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Long-term field measurements of turbidity and current speed in the Gulf of Finland leading to an estimate of natural resuspension of bottom sediment

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Long-term current and turbidity measurements were carried out at two locations in the northern Gulf of Finland using bottom-mounted, automatic turbidity and current meters. An uninterrupted three-year time series of current speeds and turbidity was obtained for the years 2009–2012. The data were originally collected for the NordStream project. The first location was in the western Gulf of Finland (59°44.0´N, 23°29.2´E), where an average turbidity close to the bottom (at a depth of 41 m) was 1.58 nephelometric turbidity units (NTU), and an average current speed 5.5 cm s^{-1}. The second location was in the eastern Gulf of Finland (60°10.6´N, 26°45.1´E) where an average turbidity close to the bottom (at a depth of 44 m) was 0.67 NTU, and an average current speed 4.45 cm s^{-1}. The Rouse profile for the vertical distribution of sediment in water was then used to calculate the amount of sediment in the water column from the measured turbidity and current speeds. Consecutive hourly values were then compared to see whether resuspension had occurred. The resuspension values were then summed up to get yearly values of natural resuspension. These were found to be approximately 10–20 kg m^{-2} for the western location and 5–10 kg m^{-2} for the eastern location.

Introduction

Water turbidity and sedimentation in coastal areas increased over the past decades (Bonsdorff *et al*. 2002) and this increase in sediment loads has been seen to be a threat to global marine biodiversity (United Nations Environmental Programme 1995). In a sea dominated by large areas of relatively shallow, sediment-covered bottoms, natural resuspension of bottom sediments can also be an important source of sediment load. Quantification of the load from rivers and e.g. dredging sites is simple as compared with the estimation of the background load from natural bottoms, which can depend on high swell or flow rate events which occur at irregular intervals. Major resuspension events have shown to be relatively rare (Tengberg *et al*. 2003) but modelling studies in the Baltic Sea proper have shown that they are possible even up to depths of 60 m and can last for several days (Danielsson *et al*. 2007).

In addition to particles themselves, nutrients and harmful substances can be introduced into the water column with the particles. Resuspen-

Editor in charge of this article: Kai Myrberg sion has been shown to be important in the fluxes of contaminants in the middle of the Gulf of Finland (Kankaanpää *et al.* 1997b). Modelling studies (Juntura *et al.* 1996) have shown that resuspension is important to substance fluxes in the first 1 m above the bottom. Experimental and *in-situ* studies in the Gothenburg archipelago and the Gulf of Finland have shown that resuspension lowers the benthic fluxes of oxygen and total carbonate (Tengberg *et al.* 2003). Viktorsson *et al.* (2012) showed that the benthic flux of soluble reactive phosphorous can be as high as ten times the river load, but Almroth *et al.* (2009) did not find any direct link between resuspension and benthic nutrient fluxes in conditions where enough oxygen is present.

When particles are in suspension they can be transported over long distances to other areas. Recent modelling studies have shown that particles can remain in suspension long enough to be transported from an erosion area to an accumulation area (Almroth *et al.* 2011). This is important because the transport of resuspended material onto a rocky bottom can harm its ecology (Airoldi 2003). Especially macroalgae, mussels and other sessile animals can be harmed by increased turbidity. From a physical point of view, increased resuspension can lead to erosion and changes in bottom morphology (Rönnbäck *et al.* 2007).

Studies in microcosms have shown that physical resuspension is just as important as bioturbation (Hedman *et al.* 2009) in causing turbidity. On the other hand, microbes can secrete sufficient extracellular polysaccharides to inhibit grain movement in sandy bottoms thus causing the threshold shear velocity required for resuspension to occur to increase (Hagadorn and McDowell 2011).

Sedimentation trap studies on sandy bottoms 16–47 m deep in the southwestern Baltic Sea show that net sedimentation is < 10 g m^{-2} day^{-1} (Christiansen *et al.* 2002), whereas resuspension fluxes are 15–20 times higher. At these locations, resuspension due to waves is more common than current-induced resuspension. The presence of a layer of loose material close to the surface keeps the resuspension threshold very low throughout the year. In this study, the residence time for suspended matter in the water column was found to be 1–2 days.

Long-term sedimentation rates have been found to be highly variable. Isotope analysis has been used to prove that sediment accumulation rates in the Baltic Sea show large variations between 60 and 6160 g m^{-2} a^{-1} (Mattila *et al.* 2006). Marine sediment coring has shown that the sedimentation rate can vary between 2.5 and 15.0 mm a^{-1} (Vallius 1999). These values become 4250 g m^{-2} a^{-1} and 25 500 g m^{-2} a^{-1} if a bulk density of 1.7 g m^{-2} is assumed (Tenzer and Gladkikh 2015). Kankaanpää *et al.* (1997a) found a value of 10 200 g m^{-2} a^{-1} for the yearly accumulation, Perttilä *et al* (1997) a value of 2720 g m^{-2} a^{-1}, and Salo *et al* (1986) a value of 6800 g m^{-2} a^{-1}. These values are large as compared with average oceanic values which are between 0.2 and 200 g m^{-2} a^{-1} (Toth and Lerman 1977).

There are many studies of sedimentation rates in the Baltic Sea and the Gulf of Finland, and some studies also exist that tried to quantify resuspension (Kankaanpää *et al.* 1997b, Vallius 1999, Christiansen *et al.* 2002, Tengberg *et al.* 2003, Erm & Soomere 2006, Mattila *et al.* 2006), but there still exists a gap in the knowledge of the amounts of naturally-occurring resuspension. One of the limits of the current understanding is the small temporal scope of the studies. Some long-term measurements of currents have been made (e.g. Lilover *et al.* 2001). Modelling studies have to some extent broadened our understanding of the resuspension patterns. They have shown that regions react in different ways, that resuspension is possible even at depths of 40–60 m (Danielsson *et al.* 2007), and that sediment transport occurs from erosion bottoms to accumulation bottoms (Almroth *et al.* 2011).

The main objectives of this study were (1) to present results from long-term measurements of turbidity and currents, and (2) to quantify the cumulative amount of sediment that experiences natural resuspension in the Gulf Finland. To achieve these objectives a three-year (November 2009 to November 2012) time series of automatic current and water-quality measurements from two locations in the Gulf of Finland was obtained as a part of the monitoring program of the NordStream project, and used to calculate resuspension. The measurement sites were originally selected based on the needs of the NordStream project.

Material and methods

Physical properties of the Gulf of Finland

The Gulf of Finland is a sub-basin of the Baltic Sea, located in its northwestern extremity, with a total area of approximately 30 000 km^2, average and maximum depths of 37 and 123 m, respectively, and a volume of approximately 1100 km^3 which is only about 5% of the Baltic Sea total volume. The Gulf of Finland has a drainage area of 420 990 km^2 which represents around 25% of the drainage area of the entire Baltic Sea. (Alenius *et al*. 1998). The latest findings on the circulation, temperature and salinity of the Gulf of Finland have been reviewed by Alenius *et al*. (1998) and more recently by Soomere *et al*. (2008b) and by Myrberg and Soomere (2013).

In the middle and western parts of the Gulf of Finland, the permanent halocline is at 60–80 m, above which the salinity is nearly uniform. The permanent halocline is missing in the eastern Gulf of Finland where the water depth is much smaller. There the salinity increases almost linearly with depth. Large horizontal gradients in temperature and salinity can be caused by upwelling and downwelling events, which can also locally affect current speeds. Upwelling and downwelling jets can produce surface currents of up to 50 cm s^{-1} (Zhurbas *et al*. 2008).

The classical view on the circulation pattern of the Gulf of Finland is that it is cyclonic and baroclinically driven due to salinity gradients. Other driving forces are winds, the freshwater inflow from the Neva River, the coriolis and sea-level differences (Alenius *et al*. 1998). Recent studies have brought new insight and shown that the Gulf of Finland has a very dynamic current field. The Finnish side part of the Gulf of Finland experiences a westward flow with a water speed of a 5–9 cm s^{-1}, and the persistency of the current direction is 50%–80%.The water can flow at this speed even close to the bottom (Alenius *et al*. 1998). In the middle of the Gulf of Finland, the surface water experiences cross flows that can be 10 km wide and flow with speeds of 10–20 cm s^{-1}. In some areas of the Gulf Finland, current speeds can be 20 cm s^{-1} for long periods of time (Elken *et al*. 2003, Lilover *et al*. 2011). Close to the Neva River the flow is very unstable with current speeds of 10 cm s^{-1}. In a measurement campaign close to the southern coast of the Gulf of Finland, a dominant westward current of 4–6 cm s^{-1} was found (Suursaar 2010). Even tides in the eastern Gulf of Finland in extreme cases can produce current speeds of up to 12 cm s^{-1} (Alenius *et al*. 1998).

In the Gulf of Finland, the significant wave heights do not exceed 0.5 and 1.3 m in summer under relatively calm conditions and in winter, respectively. The peak periods are 3.8 s in summer and 5.5 s in winter (Alenius *et al*. 1998). In normal conditions, the waves have a short wavelength and a large amplitude due to the relatively shallow waters, and they do not generally affect the bottom at 40 m. For the strongest westerly storms, significant wave heights reach 2 m and the highest waves are mostly concentrated in the central parts of the Gulf of Finland (Kurennoy and Ryabchuk 2011, Räämet and Soomere 2011).

Soomere *et al*. (2008a) studied the wave fields generated by cyclone Gudrun (8–9 Jan. 2005) and showed that the highest significant wave could be up to 5 m. A lot of damage was caused by this storm and a lot of sediment was suspended (Suursaar *et al*. 2006). Large storms can affect the bottom sediments. The bottom topography is very variable with many accumulation basins.

Measurement sites and measurements

The measurement sites were located in the Gulf of Finland (Fig. 1) and were originally selected based on the needs of the NordStream pipeline project. These stations were used to provide long-term water quality reference data throughout the pipeline construction period and were located outside the potential area of influence of the construction work to produce baseline values for comparison with the measurements made close to the areas influenced by the pipeline construction. This study includes the results of measurements from stations at Location West (59°44.0´N, 23°29.2´E) with a depth of 41 m and Location East (60°10.6´N, 26°45.1´E) with a depth of 44 m (*see* Fig. 1). The measurements lasted from the beginning of the monitoring period in November 2009 to the end of long-

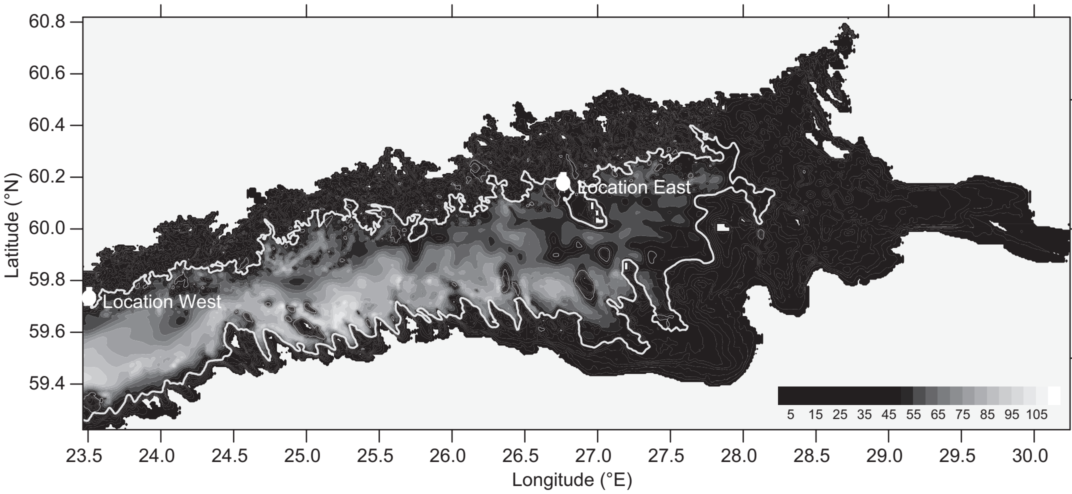

Fig. 1. Locations of measurement sites in the Gulf of Finland. The 40 m depth contour is highlighted and both locations are below this depth. The bathymetry data has been compiled by Andrejev *et al*. (2011).

term monitoring in November 2012. Location West was situated on a bottom consisting mainly of sand and rocks. Location East was located on a bottom consisting of mud. Location West was categorized using a remotely-operated vehicle and Location East was categorized from navigational charts and from the material which came up with instrument moorings.

The map of seabed sediments compiled by Al-Hamdani *et al*. (2007) shows that Location West was in an area of hard clay that can be exposed or covered with a thin layer of sand or gravel, and Location East was close to a large area with a mud bottom. The area of mud bottoms is about 40% of the total area of the Gulf of Finland (Al-Hamdani *et al*. 2007). Location West was most likely an erosion or transportation area and Location East could be a sedimentation area. When differences in hydrographic properties are excluded, differences in bottom type can be caused by for example differences in the depth of the bedrock below the sediment (Vallius 1999). Therefore, it is reasonable to find different bottom types at locations with the same water depth.

The bottom at both locations is relatively flat and the locations are far away from islands, canyons, ravines or deeper areas of the sea. The sites are also far away from point sources of suspended sediments, such as rivers, dumping areas, shipping routes and pipeline construction sites. All sediments found in the water column are therefore assumed to had come from the bottom. If we assume a lagrangian transport of 10 cm s^{-1} and a residence time of two days (Christiansen *et al*. 2002), then the particles had come from less than 20 km away. Therefore, in this case it is plausible to use the term resuspension with regard to the particles in the water, and the particles at the bottom are assumed to have been in suspension at some point. One known exception to this in the open sea is sedimentation of algal particles. In the Baltic Sea, the total amount of this is one or two orders of magnitude less than the total values presented in this study. Leipe *et al*. (2011) estimated the deposition of particulate organic carbon to be between 10 g m^{-2} a^{-1} in the western Gulf of Finland and 70 g m^{-2} a^{-1} near the northern coast of the eastern Gulf of Finland. It can therefore be concluded that algae do not substantially affect bottom turbidity values.

Measurements of turbidity and currents

The measurements were carried out using a bottom-mounted YSI measurement package (YSI-6600) that had sensors for turbidity, salinity and temperature. The package was installed at a height of 1.5 m above the bottom (Fig. 2). Turbidity was measured using an optical sensor which was cleaned with a mechanical wiper

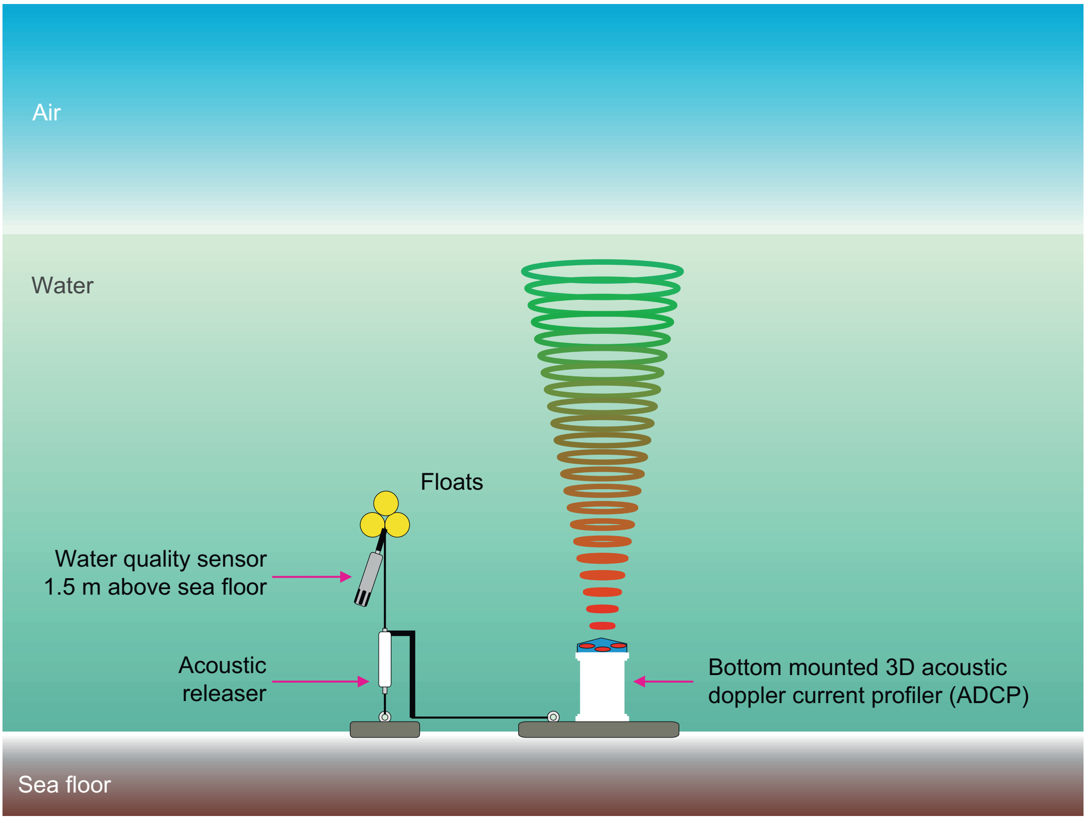

Fig. 2. Schematic illustration of the measurement setup.

before every measurement. Turbidity values were recorded every hour by taking the median of 10 measurements made at 1-s intervals.

All estimates of suspended solids concentrations were made from turbidity measurements based on light scattering from particles. The relation between turbidity and suspended solids concentration depends on the grain size and scattering properties of the solid particles. The relation is therefore dependent on measurement location and can be specific to the instrument itself. Based on a large data set obtained from the HERTTA database administered by the Finnish Environment Institute (SYKE), there is a linear 1:1 relation between sediment concentration and turbidity, i.e one unit of turbidity (NTU) corresponds to a concentration of 1 g m^{-3}. In other words, a two-fold increase in the sediment concentration results in a in two-fold increase in the sediment amount in the water column.

Currents were measured using a bottom-mounted Teledyne RD Instruments' Workhorse Mariner ADCP. It measured the current velocity components in 2-m-thick layers for the whole water column. Since the near-surface layers (0–4 m depth) were directly affected by wind and waves, these layers were excluded. Below 6 m, the effects of winds and waves decreased rapidly, hence these layers were used in the analyses. The instrument was set to measure once every hour and store the results in its internal memory.

The ADCP cannot measure in the first layer close to the instrument. Therefore, there is a 2-m gap, or blanking distance, between it and the first layer from which meaningful data could be obtained. Because of this, it was not feasible to mount the YSI turbidity sensor on the bottom as the two instruments would have measured in totally different layers. Even here, the turbidity sensor was just below the first layer of the ADCP. However, this was a compromise that needed to be made to obtain a robust setup that produced reliable measurements over the three-year period. The Gothenburg Landers (Tengberg *et al*. 2003, Almroth *et al*. 2009, Viktorsson *et al*. 2012) are another way of mounting instruments for benthic measurements and they bring an extra level of sophistication into the measurements by being able to estimate benthic fluxes. For this study however, reliability was paramount, hence the measurement setup was made as simple as possible. Some properties of the instruments are given in Table 1.

Estimation of resuspension

Suspended-matter concentrations were only available from a height of 1.5 m above the bottom. To calculate the amount of suspended matter in the whole water column, this information needed to be extrapolated to all depths. This was accomplished by using the measured current speed close to the bottom and the theoretical Rouse profile (Rouse 1938, Rouse 1940).

According to the Rouse profile, the concentration at a depth z is:

$$c_s(z) = c_0\left[\frac{z(h-z_0)}{z_0(h-z)}\right]^{-\frac{P}{\alpha}}, \quad (1)$$

where c_0 is the sediment concentration at a depth of z_0 (a value of 1.5 m was used) and h is the thickness of the flowing water layer. The sediment concentration (c_0) was calculated from the turbidity measurements. The constant α has a typical value of 1. P is the Rouse number which is defined as:

$$P = \frac{w}{\kappa u_*}, \quad (2)$$

where w is the sinking velocity (a value of 0.001 m s^{-1} was used to correspond to the grain size of silt or fine sand), u_* is the shear velocity, and κ is the von Karman constant (0.41). The shear velocity can be calculated with the aid of a logarithmic velocity profile $u = u(z)$ assuming a weak stratification:

$$u_* = \frac{u\kappa}{\ln\frac{z}{z_0}}, \quad (3)$$

Integrating the Rouse profile by depth produces the total amount of suspended sediment in the water column per unit of surface area:

$$C_s = \int_{h_1}^{h_2} c_s dz, \quad (4)$$

The integration was made numerically from the bottom (h_1) to the surface (h_2).

The yearly cumulative resuspension was calculated from the integrated values by comparing hourly values and adding the difference to the cumulative resuspension value if the difference was positive:

$$\Delta A = \begin{cases} C_{s,n+1} - C_{s,n},\ C_{s,n+1} > C_{s,n} \\ 0,\ C_{s,n+1} \le C_{s,n} \end{cases}, \quad (5)$$

where ΔA is the change in resuspension and C_s is the total amount of suspended sediment. The cumulative resuspension values were zeroed after each year. A total of three years of cumulative resuspension was obtained from both measurement sites.

Results

The current speeds close to the bottom show a large temporal variability and they reach their general maximum in winter. This temporal behaviour was evident at both locations (Fig. 3). Close to the bottom, the average speeds were ~5.0 cm s^{-1} and ~4.5 cm s^{-1} at Locations West and East, respectively (Fig. 4). At 5-m depth, these values increased to ~10.0 cm s^{-1} at Location West and 9.0 cm s^{-1} at Location East. In the surface layer, the current speeds increased to above 1.5 cm s^{-1} (for turbidity values and cur-

Table 1. Measurement devices and measured variables.

Device and variable	Range	Resolution	Accuracy
RDI current speed	0–5000 mm s^{-1}	1 mm s^{-1}	better than 10 mm s^{-1}
RDI current direction	0–360°	1°	5°
YSI turbidity	0–1000 NTU	0.1 NTU	2% or 0.3 NTU

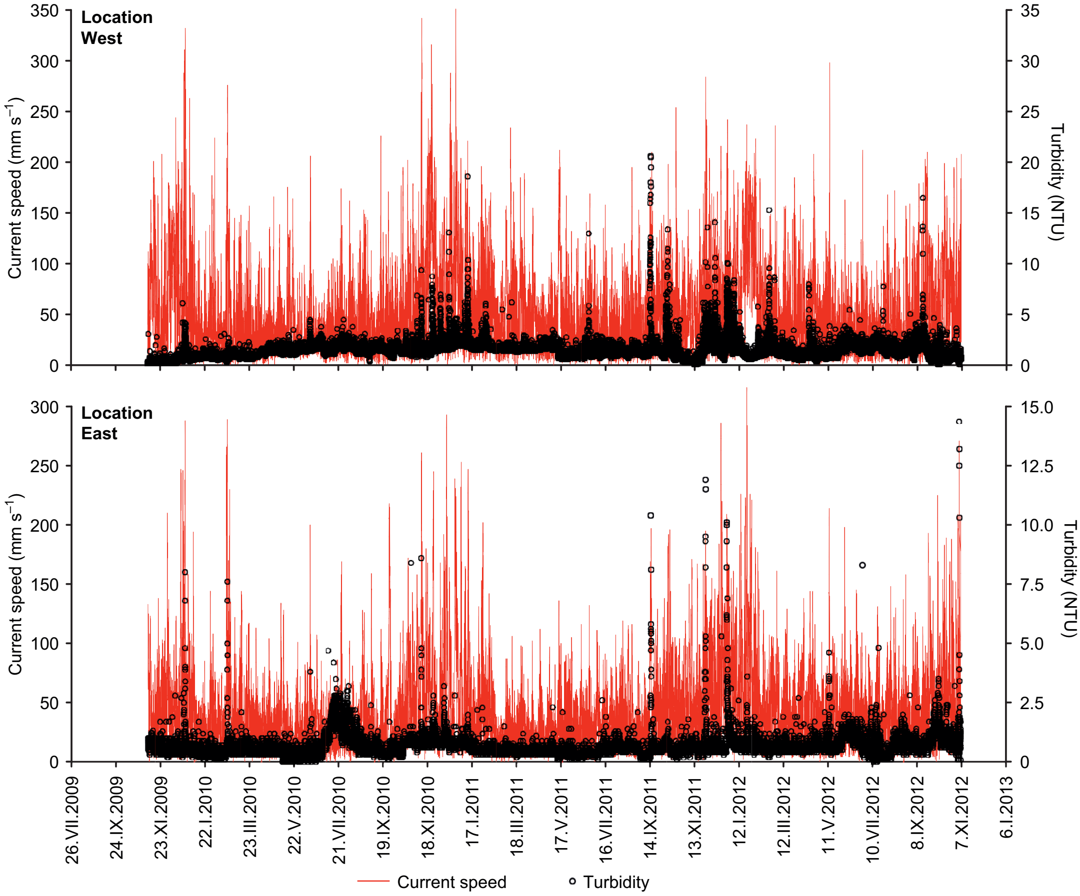

Fig. 3. Time series of near-bottom water current speeds and turbidity for the two locations. The current speeds were from the first cell of the ADCP data.

rent speeds *see* Table 2). The time series (Fig. 3) show that turbidity increases occur on average only once per month. The sites can therefore be thought of as low energy environments with rare resuspension events.

The turbidity values did not correlate well with the current speed. Of the estimated resuspension, only a part (39%) could be explained by the current speed measured *in situ*. Other factors causing resuspension can be for example the random nature of turbulent mixing, bioturbation, transport of resuspended sediments from slightly shallower areas, and noise in the optical measurement. As the particles are in suspension and not dissolved they can produce noise in the optical turbidity measurement as they float in and out of the measurement beam. There are also some nonlinear effects at work in sediment resuspension. If, for example, all available sediment is detached from the bottom and put into suspension, an increase in current speed will not cause an increase in sediment in suspension.

Table 2. Maximum, minimum and average values of currents and turbidity at the two locations.

	West		East	
Variable	Avg	Max	Avg	Min
Turbidity (NTU)	0.67	17.80	1.58	20.60
Current speed (mm s^{-1}) at				
36 m	52	514	58	371
38 m	50	501	56	365
40 m	47	455	54	351
42 m	45	375	–	–
44 m	44	316	–	–

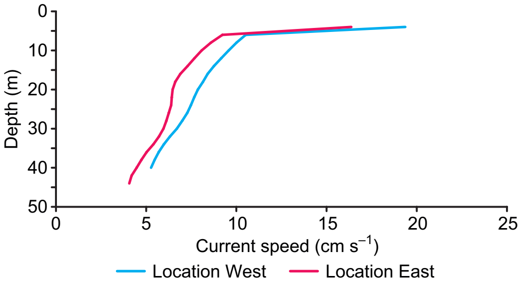

Fig. 4. Vertical profiles of mean current speed for the two locations. The surface layer can be subject to waves and other sea-level surface variations which can produce high average values.

At Location East, currents from directions between 100° and 150° slightly dominated. When binned into 10° bins and plotted as a histogram, the values for the bottom layer at Location West showed a distinctly two peaks in distribution of current speeds (Fig. 5) at 30°–70° and at 220°–230°. Nearer the surface at a depth of approximately 10 m, the peaks were at 80°–90° and 240°–260° which is about 20° more than at the bottom.

There was a large variability in monthly averages of turbidity among the years (Fig. 6), and no seasonal tendencies could be discerned from the results except for a slight increase in turbidity during the winter months. However, the November values at Location East were lower for all years.

As a result of a severe storm event on 26 Dec. 2011, the bottom turbidity increased in a matter of hours, especially at Location East (Fig. 7b) where the turbidity increased from approximately 1 NTU to over 16 NTU. The increase was not as sudden at Location West (Fig. 7a), but the it was still substantial: from approximately 2 NTU to 8 NTU. Increased turbidity lasted for three and two days at Locations West and East, respectively. This does not mean that the retention times of resuspended particles were the same as because the sinking velocity has an effect on the suspension time of particles. For example, a lower sinking velocity can cause a long-term effect resulting from a single resuspension event. The current directions show that at Location West, the increased period of turbidity coincided with a period of oscillations of current directions between southwest and northeast. This behavior was not detected at Location East.

The cumulative, yearly amount of natural resuspension was found to be 10–20 kg m^{-2} for Location West and 5–10 kg m^{-2} for Location East (Fig. 8). Several periods of increased resuspension were identified when the cumulative resuspension value increased in a stepwise manner (indicated with arrows in Fig. 8). This shows that dramatic storm events can have a large effect on the cumulative resuspension and also that these events are quite rare. At both locations during the storm on 26 Dec. 2011 the cumulative resuspension was approximately 1 kg m^{-2} which represents 5%–10% of the yearly cumulative resuspension.

Discussion

The suspended sediment loads entering the Gulf of Finland from rivers can be calculated from

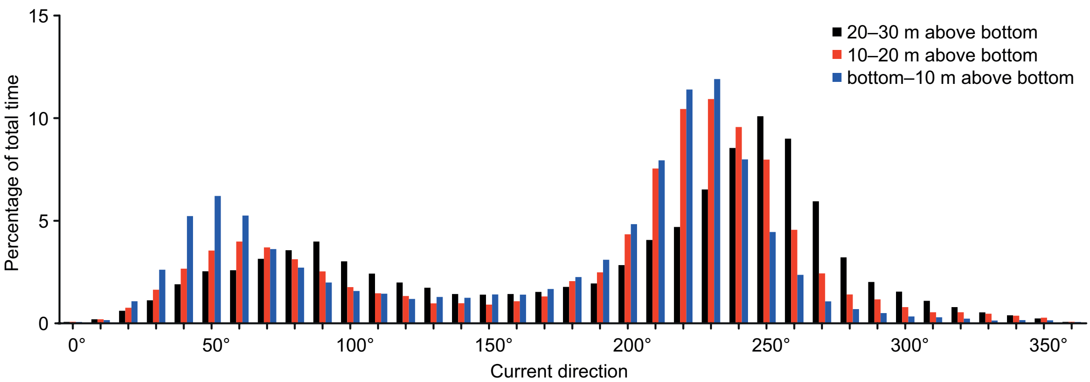

Fig. 5. Current direction histogram for Location West.

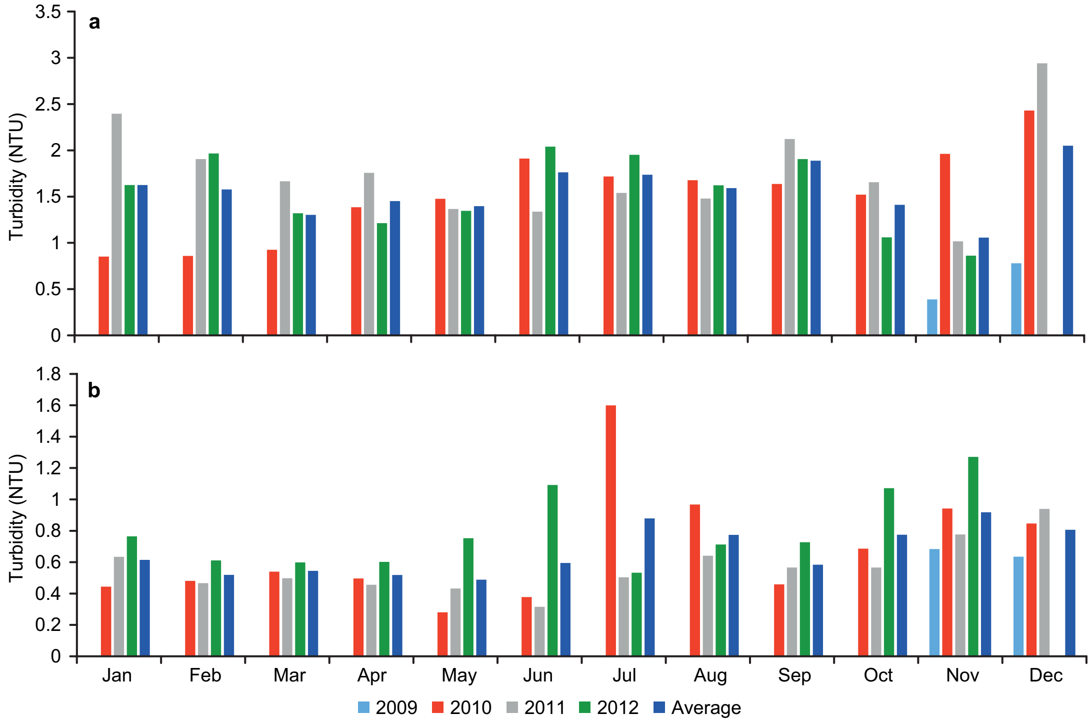

Fig. 6. Monthly averages of turbidity for (**a**) Location East and (**b**) Location West.

river discharge and suspended sediment concentrations. Lehtoranta *et al*. (2007) used the VEPS assessment system of the Finnish Environment Institute (SYKE) to find that the mean discharges for the Paimionjoki and Kymijoki for the period 1990–2003 were 9.6 m^3 s^{-1} and 149.0 m^3 s^{-1}, respectively. Respective suspended solids concentrations were 0.1920 kg m^{-3} and 0.0078 kg m^{-3}. These correspond to yearly loads of 5.8×10^7 kg a^{-1} for Paimionjoki and 3.7 10^7 kg a^{-1} for Kymijoki. Of these two rivers, Paiminjoki does not discharge into the Gulf of Finland. In recent times, the total river discharge into the Gulf of Finland has been about 3556 m^3 s^{-1} (1.1×10^{11} m^3 a^{-1}), of which most have came from the rivers Neva, Narva and Kymijoki (Graham, 1999). All these three rivers originate in large lakes and have very low suspended sediment concentrations. If the mean suspended solids concentration is assumed to be around the Kymijoki value of 0.01 kg m^3, then the whole riverine load is 1.1×10^9 kg a^{-1}. If the area of the Gulf of Finland is assumed to be 30 000 km^2, then the load associated with the resuspension is 3.8×10^{11} kg a^{-1} which is more than two orders of magnitude larger. The difference becomes smaller if the area of sediment accumulation is taken into account and assumed to be 12 000 km^2. For comparison, Viktorsson *et al*. (2012) showed that in the Gothenburg archipelago, the benthic flux of soluble reactive phosphorous can be as high as ten times the river load. Working in the same region, Almroth *et al*. (2009) however did not find any direct link between resuspension and benthic nutrient fluxes.

The work in this study was carried out at a depth of 40 m, which is more than the mean depth of the Gulf of Finland. Most likely the resuspension is greater in shallower areas meaning that the values in this study are at the lower limit of the natural resuspension. In this study the increased turbidity was assumed to be due to resuspension. The resuspension can either occur at the measurement locations or the suspended sediments can be resuspended somewhere else and then transported to the measurement location. Using this assumption, an increase in turbidity is always an indication of resuspension.

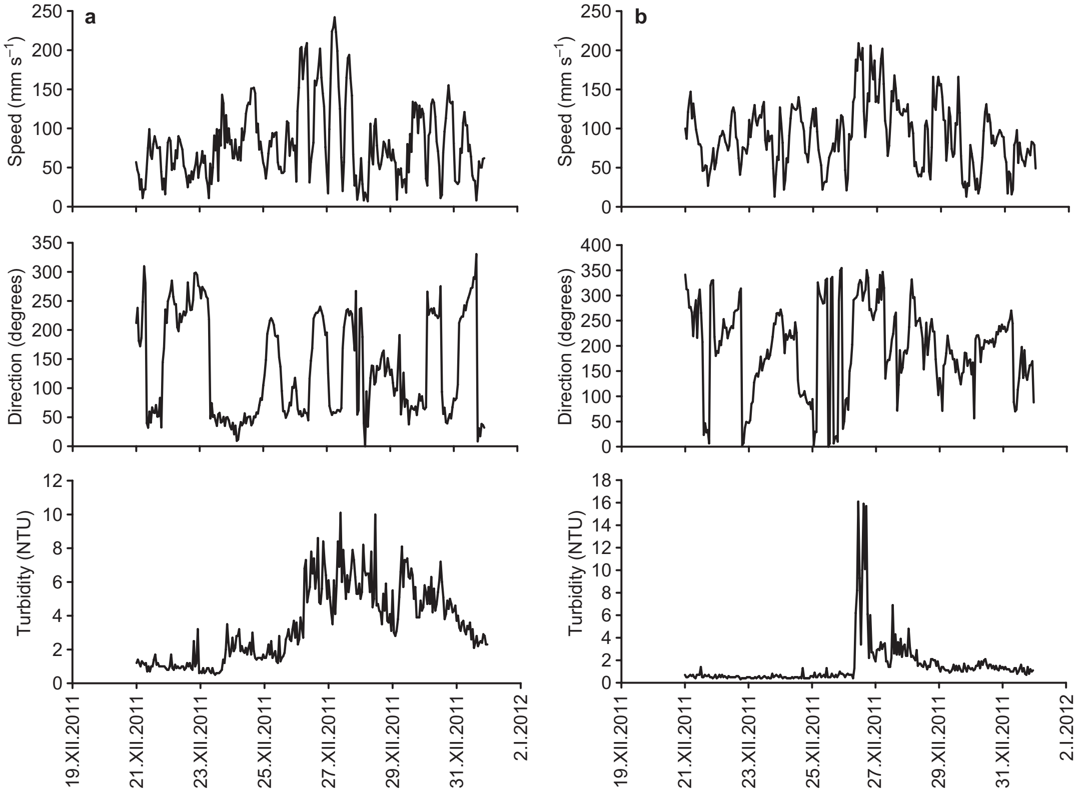

Fig. 7. The effect of a storm (26 Dec. 2011) on the near-bottom turbidity, the current speed and the current direction at (**a**) Location West (depth 41 m), and (**b**) Location East (44 m depth). Note the natural seiche of the Baltic in the current velocity.

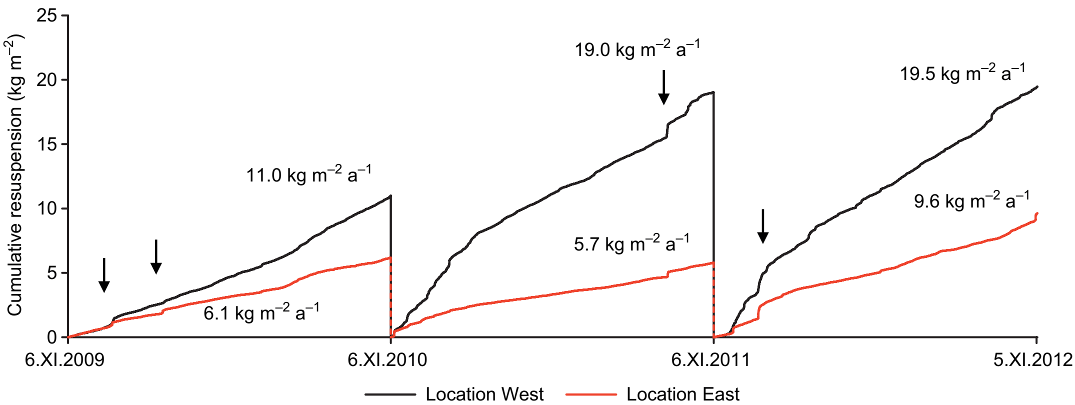

Fig. 8. The cumulative resuspension for Locations West and East for the whole water column. Some periods of increased resuspension are shown with arrows.

The resuspension values in this study are similar to those found in previous studies and especially close to the lowest values obtained by Mattila *et al*. (2006). The number of events per time is also similar to previous studies. Modelling studies in the Baltic Sea showed that resuspension events can occur 3 to 4 times per month (Danielsson *et al*. 2007), and a study of Gulf of Finland resuspension events showed that they are slightly less common there (Tengberg *et al*. 2003).

During the storm event on 26 Dec. 2011, the period of increased resuspension was three days at Location West and two days at Location East (Fig. 7), or approximately the duration of the high wind speed. Christiansen *et al*. (2002) showed that due to changes in prevailing conditions the suspended matter concentrations may double within a few hours. A similar phenomenon was seen at the beginning of the storm event at Location East.

Microbes can have an important physical effect on the resuspension. They can in some cases inhibit the formation of morphological features on sandy bottoms by secreting sufficient extracellular polysaccharides to inhibit grain movement in sandy bottoms (Hagadorn and McDowell 2011). The effect of this is increased current-speed threshold needed for resuspension to begin. It can be speculated that something like this is happening at Location East (Fig. 7b) during the storm event. The water current speed increases without an increase in turbidity. When the speed increases above a certain level then the turbidity shows a sudden increase and reaches its maximum value. Unfortunately no observations of benthic fauna were made so this cannot be confirmed.

In the beginning of 2012, the current speed increased without a coincident increase in turbidity. This was after the storm event and can be due to the fact that the pool of sediment available for resuspension had been exhausted. Tengberg *et al*. (2003) found that resuspension occurred after the wind died down and water that had been pushed by the wind flowed back. This mechanism can also cause internal waves which was probably seen at Location West.

The Rouse profile is dependent on the settling velocity which appears in the Rouse number in the exponent (*see* Eq. 1). A higher settling velocity than the one used in our study would have led to an underestimation of resuspension. This is because a higher amount of resuspension is needed to maintain a certain concentration in the water column if the settling velocity is higher.

Conclusions

A three-year study of currents and turbidity was made for two locations in the Gulf of Finland: a location in the East and a location in the West. Estimates of resuspension were then based on these measurements. At Location West an average turbidity close to the bottom at a depth of 41 m was 1.58 NTU, and an average current speed 5.50 cm s^{-1}. At Location East, an average turbidity close to the bottom at a depth of 44 m was 0.67 NTU, and an average current speed 4.45 cm s^{-1}. Those environments were found to be of a relatively low energy type where major resuspension events were relatively rare. The calculated resuspension results however show that the yearly natural resuspension at a depth of 40 m was approximately 10–20 kg m^{-2} for Location West and 5–10 kg m^{-2} for Location East. This shows that a large amount of sediments is naturally moved around in the sea even in environments with low current speeds. During a storm event, the turbidity values increased considerably in a short time.

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