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Ecosystem status of the deep Black Sea, soft sediment, benthic community

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ABSTRACT

The deep soft sediment Black Sea benthic community is dominated by cold seep habitats formed by the microbial breakdown of phytoplankton. The deep Black Sea benthic ecosystem is chemosynthetic with methanogenesis and the sulfate-driven anaerobic oxidation of methane acting as the primary metabolic pathways. Due to the depth and lack of metazoan life the deep Black Sea benthic ecosystem is generally regarded to be at low risk from anthropogenic impact and has little legislation pertaining directly to the preservation of the chemosynthetic habitats. The principal ecosystem services provided by the Black Sea include carbon sequestration and preservation of historical artefacts. Compared to other ecosystems, information on microbial biodiversity and ecosystem services in the deep Black Sea is lacking, and we highlight a need to plan and implement research programmes to address significant gaps and to enhance scientific understanding of this environment.

1. Introduction

The deep Black Sea benthic ecosystem, below the shelf edge, is one of the world's largest contiguous cold seep ecosystems. It is not generally considered at high risk from anthropogenic impacts because of the anoxic conditions which inhibit the presence of metazoa and the challenges posed by its relative inaccessibility and technological constraints. Its perceived low economic value has meant that it has not been the subject of significant research and, as a result, it is rather poorly understood. However, with technological advances, there is now growing interest in exploring the potentially significant reserves of oil and gas held in the Black Sea, much of it in deeper waters, a better understanding of the deep Black Sea ecosystem and the services it provides and which could potentially be impacted by these activities is required.

This paper presents a review of the current understanding of the deep Black Sea benthic ecosystem. It synthesizes information on the deep Black Sea benthic landscape to develop an overview of the ecosystem in terms of its key physical, chemical and biological features, and some of the ecosystem services these support. It provides a brief review of the key management frameworks currently in place, and some of the research gaps that need to be addressed.

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2. Current state of knowledge

2.1. Hydrography

The Black Sea is the world's largest semi-enclosed marginal sea with a surface area of ~422,000 km^2 [66]. The maximum depth is 2212 m; its volume is ~534,000 km^3, with the majority of water (~85%) occurring below ~100 m depth ([67]). There are only two sea water connections to other large water bodies: the narrow and shallow Bosphorus Strait that connects via the Sea of Marmara and the Aegean Sea with the Mediterranean Sea, and the Kerch Strait that connects the Black Sea with the brackish Sea of Azov (Fig. 1) [97].

Seawater exchange through the Bosphorus Strait is the only source of salt water entering the Black Sea. Deep-water salinity reaches a maximum of 22.3 ppt [64]. Sea surface salinity (SSS) is heavily influenced by freshwater inflow from several large rivers, including the Danube, Dniester, Dnieper, Don and Kuban; the Black Sea has an extremely large drainage basin of more than two million km^2, receiving water from almost all European countries except the westernmost ones. Sea surface salinities in the center of the Black Sea range ~18–18.5‰ [27]; for comparison, the salinities of the world's oceans are typically about 35% while in regions where evaporation exceeds fresh water input, salinities can reach 38% (in the eastern Mediterranean Sea) to 40% (in the Red Sea).

The different water inputs result in a strongly stratified water column both in terms of water chemistry (i.e. salinity and oxygen

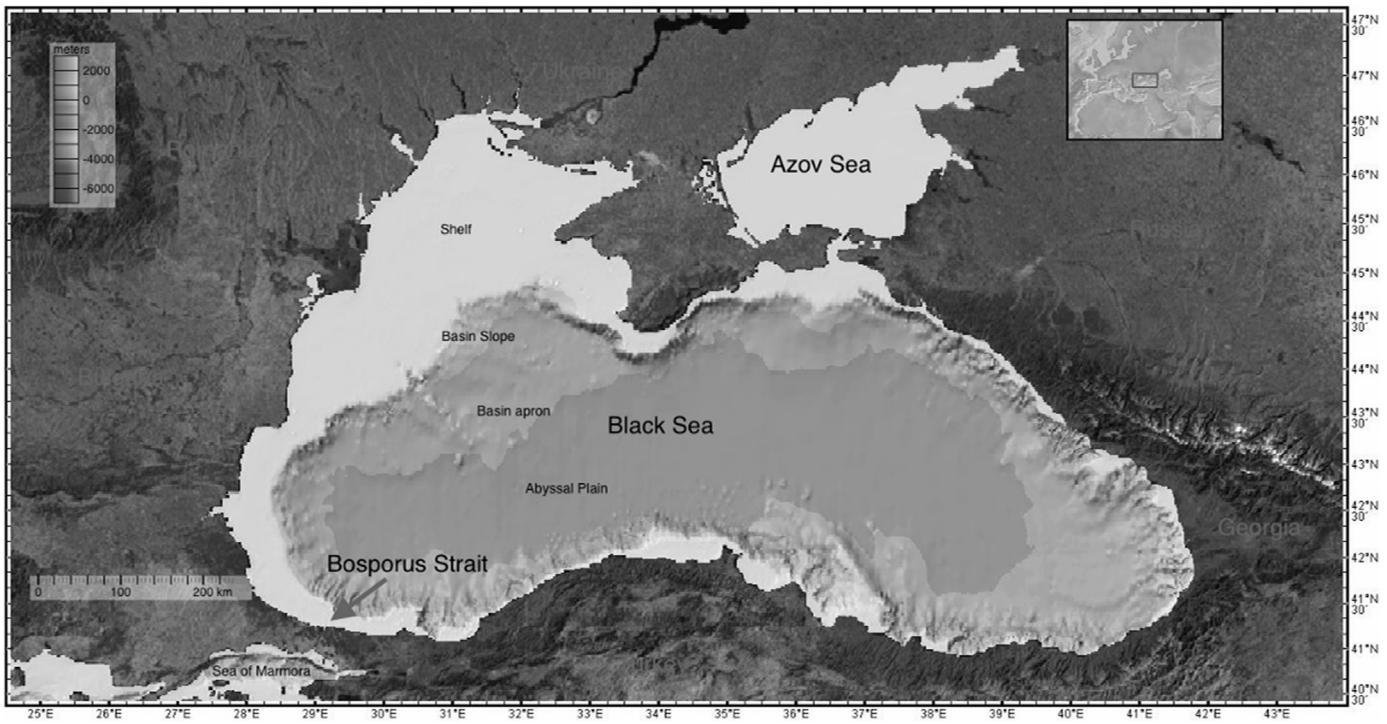

Fig. 1. Map of the Black Sea area showing approximate locations of physiographic provinces (after Ross et al., 1974, [70]).

content - the halocline) and in terms of water density (i.e. water mass - pycnocline). Cyclonal circulation in the two main Black Sea sub-basins maintains a shallower halocline in the central gyres (90–100 m depth, corresponding to the oxic and suboxic layers, see below) than in the peripheral waters (150–180 m depth; [17,36,69,95]).

In offshore waters beyond the shelf edges, the top 60 m are saturated with oxygen and support aerobic respiration. Below the oxic zone lies a permanent suboxic zone, in which dissolved oxygen concentrations are not saturated [17,61,63]. This suboxic layer occurs at depths between ~50–100 m [64,81].

Below the suboxic layer is the anoxic zone (~100–2200 m) where no dissolved oxygen is present [61,63]. In general, the presence of a permanent pycnocline (~100–200 m) in the Black Sea restricts the downward flux of oxygen and vertically decouples the oxic from the anoxic layer [42,68]. An exception occurs at the mouth of the Bosphorus, where plume generation forces mixing between the anoxic and oxic layers [40,41].

In general, water masses below the permanent pycnocline show near uniform vertical characteristics, are anoxic, with temperatures averaging 9 °C, salinities averaging 22‰, [62]. The deepest waters of the Black Sea (> 1700 m) have been described as a "vertically homogeneous and horizontally uniform water mass" [68]. The Black Sea is thus the largest anoxic basin in the world [21,58,62,64,65]. Other naturally occurring anoxic marine systems include the Cariaco basin in the Gulf of Mexico, and some fjords in Norway (e.g. Framvaren); however, these are considerably smaller than the Black Sea [42].

2.2. Soft sediments of the Deep Black Sea

The floor of the Black Sea can be separated into four physiographic zones: shelf, basin slope, basin apron, and abyssal plain (Ross et al., 1974, [70]). The shelf (~29.9% of the seafloor) is approximately delineated by the 100 m isobath, except off Crimea where it extends to 130 m depth. The basin slope (~27.3% of the seafloor) links the basin shelf to the basin apron. The basin apron (~30.6% of the seafloor) occurs at the base of the basin slope, is generally smooth and sloping 1:40 to 1:1000. The abyssal plain (~12.2% of the seafloor), at the bottom of the Black Sea is flat, with a gradient less than 1:1000.

Deep Black Sea soft sediments (those below the shelf) are derived from riverine input of lithogenic material, and from marine phytoplankton blooms and other particulate organic carbon. The sediments are described according to three distinct units based on time of deposition (Fig. 2) [30,75,76].

Unit I sediment, the top ~30 cm, was deposited during the most recent ~3000 years [14,35]. It is a micro-laminated sediment, rich in plankton-derived carbonates, with relatively low levels of organic carbon. Elevated carbonate levels in the sediment are caused by the marine coccolithophore *Emiliania huxleyi,* that first appeared in the Black Sea approximately 3000 years ago [26,75,76]. Blooms of *E. huxleyi* still occur in the Black Sea during late spring and summer each year, further building upon Unit I sediment forming a thin fluff layer and a discrete proto-white lamina layer. Both the fluff and the proto-laminate white layers are composed of lithogenic material derived from the surrounding rivers, carbonates derived from cocolithophirid blooms, the remains of diatom and silicoflagellete blooms, and particulate organic carbon [72].

Unit II sediment (ca. 30–70 cm below the sediment surface) is a micro-laminated sapropel deposited between ~3000 and 7000 years ago. Compared to Unit I sediment, Unit II sediment has a lower carbonate content and a higher (up to 20%) organic carbon content [26].

It has been postulated that during the last glacial period, approximately 110,000 to 12,000 years ago, the level of the Black Sea was 30–100 m lower than it is today; isolated from the Mediterranean and, receiving freshwater inputs from rivers, the Black Sea was then a fresh to brackish lake [84]. It has further been argued that the Bosphorus strait was breached about 7200 years ago, reconnecting the Black Sea and Mediterranean Sea, and allowing salt water from the Mediterranean to fill the basin [77].

Unit III sediment, below ~70 cm, is older than 7000 years and