments.

were collected for molecular analysis. Alternatively, a single massive event such as a benthic trawl may have removed the bones; however, there is no visible evidence of trawling (trawls typically leave distinctive linear features on the seafloor).

Although we are uncertain of the exact age of this whale-fall, it appears to have degraded rapidly. We estimated the length of the *Calyptogena kilmeri* clam to be 6.6 cm and, using the methods of Barry et al. (2007), we believe that this clam is 6–8 years old. We estimated the lengths of individual *Lamellibrachia* cf. *barhami* to range from $\sim$15 to 27 cm. The length of the solitary *Calyptogena kilmeri* found at the site suggests an estimated age of <10 years for this whale-fall. Growth estimates for *Lamellibrachia* cf. *barhami* do not exist, however, the average growth rate for *Lamellibrachia luymesi* according to Cordes et al. (2007) do correspond reasonably well with our age estimate for this whale-fall. The condition of this whale-fall is consistent with the condition of sites at similar depth and age in Monterey Canyon.

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