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”RAW – Retreat And Wither” – What is an influence of glaciers recession from tidewater to land-based on the marine biological production and biogeochemistry in Arctic?

Concept and hypothesis

Climate change is disproportionately strong in the Arctic, which is the most rapidly warming region on Earth (Pithan and Mauritsen 2014). This spectacular warming applies especially to its European sector that is one of the most sensitive marine region to both past and present global changes including natural and anthropogenic external forcing. These rapid changes are leaving a large fingerprint upon terrestrial and marine environments in Arctic. Over the last few decades air temperatures have risen significantly and precipitation patterns have changed to wetter during late summer (Zhuravskiy et al. 2012; Osuch and Wawrzyniak 2016b). It is also suggested that this process is expected to strengthen in the next century (Osuch and Wawrzyniak 2016a). The above mentioned changes cause a shortening of the sea-ice season, reduce of polar sea ice cap/or its complete disappearance in some Arctic fjords (e.g. Onarheim et al. 2014; Pavlov et al. 2013; Muckenhuber et al. 2016; Zhuravskiy et al. 2012). Climate warming and sea ice decline can also lead to increased storm surge activity, and thus, to accelerating coastal erosion (Wojtysiak et al. 2018). One of the observable consequences of the climate-related transformations in the Arctic is **the rapid recession of glaciers** (Błaszczyk et al. 2013; Pälli et al. 2003), which are leaving behind new bays and shorelines. Due to glaciers calving, submarine melting and drainage of meltwater through glacial outflows, glaciers are recognised as the main source not only of freshwater supply into the fjords (Bamber et al. 2012; Bartholomaus et al. 2013; Błaszczyk et al. 2019; Motyka et al. 2003, 2013), but also the accumulated mineral, organic matter and nutrient (Anesio and Laybourn-Parry 2012; Hood et al. 2015; Monien et al. 2017; Raiswell et al. 2008). It is worth noting that the exchange of this freshwater input with the fjord main basin and open sea is or can be spatially constrained because of bay geometry and sea bottom morphology (Moskalik et al. 2018). In such situation, sediments are mainly trapped inside the bays (Ćwiąkała et al. 2018), and thus **transport of nutrients to open sea is limited**. In glacierised basins, in addition to nutrients supplied from deep oceanic waters, biogeochemical weathering strongly enriches water in bioessential nutrients (Stachnik et al. 2016). These nutrients are transported in bioavailable and labile particulate (also termed as sediment-bound) fractions, and locally significant nutrients fluxes have been reported from glacierised basins (Hawkings et al. 2014, 2016, 2017). A significant amount of nutrients, uncluding bio-essential nutrients such as iron, ammonia, trace metals (etc. Co, Mo, Mn), are bound to glacial-derived suspended matter and delivered throughout the ablation season (Hallet at al. 1996; Hawkings et al. 2014, 2017; Hodson et al. 2017; Moskalik et al. 2018). **These nutrients are believed to affect marine primary productivity** in the areas where glaciers terminate in the landor glacial meltwater rivers flow into the sea (Arrigo et al. 2017; Bhatia et al. 2013). On contrary, there is a body of evidence suggesting that **deep water upwelling at the terminus of tidewater glaciers causes an increase in primary production** (Meire et al. 2016, 2017; Hopwood et al. 2018). These deep waters are usually rich in dissolved nutrients including nitrogen, and dissolved silica (Meire et al. 2017). As a results, marine primary (algal blooms) and secondary production (high fish catch) increases in front of tidewater glaciers (Meire et al. 2017). Consequently, increased primary productivity in the near coastal waters may create **an important and underappreciated negative feedback effect with CO_2 concentration via photosyntesis** (De Baar et al. 2008; Gerringa et al. 2012). However, the opposite effect has also been observed near the land-based glacier inputs, where low availability of nitrogen in meltwater limits the productivity (Holding et al. 2019; Meire et al. 2016). Fore more, it remains uncertain how the marine ecosystem productivity will respond to future changes in Arctic. Furthermore, sustained glacier recession will eventually change the glacial regime from predominately tidewater to land-based. The current oceanographical and sedimentological conditions (Chauché et al. 2014; Moskalik et al. 2018; Szczuciński and Zajączkowski 2013) will, therefore, adopt more characteristics of land-based glaciers and non-glacial inputs. This, in turn, **may alter the total nutrient flux supplied to euphotic zone** (either directly via runoff or indirectly via reduced tidewater glacier inducted deep water upwelling). Therefore, this project aims to test the following hypotheses:

The warming-driven glacier recession cause the reduction in marine biological production in polar coastal regions and seas due to:
- ***unfavourable nutrient balance caused by a reduction in nutrient-rich deep water upwelling from buoyant meltwaters plumes (Fig.1B, C),***
- ***shallowing the euphotic zone caused by increased surface suspended sediments concentration (Fig.1C, D)***
- ***reduction of water mass exchanges and sediment-bound nutrients transfer between the fjord/open sea and newly formed bay due to hydrography and formation of natural sediment traps (Fig.1E).***

1. State of the art
1.1. Current knowledge
Marine primary productivity and CO_2 budget

Marine productivity conditions affect to a large degree the air-sea CO_2 exchange. Conversion of CO_2 in the course of photosynthesis into organic matter and its sink downward to bottom sediments generate undersaturation in the surface seawater allowing dissolution of atmospheric CO_2 in seawater. The Arctic Ocean, its relatively high primary productivity and low water temperatures both enhancing CO_2 solubility, is responsible for as much as 5-14% of the global CO_2 uptake by marine regions (Bates and Mathis, 2009). This large sink for atmospheric CO_2 occur in the Arctic year-round even though the seasonal sea-ice cover limits the gas exchange. It is expected that the sea-ice cover reduction and increase in phytoplankton growth rate due to the global warming will lead to even more efficient sequestration of CO_2 by the Arctic waters. All this makes the Arctic marine ecosystems an important component in the global carbon cycle. The recent findings (e.g. Ericson et al. 2018, 2019; Smith et al. 2015) shown that Arctic fjords are especially effective in absorbing atmospheric CO_2 and burial of organic matter in the sediments. The biogeochemistry of the fjord systems is, however, very complex and not fully understand yet. The great unknown remains the effect of the glaciers recession on the CO_2 budget in the coastal waters. Some studies (Ericson et al. 2018, 2019; Fransson et al. 2013, 2015) shown already that processes like brine formation, ice melting and freshwater inflow have the potential to change the internal structure of the CO_2 system and CO_2 exchange through the air/sea interface. Generally, freshenin of the fjords waters due to the inflow of the meltwater enhance CO_2 uptake and strengthen ocean acidification (Ericson et al. 2018, 2019). The effect can be smaller or even entirely mitigated if the meltwater contains more alkalinity due to the flowing through the carbonate or silicate-rich bedrock. The glaciers retreat, apart from the effect of freshening the fjords' waters, can influence the local CO_2 budgets through the changes in ecosystem productivity. This mechanism is, however, poorly understood so far.

The role of nutrient delivery in marine primary productivity

Nutrient delivery from terrestrial basins influences the primary productivity in the ocean (Arrigo et al. 2017; Bhatia et al. 2013). This link forms a negative feedback effect on the CO_2 budget, whereby increased nutrient delivery intensifies primary productivity in the near-coastal ocean, which stimulates CO_2 consumption in the sea and drawdown from the atmosphere due to undersaturation. Traditionally the macronutrients nitrogen (N) and phosphorus (P) were considered most important in maintaining primary productivity, but now new evidence shows that silicon (Si), iron (Fe) and other micronutrients (Mn, Ni, Zn, Co, Cu, Mo, Cd) are also critically important for maintaining primary productivity and for altering the phytoplankton community structure (De Baar et al. 2008; Gerringa et al. 2012; Sunda et al. 2012; Moore et al. 2013). For example, the Si is essential for diatoms, which dominate marine phytoplankton blooms and play a key role in ocean ecology and the global carbon cycle, as it is the main component of their cell walls, while the supply of Fe is critical in building intercellular photosynthetic apparatus and in nitrogen acquisition enzymes (De Baar et al. 2008; Morel et al. 2013).

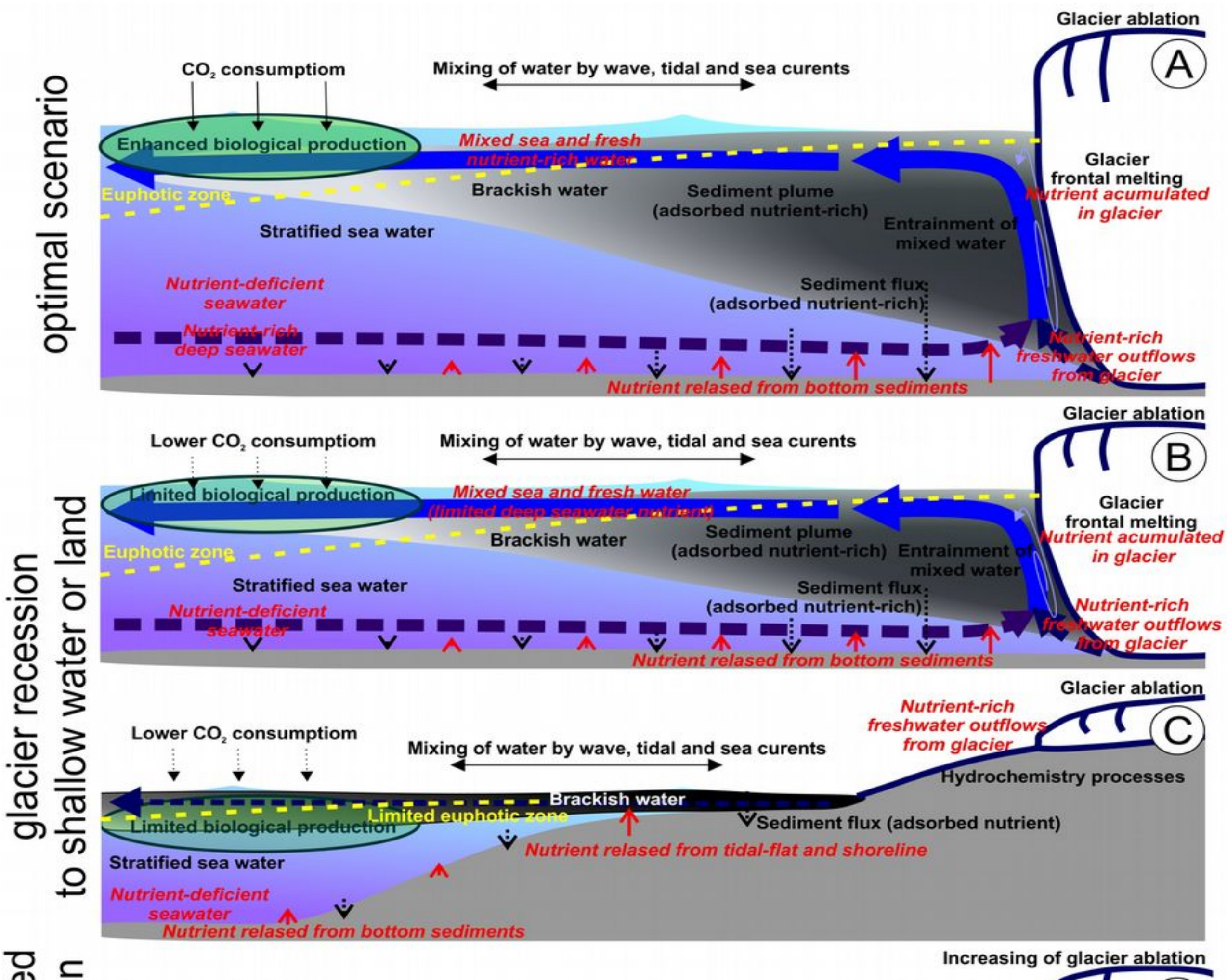

Figure 1. Graphical presentation of the project hypothesis.

The supply of nutrients from land in polar regions

A key factor increasing the supply of nutrients in polar regions is the mechanical denudation of bedrock in glaciated catchments (Anderson 2000), and elevated specific discharge (Hallet et al. 1996). Bedrock crushing as a result of glacial erosion exposes trace reactive components in the rock to chemical weathering and generates highly reactive particles with large surface areas. Glacially-derived nutrients are transported from land to sea as dissolved or adsorbed on the suspended matter or reactive minerals. In glacierised basins, the flux of labile nutrients associated with suspended matter (hereafter, referred as labile particulate nutrients) is a few orders of magnitude higher than the dissolved load (Anderson, 2000). The suspended matter with a very high specific surface area (>4m^2g^{-1}; Telling et al. 2015) is formed from physical weathering via comminution of bedrock. These properties facilitate the adsorption of dissolved nutrients on the surface of suspended particles and create high reactive amorphous mineral surfaces (Hawkings et al. 2014, 2018). The proportion of adsorbed components to solutes is different, depending on the chemical element. For some alkali metals (Na, K, Ca, Mg), the concentration of the adsorbed matter is at most 10 times higher than the concentration of dissolved ions (Oelkers et al. 2012). For other elements (e.g.: Fe, P), the concentration of the adsorbed species is several orders of magnitude higher than the dissolved elemental concentration (Jeandel and Oeklers 2015). The total labile particulate nutrient load transported from land to the sea is approximately 20 times higher than the dissolved load and the atmospheric deposition load (Oelkers et al. 2012). For nutrients essential in maintaining primary productivity (Si, P, Fe, Co, Mo, Mn), the estimated share of amorphous to dissolved Si approximately 0.99 (Hawkings et al. 2017), of bioavailable P to dissolved P is approximately 0.8 (Hawkings et al. 2016), and amorphous labile Fe to filterable "dissolved" Fe is around 0.98 (Hawkings et al. 2014). Due to the high proportion of the labile particulate nutrients in the total nutrient flux, there are a corresponding high nutrient yields from glacierised basins.

The supply of nutrient from the ocean in polar regions

Surface water is generally low in nutrients. The most important mechanisms responsible for nutrients delivery are the winter mixing with deeper nutrient-rich waters and horizontal exchange with the nutrient-rich Atlantic Water (Popova et al. 2010). It is worth noting, that, the profound changes in the shelf transport of nutrient-rich water from the Atlantic Water boundary current might have big impacts on integrated productivity however, there are no clear answers regarding its effect on nutrient transport onto the shelf (Randelhoff and Sundfjord 2018). There are also several other, less intense mechanisms affecting the nutrient supply. Sporadically, severe storms and internal waves that erode the halocline can move underlying rich in nutrients upwards (Popova et al. 2010; Rainville and Woodgate 2009; Randelhoff and Sundfjord 2018). In some regions, topography in combination with hydrodynamics can generate localized sources of nutrients via processes such as increased tidal mixing, the turbulent wake behind islands and banks, and wind-driven shelf-break upwelling. The ice edge upwelling might also increase primary production but still may be of relatively minor significance in the overall supply of nutrients. Cyclonic eddies have also been shown to impact on primary production in polar areas. The above mentioned mechanisms can be direct (vertical advection of nutrients) or indirect (adding heat to and altering the circulation of surface waters), and as a result both can decrease sea-ice concentration and increase available short-wave radiation. The organic matter cycling in the Arctic Ocean and especially in its fjords has received increased attention, however little is known about N and P deposition and burial in bottom sediments. Bourgeois et al. (2017) provided a large-scale assessment of the current knowledge on the benthic organic matter remineralization and benthic nutrients fluxes. The noticeable high variability of nutrients release and sink into the sediments was correlated with spatial variability e.g. continental shelves influenced by large river inputs and/or in sediments receiving high organic matter loads. However in Hornsund and Kongsfjorden (Svalbard), both the deposition to sediments of N and P ranged between 2.3–8.3 $g{\cdot}m^{-2}$ for N and 0.9–2.8 $g{\cdot}m^{-2}$ for P, respectively (Koziorowska et al. 2018). The N return fluxes ranged from 0.12 to 1.46 $g{\cdot}m^{-2}{\cdot}y^{-1}$. At most stations, the N flux was mostly of dissolved organic (about 60–70%) rather than inorganic N. The P return flux ranged from 0.01 and 0.11 $g{\cdot}m^{-2}{\cdot}y^{-1}$, with organic species constituting 60–97%. The N and P burial rates differed between fjords: N – 2.3–7.9 $g{\cdot}m^{-2}{\cdot}y^{-1}$ and P – 0.9–2.8 $g{\cdot}m^{-2}{\cdot}y^{-1}$ in Hornsund vs. N – 0.9–

1.3 g·m^{-2}·y^{-1} and P – 1.0–1.2 g·m^{-2}·y^{-1} in Kongsfjorden. This was accompanied by a different efficiency of N and P burial – higher in Hornsund than in Kongsfjorden, in both cases. Most likely caused by the differences in the quality and quantity of N and P organic species deposited to sediments and differences in the intensity of their mineralization and/or decomposition.

Marine biogeochemical processes and their significance for nutrient cycling

The biogeochemical processes in the sea, related to the supply of nutrients from glacierised basins, are still poorly understood. Considerable changes in the biogeochemical conditions in freshwater inflow into the sea are caused by the rapid increase in salinity, change in pH, a large increase in total solute load and flocculation of charged clay particles. The role of labile particulate nutrients in oceanic nutrient cycling is poorly understood in nutrient cycling in the sea (Jeandel and Oelkers 2015; Oelkers et al. 2012). The particulate nutrient fraction is at least ~3 orders of magnitude higher in the case of P, ~5 orders of magnitude higher for Si and ~6 orders of magnitude higher for Fe, compared to the dissolved fraction in marine waters (Oelkers et al. 2012). The processes of dissolution, desorption and adsorption occur along with salinity gradient, but the intensity of these processes is not unequivocally determined. For example, evidence of dissolution of Si reactive phases on suspended particulate material was observed across a salinity gradient in a Greenland fjord fed by land-based glaciers (Hawkings et al. 2017). Research from glacierised coast and near coastal regions in Greenland and the Bay of Alaska indicates that Fe concentrations are locally elevated, but a rapid non-conservative decrease occurs with increasing salinity due to flocculation/aggregation and settling of particulate matter (Hopwood et al. 2016; Schroth et al. 2014).

Inputs of nitrogen from land-based glaciers are likely to be low (Wadham et al. 2016), which may induce N limitation in fjord systems (Meire et al. 2016) causing lower primary productivity (Meire et al. 2017) (Fig. 1C). This is likely to suppress lower primary productivity in low salinity glacial river mouths and displace algal blooms towards areas where the nutrient ratio is at its optimum for primary producers (Meire et al. 2017). A different situation occurs in the tidewater glaciers (Fig. 1A, B). Meltwater induced upwelling in front of the ice terminus delivers nutrient-rich (mainly N-, Si-, and P-rich) marine deep waters in combination with glacier meltwaters stimulating primary productivity and occurrence of higher trophic organisms (Hopwood et al. 2018; Kanna et al. 2018; Meire et al. 2016). This also appears to be important for fishing since greater halibut catch are found in Greenlandic fjords that have tidewater glaciers (Meire et al. 2017). The supply of silica from land and tidewater glaciers favour development of diatom dominated phytoplankton communities (Halbach et al. 2019; Meire et al., 2016). For Fe, despite the high flux of labile particulate fractions (Hawkings et al. 2014; Schroth et al. 2011), it is not well understood to what extent particulate Fe is bioavailable (Hopwood et al. 2016, 2018). Filterable Fe (<0.45 μm fraction consisting mainly of colloidal and nanoparticulate Fe) is likely to be at least partly bioavailable (Raiswell et al., 2016). However this fraction undergoes non-conservative estuarine removal over salinity gradients and is usually found in sparingly at low concentration in high salinity waters (Hopwood et al. 2016).

Significance of fjord hydrography, sedimentation and sediment-bound nutrients

Fjord geometry, physical oceanographic processes and high sedimentation rates form a trap for particulate matter (Fig. 1E). In the fjords, sedimentation basins formed during glacier retreat are limited in marine exchange with the fjord or open sea by shallow sills (Moskalik et al. 2018). Sedimentation is magnified by the flocculation processes by forming heavy granules and accelerating particles deposition to the bottom of the fjord (Moskalik et al. 2018). Therefore, the direct transport of labile particulate nutrients into the open ocean may be limited. A different situation potentially occurs in short fjords and when tidewater glaciers terminating directly to the open sea. On the other hand, the high concentration of labile particulate Fe in sea water accelerates the aggregation of suspended particles into buoyant flake-shaped conglomerates inhibiting the deposition (Markussen et al. 2016). The concentration of Fe in sea water is high in vicinity of tidewater and land-basedglaciers that enables strong flocculation (Hopwood et al. 2016). In turn, this limits the deposition of suspended particles to bottom sea sediments and leads to long range transport of labile particulate nutrients (Markussen et al. 2016). Despite the significant drop in e.g. Fe concentration with the increasing salinity (Schroth et al. 2011, 2014), concentrations are still orders of magnitude higher than those found in the open ocean (Markussen et al. 2016). With glacier recession and increased delivery of organic matter, the flocculation processes enhance Fe precipitation kinetics on the organic matter decreasing the dissolved Fe delivery (Hunter et al. 1997; Mylon et al. 2004; Nowostawska et al. 2008). It may be an important process since the organic matter load transported by glaciers may be significant (Hood et al. 2015; Moskalik et al. 2018) and Fe-OM binding has now been observed in a range of different glacial streams (Hodson et al. 2017). The organic matter supply may further increase in consequence of deglaciation and vegetation expansion potentially mitigating a long range transport of labile particulate nutrients in seawater (Schroth et al. 2011), but it is still poorly understood.

Together with increasing freshwater runoff from the glaciers, vast amounts of suspended particles and optically active substances are released, make water less transparent resulting in lowering of the depth of the euphotic zone. While light availability is known to influence phytoplankton communities and primary production, it also affects biodiversity and species interactions in coastal ecosystems (Pavlov et al. 2019).

Among important aspects is also the role of buried nutrients in fjord and coastal sediments. Sediments reworking by benthic macrofauna, sediments redepositon and resuspension (mass movements, glacier calving, iceberg ploughing etc.), coastal erosion (wave action) may be the additional factors that alter nutrient cycling in fjords (for example iron and manganese; Wehrmann et al. 2014). Diffusion of by-products from microbially-mediated pore water processes linked to Fe, S cycles and sediment diagenesis. Additionally, ebullition of gases from the bed of Svalbard fjords could help bring nutrient-rich bottom waters to the photic zone (Pohlman et al. 2017).

1.2. State of preliminary and initial research indicating the feasibility of research objectives

Preliminary research with project investigators participation on glaciology, sedimentology, oceanography, geochemistry, and marine biology in SW Spitsbergen clearly demonstrates the urgent need for detailed studies of the nutrient cycling, and marine production in rapidly changing polar environments. To meet this aim, the influence of glacial recession on the nutrient flows and fluxes must be better quantified. To date, the research work in the Spitsbergen and broadly speaking in the high Arctic have been fragmented, and have separately concentrated on the processes of sedimentation, coastal erosion, glacial riverine nutrient fluxes, and marine biology (phytoplankton and zooplankton) in the fjords. No comprehensive studies on nutrient flows and fluxes from the glacier to the sea have integrated these key processes.

Glaciers draining to the Hornsund are retreating and the input of freshwater into the fjord increases. The contribution of freshwater runoff into fjord components are following: melt water runoff from glaciers 39%, glaciers frontal ablation 25%, total precipitation over the entire basin except winter snowfall 21%, snow cover melt over unglaciated areas 8%, precipitation over the fjord area 7% (Błaszczyk et al. 2019). Assuming that high runoff of fresh water with high sediment concentration is associated with high yields of nutrients, we expect that the main source of nutrients from land are outflows from glaciers and less important glacier melt and ice cliff frontal ablation. Preliminary research conducted in the front of tidewater Hansbreen glacier shows a high seasonal variability in the delivery of suspended matter to the fjord in organic and inorganic fractions. The maximum concentration of suspended matter occurs in autumn(September, October) as a result of heavy rainfall (Moskalik et al. 2018). On the other hand, the highest sediment fluxes from this glacier occur in July (unpublished data), which correlate with maximum of glacier ablation (Laska et al. 2016, 2017). It should be noted that the preliminary research has also been carried out on the formation of aggregates in the seawater at glacial front and in the river mouths (Szczuciński and Moskalik 2017). In the scenario with tidewater glacier, aggregates have been observed with a size of 4-5 phi in the uppermost layer of brackish water (down to approximately 10 meters depth), below which a threshold change in their size to 2-3 phi occurred. For glacial river mouth, the situation was completely different. In the river the particle size was lower (6-7 phi). Following contact with sea water, an intensive flocculation process was taking place and the aggregates with 2-3 phi size were formed. The freshwater layer appear not to exceed 2 meters depth and, on its boundary, suspended matter concentration was elevated. Therefore, it should be considered to what extent the flocculation process in the river mouth area is magnified by the labile particulate nutrients. Potentially, the aggregates formed in the river mouth was flake-shaped. In spite of this fact they were not able to pass the density threshold required to deposit those particles in the bottom sediments.

Bottom waters have been found to have a high concentration of suspended matter, even in winter. The suspended matter is likely sourced from sediment re-deposition. In consenquence, this potentially leads to the release of nutrients from recycled bottom sediments into the water column, although that process has not been fully understood yet. The research in front of Hansbreen shows that the range of suspended matter transport is strongly limited by the moraine ridge formed during the Little Ice Age. The effectiveness of ridge is confirmed by the estimated amount of the deposited sediment at the sea bottom in front of Hansbreen. According to the preliminary research, the mean annual sedimentation rate exceeds tens of centimetres per year, which is higher by one and more orders of magnitude than typical annual sedimentation rate (~1 cm/year) in the Hornsund Fjord (Ćwiąkała et al. 2018). The available bathymetric data from the vicinity of other tidewater glaciers show similar morphological features of the sea bottom. For land-based glaciers, sediment traps are formed by the shallow bay, where a fast expansion of a delta is observed due to sediment deposition. Its occurrence within the tidal zone likely facilitate a re-suspension of bottom sediment and labile particulate nutrientsduring storms and wave actions. Both processes show increasing trend in the Svalbard as have been shown through the analysis of storm intensity in western Spitsbergen (Wojtysiak et al. 2018) and coastal erosion (Zagórski et al. 2015).

Research into the biogeochemical weathering under conditions of subglacial drainage and proglacial zone have been conducted in the Werenskiöldbreen (Stachnik et al. 2016 a, b). In 2017, a pilot study was conducted to compare the nutrient loads (primarily of Fe, Si) adsorbed to suspended matter and dissolved in the water, in the Werenskiöldbreen basin. Preliminary results show that the concentration of ferrihydrite (a bioavailable Fe oxyhydroxide mineral) adsorbed to suspended matter was higher than concentrations observed in Greenland. Furthermore, the biolabile Fe and Si load in the Werenskiöldbreen basin was 15 and 3 times higher, respectively, than the loads of these elements in filterable forms (nanoparticule <0.45μm), if the mean weighted concentration of suspended particles is taken into account. However, in the case of higher suspended matter loads, e.g. associated with higher runoff from the basin caused to heavy rainfalls or glacier ablation, this ratio may reach even 35 and 7 times, for Fe and Si, respectively (Stachnik, unpublished data). Suspended particulate material-bound nutrients comprise the vast majority of the total nutrient load in a glacierised catchment but their importance in downstream biogeochemical cycles (seawater and freshwater) is still to be fully established.

An important element to determine the role of the glaciers in nutrient transport from land to sea is the determination of differences in the geochemical composition of the sediment deposited in fjord bottoms. Preliminary work on the concentrations of i.a. Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Zn was conducted in the Recherchefjorden. Surface sediments were collected in three bays, which are examples of three different catchment – with tidewater glacier, land-based glacier and glacier-free. The results show that despite only a short distance between these sites and their similar geological substratum, there were observed differences in the concentration of analyses elements in sediments from each of the bays (Zagórski, unpublished data). Such differences in the marine sediments geochemistry sourced from basins underlined with similar bedrock indicates both the differences in the physical and chemical denudation for different glacier recession stages, and the influence of the nutrients transport and biogeochemical processes.

Even though the problem of the glacier retreat is proliferating, still very little is known about the ecology of turbid glacier-fed aquatic ecosystems. Recently, the optical water properties have been shown to be as important as hydrography on shaping zooplankton composition structure in coastal Svalbard waters (Trudnowska et al. 2015). The new study of the wide range of plankton fractions (from nano- to meso-) along short distances from the glaciers indicates that influence of glacier discharge on marine life is complex. In many cases, the ratio between photo- to heterotrophic protists was high even at stations in vicinity of glaciers. In Hornsund the secondary production was estimated to be very high, even in highly turbid water s in glacial bays (Trudnowska et al. 2014). According to new, simultaneous observations of particles, phytoplankton and zooplankton in Svalbard region, their relations may change drastically due to the combination of many biological and physical processes (Trudnowska et al. 2018), which substantially alter 'life history' of organic matter in the sea and phenomenon still needs to be better evaluated. Many properties of particles and marine snow aggregates (size, structure, transparency) also changed drastically across gradients caused by the various glacier types . Therefore the knowledge about the amount, nature and fate of the material released to the water column through increasing glacial melting, is critical to understand the biogeochemical mechanisms that sustain and/or threaten life in the surrounding ecosystems. Since planktonic protists are key contributors to biogeochemical cycles, it is particularly important to determine their reaction to the increased inflow of glacier derived suspended sediments. The previous studies have shown that increase in the amount of organic and mineral suspended matter may cause the agglutination of protozoan cells, result in an increase in their specific gravity and, as a consequence, falling out of the euphotic zone (e.g., Kubiszyn et al. 2014). Additionally, as the upper water column receive more freshwater, it becomes more difficult for mixing processes to deliver nutrients from depth to the surface for protists growth. Competitive advantage presumably accrues to small cells because they are more effective in acquiring nutrients and less susceptible to gravitational settling than large cells (e.g. pelagic diatoms). This applies especially to flagellates, which are able to actively move in the water column, toward nutrient-richer regions or more favourable light conditions (Piwosz et al. 2014; Kubiszyn et al. 2017). Furthermore, these flagellated forms are frequently capable to use a mix of different sources of energy and carbon, switching from phototrophy to phagotrophy (so-called mixotrophy), depending on the environmental conditions (Stoecker 1998). The significant increase in the smallest plankton fractions, along with a decrease in microplanktonic (20-200 µm) primary producers, seems to be accompanied with an increase in microplanktonic grazers (mostly mixo- and heterotrophic ciliates and dinoflagellates; Kubiszyn et al. 2014; Onda et al. 2017), probably due to their ability to exploit a wide range of numerous smaller preys (bacterioplankton, pico- and nano-protistan plankton). Because of rapid doubling rates of microzooplankton, as well as their adaptation to utilize particles one order of magnitude smaller (out of reach for mesozooplankton; Sheldon et al. 1972), it is assumed that microplankton will become more of a direct control on protist loss rates than mesozooplankton along with further warming (Friedland et al. 2016). Consequently, the expected effect of warming and is an elongation of the short food chain of at least one link which are microplanktonic grazers and serious losses in the energy flow in the trophic web and redirection of a significant part of it to the pelagic food chain.

2. Objectives

2.1. Specific research objectives

In this project several aims will be executed:

Objective 1. Assessment of of variability in the hydrochemistry, sedimentation processes and physicochemical properties of marine water in the areas of tidewater, land-based glacier and river input.
Investigating the sedimentation processes in the fjord together with associated biogeochemical implications are one of the key elements of this project. This research will improve our knowledge of processes occurring in a wide range of estuary type in polar fjord environments. This will obtained because of the homogeneity of location and time of sampling in study sites. The advanced optical methods (e.g. particle counters, underwater cameras) will be used in order to characterize the size, transparency, type and structure of marine aggregates (marine snow) that are formed as a result of turbid freshwaters input from glaciers/non-glacierised basins.
Objective 2. Assessment of the spatial distribution and concentrations of macro and micronutrients bound to suspended particulate matter and in dissolved phases in terrestrial and marine waters.
Through the analysis of the spatial distribution of nutrients combined with the results of the first objective, we will determine nutrients flux from different sources in order to estimate the potential sources and sinks. This analysis will allow us to obtain nutrient budgets and to evaluate potential

future biogeochemical changes associated with glacier recession related to warming in Arctic.

Objective 3. Evaluation of the bioavailability of suspended particulate material bound nutrients in sea-water and significance in near coastal biogeochemical cycling.

As part of this project, we will evaluate the processes occurring over the salinity gradient and potential nutrient transport to the open sea, based upon sequence extraction to define the bioavailability of nutrients. These processes are currently poorly understood.

Objective 4. Determination of the burial and sedimentation rates of suspended particulate material, and potential benthic recycling of nutrients into the fjord water column from early diagenetic processes.

The impact of benthic recycling on fjord nutrient budget is still poorly understood. An analysis of fjord bottom sediments will be conducted to estimate contribution benthic recycling an early diagenic processes to source/sink of nutrients. This will also enable to estimate the sedimentation rate of nutrients and organic carbon, which may be remobilised as a result of wave action and coastal erosion.

Objective 5. Comparison of the plankton community structures and primary productivity between the tidewater and land-based outflow areas of glaciers.

Photo- and heterotrophic protists including zooplankton organisms will be investigated in various locations with respect to glacier recession stage (tidewater and land-based glaciers, and glacier free basin) in order to verify an influence of the salinity, nutrient and turbidity gradients on microorganisms community structure and rate of primary productivity.

Objective 6. Assessment of the possible transfer of nutrients and energy through the food web based on plankton community structure.

The protists and zooplankton abundance will be determined in terms of functional groups (e.g. size classes, trophic modes of nutrition) in order to define their role in nutrients and organic matter cycling in the system and potential sensitivity to the differences between glacier/river impacts.

2.2. The justification for tackling specific scientific problems, and the impact of the project results on the development of the research fields and scientific discipline

The RAW project aims to determine whether the warming-driven glacier recession causes the reduction in marine biological production. Moreover, this project will be executed based upon the tasks that will provide new meaningful knowledge in the development of the following research fields:

Task 1. Analyses of sedimentation and hydrological processes in bays with difference geomorphology and different stage of glaciers recession.

Previous studies on the suspended sediment concentration and sedimentation in fjords of Spitsbergen were carried mostly during summer and separately in different catchments (tidewater, land-based and glacier free basins). In this project, we will extend our knowledge about the influence of bottom morphology, water circulation, tidal currents, and biogeochemical processes on flocculation and sedimentation processes in different stage of glaciers recessions. It is important to know this to analyze the influence of glacier recessions on biogeochemical cycles (including C, S, Fe, other bioessential trace metals) and biological productivity. Also, interannual changes in these processes remain unknown. Oceanographical monitoring conducted at the Polish Polar Station in Hornsund Fjord and fore-field of Hansbreen tidewater glacier enables to determine those changes.

Task 2. Quantification of the impact of different concentration of suspended matter on the depth of the euphotic zone.

The recession of glaciers is accompanied by an increase in meltwater runoff and suspended particles concentration. The concentration and spatial distribution of the suspended particles affect the underwater light field. While light availability is known to control primary productivity, it also affects biodiversity and species interactions in coastal ecosystems. The scale and intensity of these processes depend on the glacier activity and they have not been fully addressed yet.

Task 3. Assessment of the amounts and rates of dissolved and labile particulate nutrient delivery into the near-coastal environment from tidewater and land-based glacial catchments.

Only handful of publications have considered nutrients inputs from glaciers but the majority of the research conducted to date is focused on the Antarctic and Greenland ice sheets.

Task 4. Assessment of the bioavailability of labile particulate nutrients and quantify the importance of their delivery into marine waters.

Former research on the glacier-derived nutrients adsorbed on the suspended matter fail to use sequential extractions that help to partially address nutrients bioavailability of sediment-bound. For example, research conducted to date on sediment-bound Fe uses acidified unfiltered sea water samples, which is poorly calibrated to bioavailability (Schroth et al. 2014). The determination of the bioavailable forms of particulate Fe in sea-water is limited (Hopwood et al. 2016). This is an important unresolved issue, especially with regards to spatial variability of the bioavailable forms of Fe over salinity gradient.

Task 5. Determination the role of direct supply of nutrients from glaciers, deep water upwelling by buoyant glacial meltwaters plumes, and the thickness of euphotic zone on sustaining fjord primary productivity

It has not been fully known yet to what extent the circulation of deep, nutrient-rich water, and its upwelling in the vicinity of tidewater glaciers influences the increase in primary productivity (Meire et al. 2016, 2017). Glacially supplied suspended particles may supplement the upwelled marine nutrients. The research planned within the RAW project aims to deliver data (acquired from oceanographical, sedimentological measurements and chemical analyses) which will enable to solve this problem. Euphotic zone is a very important factor in primary productivity and high load of suspended sediment cause its shrink.

Task 6. Infer physical and biogeochemical processes in glacial catchments at different stages of recession – from tidewater through land-based to the lack of glaciers.

Majority of research are frequently conducted only one of the glacier recession stage: tidewater, through land-based, to glacier free catchment. In the RAW project, oceanographical, ecological and sedimentological research will be conducted at sites featured with those three stages of glacier recession. Research will be carried out at the similar period for catchment situated situated close to each other. It will enable obtaining results with a minor influence of local conditions such as climate and oceanographic conditions and geological substrate. Moreover, all chemical analyses will be made using the same analytical methods in the same laboratories so they will be comparable.

Task 7. Determination of the fate of glacially derived particulate matter, including nutrients entering the marine system.

This process is poorly understood and the variability in physicochemical parameters in the freshwater and seawater could lead to nutrients adsorption/desorption, and flocculation of particles. New, optical methods and underwater cameras enable to analyse the size, transparency and structure of particles and marine snow aggregates. he study of plankton concentrations and structure will enable to quantify how much of the nutrient discharge could be utilised/used for primary and secondary production.

Task 8. Quantification of the significance of benthic recycling in remobilising nutrients into fjord bottom waters, the near shore zone, and in tidal flats through early diagenetic processes.

According to our research hypothesis, an unfavourable nutrient balance for primary production

may occur due to glacial recession. However, recent studies indicate that highly reactive sediments deposited in the glacier forefield and in near-shore environments should be considered. Benthically derived nutrients may partially alleviate the effect of depleted glacier cover.
Task 9. Comparison of marine plankton community structures between the bays sourced from tidewater and land-based glaciers.
It is crucial to verify what is the response of plankton organisms (phytoplankton/protists and zooplankton), their concentrations and community structure, to the various conditions associated with glacier recession such as pattern of discharge of sediments, nutrients and other particulates along with the impact of salinity gradient.
Task 10. Assessment of primary production in water column in the areas of tidewater and land-based glaciers.
Investigating the difference in primary production in water column among areas of different glacier types (tidewater and land-based) to determine the impact of nutrients, biogeochemical processes and optical properties of water.
Task 11. Infer about the possible transfer of nutrients and energy through the food web using the structure of marine plankton community.
By knowing the plankton community structure and their position and role in the food web, the possible pathways and transfer of the transported nutrients can be tracked along with the effect on the CO_2 budget.
Task 12. Analysis the quantity and quality of marine snow aggregates in the water column and thir association wit glacier type.
The knowledge about the enhanced formation of marine aggregates due to the glacier/river discharges is known only for a very few marine estuaries, but regarding the Arctic glacier melting and retreat this issue constitutes still a gap in knowledge, which should definitely be filled if we are to fully understand the biogeochemical cycles of those systems.

2.3. Pioneering nature of the project

Project participants represent a few research disciplines that will work as one, interdisciplinary research team rather than as independent "Work Packages" for separate research groups. Only such a holistic approach give an opportunity to find an answer for complex problems, like the RAW project hypothesis: whether the regime shift, from tidewater to land-based glaciers would cause the reduction in marine biological productivity in coastal polar seas. With such approach, this research project is truly interdisciplinary and wide-ranging, with sedimentology, physical oceanography, marine biogeochemistry, microbiology, and ecology, land hydrology and glaciology components providing a much-needed holistic approach to the entire system. Simultaneous marine measurements are planned in closely located catchments having similar bedrock but different stages of the glacial recession (tidewater, land-based and lack of glacier). The oceanographical, biogeochemical, ecological and hydrological processes will be assessed simultaneously. A comprehensive approach to the investigation of nutrient cycling, beginning from delivery from land to the marine environment, to the marine production and utilization will be performed. The analysis will also include a wide range of nutrient phases and cutting-edge analysis, targeting characterisation of biolabile dissolved/colloidal and labile particulate nutrients. Finally, because the goal of the project is aiming at studying the real, on-going process that is expected to affect the entire Arctic coastal ecosystems, the planned research is a kind of the natural experiment of the crucial problem that Earth system is now facing.

2.4. Project impact on society/communities and project result dissemination plan

Productivity of marine ecosystems is an important factor affecting biogeochemical cycles on the Earth. It has also a potential to influence composition of the atmosphere and thus to shape the climate. World ocean is a great source of O_2 and sink for atmospheric CO_2. It was reported that oceans absorb about 22% of the anthropogenic CO_2 emissions limiting in that way global warming and all its consequences (Le Quéré et al. 2018). The CO_2 uptake and O_2 production by the marine regions are to large degree propelled by the mechanism called "biological pump". Phytoplankton, in the course of photosynthesis, releases O_2 and consumes CO_2 dissolved in water transforming it into organic matter. The organic matter is partially recycled already in the water column. However, some portion is exported to bottom sediments, where it is buried and excluded from the contemporary cycling. This causes that surface seawater is often oversaturated with O_2 and undersaturated with CO_2 in the productive periods, which, in turn, drives the gas exchange through the air-sea interface. The polar regions, and especially the fjords, are known from high productivity and very efficient export of organic matter to sediments (Smith et al., 2015). Additionally, the biological pump is enhanced there by low water temperature, that allows more CO_2 to dissolve in.

The proposed project directly addresses the problem of changing productivity in the Arctic fjords due to the glaciers recession. As such it is of great importance for understanding the role of high latitude coastal regions for the global carbon cycling in the future warm, CO_2-rich world. As the pelagic productivity shapes the structure and condition of the entire ecosystems, the project results will also provide important knowledge to assess ecological consequences of the changing climate in the delicate Arctic ecosystems.

The knowledge gained in the project will be spread out to the society during science popularization events, like scientific festivals or picnics. Additionally, a dedicated project web page (with Polish, Norwegian and English language versions) will be updated regularly with recent scientific findings, while the popular social networking portals will be used to communicate actively the project results. It is a plan to organize three project workshop, involving all of the project participants, one at the start (kicked-off meeting) and two others over the project duration. During all of this three workshops will be also time for information events on the project progress, achievements the goals and results in forms such us seminars and conferences with entities interested parties and a press conferences or other press events. Science communities will be also informed about project results based on publications in peer review journals (minimum 10) and presentations (oral or poster) at national or international conferences (at least one per year per researcher).

3. Work programme

3.1. Work plan, research methodology

The work related to the realisation of this project has already begun in early 2019 when the framework of this project was defined. Two sets of field-work are planned – summer 2022 and spring-summer 2023. During summer 2022, we have a plan to investigate all of the chosen localizations (Fig. 3, 4). Laboratory analyses will start after first field season. Results of the first field-work and laboratory analyses will be discussed during second meeting (beginning of 2023). After that we will choose 3-5 places for more extensive studies and a plan for the next set of spring-summer fieldwork (2023) will be prepared. Research meetings, summarizing results of all actual work will be organized at the beginning of 2023 and 2024. These discussions will be also organised to prepare yearly project reports. Results will be presented at the national- and international-level conferences (three conferences for each researcher participating in the project) and prepared for peer-reviewed publications.

Project Partners (Institute of Geophysics Polish Academy of Sciences – IG PAS, Institute of Oceanology Polish Academy of Sciences – IO PAS, Institute of Environmental Sciences in Western Norway University of Applied Sciences – HVL) have appropriate research equipment to realize project hypothesis and goals. IG PAS will also provide specialist equipment, being a part of PolarPol. Moreover, it is important to notice that, Project Partners has special research infrastructures based on which this project will be also realized: Polish Polar Station in Hornsund (PPS) operated by IG PAS, and r/v OCEANIA belonging to IO PAS. In order to realize the RAW project hypothesis and goals, we will work on five research fields with a wide spectrum of research methods is presented on Figure 2 and Table 1.

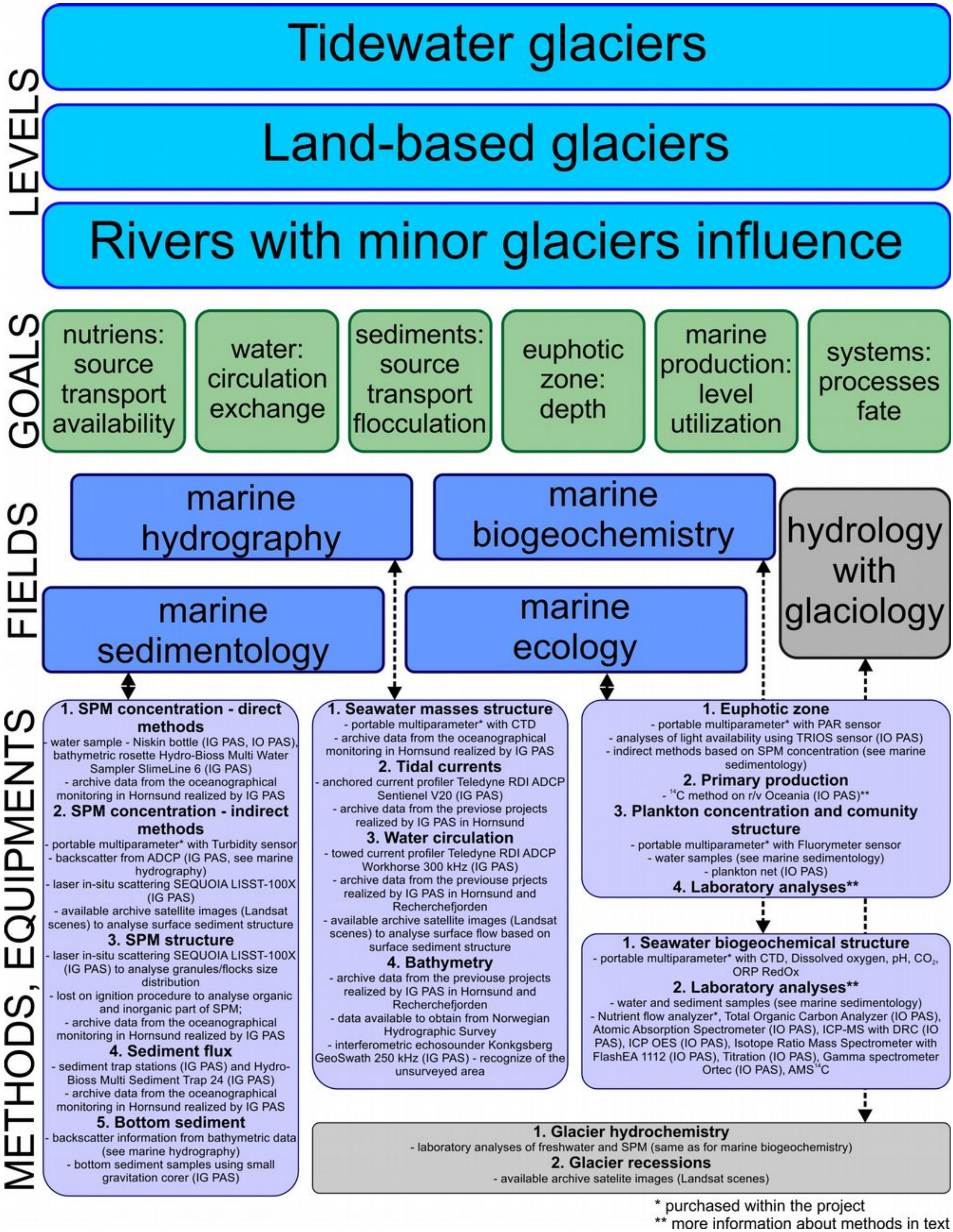

Figure 2. RAW project levels, goals, fields, methods and equipments

Table 1. Biogeochemical analysis planed in project based in IO PAS laboratories (* outsourced laboratories).

Type of sample	Item	Method
Water column	DOC, DIC, TN (DON will be calculated from the difference between TN and DIN)	Total Organic Carbon Analyzer TOC-L (Shimadzu)
	NO_3^-+NO_2^-, NH_4^+ , SiO_2, PO_4^{3-}	Nutrient flow analyzer, purchased within the project by IO PAS
	Ca, Mg, Na, K	Atomic Absorption Spectrometer, SHIMADZU 6800 (ICP-MS Perkin Elmer)
	Trace metal micronutrients (Fe, Mn, Ni, Zn, Co, Cu, Mo, Cd, Fe*)	ICP-MS with DRC or ICP OES* * Fe will be analysed in an outsourced laboratory
	POC, PIC	Isotope Ratio Mass Spectrometer combined with Flash EA 1112 Series (THERMO SCIENTIFIC)
	AT	Titration
Pore water	DOC, DIC, TN (DON will be calculated from the difference between TN and DIN)	Total Organic Carbon Analyzer TOC-L (Shimadzu)
	NO_3^-+NO_2^-, NH_4^+ , SiO_2, PO_4^{3-}	Nutrient flow analyzer, purchased within the project by IO PAS
	Trace metal micronutrients (Fe, Mn, Ni, Zn, Co, Cu, Mo, Cd, Fe*)	ICP-MS with DRC or ICP OES * Fe will be analysed in an outsourced laboratory
	Ca, Mg, Na, K	Atomic Absorption Spectrometer, SHIMADZU 6800
Sediment	^{210}Pb	Gamma spectrometer Ortec
	C,N, δ^{13}C, δ^{15}N	Isotope Ratio Mass Spectrometer combined with Flash EA 1112 Series (THERMO SCIENTIFIC)
	Sequential extraction of sediment-bound species	Ascorbate Fe extraction of suspended sediments (Hawkings et al. 2014), extraction of Fe species from benthic sediments (Henkel et al. 2016)
	Ca, Mg, Fe, Mn	Atomic Absorption Spectrophotometer AA-6800 Series (SHIMADZU)

3.2. Location of the study sites

The RAW project research will be conducted on the west coast and in the central part of Spitsbergen, the largest island of Svalbard Archipelago in the high Arctic, at the study locations representing direct contact between glacierised and river-influenced basins in the open ocean or fjords (Fig.3). At present, the important consequences of critical change in the glacier regime have only been explored in the context of Greenland fjords with glaciological and oceanographic conditions quite different from those in other parts of the Arctic. The broad fjord circulation pattern typical of Svalbard, and with glaciers grounded at the calving front might be different here and perhaps provide a better analogue for other parts of the Arctic and the Antarctic Peninsula. The research will be performed over the salinity gradient from low salinity waters with high glacial influence in coastal waters to more saline waters more indicative of open sea. The important thing is to measure the entire process of land and deep-sea nutrient export, and all physical-biogeochemical processes in the sea influence on marine productivity. In polar regions the mixing sea-land-glacier conditions are occurring commonly, but the idea of this project is to investigate the fundamental processes in a specific stage of glacier recessions without the need to include factors which modify

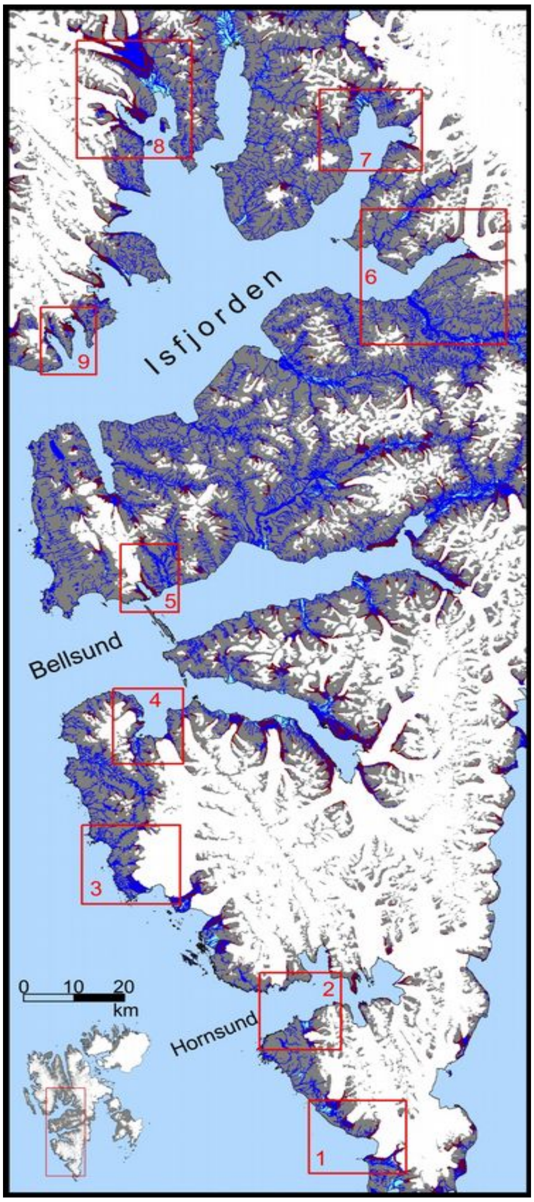

Figure 3. The research area with the planed field sites (red squares). For legend see Fig.4.

physical-biogeochemical parameters. Specific places will be chosen to eliminate, as much as possible, the influence of fjord geometry on the oceanographic processes, such as the circulation affected by the Coriolis force, the mixing of waters from various glaciers based on preliminary study (for first field season). Preliminarily selected localizations, to compare different glacier stages are (Fig.4):

1. Stormbukta with Olsokbreen a tidewater glacier, Olsokvatnet with a river (partly fed by land-based Beleopol'skijbreen) on the south of the bay, and Bungeleira fed by two land-based glaciers (Bungebreen and Vitkovskijbreen) on the north of the bay.
2. Hornsund Fjord with two bays fed by tidewater glaciers (Hansbreen and Korberbreen), Gåshamna fed by land-based Gåsbreen, and Sigfredbogen fed by Lisbetelva, river with none glaciers.
3. Isfjellbukta fed by a tidewater glacier VestreTorellbreen, and Storvika fed by Orvinelva, river with minor glaciers influence.
4. Recherchefjorden with three different glacial systems: Josephbukta fed by land-based Renardbreen, Vestervågen fed by Chamberlinelva, river system with minor glaciers influence, and Fagerbukta with isolate lagoon with Recherchebreen a tidewater glacier.
5. The outer part of northern Van Mijenfjorden with two systems: Fridtjovhamna with tidewater glacier, and small bay to east from it fed by Berzeliuselva, that is the river system without a glacier.
6.
7. Sassenfjorden and Tempelfjorden (east Isfjorden) with four systems: inner Tempelfjorden with Tunabreen a tidewater glacier, and two land-based glaciers (Von Postbreen and Bogebreen), Gipsvika with Gipsdalselva on the north, and Sassenelva on the south. Both of the river systems have minor glaciers influence.Inner part of Billefjorden (inner north part of Isfjorden) with three systems: Adolfbukta with Nordenskiöldbreen a tidewater glacier, and two rivers systems: Petuniabukta with Hørbyedalen and Ragnardallen rivers systems, and Mimerbukta with Mimerelva. All of the rivers systems are minor glacier influence.
8. Ekmanfjorden (central north part of Isfjorden) with Brevika and Sefströmbreen, a tidewater glacier and Mudderbukta with Holmströmøyra rivers systems flows mostly from Trebrevatnet, lake influenced by three land-based glaciers.
9. Two bays on the northern part of outer Isfjord: Ymerbukta with Esmarkbreen, a tidewater glacier, and Trygghamna with two glaciers – land-based Kjerulfbreen and Harrietbreen with a shallow lagoon.

Before the second year of field works (in 2022) the locations and field techniques will be verified, and if necessary modified, based on results from the previous year and all finished laboratory analyses.

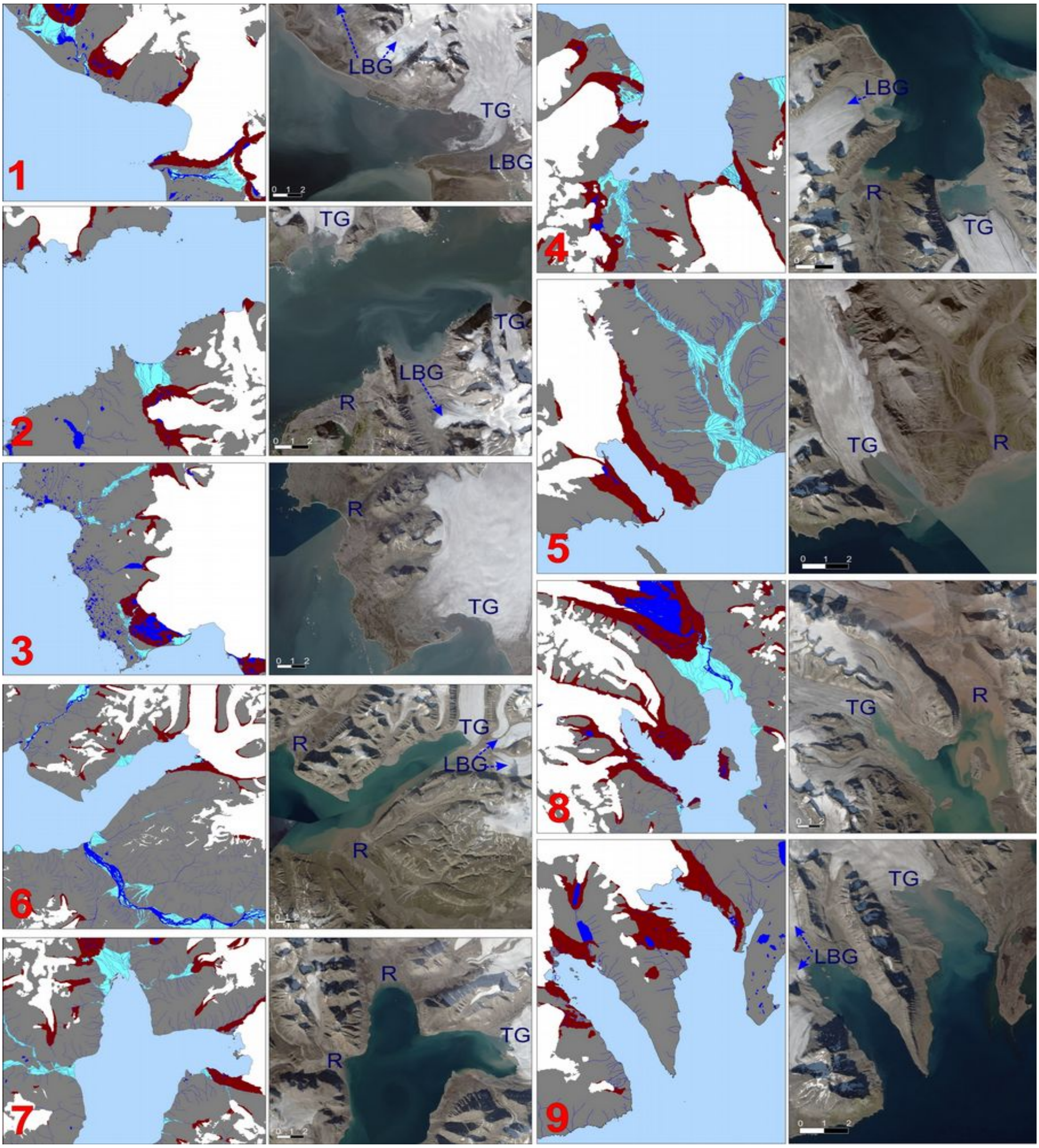

Figure 4. Preliminary chosen localizations for field study (for localization on Spitsbergen map see Fig.1). Colors on maps: light blue - fjord or sea; grey - land; white - glaciers; blue - lakes, and rivers; light blue - flood plain; brown – moraines. Symbols on satellite images (source: toposvalbard.npolar.no). Different type of catchments: TG - tidewater glacier, LBG - land-based glacier, R - river with negligible glacier influence.

4. Treatment of results Data acquired from all field surveys and laboratory analyses will be processed in dedicated software, GIS software and used for mathematical calculations, statistical analyses. They will be combined and the analyses will involve:

- **Water properties at the nutrient source; geochemistry of glacial meltwaters flowing directly into the sea.** This will be achieved by monitoring the physicochemical properties of freshwater and detailed chemical analyses at the freshwater inlet to the sea.
- **Suspended sediment matter concentration, suspended sediment flux, importance and intensity of flocculation processes, changes of biogeochemical properties of sediments during sedimentation processes.** Data for such analyses will be obtained from sediment traps and water column samples in combination with marine hydrography measurements and laboratory analyses.

- **Light availability in the water column as a factor affecting primary production.** Direct measurements of euphotic zone compared with concentration and flux data obtained from sediment traps, and water column samples in combination with marine hydrography and indirect marine sedimentology measurements.
- **Spatial variability of physiochemical properties of seawater.** The focus will be on the regions influenced by different scenarios of glacier recession, based on all marine hydrography, sedimentology and chemical analyses.
- **Influence of river transport from glaciers on the adsorption and release of nutrients.** Statistical comparison of physicochemical properties of freshwater and transported sediment samples based on samples from land-based glacier outflows and estuaries.
- **Influence of mixing of seawater, freshwater and melting glacier on the adsorption and release of nutrients.** Statistical comparison of chemical analysis, physiochemical properties of fresh and seawater in the estuaries and throughout the water column in each study area will be made. To analyse the direct influence of melting glacier on seawater properties, comparison analysis of seawater samples without and with glacier ice will be done.
- **Nutrient release from and burial in sediments and spatial differences due to hydrographic conditions.** Comparing chemical analyses of marine sediments and pore water with sediment samples from sediment traps and near-bottom water samples.
- **The role of tides on the sedimentation processes in the fjord and the adsorption and release of sediment-bound nutrient on the tidal flat.** Analysis of hydrographical, sedimentological and chemical results obtained in a field experiment during tidal cycles.
- **Nutrient balance in three scenarios of glacier recession.** Field data from each location will be compared and the optimal values for plankton growth will be assessed.
- **Plankton community structures in tidewater vs. land-based glacier outflow – the significance for marine biological production in coastal Svalbard waters.** The estimation of marine biological productivity potential based on plankton community structures (abundance) and direct primary productivity measurements in various regimes studied.
- **The fate of marine biological production in coastal Svalbard waters under various sources of nutrients discharge – seasonal and spatial perspective.** The spatio-temporal perspective for the utilization of marine biological production.
- **Living in turbid waters – the significance of glacier/river discharge for biological production and utilization.** The comparison between the environmental conditions and community structure and functional roles of plankton.

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