Biological activity: an overlooked, mechanism for sediment resuspension, transport, and modification in the ocean

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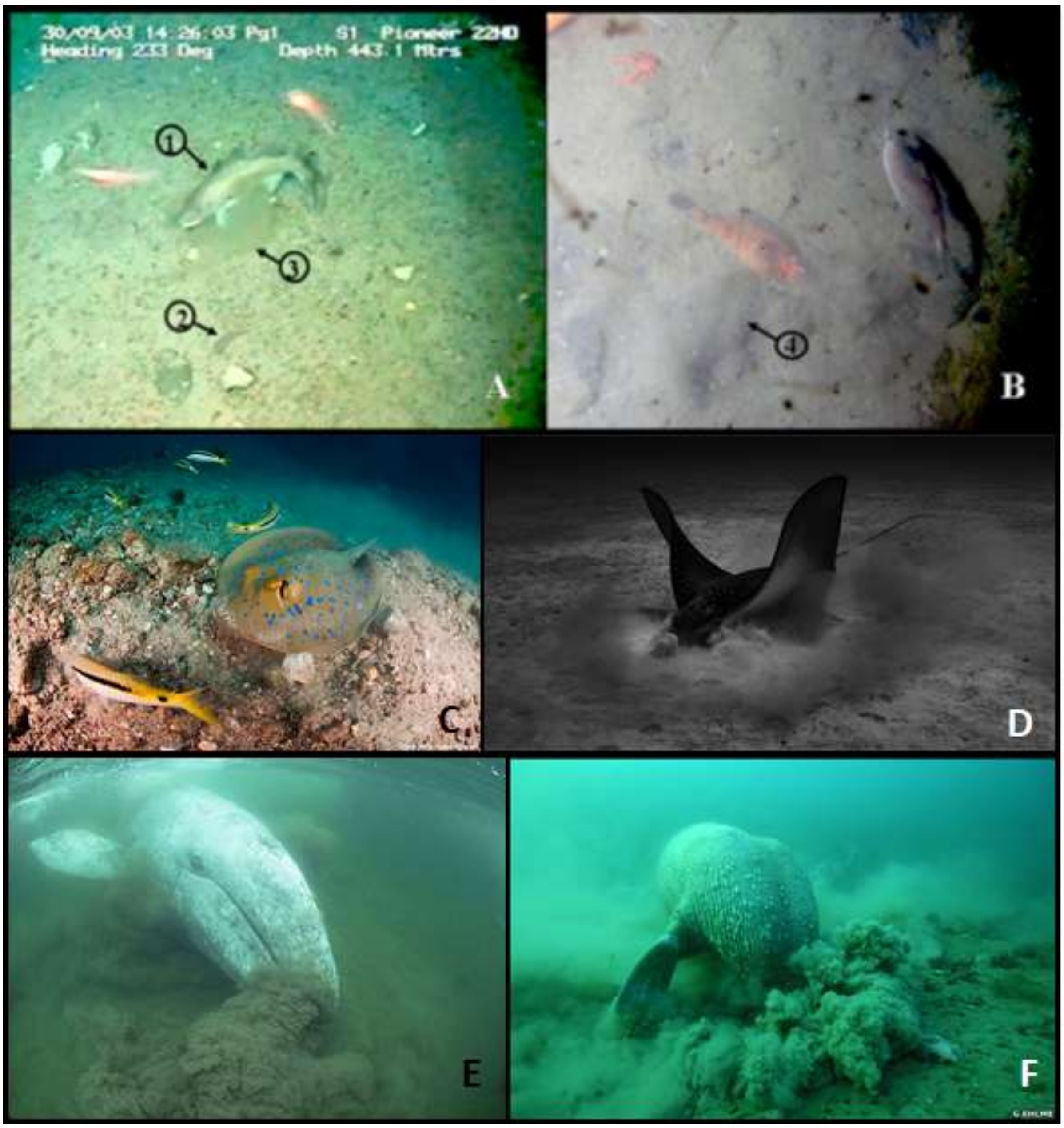
In high-energy habitats; waves and currents dominate sediment resuspension dynamics and, therefore, also mass transfer processes from the sediment to the overlying water (Ståhlberg et al., 2006) and ultimately, sediment geochemistry and composition (Sarmiento & Gruber 2006). However, even in relatively shallow coastal seas, physical resuspension is a rare event and bottom areas deeper than 50 m are rarely affected by physical forcing (Danielsson et al., 2007; Capet et al., 2016). In the deep sea and abyssal plains as well as in calm coastal habitats, organic matter accumulates and other processes such as molecular diffusion and bioturbation by invertebrates living in the sediment (Meysman et al., 2006) were believed to control sediment transformation and mass flux across the sediment–water interface (Aller and Aller, 1998; Berner, 1980). Systematic observation and anecdotal evidence have been mounting in the last two decades suggesting that large mobile animals such as fish, marine mammals, and crustaceans resuspend large amount of sediment as they search for food or find shelter in the seafloor (Fig 1, (Katz et al., 2012, 2009; Robert and Juniper, 2012; Yahel et al., 2008, 2002). In some low energy environment, this biologically induced resuspension was shown to be a major controller of the near-bottom suspended sediment concentration and composition (Villéger et al., 2017). Observations of biologically induce resuspension range from tropical coral reefs to boreal fjords and from shallow water all the way to the abyss and submarine tranches, where other resuspension process are largely absent. Nevertheless, to date, biologically induced resuspension is not accounted for in geochemical models of the ocean (Capet et al., 2016) or in assessing sediment transport.

The prominence of fish activity was shown at coral reefs (<20 m) in the sheltered Gulf of Aqaba, Red Sea, where, despite the shallowness of these systems, the effect of wind, waves and currents on sediment resuspension was minor. Resuspension activities by fish numbered >1.5 resuspension events m^{-2} h^{--1} and were confined to daytime. Correspondingly, the concentration of suspended sand near the bottom was twice as high during the day than at night (Fig.2) and vertical profiles showed a sharp increase of SSC (2-6 folds) toward the bottom during the daytime, but not at night. An in situ experiment in which fish were excluded from a large section (250 m^2) of the reef resulted in elimination of the day - night differences and a significant decrease in daytime SSC over the treated reef section in comparison to open control sites (Yahel et al., 2002).

Figure 1. Groundfish and marine mammals activity resulting in sediment resuspension. In all photos but B animals are searching for food at the bottom. A. Atlantic cod (*Gadus morhua,* depth of 450 m) in the North sea (see Katz et al. 2009 for more details). B. Slender sole (*Lyopsetta exilis*; 10 cm length) in Saanich Inlet (~90 m depth) borrowing for shelter in the bottom (see Katz et al. 2009 for more details). C. A Bluespotted ribbontail ray (*Taeniura lymma*) and Red Sea goatfish (*Parupeneus forsskali*) at the Gulf of Aqaba (Photo. Hagai Nativ). D. Spotted eagle ray (*Aetobatus narinari*, Photo: Lance Sagar). E. Grey whale (*Eschrichtius robustus,* Photo: Flip Nicklin), and F. Walrus (*Odobenus rosmarus, Photo: Goran Ehlme*)



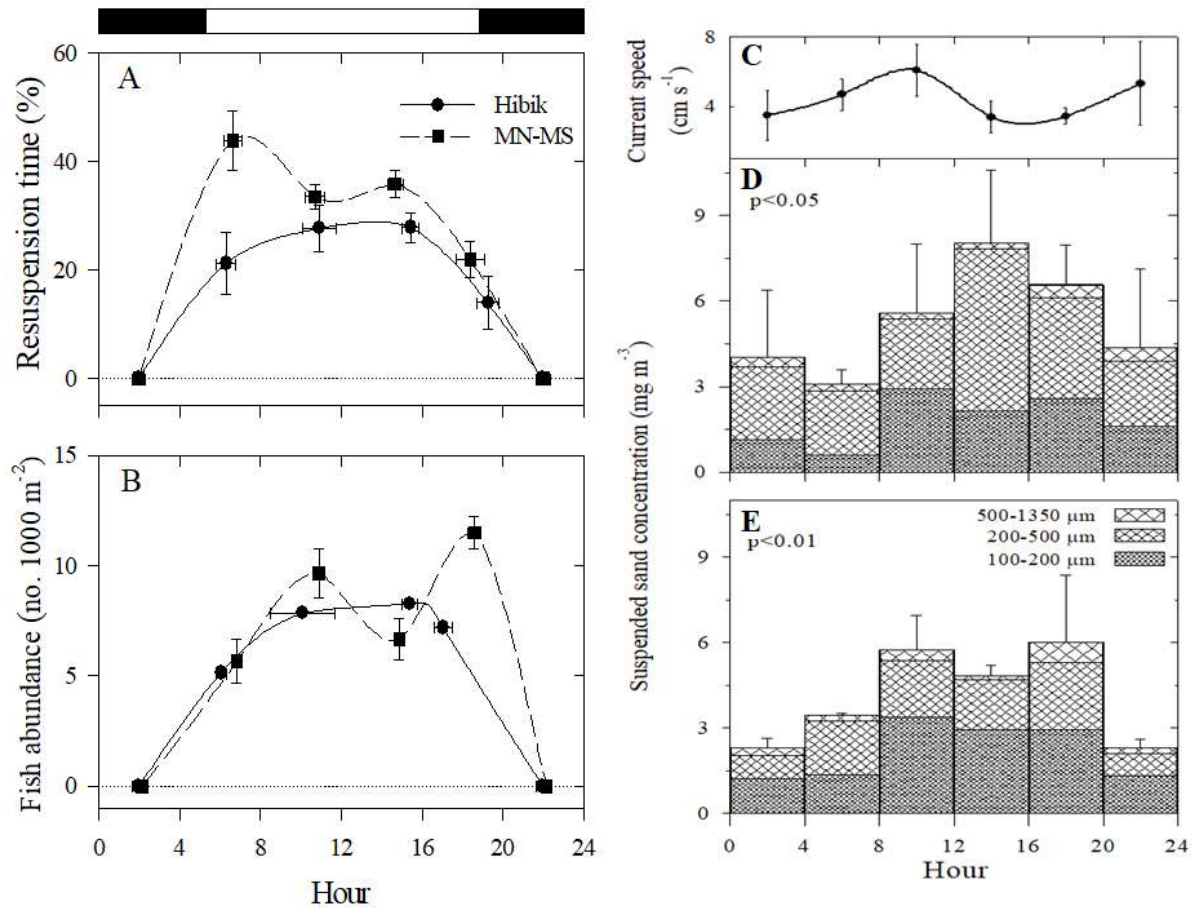


Figure 2. Daily cycles of fish activity (left) and the levels of suspended sediment (sand) in two coral reefs in the gulf of Aqaba. A. Sediment disturbance time, B. Abundance of the Goatfish *Parupeneus forsskali* at the coral reefs of Hibik and Eilat. C. Near-bottom current speed during the time of the sampling. D. and E. Daily cycle of suspended sand concentration in Eilat (D) and Hibik (E). Vertical error bars = SE; Horizontal bars and column width = time span of surveys or sampling. See Yahel et al. (2002) for more details.

Some 20000 km from the Gulf of Aqaba, in partly anoxic Northeast pacific fjords, a dense population of slender sole fish were shown to cause about 4 resuspension events m^{-2} h^{-1} and were also by far the dominant cause for sediment resuspension (Yahel et al. 2008). Rough estimates suggest that the activity of these fish, as they borrow for shelter in the sediment, resuspended about a kg of sediment m^{-2} d^{-1} causing a distinct benthic nepheloid layer over the oxygenated margins (Katz et al. 2012). The benthic nepheloid layer disappear few tens of meters deeper in the anoxic and azoic basin below. This intense fish activity, evident by distinct “spikes” of turbidity, was shown to decrease carbon sequestration (Yahel et al. 2008), enhance silica dissolution (Katz et al. 2009) and nutrient mineralization, and transport large amount of sediment from the oxygenated margins where the fish dwelt, to the deep, anoxic, and azoic basin of the fjord (Katz et al. 2012).

Fish induced resuspension is very different from the resuspension induced by bottom currents or waves. Physical agents are relatively rare events (e.g., storms) that acts over large swaths of the bottom, affect mostly the upper few mm, and last prolong periods (hours-days). In contrast, biological resuspension, is punctuated, acting over a small patches of sediments, penetrates deep (up to tens of cm) and is chronic in nature, as fish (and other animals) are commonly present in most habitats throughout the year. In the deep sea and the abyssal plains, where physical forcing are absent, the persistent biological activity may be the sole force that disturb and resuspended sediment (Robert and Juniper, 2012).

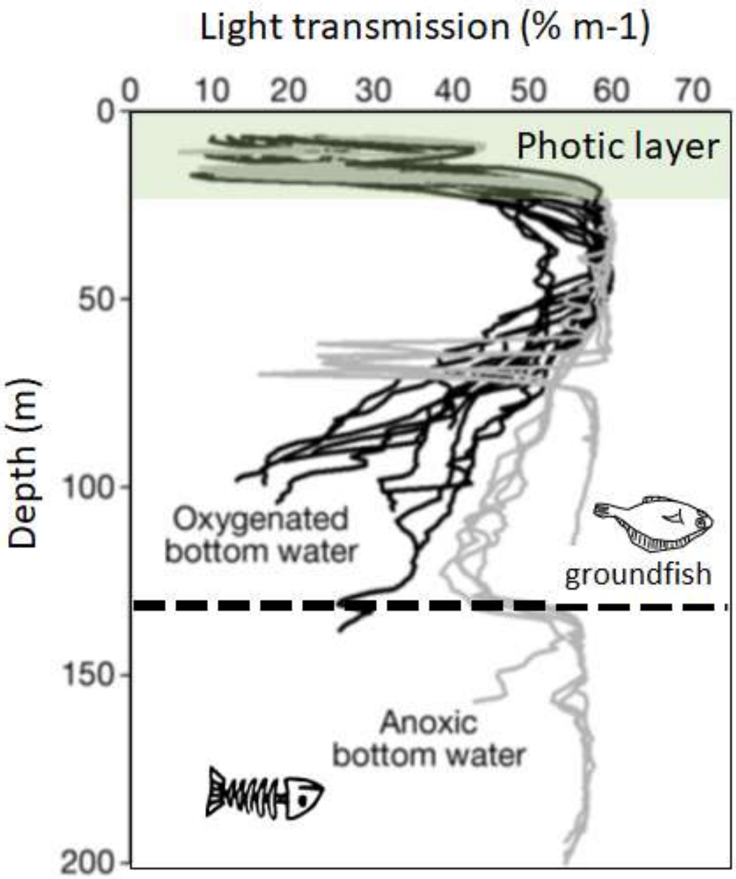


Figure 3: Vertical profiles of light transmission (a proxy for suspended particles concentration) along a transect beginning at the inner anoxic basin of Effingham Inlet, (West coast Vancouver Island, Dallimore et al. 2005). Black lines are profiles taken in locations of oxygenated bottom water where fish would be active, grey lines are profiles taken in the same day in regions having anoxic bottom water with no fish. A well-developed nepheloid layer was always present over oxygenated bottom water but absent in 7 of the 8 profiles taken over anoxic bottom water. (see Yahel et al. 2008 for more details)

To date, our knowledge regarding the rate and extent of sediment resuspension in the ocean is scarce, partly due to the lack of accepted and applicable methods designed for its quantification. Specifically, there is a lack in methods to quantify resuspension flux continuously and to estimate the contribution of biological resuspension to this flux. The sporadic and intens nature of fish (and other animals) induced resuspension pose a special challenge when trying to approach this problem. Simulation and visualization of sediment "clouds" initiated by fish may help to better understand particle dynamics. Such efforts presented by Grosbard et al. and Vainiger et al. (this meeting) whereas Gilboa et al. and Shavit et al. (this meeting) suggest novel methodology, aimed quantify overall and biologically induced resuspension flux in the ocean, respectively.

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