6.2 Potential consequences for deep-sea ecosystems

The decline in whale falls can lead to decreased biodiversity and loss of ecosystem services in the deep sea. Whale falls support unique assemblages and contribute to nutrient cycling, so their reduction may have cascading effects on deep-sea food webs and biogeochemical processes (Ramirez-Llodra et al., 2011; Armstrong et al., 2019). Additionally, the deep sea is already facing multiple anthropogenic pressures, including pollution, overfishing, and oil and gas extraction, which further threaten its biodiversity and resilience (Glover and Smith, 2003; Armstrong et al., 2019).

6.3 Deep-sea mining, trawling, and climate change threats

Emerging threats such as deep-sea mining and bottom trawling pose significant risks to deep-sea habitats. Mining activities can cause long-lasting and potentially irreversible damage through habitat destruction, sediment plumes, and pollution, directly impacting both whale falls and the broader deep-sea environment (Levin et al., 2020; Smith et al., 2020; Thompson et al., 2023). Bottom trawling disrupts sedimentary habitats and can reduce carbon sequestration capacity (Levin et al., 2020). Climate change compounds these threats by increasing ocean temperatures, acidification, and hypoxia, which can alter deep-sea community structure and reduce the resilience of ecosystems to other stressors (Ramirez-Llodra et al., 2011; Armstrong et al., 2019; Levin et al., 2020). The cumulative and synergistic effects of these activities are likely to intensify the vulnerability of deep-sea ecosystems, making effective management and conservation strategies increasingly urgent (Ramirez-Llodra et al., 2011; Armstrong et al., 2019; Levin et al., 2020; Smith et al., 2020).

The combined pressures of exploitation, pollution, and climate change highlight the urgent need for comprehensive conservation and management of deep-sea environments, including the protection of whale fall habitats.

7 Case Study: The Monterey Canyon Whale Fall

7.1 Background – discovery and placement of a gray whale carcass

In 2002, a well-preserved gray whale carcass, approximately 9-10 meters long and weighing about 20,000 kg, was discovered at a depth of 2891 meters in Monterey Canyon, California. This site, along with several experimentally implanted carcasses at varying depths, enabled researchers to systematically study whale-fall community development and ecological processes in the deep sea (Goffredi et al., 2004; Lundsten et al., 2010).

7.2 Observations – successional stages documented over several years

Long-term monitoring using remotely operated vehicles (ROVs) revealed that whale-fall communities in Monterey Canyon progress through distinct successional stages. Initial colonization by mobile scavengers (e.g., hagfish, amphipods) was followed by enrichment opportunists and, over time, the establishment of chemosynthetic and bone-specialist fauna. The rate and nature of succession were influenced by depth and environmental conditions, with carcass degradation occurring over sub-decadal timescales (Goffredi et al., 2004; Braby et al., 2007; Lundsten et al., 2010; McGann and Lundsten, 2019).

7.3 Key findings – new species discovery, microbial activity patterns, and food web complexity

The Monterey Canyon whale fall led to the discovery of several new species, including novel polychaetes such as Osedax bone-eating worms, with at least four new species described from the site (Goffredi et al., 2004; Braby et al., 2007). Microbial studies revealed a dynamic succession of methanogenic and sulfate-reducing archaea and bacteria, with methane cycling and elevated carbon concentrations extending up to 10 meters from the carcass (Goffredi et al., 2008; Hasegawa, 2009). The food web was found to be highly complex, involving background deep-sea taxa, opportunists, and chemosynthetic specialists, with Osedax worms acting as foundation species that regulate bone degradation and community succession (Goffredi et al., 2004; Braby et al., 2007; Goffredi et al., 2008; Lundsten et al., 2010).

7.4 Ecological insights – comparisons with other deep-sea chemosynthetic habitats

The Monterey Canyon whale fall shares key features with other chemosynthetic environments, such as hydrothermal vents and cold seeps, including the presence of chemosymbiotic invertebrates and similar microbial