Invited reply

Bone-eating marine worms: habitat specialists or generalists?

We are happy to see the acknowledgement by [Glover *et al.* \(2008\)](#) ‘that absence of evidence cannot in itself lend support to the theory that *Osedax* are exclusively whale-fall specialists’. [Jones *et al.* \(2008\)](#) reported that bone-eating marine worms of the genus *Osedax* will grow on cow bones deposited at various depths in Monterey Bay, California. The report clearly stated that cow bones suspended from a short ‘tree’ made of PVC pipe presented an ‘unlikely resource for marine worms’. Nevertheless, several *Osedax* species colonized the cow bones, grew and produced mature eggs, an indication that the worms do not require substances found only in cetacean bones for settlement cues or nutrition. *Osedax* employ a branching ‘root’ system that hosts heterotrophic bacterial endosymbionts to extract organic compounds such as collagen and cholesterol from bones ([Goffredi *et al.* 2005, 2007](#)). Because animal tissues are rich in these compounds *Osedax* may be capable of living on a variety of vertebrate bones and other substrates. [Fujikura *et al.* \(2006\)](#) reported that *Osedax japonicus* also grew on ‘tainted spermaceti’, a waxy substance found in the head of a sperm whale. Indeed, some *Osedax* species are plastic in their substrate requirements.

The burden of proof that *Osedax* are ‘whale-fall specialists’ lies with authors of these statements ([Glover *et al.* 2005](#); [Dahlgren *et al.* 2006](#)), because ‘absence of evidence’ also cannot be used to reject alternative hypotheses that these worms can live naturally on other animal bones. The negative studies of experimentally submerged fish bones and shark cartilage previously cited by [Glover *et al.* \(2008\)](#) were too short in duration to expect the visible growth of *Osedax*. Furthermore, the cited studies were conducted several years before *Osedax* was known to science ([Rouse *et al.* 2004](#)). If the bones had been deployed long enough for the growth of *Osedax*, the cited researchers probably would not have recognized these unusual worms in their videos or time-lapse photography. Even [Glover *et al.* \(2005\)](#) report that ‘Live specimens of *Osedax mucofloris* were not observed during the original remotely operated vehicle video surveys, and we confirmed the presence of *O. mucofloris* only after detailed aquaria-based observations’. The bones of most fishes and small marine mammals may not persist long enough for the growth of *Osedax*, but no experimental evidence allows us to exclude the hypothesis that large fish skulls or the calcified chondocrania of large sharks may also serve as sources of nutrition for these worms. Like spermaceti, these potential resources will be more

ephemeral than the bones of large cetaceans, so researchers are unlikely to encounter them in dredges, bottom trawls or routine exploration with submarines. We hope this dialogue will stimulate experimental studies of sufficient duration and with appropriate search strategies for *Osedax*.

[Jones *et al.* \(2008\)](#) stated that ‘Historically, the large lipid-rich bones of whales ... have undoubtedly provided a substantial food resource for *Osedax*’. Furthermore, these authors recognized that ‘Cows and other terrestrial quadrupeds probably do not provide regular food sources for *Osedax*, but native and domesticated ungulates are abundant in the flood plains of coastal rivers and their carcasses will probably be found in storm debris that settles in the submarine canyons’. Finding these bones during routine explorations of the ocean floor is unlikely, but again, the absence of evidence does not allow us to exclude the possibility that they exist. Smaller bones may be buried in sediment flows that delivered them to the sea, but the rarity of such bones may also stem from rapid decomposition. For example, bones from a blue whale carcass, sunk at 1018 m depth in Monterey Bay, decomposed rapidly due the actions of *Osedax* and crabs ([Braby *et al.* 2007](#)). Lateral processes of the vertebrae were covered with *Osedax roseus*, a species whose females produce thousands of small eggs (approx. 100 µm in diameter) in an ovisac buried beneath the surface of the bone ([Rouse *et al.* 2008](#)). The friable whalebones created a rich food source (a sandwich of *Osedax* eggs) for Tanner crabs that voraciously ate them (see the electronic supplementary material). After only 3.5 years, little more than a few large ribs and the centra of large thoracic vertebrae are all that remain from this immense (20 m long) carcass. How long would exposed ungulate bones persist in this environment?

Despite the unlikely prospect, bones from a terrestrial quadruped ([figure 1](#)) were observed on 25 April 2007 while surveying a previously unexplored area of the seafloor at 1551 m depth near Manus Basin hydrothermal vents, between the Papua New Guinea islands of New Ireland and New Britain (3°47′21.954″ S; 152°5′31.247″ E). The robust pelvis and leg bones did not belong to a cetacean. The bones were disarticulated ([figure 1b](#), arrow) and probably belonged to more than one individual. One of the bones housed a cluster of *Osedax* worms. Red plumes that emerged from their bulbous gelatinous tubes were composed of four palps bearing a distinctive white longitudinal stripe, a feature seen on *Osedax frankpressi* from Monterey Bay ([Rouse *et al.* 2004](#)). The bones were not collected so we could not positively identify the Manus Basin species, but a trans-Pacific distribution is not unrealistic. *Osedax rubiplumus*, another

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Figure 1. Quadruped bones found at 1551 m depth in Manus Basin. (a) Setting included three leg bones and part of a pelvis; (b) close-up of left ilium showing butcher marks (arrow) and scattered white rice; (c) close-up of leg bone with *Osedax* (arrow) and (d) discarded rice found in the vicinity of bones. Distance between red laser dots is 10 cm in images (a), (b) and (d). Images were obtained with a digital still camera mounted on a Perry Slingsby ST200 series remotely operated vehicle, operated by Canyon Offshore for a survey conducted by UTEC Survey Ltd.

common species found in Monterey Bay, was recovered from a whale-fall off southern Japan (Y. Fujiwara 2008, personal communication). Consequently, some *Osedax* may indeed have the broad geographical distributions, as Glover *et al.* suggest.

Two lines of evidence suggest that the Manus Basin bones arrived on the seafloor as galley waste from a surface vessel. First, white rice was scattered around the pelvic bone (figure 1d), and a discrete pile of rice lay nearby. How it arrived there nearly intact is a mystery, but it may have been frozen prior to disposal. Second, the ilium was cleanly cut (figure 1b), where a butcher would sever a ham. Pork and rice are common foods on vessels traversing southwest Pacific waters, and the disposal at sea of biodegradable galley waste is routine. With numerous fishing, commercial transport, passenger and military vessels sailing the world's oceans, we wonder how frequently bones from galley waste might reach the ocean floor. We do not suggest that such bones provide a more bountiful and temporally stable resource for *Osedax* than large cetacean carcasses, but every food fall may help these bone-eating worms continue to flourish in a world that now has fewer large whales.

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