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Report on National ICP IM activities in Sweden in 2017

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Introduction

The Swedish integrated monitoring programme is run on four sites distributed from south central Sweden (SE14 Aneboda), over the middle part (SE15 Kindla), to a northerly site (SE16 Gammtratten). The long-term monitoring site SE04 Gårdsjön F1 is complementary on the inland of the West Coast and has been influenced by long-term high deposition loads. The sites are well-defined catchments with mainly coniferous forest stands dominated by bilberry spruce forests on glacial till deposited above the highest coastline. Hence, there has been no water sorting of the soil material. Both climate and deposition gradients coincide with the distribution of the sites from south to north (Table 1). The forest stands are mainly over 100 years old and at least three of them have several hundred years of natural continuity. Until the 1950's, the woodlands were lightly grazed in restricted areas. In early 2005, a heavy storm struck the IM site SE14 Aneboda. Compared with other forests in the region, however, this site managed rather well and roughly 20–30% of the trees in the area were storm-felled. In 1996, the total number of large woody debris in the form of logs was 317 in the surveyed plots, which decreased to 257 in 2001. In 2006, after the storm, the number of logs increased to 433, corresponding to 2711 logs in the whole catchment. In later years, 2007–2010, bark beetle (*Ips typographus)* infestation has almost totally erased the old spruce trees. In 2011 more than 80% of the trees with a breast height over 35 cm where dead (Löfgren et al. 2014) and currently almost all spruce trees with diameter of ≥20 cm are dead.

Table 1. Geographic location and long-term climate and hydrology at the Swedish IM sites (long-term average values, 1961–1990).

	SE04	SE14	SE15	SE16
Latitude; Longitude	N 58° 03´; E 12° 01´	N 57° 05´; E 14° 32´	N 59° 45´; E 14° 54´	N 63° 51´; E 18° 06´
Altitude, m	114–140	210–240	312–415	410–545
Area, ha	3.7	18.9	20.4	45
Mean annual temperature, ºC	+6.7	+5.8	+4.2	+1.2
Mean annual precipitation, mm	1000	750	900	750
Mean annual evapotransporation, mm	480	470	450	370
Mean annual runoff, mm	520	280	450	380

In the following, presentation of climate, hydrology, water chemistry and some ongoing work at the four Swedish IM sites relate mainly to the year 2017 (Löfgren 2018).

Climate and Hydrology in 2017

In 2017, the annual mean temperatures were higher (0.6–1.1 ºC) compared to the long-term mean (1961–1990) for all four sites. Largest deviation occurred at the northern SE16 Gammtratten site. Compared with the measured time series, 17 years at site SE16 Gammtratten and 21 years at the other sites, the temperatures in 2017 were somewhat higher at the two southern IM sites (0.5 and 0.7 ºC) while the two northern sites actually showed lower values with 0.3 and 0.4 ºC. The annual mean values were slightly lower compared to the period 2014–2016 when temperatures were the highest observed for the whole measurement period with exception for SE15 Kindla where the temperature was slightly higher in the years 1999 and 2000. The variations between years have been considerable, especially for the last five years, over 3°C at three of the sites. Smaller variations were found at the central site SE15 Kindla, only 1°C. Low temperatures were observed in the years 2010 and 2012 with 3.1–3.6 ºC below the 21 year mean at three sites while SE15 Kindla only deviated with 1.3 ºC below.

Compared to the long-term average values (1961–1990), the precipitation amounts in 2017 were close to average at SE14 Aneboda and SE15 Kindla (2 and 6% excess). For SE04 Gårdsjön 20% higher precipitation was observed. Only SE16 Gammtratten in the north followed previous year with lower precipitation than the long-term mean, reaching 83%. This was similar to 2016. For site SE04 Gårdsjön, the precipitation amount compared to average was comparably low in May and July while most other months had higher values.

The characteristic annual hydrological patterns of the catchments are for the southern sites high groundwater levels during winter and lower levels in summer and early autumn. In northern locations, water levels often are low in winter when precipitation is stored as snow, raising levels at snowmelt in spring and turning to lower levels in summer due to evapotranspiration. However, depending on rainfall amounts in summer, the groundwater levels could occasionally be elevated also in this period. Rainfall in autumn would yield the same result. In 2017 at SE14 Aneboda, slightly elevated groundwater levels occurred in spring and also in June due to high rainfall (129 mm). Autumn was quite wet, starting already in August with consecutive higher and higher levels until the end of the year. In the central parts of the catchment, the groundwater pressure got artesian. For SE16 Gammtratten in the north, snowmelt occurred in May and rather high rainfall in June resulted in high groundwater levels in June. After that, the groundwater level was lowered, but 160 mm precipitation in September-October elevated the levels again. Later, cold weather and snow made the groundwater levels to recede. At site SE15 Kindla, a more varying pattern was observed with several peaks 0.2 m below the soil surface during snowmelt in March – April, summer rains in June and also in autumn created groundwater level peaks. The lowest levels, 0.8 m below soil surface, were observed in early August whereafter rain successively elevated the groundwater levels until the end of the year. These patterns were fairly similar to those in 2015. The groundwater levels were reflected in the stream water discharge patterns (Fig. 1).

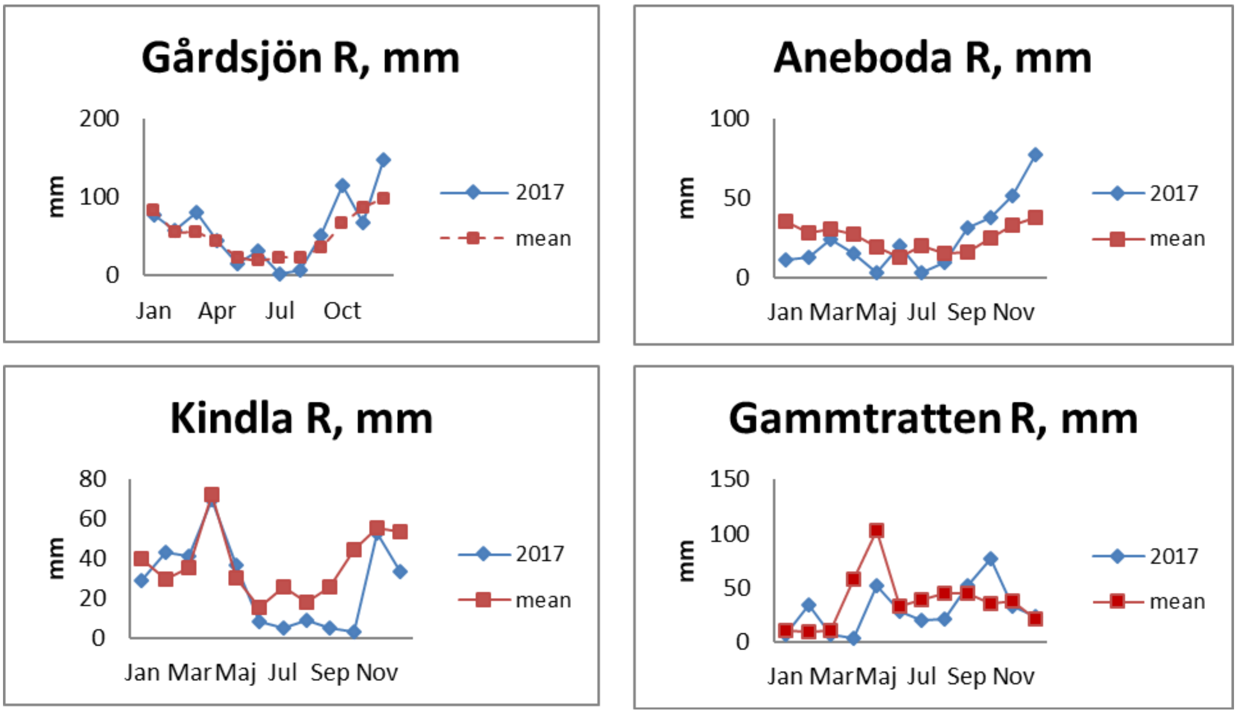

Figure 1. Discharge patterns at the Swedish IM sites in 2017 compared to monthly averages for the period 1996–2017 (mean). Note the different scales at the Y-axis.

In addition to precipitation, evapotranspiration affects the runoff pattern. The runoff pattern for SE16 Gammtratten, was fairly typical but with a snowmelt peak in May and a higher discharge in October. At SE04 Gårdsjön, the pattern was in accordance with the average except for at the end of the year when runoff was higher than normal in December. Runoff at SE15 Kindla followed the ordinary pattern during the first half of the year whereafter it subsided and was low until October. Thereafter runoff increased to higher values during the last two months of the year. Runoff at SE14 Aneboda showed slightly lower monthly values in the beginning of the year, turning high during the last four months (Fig. 1) in line with the groundwater levels.

At the two northern sites, generally, snow accumulates during winter, resulting in low groundwater levels and low stream water discharge. However, warm winter periods with temperatures above 0 °C have during a number of years contributed to snowmelt and excess runoff also during this season. Consequently, the spring discharges have been comparably low during snowmelt, deviating from the normal conditions, this could be seen at SE16 Gammtratten. In southern Sweden, SE04 Gårdsjön and SE14 Aneboda the situation deviated somewhat from the average pattern with higher runoff than normal in autumn (Fig. 1).

In 2017, the annual runoff made up 27–63% of the annual precipitation (Table 2), a wide range compared to the ordinary 40–60% found in previous years except for 2016 when the range was even larger (31–83%). The highest share was found at the southwest site SE04 Gårdsjön (63%), due to high runoff in the end of the year when evapotranspiration was low (Table 2). Runoff at this site, being almost 2/3 of precipitation would be quite normal. At SE14 Aneboda, storm felling, followed by bark beetle attacks, have reduced the forest canopy cover, inducing low interception. Actually, the measured throughfall reached 94% of the precipitation (89% in 2016). The total evapotranspiration was estimated to 477 mm (349 mm in 2016), a value considerably higher than in the previous years. At SE15 Kindla, the water balance was rather normal, however, with slightly high evapotranspiration and somewhat low runoff. At the northern site SE16 Gammtratten, throughfall and bulk precipitation were very similar (1% deviation), which is erroneous and indicates large uncertainties in any of these two measurements. Presumably, snow deposition in bulk precipitation infers the largest uncertainty.

Table 2. Compilation of the 2017 water balances for the four Swedish IM sites.
P – Precipitation, TF – Throughfall, I – Interception, R – Water runoff

	Gårdsjön SE04		Aneboda SE14		Kindla SE15		Gammtratten SE16	
	mm	% of P	mm	% of P	mm	% of P	mm	% of P
Bulk precipitation, P	1112	100	772	100	977	100	624	100
Throughfall, TF	909	82	729	94	595	61	630	101
Interception, P–TF	203	18	44	6	382	39	-6	-1
Runoff, R	696	63	295	27	415	42	363	58
P–R	416	37	447	73	562	58	261	42

Water chemistry in 2017
Low ion concentrations in bulk deposition (electrolytical conductivity 1–2 mS m^{-1}) characterise all four Swedish IM sites. The concentrations of ions in throughfall, including dry deposition, were higher at the three most southern sites. At the northern site SE16 Gammtratten, the conductivity in throughfall (0.7 mS m^{-1}) was almost the same as in bulk deposition indicating very low sea salt deposition and uptake of ions by the trees. At the two most southern sites, sea salt deposition provides tangibly higher ion concentrations, especially at the west coast SE04 Gårdsjön site (4.9 mS m^{-1} in throughfall).

The groundwater pathways are fairly short and shallow in the catchments, providing rapid soil solution flow paths from infiltration to surface water runoff. However, the conductivity in soil water was higher compared to throughfall showing influences from evapotranspiration and soil chemical processes. The deposition acidity has during the last 10 years been rather similar at all sites with somewhat higher pH values (0–0.5 units) in throughfall compared with bulk deposition. However, in 2017, SE04 Gårdsjön had a throughfall pH on 5.2 while the two sites SE14 Aneboda and SE15 Kindla had values on c. 5.4 (Table 3). For SE16 Gammtratten, the pH value was 5.2 both in bulk deposition and in throughfall.

Table 3. Mean deposition chemistry values 2017 at the four Swedish IM sites. S and N in kg ha^{-1} yr^{-1}.

	SE04	SE14	SE15	SE16
pH, bulk deposition	5.1	5.1	5.4	5.2
pH, throughfall	5.2	5.5	5.4	5.2
S, bulk deposition	3.3	1.3	1.4	0.8
N, bulk deposition	8.6	4.0	4.9	1.7

During the water passage through the catchment soils, organic acids were added and leached to the stream runoff. In the upslope recharge areas, pH in the upper soil layers (E-horizon) was mainly lower than in throughfall. However, in the peat in discharge areas at SE15 Kindla and SE16 Gammtratten, pH was higher compared to throughfall while it was slightly lower compared to throughfall at SE14 Aneboda but considerably lower at SE04 Gårdsjön with a pH of 4.3. In the recharge areas, the buffering capacity in soil water and groundwater varied between negative and positive values, but were most frequently on the negative side, especially for SE04 Gårdsjön with constantly negative values. In the discharge areas, the buffering capacity in groundwater was fairly high with ANC exceeding 0.22 mEq L^{-1} at SE14 Aneboda and SE15 Kindla and with bicarbonate (HCO_3^-) occasionally present at Aneboda, Kindla and Gammtratten at average concentrations of 0.02, 0.14 and 0.05 mEq L^{-1}, respectively. At SE04 Gårdsjön ANC was negative (-0.01 mEq L^{-1}). The stream waters were acidic with pH values below 4.7 at all sites except Gammtratten having a pH of 5.6. The stream water buffer capacity was positive at all sites (ANC $\geq$ 0.004 mEq L^{-1}), except for SE04 Gårdsjön (ANC -0.022 mEq L^{-1}). Anions of weak organic acids and bicarbonate contributed to the positive ANC (0.1 mEq L^{-1}) at SE16 Gammtratten.

The share of major anions in bulk deposition was similar for sulphate, chloride and nitrate at three of the sites, while chloride dominated at SE04 Gårdsjön due to the proximity of the sea. Sea salt showed clear influences on throughfall at SE04 Gårdsjön and also at SE14 Aneboda indicating effects of dry deposition. In throughfall, organic anions contributed significantly at all four sites. The chemical composition changed during the catchment soils passage and the sulphate concentrations were higher in stream water compared with deposition, indicating desorption or mineralization of previously accumulated sulphur in the soils. For Aneboda, nitrification contributed to fairly high nitrate values in the recharge area soil water (0.02–0.23 mEq L^{-1}), values being lower compared to previous year. Considerably lower concentrations occurred in the discharge areas, probably due to nitrogen uptake and denitrification.

For site SE16 Gammtratten in the north, sulphate concentrations in soil water and stream water were considerably higher compared to throughfall, indicating release from the soil pool. Organic anions dominated anion flow in the stream with 2/3 of the content to be compared to 25% in SE14 Aneboda and SE15 Kindla reaching only 10% in SE04 Gårdsjön.

Besides effects on ANC and pH, the stream water chemistry is to a considerable extent influenced by organic matter. At SE14 Aneboda, the DOC concentration was high with 28 mg L^{-1} while the other sites SE04 Gårdsjön, SE15 Kindla and SE16 Gammtratten showed lower values 14, 10, and 10 mg L^{-1}, respectively. High DOC concentrations create prerequisites for metal complexation and transport as well as high organic nitrogen fluxes. The organic nitrogen concentrations in stream water ranged from 0.18 to 0.66 mg N L^{-1}. The shares of Norg/Ntot were 87–90%, showing Norg dominating Ntot, and with SE14 Aneboda having the lowest share while SE16 Gammtratten and SE15 Kindla were on the highest range. Inorganic nitrogen (NO_3–N and NH_4–N) was low at the two sites SE15 Kindla and SE16 Gammtratten with 15 and 7 μg L^{-1}, respectively. Somewhat higher concentration in SE04 Gårdsjön with 43 μg L^{-1} reflecting still somewhat high deposition. Higher concentration in stream water was noticed for SE14 Aneboda with 100 μg L^{-1}, possibly due to the forest damage. However, compared to 2016 value 191 μg L^{-1}, the inorganic N concentrations decreased considerably.

Total phosphorus (Ptot) in bulk deposition varied between 5 and 14 μg L^{-1} with the highest values at SE04 Gårdsjön and lowest in the northernmost site. In stream water, SE14 Aneboda also showed the highest Ptot (22 μg L^{-1}) as well as DOC concentrations. The other sites had average Ptot concentrations between 3 and 6 μg L^{-1} with the lowest value at SE15 Kindla.

Inorganic aluminum (Al_i), toxic to fish and other gill-breathing organisms, has been analyzed in soil solution, groundwater and surface waters at the IM sites. Relatively high total Al concentrations occurred in the soil solution (0.7–3.6 mg L^{-1}) as well as in stream water (0.25–0.50 mg L^{-1}) at the southern sites SE14 Aneboda and SE15 Kindla with low pH (c. 4.8). At the northern site SE16 Gammtratten with a pH of 5.6, the total Al concentrations were low, approximately 0.23 mg L^{-1} and higher in SE14 Aneboda and SE15 Kindla with 0.5 mg L^{-1}. Inorganic Al made up 13–44% of the total Al with the highest value in SE15 Kindla and lowest in SE16 Gammtratten, corresponding to 0.03–0.22 mg Al_i L^{-1} with high Al_i at low pH, and the 0.03 mg Al_i L^{-1} at the northern site SE16 Gammtratten with higher pH. According to the SEPA classification system, the Al_i concentrations at SE04 Gårdsjön, SE14 Aneboda and SE15 Kindla are considered extremely high and high at SE16 Gammtratten. The priority heavy metals Pb, Cd and Hg were still accumulating in the catchment soils, while the stream concentrations were low compared with the levels causing biological effects. However, methyl mercury, only measured at Aneboda and financed by SITES, was still relatively high creating prerequisites for bioaccumulation. In stream water Hg-tot concentration was 8.3 ng L^{-1} with Hg-methyl on 2.5 ng L^{-1}.

In summary, the four Swedish IM sites show low ion contents and permanently acidic conditions. In stream water, only the northern site SE16 Gammtratten had buffering capacity related to bicarbonate alkalinity. Organic matter has an impact on the water quality with respect to colour, metal complexation, and phosphorus concentrations at all sites, but less at SE15 Kindla, where rapid soil water flow paths provide low DOC and acidic waters. For SE14 Aneboda, the forest dieback provides a relatively high share of water runoff as well as high nitrate concentrations compared with the other three sites. In SE04 Gårdsjön, deposition is strongly influenced by the sea.

Major disturbances test forest resilience

The impact of disturbances on boreal forest plant communities is not fully understood, particularly when different disturbances are combined, and enduring changes in the dominant species are possible after disturbance. Our study site is a long term monitored semi-natural forest in Sweden (SE14 Aneboda) which was subject to intense combined storm and bark beetle damage, beginning with storm Gudrun in 2005. This provided a valuable opportunity to investigate the post-disturbance development of the vegetation community (Weldon and Grandin, 2019). Previous studies suggested that a shift from a Norway spruce to a beech dominated forest was possible here, and field workers had remarked on a drastic increase in beech saplings.

We analysed pre- and post-disturbance vegetation data to investigate to what extent vascular plant species abundances, diversity, traits, and community composition have changed. We were particularly interested in differences between the remaining apparently unaffected areas (which could potentially act as refuges) and disturbed areas, and in signs of consistent change over time in community composition in response to disturbance that could indicate an impending regime shift (to a beech dominated state for example).

We found that the vegetation community present in the refuge areas has remained substantially intact throughout the period of disturbance. However, non-refuge areas diverged over time from the refuges in community composition and showed increased taxonomic and functional diversity. Despite this, an increase in deciduous tree species (particularly beech), spruce has shown strong post-disturbance regeneration across the site. The refuges are likely to be important as a seed source in the apparent ongoing recovery of the disturbed areas to a spruce-dominated state similar to that found pre-disturbance. This fast recovery is evidence of a system resilient to a potential shift to a deciduous-dominated state.

Our results show that even powerful combined disturbances in a system with alternative stable states can be insufficient to initiate a regime shift. The resilience of the spruce-dominated forest community is increased by the survival of refuge areas functioning as a form of ecological memory of the previous ecosystem state. Finally, it is important to note that studies such as this are only possible with the valuable data generated by long-term monitoring programs.

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