



*How weather conditions affect  
matsutake yields?*

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## *Outline of this talk:*

### 1. The mechanism of fruit-body formation of matsukake in nature:

- Which is the environmental trigger that induce fruiting of matsutake in Japan?
- World-wide pattern of matsutake fruiting in relation to climate.

### 2. How weather condition affects matsutake yields?

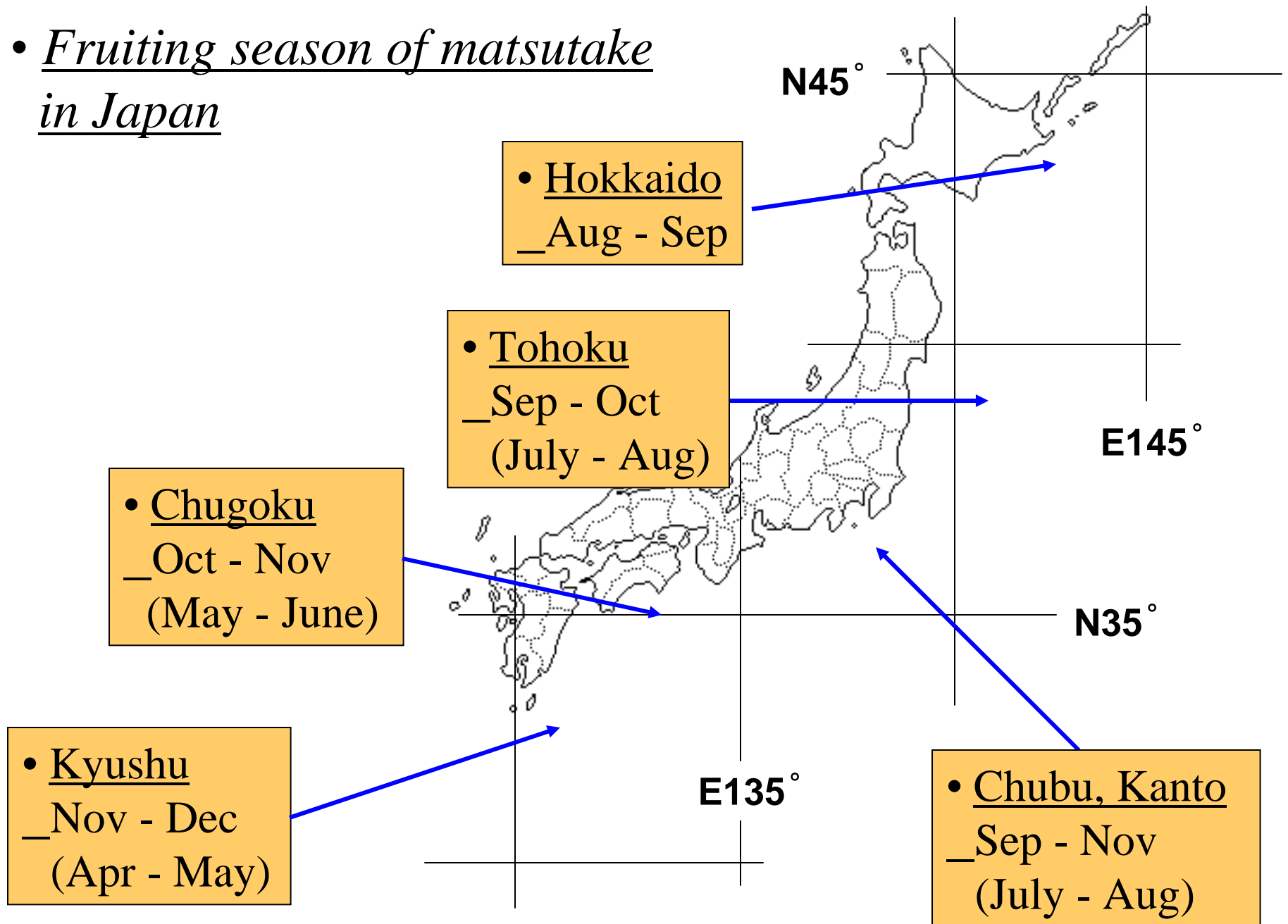
1. The mechanism of fruit-body formation of matsukake in nature:

- Which is the environmental trigger that induce fruiting of matsutake in Japan?

- Matsutake fruits mainly in autumn (October- November) in lowland *Pinus densiflora* forests.
- However, matsutake fruits earlier season (August-September) in northern or highland conifer forests.
- In addition, fruiting is occasionally observed in the late spring or early summer seasons.
- Japanese climate is generally humid with constant precipitations, i.e. lacking in a distinctly dry season.

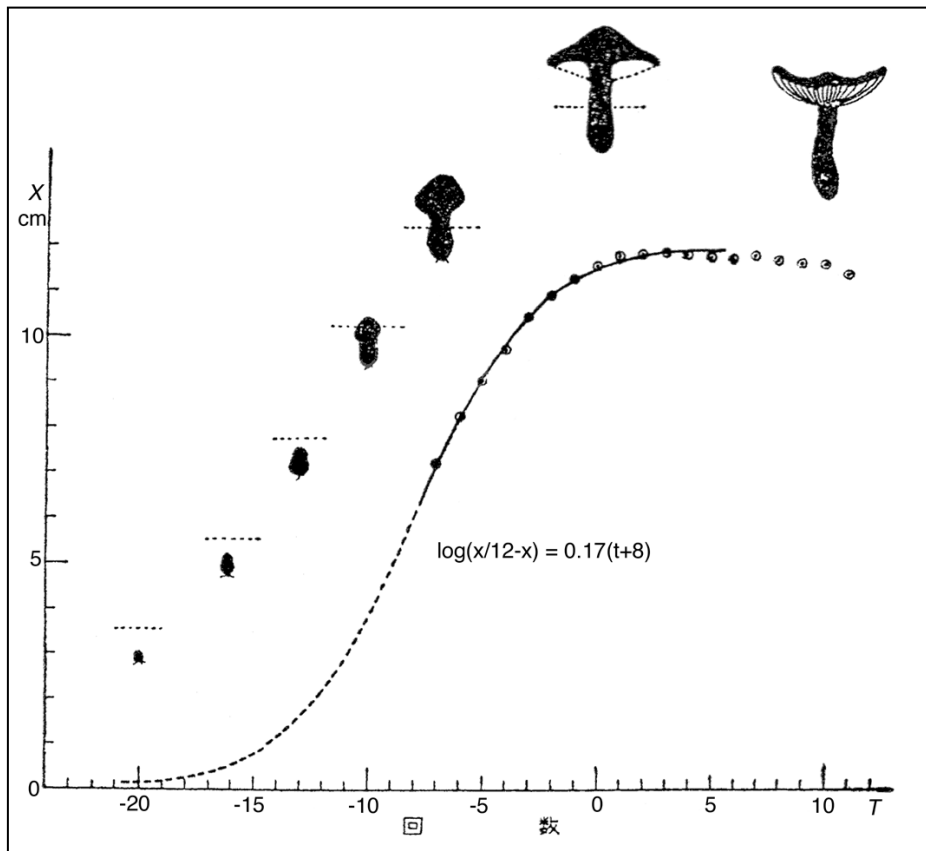
- Therefore, induction of matsutake's fruiting is primarily determined by temperature.

• Fruiting season of matsutake  
in Japan



- Induction of matsutake's fruiting is primarily determined by temperature:

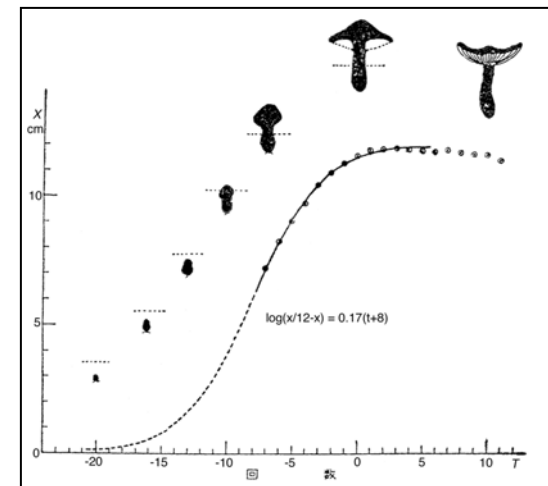
- *Growth curve of a fruit-body of matsutake (Hamada, 1953)*



- Y-axis: height of the fruit body
- X-axis: days before/after maturation of the fruit-body
- black line: actual measured data
- dotted line: estimated by the formula
- A primordium formation starts about 20 days before maturation of the fruit-body.

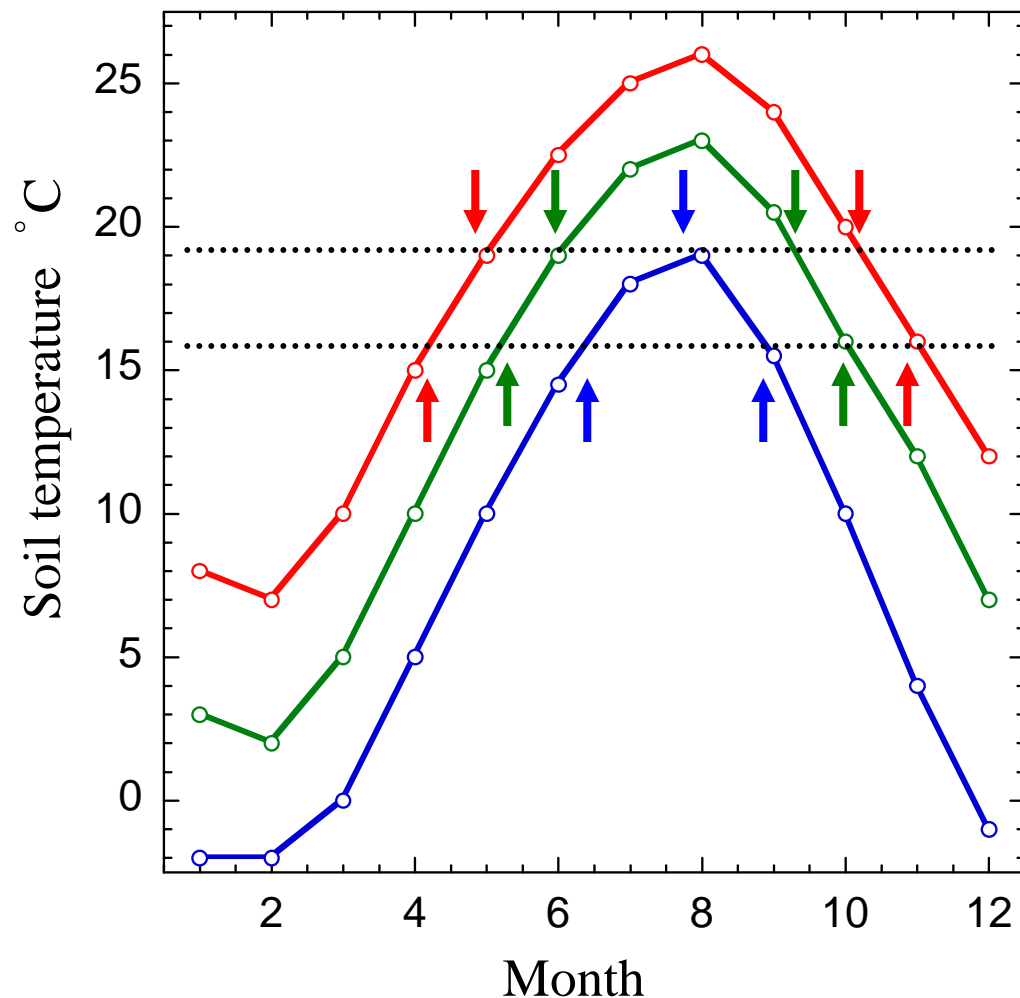
- Induction of matsutake's fruiting is primarily determined by temperature:
- *The triggered temperature for the primordia formation of matsutake is ca. 19 °C in soil (Kinugawa, 1964)*

- Based on the growth curve, primordia formation may start when the soil temperature reached at 19 °C in autumn season in Kyoto.
- This estimation can be verified by field researches in various local areas in Japan.
- The triggered temperature ranges in the lower area than 19 °C, e.g. at 16 °C especially in the northern or highland forests in Japan.



• Induction of matsutake's fruiting is primarily determined by temperature:

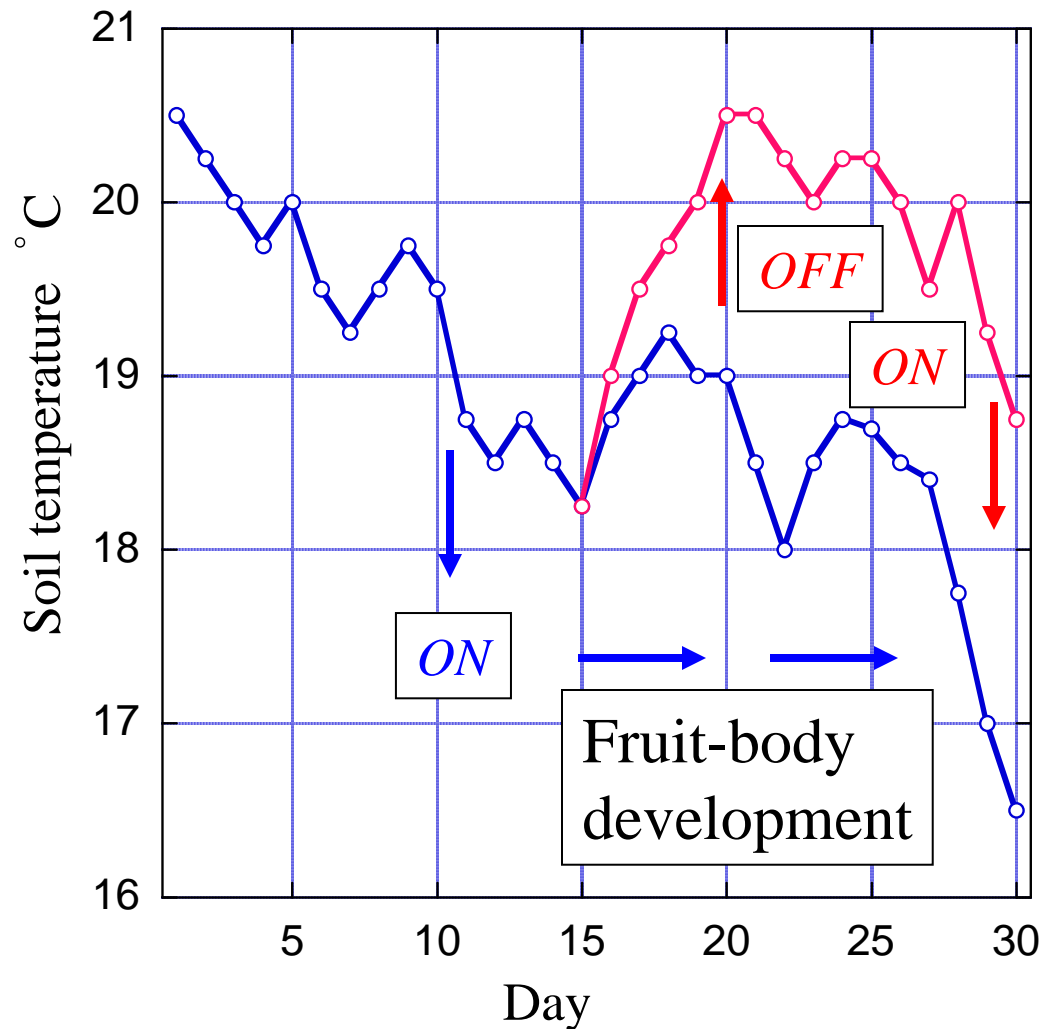
• *The temperature-dependency of matsutake's fruiting explains when fruit-bodies occur under different climates*



- Red: western (warmer) region
- Green: central region
- Blue: northern or highland region
- Arrows: switch ON of sexual reproduction
- This idea can explain both phenomena: why fruiting season differ in in the local area, and why two fruiting seasons are present in some local area.

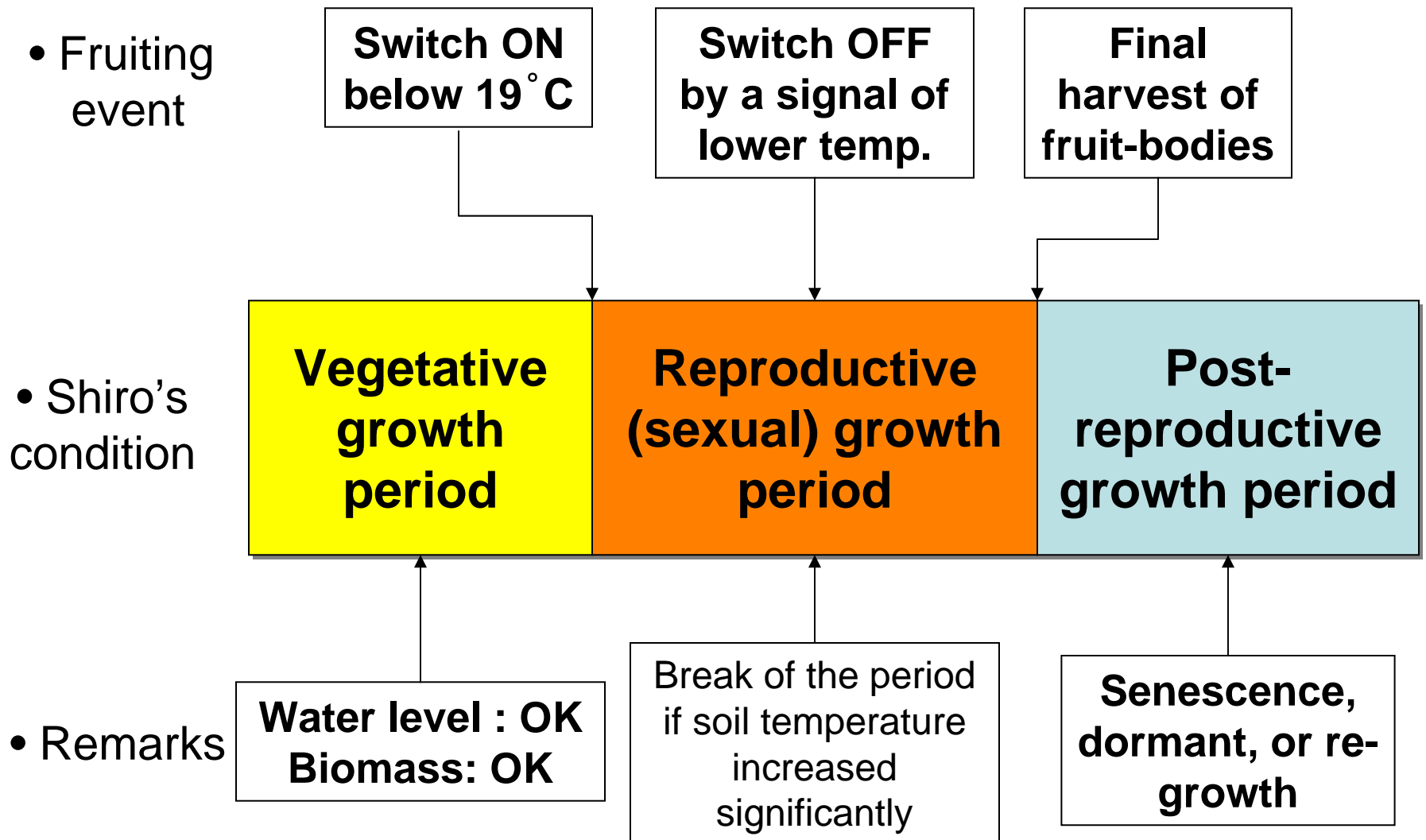
• Induction of matsutake's fruiting is primarily determined by temperature:

• *Fluctuation of soil temperature determines both switch "ON" or "OFF" of fruiting induction of matsutake*

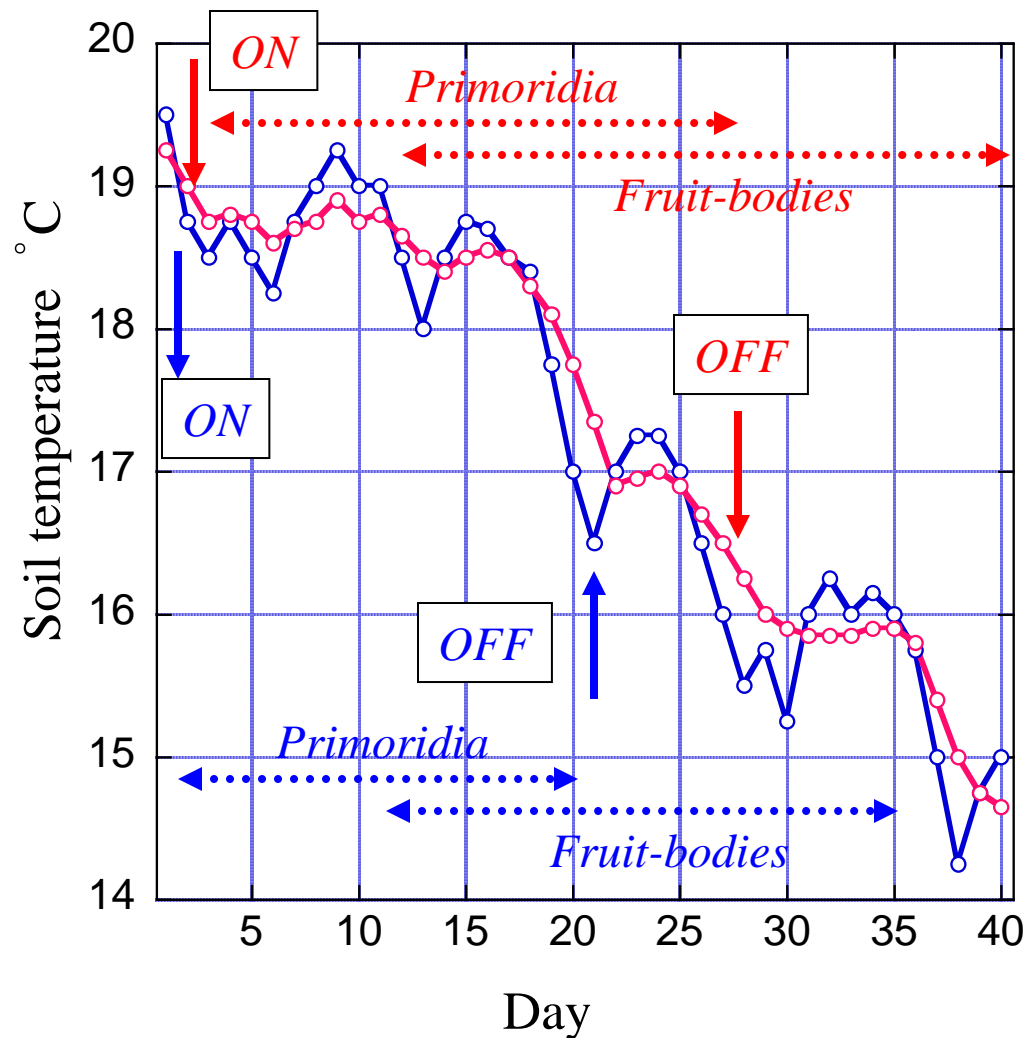


- Blue line: typical fluctuation of soil temperature in autumn
- Red line: rebound of the temperature
- Rebound to higher temperature can reset the developing system of fruit-body
- In fact, two related signals are required for fruiting, i.e. "switch on" at 19°C and maintenance of "switch on" condition at lower temperature for a fruit-body's development from a primordium

- Induction of matsutake's fruiting is primarily determined by temperature:
  - Probable sequential event of matsutake's shiro in the fruiting season



- Induction of matsutake's fruiting is primarily determined by temperature:
- *The depth of matsutake's shiro in soil also affects its fruiting period*



- Thinner litter layer on the steep slope, and thicker litter layer on the flat slope of pine forests
- Moderate fluctuation of soil temperature in the deeper area
- Matsutake sometimes fruit for longer period in the forests with thicker litter layer

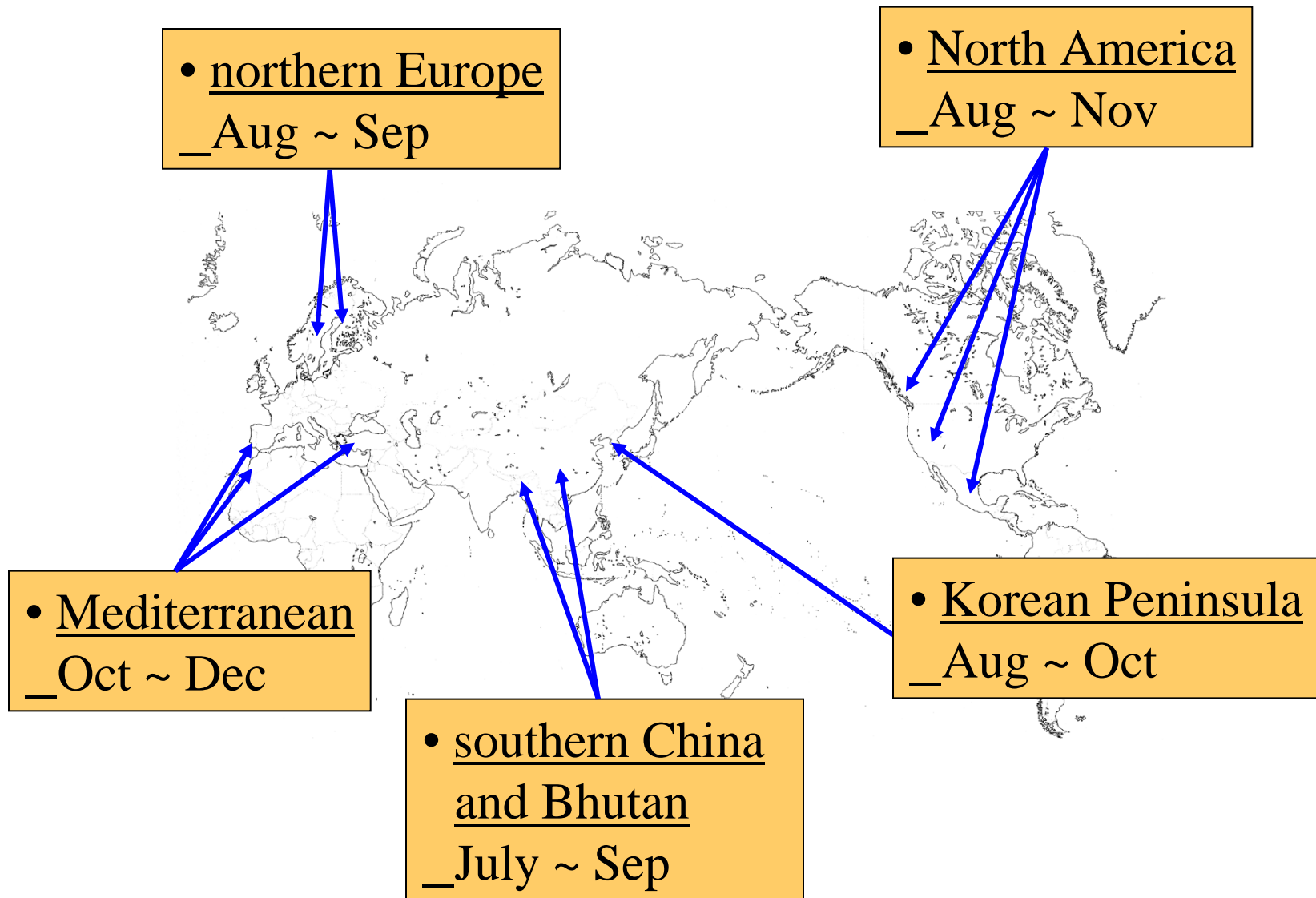
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2. How weather condition affects matsutake yields?

- *Fruiting seasons of matsutake in the world*



- *Climatic factors that may determine fruiting seasons of matsutake in the world*

Geographic region	Fruiting period	Vegetation	Köppen's climatic zone*	Putative triggers for fruiting
northern Europe	Aug ~ Sep	Coniferous forests	Df	Temperature
Mediterranean	Oct ~ Dec	Coniferous forests	Cs, Df	Water level or temperature
North America	Sep ~ Nov	Coniferous forests	Cfb, Cw, Cs, Df	Water level or temperature
southern China and Bhutan	July ~ Sep	Pine and oak forests	Cw, Dw	Temperature
Korean Peninsula	Aug ~ Oct	Pine forests	Cfa, Cw, Dw	Temperature

\*Temperature: C > D. Precipitation pattern: “w” is few in winter; “s” is few in summer; “f” is not distinct; “fa” is not distinct, relatively humid; “fb” is not distinct, relatively dry.

- World-wide pattern of matsutake fruiting in relation to climate

## Generalization

### Cs, Cfb

- relatively dry of soil in summer
- temperature moderate in autumn

Switch ON of temperature

Water level OK

Shiro's condition of matsutake

Vegetative growth period

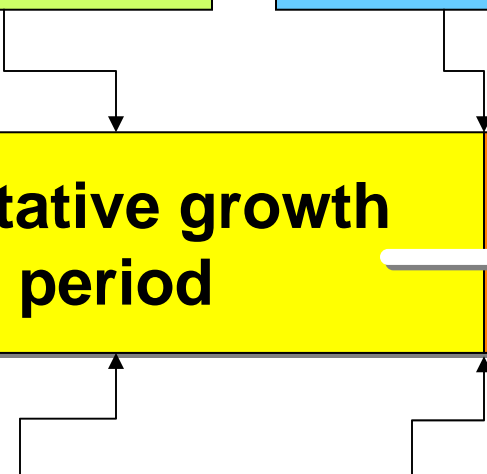
Reproductive (sexual) growth period

### Cfa, Cw, Dw, Df

- enough soil water level in summer
- temperature decreases from summer to autumn

Water level OK at any time

Switch ON of temperature



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- Much precipitation with constant rain fall in summer and early autumn brings much matsutake yield in autumn. In contrast, less precipitation in summer and early autumn brings less matsutake yield in autumn.
- Higher temperature in autumn leads delay of fruiting season.
- Significant rebound of soil temperature after the “switch ON” of fruiting brings lesser matsutake yields.

- Therefore, both precipitation and temperature affect matsutake's yields

## 2. How weather condition affects matsutake yields?

- How precipitation affects matsutake yields in Japan?

• *Much precipitation with constant rain fall in summer and early autumn brings much matsutake yield in autumn. In contrast, less precipitation in summer and early autumn brings less matsutake yield in autumn.*

- *Probable reason for this:*

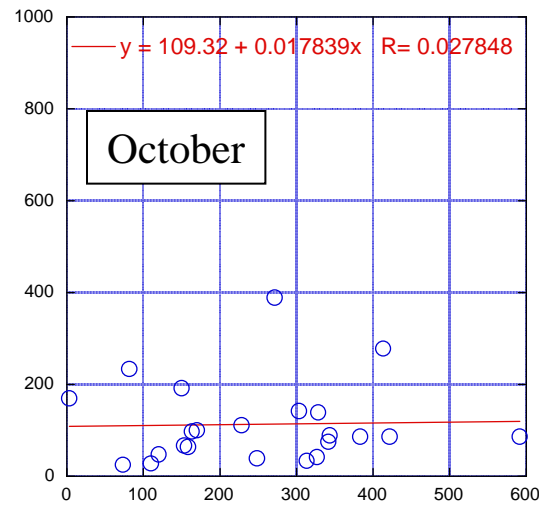
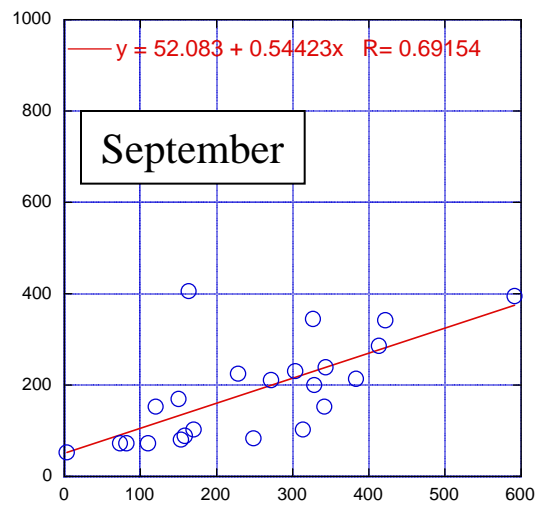
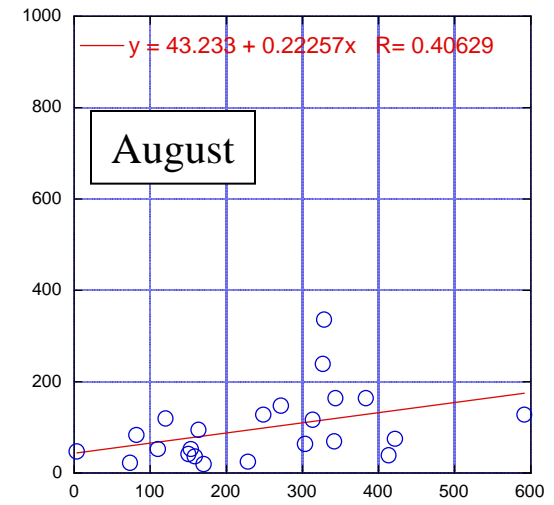
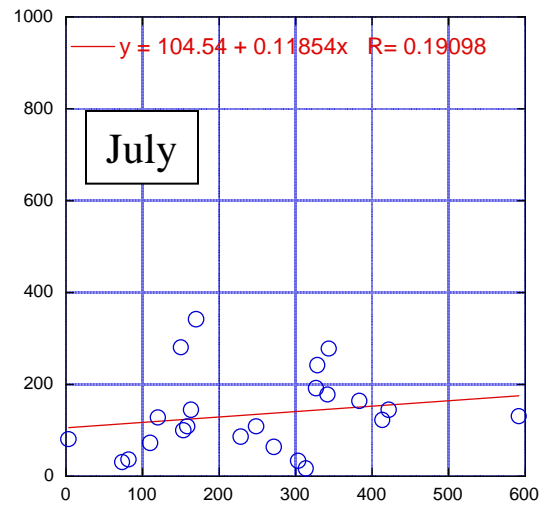
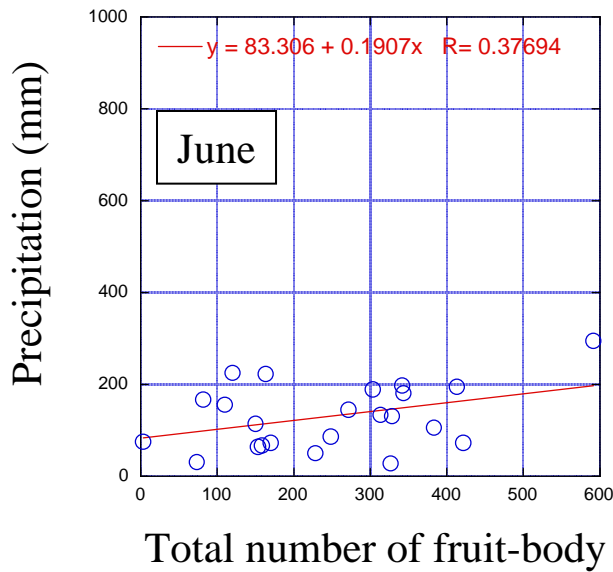
• **As well as other mycorrhizal mushroom fungi, increased biomass of matsutake's shiro mycelium in summer (pre-fruiting season) may be primarily determined by the level of available water.**

- *Relationship between precipitation and matsutake yield*

- *Study example: Toyooka experimental site, Nagano Prefecture*

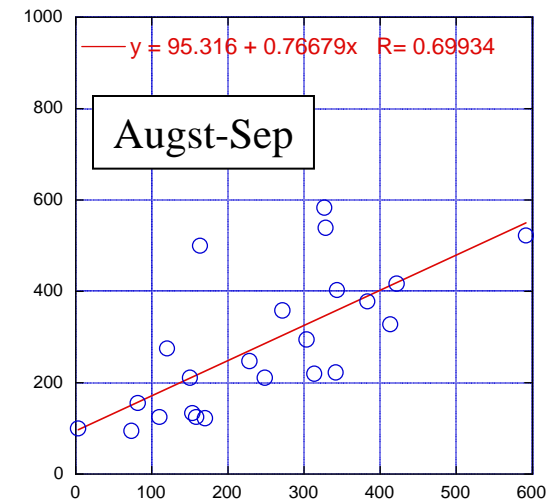
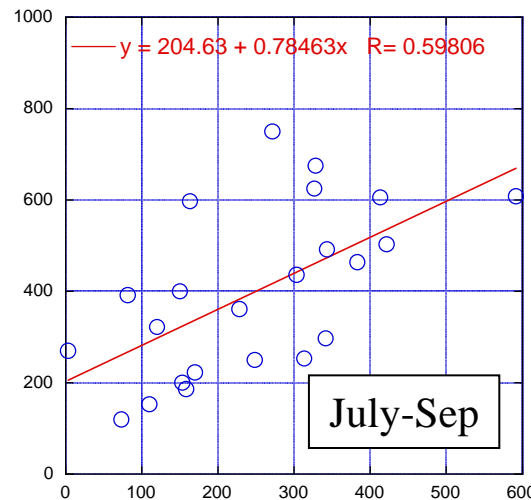
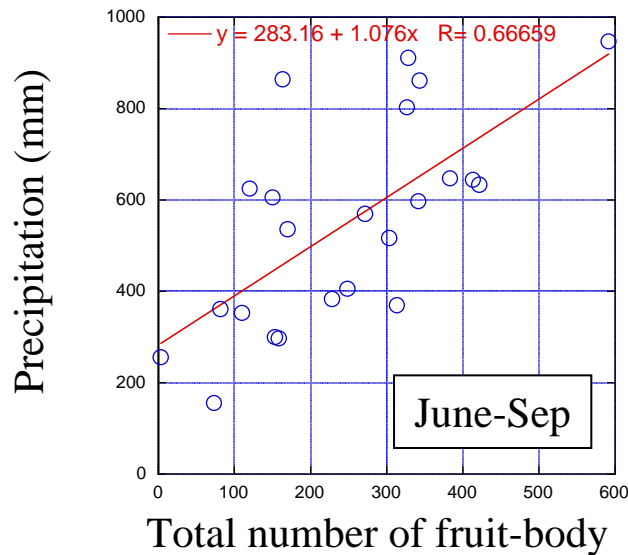
- Observation for 23 years (1982-2004)
- Managed pine forest, commercially harvested
- Area: ca 0.5ha (100m x 50m)
- Fruiting season: from late September to middle October
  
- Precipitation was continuously recorded from June to October
- Number of harvested matsutake fruit-bodies were recorded every day throughout the harvesting season

• Relationship between precipitation and matsutake yield



- September shows the highest correlation
- October shows no correlation

- *Relationship between precipitation and matsutake yield*



- Aug-Sep shows the highest correlation

### Conclusion

- Precipitation just before “switch ON” of fruiting strongly correlates with matsutake yield.
- As well, total precipitation by the date of “switch ON” (i.e. from summer to early autumn) is important.

*Therefore, irrigation of pine forests in the year of  
dry summer may escape from famine of  
matsutake....*

- Irrigation system in a pine forest, Nagano Prefecture
- Pump-up water from stream, deposit in a tank, and spray it on the forest floor from late summer to early autumn

## 2. How weather condition affects matsutake yields?

### • How temperature affects matsutake yields in Japan?

- Higher temperature in autumn leads delay of fruiting season. In addition, significant rebound of soil temperature after the “switch ON” of fruiting brings lesser matsutake yields.

### *• Probable reason for this:*

- Higher temperature in autumn season delays the “switch ON” of fruiting. Break of the reproductive stage by the rebound of soil temperature may decrease total number of promiridia that develop fruit-bodies.

### Remark:

- In sub-alpine conifer forests, the limiting factor for fruit-body's yield may be temperature, because fruiting of matsutake in such areas are sometimes biennial for the slow mycelium growth ratio.

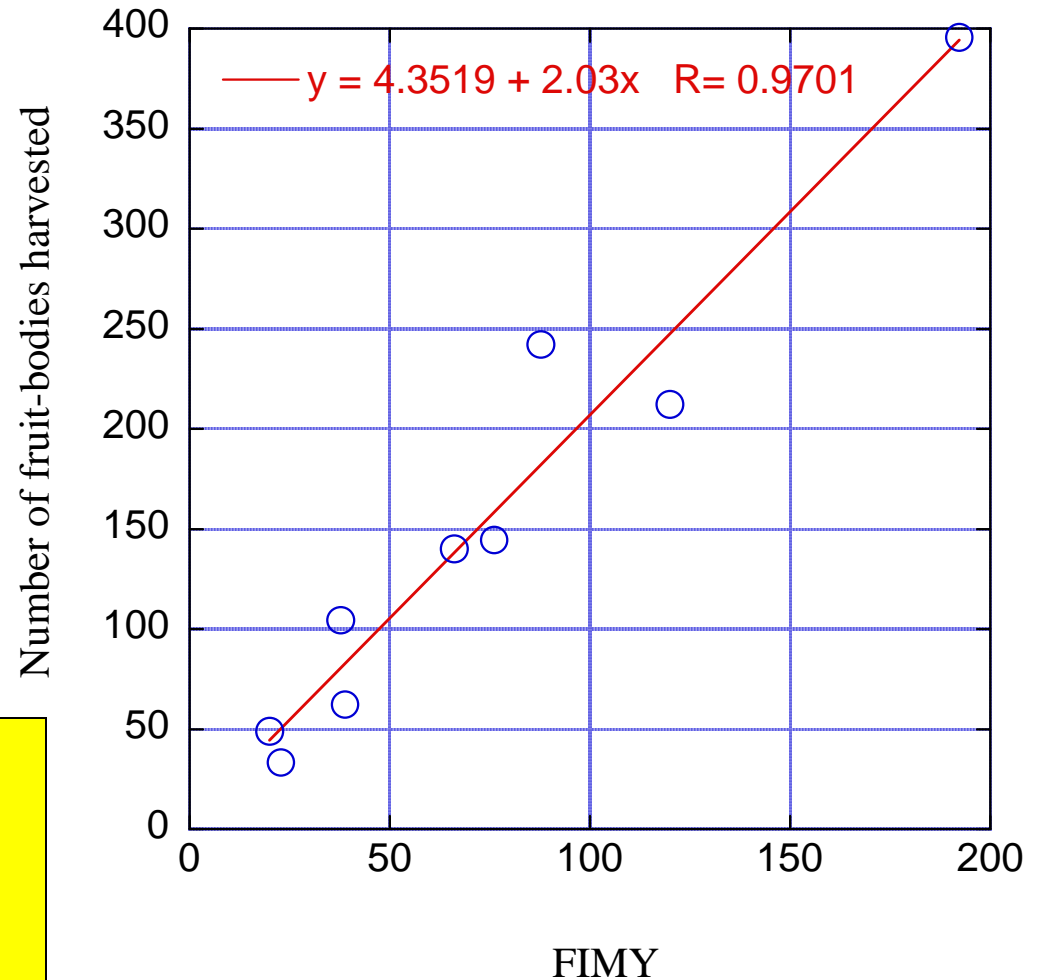
- *How temperature affects matsutake yields in Japan?*
- *Forecast index of matsutake yield (FIMY) in Nagano Prefecture:*
  - Basic idea: Conversion of developed mycelial biomass (that is primarily determined by precipitation) into the fruit-body biomass is determined by the fluctuation of temperature.
  - $FIMY = \text{Precipitation (mm) in the last two months before the date of "switch on" of fruiting (below } 19^{\circ}\text{C)} / \text{days of rebound of soil temperature (above } 19^{\circ}\text{C)} \text{ after the date}$
  - According to the index:
    - FIMY below 50: less yield
    - FIMY 50~100: moderate yield
    - FIMY above 100: much yield

- *How temperature affects matsutake yields in Japan?*
- *Study example: Shiojiri experimental site, Nagano Prefecture*

- Observation for 9 years (1996-2004)
- Managed pine forest, commercially harvested
- Area: ca 0.25ha (100m x 50m)
- Fruiting season: from middle September to early October
- Soil temperature and precipitation were continuously recorded from June to October
- Number of harvested matsutake fruit-bodies were recorded every day throughout the harvesting season

• How temperature affects matsutake yields in Japan?

Year	Precipitation	Days of rebound of soil temperature	FIMY	Number of fruit-bodies harvested
1996	240.5	2	120	212
1997	152.0	2	76	145
1998	191.5	1	192	396
1999	265.5	4	66	140
2000	263.0	7	38	104
2001	137.0	7	20	49
2002	273.5	12	23	33
2003	385.5	10	39	62
2004	175.5	2	88	242



Conclusion

- Suitable fluctuation of soil temperature (i.e. no rebound) leads efficient conversion from vegetative mycelia into fruit-bodies.

## 2. How weather condition affects matsutake yields?

### Generalization

(cool) ← Temperature → (optimum)	<u>Cfa and Cw climatic areas:</u> <ul style="list-style-type: none"><li>• Precipitation in summer (and early autumn) primarily determines matsutake yield.</li><li>• In addition, suitable fluctuation of soil temperature is important.</li></ul>	<u>Cs and Cfb climatic areas:</u> <ul style="list-style-type: none"><li>• Annual (or winter) precipitation may determine matsutake yield.</li><li>• Warm autumn and winter may be also important.</li></ul>
	<u>Dw and Df climatic areas:</u> <ul style="list-style-type: none"><li>• Temperature in summer may primarily determine matsutake yield.</li><li>• Suitable precipitation may be also important.</li></ul>	(grassland or desert; no matsutake present under the climatic condition)
	← (optimum) ———— Precipitation ———— → (scarce)	



*Kiiitos!*  
*Thank you!*



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