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Canopy Rainfall Interception and Fog Capture by *Pinus pumila* Regal at Mt. Tateyama in the Northern Japan Alps, Japan

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Abstract

The importance of fog precipitation in the alpine hydrological processes of *Pinus pumila* canopy was evaluated on Mt. Tateyama, central Japan. We observed rain and fog precipitation, throughfall, and wind direction and velocity at Jodo-daira (36.566°N, 137.606°E, 2840 m a.s.l.) for 3 years. During the snow-free period (August and September), mean monthly rain and fog precipitation was 0.45 mm h^{-1} and 0.14 mm h^{-1}, respectively. The mean rainfall interception by *P. pumila* canopy was about 48%, which is higher than that of other forest canopies at lower altitudes. During rainfall, the dense canopy intercepts rain and the water evaporates from the needle surfaces. On the other hand, the canopy captured fog precipitation even in the absence of rainfall. The amount of throughfall increased with increasing fog deposition. Using $\delta^{18}O$ and δD analysis, the mean contribution of fog water to the throughfall was estimated at approximately 35%, consistent with the result from direct measurement. These results indicate that *P. pumila* should have a significant influence on the local hydrological processes of the high mountain ecosystem. The large contribution of fog precipitation can be attributed to the high wind velocity and humidity of the Japan Alps.

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Introduction

One of the distinctive features of the Japanese alpine zone (above timberline) is the domination of *Pinus pumila* Regal, a dwarf coniferous shrub (Yanagimachi and Ohmori, 1991). The presence of *P. pumila* greatly impacts the alpine plant community (Okitsu and Ito, 1983; Wada, 2007). This shrubby pine has creeping branches and does not show monopodial growth (Richardson and Rundel, 1998). *P. pumila* forms a dense canopy, and the canopy height is about 0.2–3 m. The amount of leaf biomass in the closed canopy of *P. pumila* is about 15–25 t ha^{-1} (Kajimoto, 1994), and the leaf area index (LAI) exceeds 5 m^2 m^{-2} regardless of the stand height. These values roughly correspond to those of the evergreen coniferous forest in the subalpine zone, and are much larger than those of *Pinus densiflora* stands (4–7 t ha^{-1}) and *Pinus thunbergii* stands (6–12 t ha^{-1}) in the lowlands (Gower et al., 1994). These characteristics suggest that *P. pumila* has high rates of transpiration and photosynthesis in summer. On the other hand, it is known that in the alpine region where *P. pumila* is growing, the soil is frozen in winter and undeveloped, and the development of deep root system is inhibited. Therefore, it is important to reveal how, and from where, a large amount of water is supplied to the tree for it to maintain the large amount of evergreen needles.

In the mountain areas, precipitation can occur in solid or liquid form. In addition to rain, fog has a significant contribution to the local liquid precipitation (Yoshino, 1975; Holder, 2004; Chang et al., 2006). The greatest amount of fog deposition can usually be expected in alpine forests at high altitudes (Wehren et al., 2010). In the Japanese mountain forest areas, sometimes the contribution of fog to the total volume of precipitation exceeds that of rain (Kobayashi et al., 2001; Igawa et al., 2002). Therefore, it is very important to evaluate the fog deposition on *P. pumila* canopy to identify the availability of water resources for tree growth. The canopy of *P. pumila* commonly has a patchy distribution on the ridges and peaks of the high mountains, with canopies adjacent to patches of bare ground or a shorter herbaceous community. Fog precipitation occurs as a result of drifting fog and clouds; and the volume of precipitation is determined by the drift velocity, density of droplets, and attributes of the vegetation that affect the trapping of water from the air (Lovett, 1984). The capture efficiency of fog droplets on *P. pumila* canopies should be higher than that of other vegetation surfaces because the *P. pumila* canopy surface area per ground area is several times greater than that of other vegetation types. Therefore, hydrological inputs can be expected to differ between areas with and without *P. pumila*.

To our knowledge, no research has been published on the water dynamics of *P. pumila* stands in Japanese mountain areas. In addition to the logistical difficulties of conducting fieldwork on the steep alpine terrain, most *P. pumila* stands are under legal protection in the special preserved areas of national parks, which makes it problematic to install large-scale measurement equipment. To overcome these difficulties, we made special instruments for measuring throughfall during the snow-free period. We also applied analysis of stable water isotopes. Stable isotopes, such as $\delta^{18}O$ and δD, are widely used in hydrology as environmental tracers, because they move with the water itself (Taniguchi et al., 2000). These tracers are very useful to identify the origin of water in the water cycles, and can be used even in the alpine regions (Zhang et al., 2010).

The objectives of this study were (1) to evaluate the basic hydrological inputs in the *P. pumila* canopy on the top of alpine areas in Japan; (2) to estimate the contribution of fog precipitation in the water supply of *P. pumila*; and (3) to evaluate the effects of

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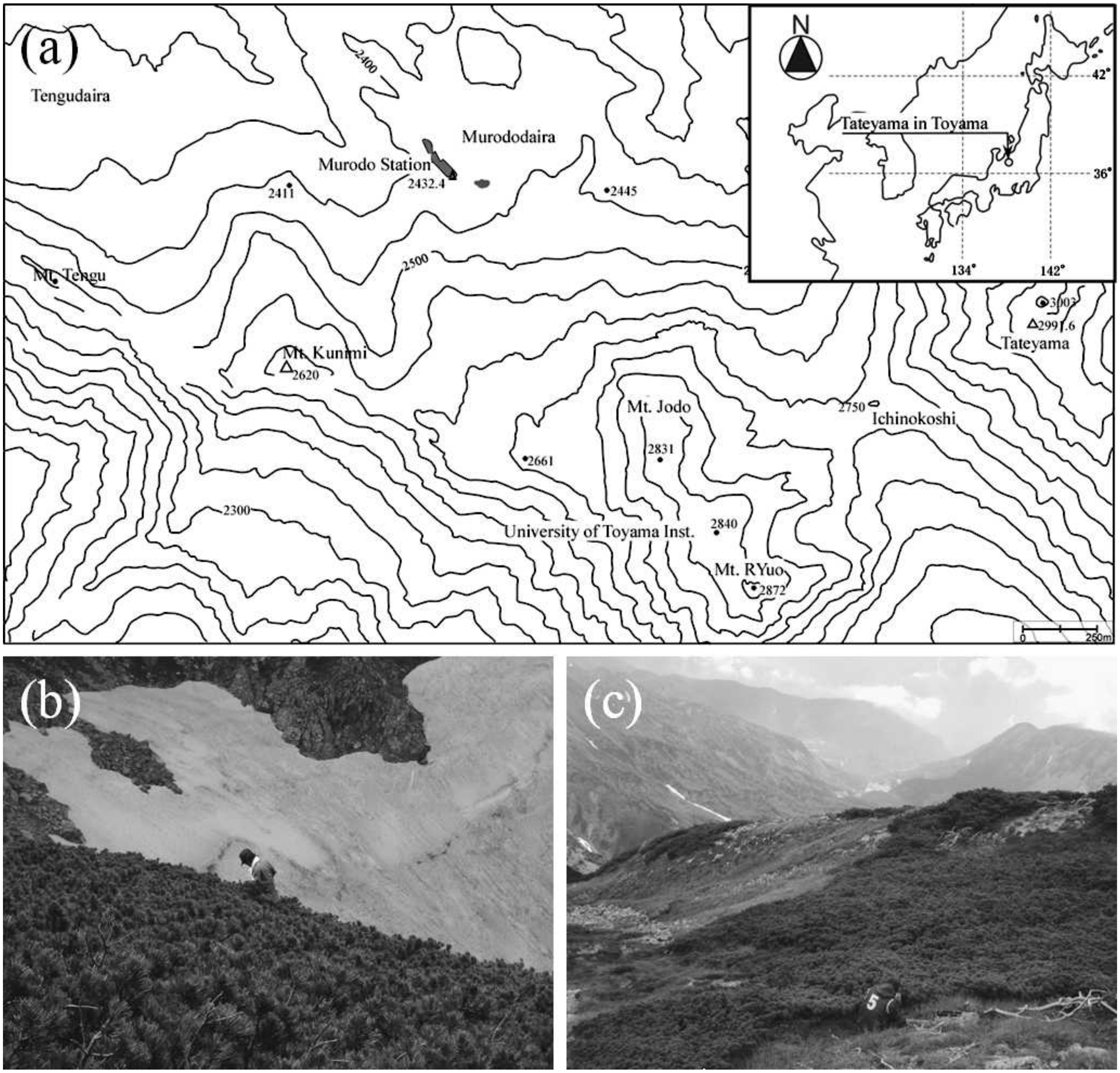

FIGURE 1. (a) The location of the study sites, Mt. Tateyama and Chubusangaku National Park in Japan. (b) North slope site, and (c) southwest slope site.

the *P. pumila* canopy on the local alpine hydrological process during the snow-free period.

Material and Method

STUDY SITES

Jodo-daira (36.566°N, 137.606°E, 2840 m a.s.l.) is one of the peaks in the Hida Mountains in the Northern Japan Alps, Tateyama, and is in the Chubu-Sangaku National Park. The Toyama University research facility with a monitoring tower is located at the top of Jodo-daira for environmental monitoring (Fig. 1, part a). During 2006–2008, the annual mean air temperature at Jodo-daira was −2.6 °C, and the monthly mean of the daily maximum and minimum air temperatures in August was 13.0 °C and 8.8 °C, respectively. Jodo-daira consists mainly of three slopes, and the *P. pumila* canopy was distributed continuously on two of three slopes (north: Fig. 1, part b, and southwest: Fig. 1, part c). The height of the canopy was about 0.6 m.

METEOROLOGICAL OBSERVATION

Air temperature, relative humidity (Pt1000 and capacitance type, CVS-50, Climatec Inc., Tokyo, Japan), wind direction and velocity (Windmill anemometer, 05103, R.M. Young., Traverse City, Michigan, U.S.A.) were measured at the top of the university monitoring tower on Jodo-daira. Two capacitive grid sensors (Capacitive grid sensor, S-LWA-M003, Onset Computer Co., Bourne, Massachusetts, U.S.A.) were also installed at the top of the monitoring tower to observe fog and dew period: one sensor was installed facing upward (the upper surface was mounted at an angle of 45° from horizontal), another sensor was installed facing

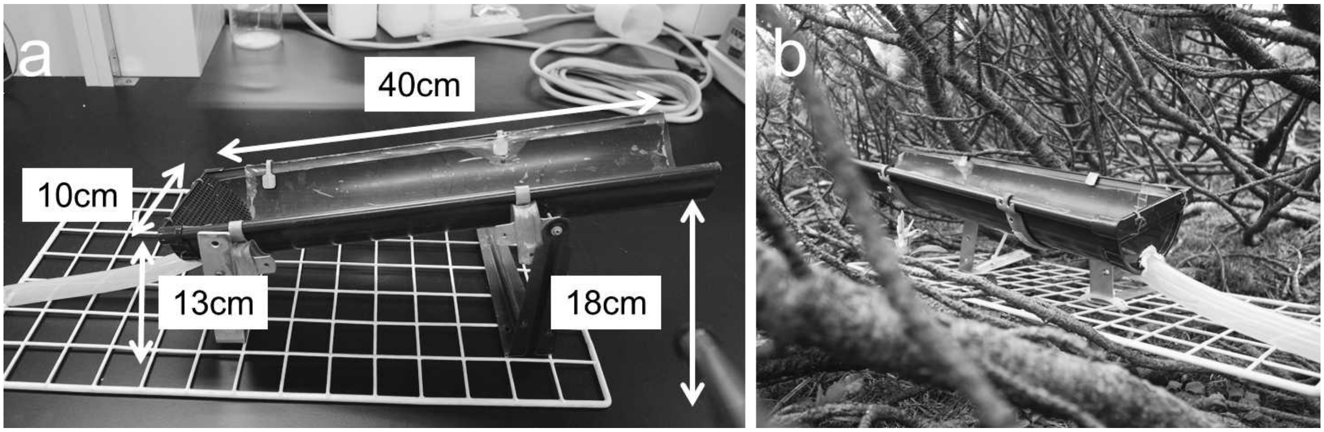

FIGURE 2. (a) The gutter type bulk precipitation collector. (b) The placement of the collector in the pine canopy.

downward (the under surface was mounted at an angle of 315° from horizontal). To measure rainfall, a 0.2 mm tipping bucket rain gauge (Rain Collector II, Davis Instruments Co., Hayward, California, U.S.A.) was placed on the monitoring tower. Data on the amounts of precipitation falling in the city of Toyama (36.708°N, 137.202°E, 8.6 m a.s.l.) and Tateyama (on Tengu-daira) (36.582°N, 137.578°E, 2291 m a.s.l.) were obtained from the Japan Meteorological Agency.

RAIN AND FOG WATER COLLECTION

Rainwater was collected at the top of the university monitoring tower, and fog water was collected at the base of the tower on Jodo-daira during the snow-free period (late July to early October). Rainwater was collected using a bulk collector, with a 15-cm-diameter polyethylene funnel draining to a 10 L polyethylene bottle. Fog water was collected using a passive thin string fog sampler (Model FWP-500, Usui Kogyo Kenkyusho Inc, Tokyo, Japan) with a polyethylene tank volume of 10 L. The sampler was set up at 1.5 m height and a large hood was mounted on the sampler to keep out rain. The use of this sampler, which does not require electricity, is advantageous at high elevations and has been used on Mt. Fuji as well as on Mt. Tateyama (Dokiya et al., 2001; Watanabe et al., 2006, 2010). Fog collection efficiency depends on the frequency of foggy weather, and the amount of fog deposition on the forest canopies is affected by wind speed and fog particle size (Lovett, 1984; Kobayashi et al., 2001). A monofilament-type passive fog water sampler has been suggested as a good proxy surface of coniferous vegetation to evaluate the water supply from fog (Mueller and Imhoff, 1989; Scholl et al., 2007; Fischer and Still, 2007). Thus, we calculated the amount of fog water deposition per surface area based on the amount of fog water collected by the passive sampler and regarded this as total fog water per unit area. The amount of fog water deposition was calculated as the amount of water in the reservoir bottle divided by the projected surface area of the total Teflon wire (0.2 mm [wire radius] × 350 mm [wire length] × 513 [number of wires]).

THROUGHFALL COLLECTION

To measure the throughfall of the *P. pumila* canopy with a maximum height lower than 0.8 m, we made moveable gutter-type bulk precipitation collectors (Fig. 2). Each of these collectors was 10 × 40 cm. The surface of the collectors was specially coated with fluoropolymer film (ASF-110, Chukoh chemical industries, LTD., Tokyo, Japan) to facilitate the movement of the water into a reservoir. Each reservoir was made of thick polyethylene film and was completely covered with aluminum foil and a black plastic sheet to prevent water evaporation and alteration of chemical composition. Six rain collectors were placed on the vegetation floor as low as possible (about 30 cm above the ground) on Jodo-daira from late July to early October. The water samples were collected every other week. A proportion of the collected water was brought back to the laboratory for stable isotope analysis.

CALCULATION OF APPARENT CANOPY INTERCEPTION

Canopy interception is the process whereby rainfall is intercepted by the canopy (leaves, branches) of a tree. Some of the rain contacted with the vegetation surface is stored temporarily, and either evaporates into the atmosphere or falls down to the ground as drops.

The apparent canopy interception (ACI) rate was calculated as follows:

$$\mathrm{ACI} = (\mathrm{Pg} - \mathrm{T})/\mathrm{Pg} \times 100, \quad (1)$$

where Pg is the amount obtained by the bulk rain collector at the monitoring tower and T is throughfall estimated by each throughfall collector. This equation includes the effects of fog water impaction. Stem flow was not considered in this study because no stem was erected (Fig. 2, part b), and we had verified that the amount of stem flow was negligible in a preliminary experiment.

ISOTOPE ANALYSIS

Hydrogen and oxygen isotope ratios of all the samples were measured using a mass spectrometer (Micromass, model PRISM). Samples were prepared using H_2O-H_2 equilibration with a hydrophobic platinum catalyst for δD (Coleman et al., 1982) and H_2O-CO_2 equilibration for $\delta^{18}O$ (Epstein and Mayeda, 1953). Stable isotope results were expressed with respect to Vienna standard mean ocean water in δ units (‰):

$$\delta^{18}\mathrm{O} = \{[(^{18}\mathrm{O}/^{16}\mathrm{O})\mathrm{sample} - (^{18}\mathrm{O}/^{16}\mathrm{O})\mathrm{standard}] / (^{18}\mathrm{O}/^{16}\mathrm{O})\mathrm{standard}\} \times 10^3 \left(‰\right) \quad (2)$$

$$\delta\mathrm{D} = \{[(\mathrm{D}/\mathrm{H})\mathrm{sample} - (\mathrm{D}/\mathrm{H})\mathrm{standard}]/(\mathrm{D}/\mathrm{H})\mathrm{standard}\} \times 10^3 \left(‰\right), \quad (3)$$

TABLE 1

Altitude and precipitation at Jodo-daira, Tengu-daira, and Toyama.

Year	Site	Elevation (m)	Precipitation (mm month^{-1})		
			July	August	September
2006	Jodo-daira	2840	—	100.4	412.4
	Tengu-daira	2300	1469.0	36.0	361.0
	Toyama	13	569.5	113.0	126.0
2007	Jodo-daira	2840	492.9	326.8	420.1
	Tengudaira	2300	421.0	507.0	420.0
	Toyama	13	117.0	122.5	126.0
2008	Jodo-daira	2840	469.4	465.4	232.5
	Tengu-daira	2300	330.5	539.0	280.0
	Toyama	13	240.5	262.5	185.0

where oxygen and hydrogen isotope ratios are expressed by $\delta^{18}O$ and δD, respectively. The $(^{18}O/^{16}O)$ sample or D/H sample is the isotopic ratio in the sample water, and the $(^{18}O/^{16}O)$ standard or D/H standard is the isotopic ratio in standard mean ocean water. The precision was ±0.1‰ for $\delta^{18}O$ and ±1.5‰ for δD.

Result

RAINFALL

The amount of rainfall varied considerably according to altitude and year (Table 1). During 2006–2008, the mean monthly (August and September) rainfall at Jodo-daira, Tengu-daira, and Toyama were 0.45 mm h^{-1}, 0.50 mm h^{-1}, and 0.22 mm h^{-1}, respectively. The amount of rainfall at the two mountain sites was twice the amount of that at the lowland site. The rainfall at Tengu-daira in August 2006 was 0.05 mm h^{-1}, which was the lowest in the three years.

FOG AND DEW DEPOSITION

The relative humidity at Jodo-daira in August 2006 and August 2008 are shown in Figure 3 (parts a and b). Despite the differences in rainfall between August 2006 and August 2008 (Table 1), the patterns of daily change in relative humidity were similar between the years, with the relative humidity almost reaching 100% in the late afternoon. The drenched period is also long at Jodo-daira (Fig. 3, part c). The data suggest that the surface was drenched, on average, for about one-third of the day, and that during 60% of the days in August, the surface was drenched in the evening (19:00 to 22:00).

The relationships between wind velocity and direction during periods of rain and high humidity periods (defined as no rain and relative humidity more than 90%) and the remaining periods (no rain and relative humidity less than 90%) in August 2008 are shown in Figure 4. These data show the averages of every 10 min. The mean wind velocity in August 2008 was 4.4 m s^{-1}, and the maximum wind velocity was 16.8 m s^{-1}. The mean wind velocity during rain periods and high humidity periods was 4.0 m s^{-1} and 4.7 m s^{-1}, and the maximum wind velocity was 16.0 m s^{-1} and 16.8 m s^{-1}, respectively. During observation periods in August 2008, the wind was blowing mainly from the southwest, 20% of the time during rain period and 22% of the time during high humidity periods. The southwest of this site is a part of the wall of Tateyama caldera, which forms a steep, long slope. These wind directions suggest that upslope fog formed by moist air masses come up from the lower part of caldera.

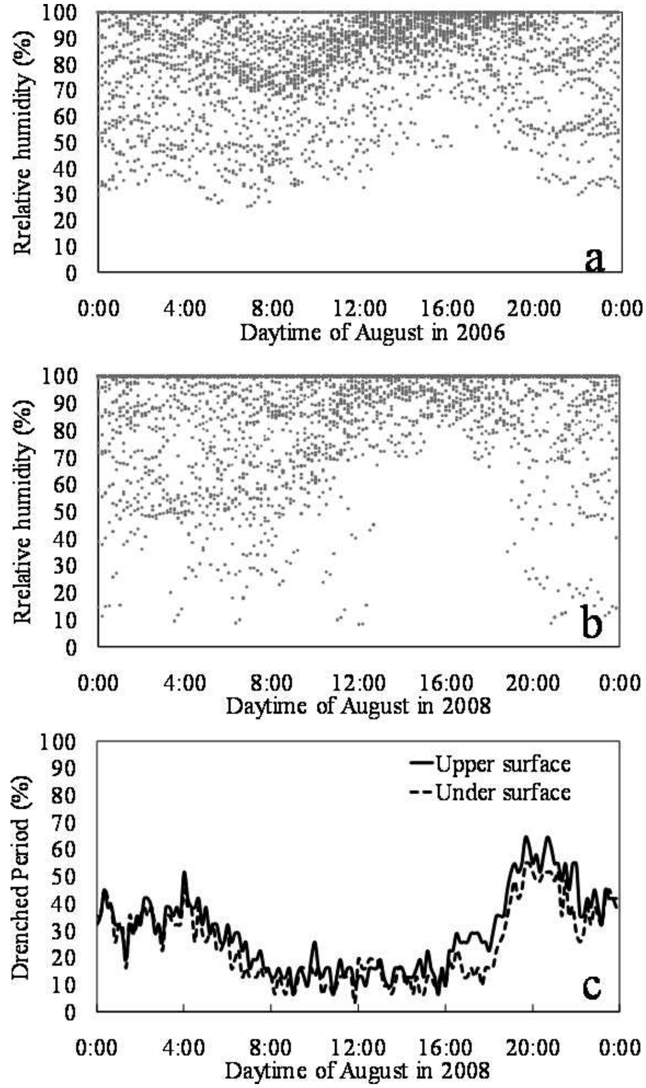

FIGURE 3. Relative humidity in (a) August 2006 and (b) August 2008. c) Drenched period (%) of the upper surfaces and under surfaces of leaves as measured by wetness sensors at Jodo-daira in August 2008. The drenched period was defined as the proportion that the wetness value was over 90% each time during a month.

During August and September in 2007–2008, the mean monthly fog deposition collected by the passive thin string sampler was 0.14 mm h^{-1} (range, 0.09–0.20 mm h^{-1}), which is about 30% of rain deposition (mean, 0.45 mm h^{-1}; range, 0.32–0.61 mm h^{-1}).

THROUGHFALL AND GROSS PRECIPITATION

The amount of gross precipitation and throughfall at Jodo-daira in 2007, 2008, and 2009 is shown in Table 2. We assumed that the amount collected by the bulk rain collector at the monitoring tower was gross precipitation. When the rain collector was blown by strong winds, and the data were lost, we considered the mean value of the bulk rain collectors set up on the two slopes as the gross precipitation. When the values of the bulk rain collectors were compared with that of the tipping bucket rain gauge, the former obtained about 20% more precipitation than the latter. There was considerable rain in 2007, and the reservoirs sometimes overflowed with water, which means that our precipitation values at Jodo-daira are likely to be underestimates.

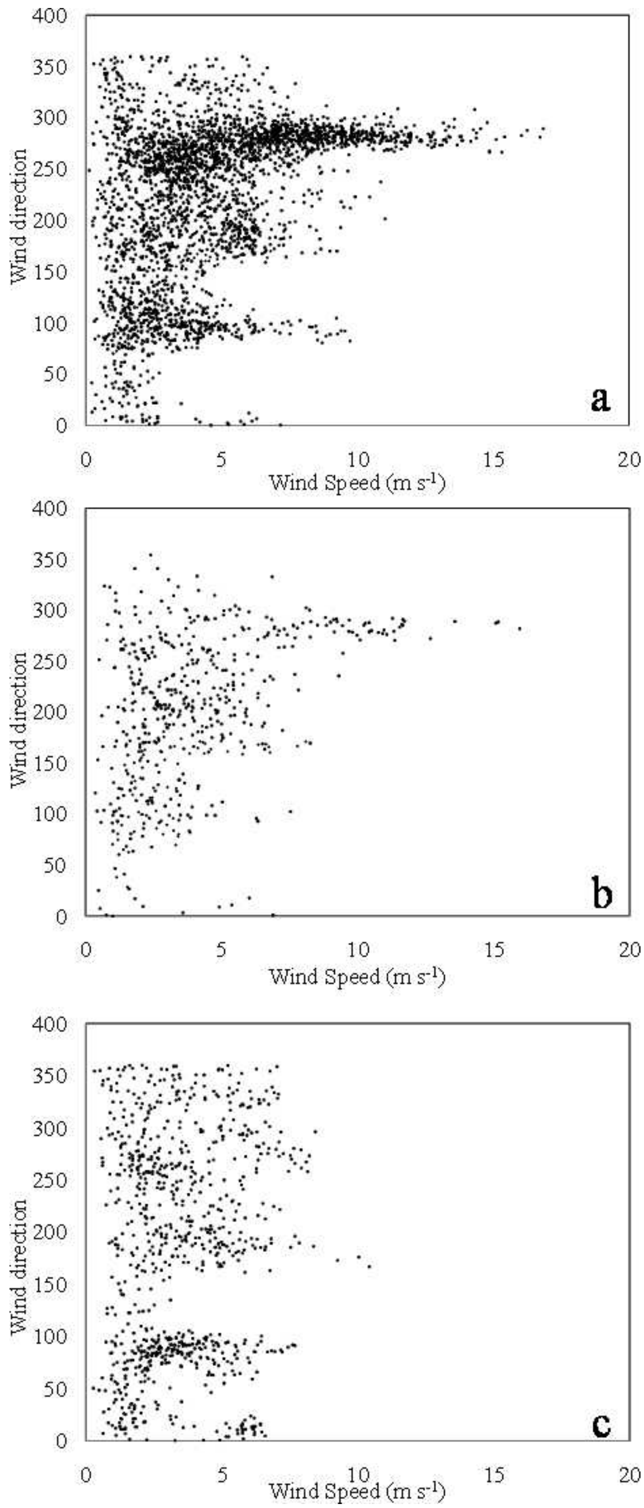

FIGURE 4. The relationship between wind direction and wind speed in August 2008 for (a) fog period (no rain and humidity more than 90%), (b) rain period, and (c) the period of no rain and relative humidity lower than 90%. One point represents the average of 10 min.

Figure 5 shows the relationship between gross precipitation and throughfall. The amount of throughfall increased with increasing gross precipitation. The mean ACI of the *P. pumila* canopy changed considerably year by year: 80.0% (range, −57.6 to 96.7%; SD = 34.7%) in 2006, 37.4% (range, −315.2 to 93.0%; SD = 78.3%) in 2007, and 65.7% (range, −101.1 to 98.0%; SD = 52.6%) in 2008.

ISOTOPIC COMPOSITION OF FOG WATER, RAINFALL AND THROUGHFALL

Figure 6 shows the relationship between $\delta^{18}O$ and δD for fog water, gross precipitation, and throughfall water. The gross precipitation was −13.5‰ for $\delta^{18}O$ and −93.5‰ for δD, the fog water was −11.7‰ for $\delta^{18}O$ and −83‰ for δD, and the throughfall was −12.6‰ for $\delta^{18}O$ and −88‰ for δD. Stable isotope ratios of rain and fog were different, and the ratios of throughfall were intermediate.

Discussion

RAINFALL AT JODO-DAIRA

The effect of altitude on rainfall is one of the most important subjects for hydrological research. Wehren et al. (2010) suggested that the effect of topography on approaching air masses is crucially important in determining precipitation volumes but that there is no simple causal relationship between altitude and precipitation volume. In this sense, the Japan Alps are quite unique compared with the continental Alps (e.g. Wehren et al., 2010). In the Japan Alps, air above the warm sea rises when it meets the adjacent steep mountains and strong monsoons bring high concentrations of water vapor. This situation causes strong orographic-induced precipitation in the mountains. As shown in Figure 7, a strong linear relationship between rainfall and altitude was detected, regardless of year. The amount of rainfall increased with increasing altitude without a plateau. Therefore, it is suggested that the air humidity was almost saturated, even at the top of the mountains, during precipitation events. This abundant supply of humid air mass explains the high frequency of fog generation at the top of the Japan Alps.

CANOPY INTERCEPTION

Throughfall can be divided into two main parts. One part is the rain that reaches the forest floor directly, without touching the forest canopy. The other part is the rain that has some contact with the canopy. Because these were difficult to precisely divide, they were both treated as throughfall. However, as the leaf area density of *P. pumila* canopy is quite large (4–6 $m^2\ m^{-3}$) (Kajimoto, 1989), a large proportion of the rainfall should have contact with the needles. We found that the mean proportion of rain intercepted by *P. pumila* canopy was 47.7% over the 3 years and this value was higher than that of other forest canopies at lower altitudes (e.g. the values for evergreen confers, *Cryptomeria japonica* and *Chamaecyparis obtusa*, are about 16–35% [Tanaka et al., 2005]; evergreen broad-leaved tree, *Lithocarpus edulis*, is 6–37% [Sato et al., 2002]; deciduous broad-leaved tree, *Fagus crenata*, is 32% [Inoue et al., 1993; mountain coniferous forest is 32% [*Abies veitchii*, 1705 m a.s.l.]; and mountain deciduous broad-leaved forest is 19% [*Betula platyphylla*, 1610 m a.s.l.] [Muramoto et al., 2007]). The high interception ratio of the *P. pumila* canopy may be attributed to the high leaf area density. During a rainfall event, the dense canopy intercepts precipitation and the stored water evaporates from the needle surfaces continuously (Rutter, 1967).

FOG DEPOSITION ON THE PINE CANOPY

On average, the canopy interception at Jodo-daira was reasonably high. However, the amount of throughfall was sometimes larger than the gross precipitation (22 out of 113 samples in the three years). Similar patterns have been reported in

TABLE 2

Summary of precipitation, throughfall, and fog deposition in summer (August and September) at *Pinus pumilia* stands at Jodo-daira.

Year	2006	2007	2008
Gross precipitation (mm month^{-1})	256.4	373.5	349.0
Throughfall (mm month^{-1})	51.2	233.9	119.6
Fog deposition (mm month^{-1})	—	115.3	80.1
Canopy interception (%)	80.0	37.4	65.7
Canopy interception range (%)	−57.6 to 96.7	−315.2 to 93	−101.1 to 98

other high-elevation regions (Prada et al., 2009; Kobayashi et al., 1998) and in areas where fog is often observed (Ewing et al., 2009). Igawa et al. (2002) found that the frequency of fog events, and the amount of throughfall, increased with increasing altitude on Mt. Oyama in Japan. Kobayashi et al. (1999) reported that fog events were more likely when relative humidity was over 80%. The chance of a fog event exceeded 70% when the relative humidity was 86% or more. We observed fog events nearly every day during our fieldwork on Jodo-daira. As shown in Figure 3, the relative humidity at Jodo-daira was reasonably high and frequently saturated, even in the absence of rain. The LAI of the *P. pumila* canopy is quite large and we found that the leaf surfaces were drenched for long periods when there was no rainfall. This suggests that the needle leaves of *P. pumila* worked as efficient fog water collectors. We also found a significant positive relationship between the amounts of fog deposition and throughfall (Fig. 8). Sometimes the amount of throughfall exceeded that of gross precipitation, for instance, when there was little rainfall. During these periods, it is suggested that the *P. pumila* canopy collected throughfall water by fog capture.

Fog precipitation may occur when fog passes through the forest canopy and intercepted fog droplets coalesce on needle surfaces and drip to the forest floor. Went (1995) described how tiny leaf surfaces, such as pine or redwood needles, are very effective for fog water capture.

The δ^{18}O and δD of fog and rain were consistently different as shown in Table 3 and Figure 6. The composition of fog was isotopically enriched compared with rain. Similar results were also reported in other previous studies (e.g. Dawson, 1998; Liu et al., 2007; Scholl et al., 2007). In this study, for isotopic differences between monthly weighted average ratio of rain and fog, the maximum was 4.5‰ for δ^{18}O and 45‰ for δD, and the minimum was 0.9‰ and δ^{18}O and 1.7‰ for δD. Scholl et al. (2010) found that differences between fog and rain isotopes are largest when rain is from synoptic-scale storms, and fog or orographic cloud water is generated locally. Smaller isotopic differences have been observed between rain and fog on mountains with orographic clouds, but only a few studies have been conducted (Scholl et al., 2010). The δ^{18}O and δD of throughfall water was higher than those of rainfall but lower than those of fog deposition (Fig. 6). Therefore, it is inferred that the throughfall was a mixture of rain and fog. To estimate the mixing ratio, we applied a simple isotope mixing model. In this model, one end member is fog and the other end member is gross precipitation:

$$\delta^{18}O_{Tf} = \delta^{18}O_{Pg} \times (1 - a) + \delta^{18}O_F \times a, \quad (4)$$

where $\delta^{18}OT_f$ is the oxygen isotopic composition of the throughfall water, $\delta^{18}O_{Pg}$ is the oxygen isotopic composition of the gross precipitation, $\delta^{18}O_F$ is the oxygen isotopic composition of the fog water collected by the passive string fog collector, and a was the contribution ratio of fog to throughfall. Based on this model, the mean contribution to the throughfall of fog was about 35% (14–98%). The weighted average ratio of oxygen and hydrogen isotopes in the three years was −13.5‰ for rain, −12.6‰ for throughfall, and −11.7‰ for fog (Table 3). However, there were some events when the contribution ratio of the isotopes was less than zero or more than one. Throughfall ^{18}O enrichment could be observed because of the high canopy interception of *P. pumila* at Jodo-daira. DeWalle and Swistock (1994) reported that average throughfall ^{18}O enrichment of a pine forest in central Pennsylvania,

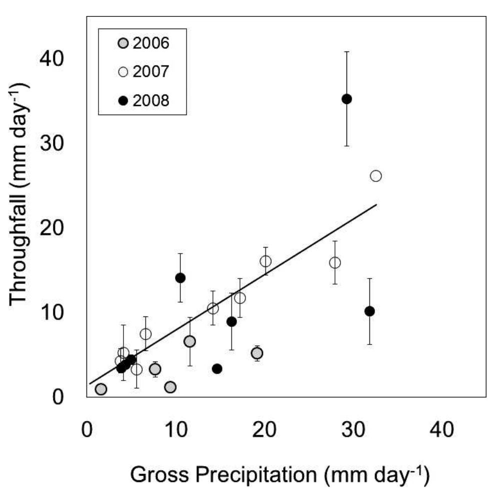

FIGURE 5. The relationship between gross precipitation and throughfall in summer (August and September) at Jodo-daira. Points are the mean values, and error bars show the standard error of four rain collectors in 2006 and six rain collectors in 2007 and 2008 (R^2 = 0.58; y = 0.66x + 0.25).

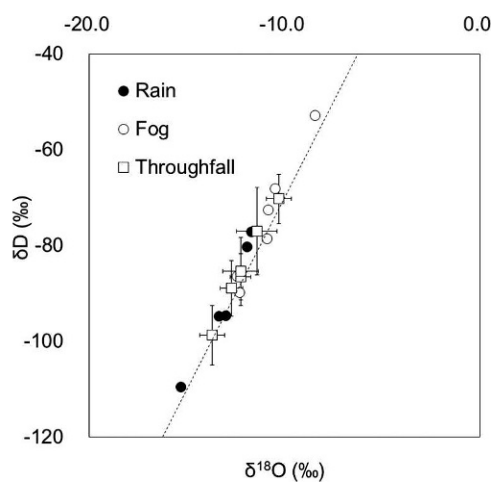

FIGURE 6. The relationships between δD and δ^{18}O of rainfall(●), throughfall(□), and fog(○) deposition for summer (July–September) at Jodo-daira in 2007 and 2008. Each point shows the precipitation-weighted average value of a month. Error bars show the standard deviation of six throughfall collectors in each month. The dotted line shows the global meteoric water line ($\delta D = 8 \times \delta^{18}O$ + 10; Craig, 1961).

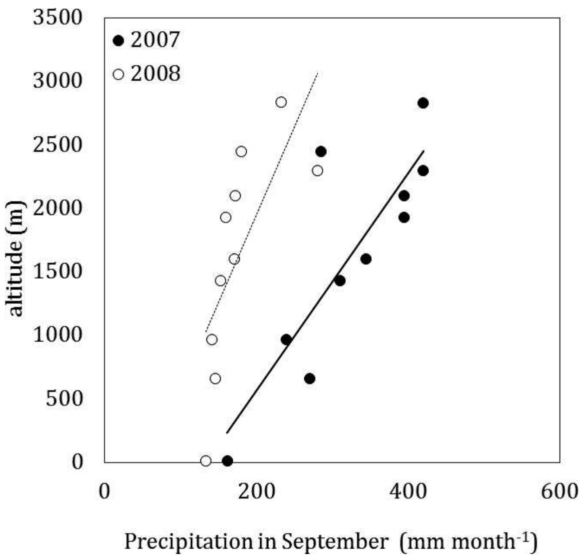

FIGURE 7. The relationship between rainfall and altitude in 2007 and 2008. ● and the dotted line represent September 2007 (R^2 = 0.52, y = 13.86x − 821.8). ○ and the solid line represent September 2008 (R^2 = 0.71, y = 8.57x − 1146.8). Except for Jodo-daira, the rainfall data are from Honoki and Watanabe (2008) and Honoki et al. (2009).

U.S.A., was 0.32‰. The high humidity at Jodo-daira may explain why the value of throughfall ^{18}O enrichment in our study was smaller than this reported value. Overall, this result supports our hypothesis that fog water greatly contributes to throughfall water. It also suggests that the amount of throughfall was not simply determined by the input of precipitation and fog but was also affected by the evaporation process from the canopy.

Conclusion

Our results showed that fog deposition on the *P. pumila* canopy had a large contribution to the amount of throughfall during the snow-free period on Mt. Tateyama, central Japan. The dense *P. pumila* canopy intercepted a large proportion of the gross precipitation, and the interception of gross precipitation increased with the amount of gross precipitation. The mean rainfall interception rate was 47.7% across the three years, and this was higher than that of other tree species canopies at lower altitudes. We found that the canopy efficiently captured fog, and supplied it as throughfall water, even in the absence of rainfall. The presence of the *P. pumila* canopy may therefore stabilize the water supply to the soil surface. The high efficiency of fog capture can be attributed largely to the canopy surface area and the microtopography of the ground surface, while the large contribution of fog deposition to the amount

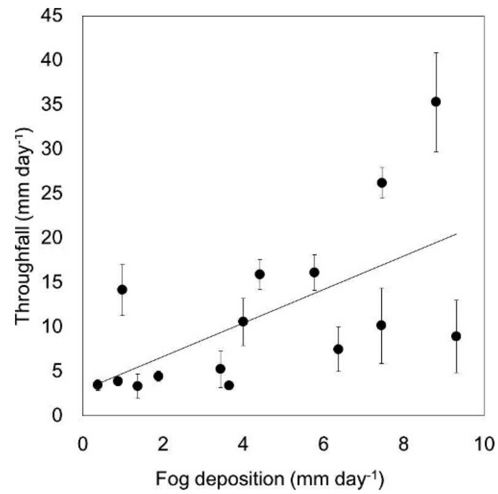

FIGURE 8. The relationship between throughfall and fog deposition in 2007 and 2008. Error bars show the standard error of six throughfall collectors (R^2 = 0.37, y = 1.89x + 2.91).

of throughfall can be explained by the high humidity in the Japan Alps due to their particular geography. Overall, the presence of the *P. pumila* canopy can be predicted to have a significant influence on the local hydrological processes of the high mountain ecosystem.

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TABLE 3

Volume-weight average (VWA) and $\delta^{18}O$ and δD for gross precipitation, throughfall, and fog deposition at Jodo-daira in summer (August and September).

	$\delta^{18}O$ (‰)		δD (‰)	
Year	2007	2008	2007	2008
Gross precipitation VWA	−14.1	−12.8	−97	−89
Gross precipitation range	−16.1 to −0.8	−15.5 to −8.7	−118 to −63	−117 to −49
Throughfall VWA	−12.5	−12.7	−88	−89
Throughfall range	−15.2 to −8.8	−15.8 to −7.9	−110 to −49	−116 to −46
Fog deposition VWA	−11.8	−11.6	−86	−79
Fog deposition range	−15.5 to −7.5	−12.5 to −7.6	−117 to −50	−87 to −46

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