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Annual production of the beech（*Fagus crenata*）reproductive-organ in stands with different elevations and histories in a snowy rural area of central Japan over 24 years（1999–2022）

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Annual production of the beech（*Fagus crenata*）reproductive-organ in stands with different elevations and histories in a snowy rural area of central Japan over 24 years（1999–2022）. Hideyuki Ida*, Tatsuya Kamijo, Kaichi Harada and Masayuki Miyazaki（Faculty of Education, Shinshu University, Nagano 380-8544, Japan, E-mail : pida@shinshu-u.ac.jp）*Bulletin of the Institute of Nature Education in Shiga Heights, Shinshu University* **60**： 43-48（2023）.

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Introduction

Siebold's beech（*Fagus crenata*）, a representative temperate deciduous forest-forming tree in Japan, is well known as a nut-producing species with strong masting habit（the periodic synchronous production of large seed production）. Beech-dominated forests are distributed widely in and around mountainous regions along the Sea of Japan ; however, the number of stands has declined significantly due to the intensive conifer plantation policy implemented after the Second World War and as a consequence of rural development following Japan's rapid economic growth in the 1960s. Specifically, in the hilly regions of Japan, large areas of beech stands have vanished and only fragmented stands remain. The validation of fragmentation effects on beech forests that have been influenced significantly by human activities is an important issue as fragmented and isolated beech stands at the lower limit of the vertical distribution might retreat under climate change conditions such as global warming（Matsui et al. 2004）.

There have been several studies of the masting behavior in beech（Yasaka et al. 2003 ; Kon et al. 2005a, b ; Masaki et al. 2008）. The property of masting is difficult to clarify but should be considered together with an understanding of the effects of fragmentation on the population. However, no empirical studies consider both masting and forest fragmentation in this species and therefore little information is available regarding the effects of fragmentation on masting and reproductive success. Nilsson and Wästljung（1987）suggested the importance of cross-pollination for producing a large proportion of sound seeds in European beech（*Fagus sylvatica*）trees growing in isolated or small stands. Knapp et al.（2001）found that acorn production in blue oak（*Quercus douglasii*）would reduce pollen availability and limit reproduction through fragmentation and thinning of the woodlands. These are only suggestions based on data covering a maximum of 2 to 4 years ; thus, the impact of fragmentation on reproductive demography remains unclear.

To examine the demographic impacts of forest fragmentation for masting species, analysis based on long-term monitoring is essential. In this data paper, we have compiled data over 24 years（1999-2022）for annual reproductive-organ production of beech in two fragmented stands and one continuous stand in Iiyama, central Japan. This dataset is useful as a basis for the elucidation of masting behavior of beech as well as for the examination of effects of forest fragmentation and climate change. In addition, beech reproductive-organs are the main food resources of Japanese black bears（*Ursus thibetanus japonicus*）and monitoring data can contribute to the prediction of mass occurrence of bear intrusions into in this residential area（Ida 2021）. Furthermore, beechnut embryos have higher protein and lower lipid contents than those of commercial walnut, and oxidative stability of the former's embryonic oil was greater than that of the latter, suggesting that beechnut will be available as a local specialty in this beech-dominated area（Ida et al. 2017）. Therefore, continuing this monitoring is also important to reduce human-bear conflicts and increase resource use value with appropriate forest management.

Site description

Iiyama City, in the northern sector of Nagano Prefecture in central Japan, is one of Japan's foremost heavy snowfall areas, designated as a special heavy snowfall zone in accordance with the Act on Special Measures concerning Countermeasures for Heavy Snowfall Areas by the Ministry of Land, Infrastructure, and Transport and Tourism of Japan. The mean annual precipitation is 1450.3 mm ; the mean annual temperature is 11.0 ℃ , ranging from −1.9 ℃ in January to 24.6 ℃ in August (1981–2010 ; Iiyama Meteorological Station located at 36° 52.5' N, 138° 22.5' E, 313.0 m asl). The city is located at an altitude of 300–1288 m and the upper mountainous area (>900 m asl) mainly comprises mature beech woodlands, which are old-growth or secondary stands originating from coppices (Ida et al. 2007). Residential areas (ca. 300–500 m asl) are characterized by farm villages and rice paddies. The rural woodlands distributed at ca. 300–900 m asl are mainly covered by fagaceous species (*Quercus crispula, Q. serrata* and *Castanea crenata*) and cultivated Japanese cedar (*Cryptomeria japonica*), with sparse distributions of fragmented beech stands (Ida et al. 2010). Fagaceous woodlands were sustainably coppiced to produce firewood and charcoal until the 1970s, and thereafter have developed into secondary forest.

Stand description

The production of reproductive organs was monitored in three beech-dominated stands : montane old-growth (MO, Fig.1a), rural secondary (RS, Fig.1b), and isolated stand in a residential area (IR, Fig.1c) (Ida et al. 2017 ; Ida 2021) (Table 1). Stand MO (1000 m elevation), located in Mt. Nabekura, was dominated by aged beech trees with various sizes (Ida et al. 2007). Stand RS (540 m elevation) was part of an unmanaged rural forest situated in a hilly area behind a small village. The overstory of the stand comprised large and densely packed canopy beech trees, implying that the forest had previously been used for watershed protection and as a source of building timber (Ida et al. 2010 ; Shoji et al. 2010 ; Ida 2017). Stand IR (318 m elevation) was an isolated patch (*ca.* 0.15 ha) on a small hill in a residential area. This stand was a temple forest previously used as a source of daily living resources (e.g., fuelwoods and composts) but is unmanaged at present. The overstory consisted of beech trees mixed with oak. A dense cover of shrub species, including beech saplings, made up the understory. This stand was approximately halved in area due to land development in the fall of 2016.

Sample collection

To evaluate the annual production of beech reproductive-organs at the stand level, fallen litters, including reproductive organs, were captured using litter traps (Ida et al. 2017 ; Ida 2021). The litter traps (Fig.2), each with a 0.5-m^2 mouth, were constructed from white fabric (1-mm mesh) shaped into funnels supported by three polyvinyl chloride pipes. Five traps were set in MO and RS, and six traps in IR were placed 1.0 m aboveground and 7–15 m apart, under separate canopy beech trees. In IR, traps were

Fig.1. Monitoring stands in Iiyama, central Japan : a, montane old-growth stand (MO) (Oct. 2021) ; b, rural secondary stand (RS) (May 2022) ; c, isolated stand in a residential area (IR) (Aug. 2018).

Table 1. Descriptions of the investigated Siebold's beech (*Fagus crenata*) stands in Iiyama City, Nagano Prefecture, central Japan (partly revised and updated from Ida et al. 2017).

Stand type (Abbreviation)	Montane old-growth stand (MO)	Rural secondary stand (RS)	Isolated stand in a residential area (IR)
Site name	Mt. Nabekura	Karayama	Shinshu-ji Temple
Beech stand size (ha)	>10	2.0	0.15 (0.05 ha from 2016 onwards)
Longitude (E)	138° 23'31"	138° 26'58"	138° 23'48"
Latitude (N)	36° 58'38"	36° 59'10"	36° 55'01"
Altitude (m)	1000	540	318
Mean annual temperature (℃)[a]	7.7	9.9	11.4
Annual precipitation (mm)[a]	2180	2288	1830
Mean maximum snow depth (cm)[b]	436	298	139
Total basal area (m^2 ha^{-1})	39.8	88.5	64.1
% basal area of beech trees	95.9	99.9	62.2
No. seed trap set	5	5	6 (10 in 1999 and 2000)
Period of the seed trap monitoring	2004 Oct. – 2022 Nov.	2001 Sep. – 2022 Dec.	1999 Apr. – 2022 Dec.

[a] Data for 1981 to 2010 are from Mesh Climate Data 2010 (Japan Meteorological Agency 2012)

[b] Data from an author (H. Ida)'s observations includes the period from 2003 to winter 2020, except for MO in which the observations began in winter 2004 (Ida, umpublished data)

Fig.2. Litter trap set in stand RS.

moved under the remaining beech population on 14 April 2018 and placed 2–4 m apart from each other due to the land development.

Samplings were conducted continually from 5 October 2004 to 7 November 2022 at MO, from 14 September 2001 to 6 December 2022 at RS, and from 20 April 1999 to 6 December 2022 at IR. Litterfall caught within the traps was typically collected once in each 2–9-week period, except during the snowy season when the traps were placed on the ground and collected after snowmelt in the following spring to early summer.

Trap contents were transferred into paper bags and transported to the laboratory for sorting. Litter that fell during the snowy season was sorted based on the year of flowering. We extracted beech reproductive-organs and separated into female inflorescence (green cupule, Fig.3b), male inflorescences (Fig.3c), filled (sound seed, Fig.3a) or unfilled (unsound or sterile seed) masts based on visual observations. Almost all of the green cupules captured in litter traps had fallen immediately after flowering due to insect predation (Ida et al. 2013). We assumed that fallen female flowers were insect-damaged masts (undermentioned), the number of which was estimated to be double that of fallen female inflorescences (damaged green cupules) because each beech cupule normally contains two masts (the individual fruit in the cupule). Male inflorescences had almost completely fallen by July. The filled masts, which started to fall from mid-September at these stands, have vigorous embryos that are potentially viable seed. The unfilled masts were divided into five categories : vertebrate-damaged, insect-damaged, immature, empty, and fungus-damaged. Vertebrate-damaged masts were cracked and all or most of the embryos were lacking, which were likely predated by vertebrates (e.g. birds or rodents) in the tree crowns (Ida et al. 2004). Insect-damaged masts were filled with dark frass and/or had pinholes on the seed coat. They were predated by lepidopteran larvae, such as *Pseudopammene fagivora*, *Argyresthia* spp., and *Venusia phasma* (Igarashi and Kamata 1997). Immature masts had incomplete embryos, and empty masts had no embryos. The im-

Fig.3. Beech reproductive-organs : a, female inflorescence ; b, male inflorescences ; c, filled masts (beechnuts).

Table 2. Annual production (number m^{-2}) of female flowers (FFs), male inflorescences (MIs), and filled masts (FMs) for Siebold's beech (*Fagus crenata*) in montane old-growth (MO), rural secondary (RS), and isolated (IR) stands in Iiyama City, Nagano Prefecture, central Japan. Data for 2004–2019 were listed in Ida et al. (2017) and Ida (2021).

	MO			RS			IR		
Year	FFs	MIs	FMs	FFs	MIs	FMs	FFs	MIs	FMs
1999	nd	nd	nd	nd	nd	nd	121	161	1
2000	nd	nd	nd	nd	nd	nd	5	2	0
2001	nd	nd	nd	*0*	0	0	58	17	0
2002	nd	nd	nd	31	29	6	4	1	0
2003	nd	nd	nd	8	3	0	62	45	2
2004	*74*	nd	17	47	35	0	37	24	0
2005	1127	nd	682	1284	2353	771	1159	779	250
2006	1	28	0	2	0	0	0	0	0
2007	269	488	60	52	109	12	170	47	3
2008	78	119	8	7	27	0	18	1	0
2009	462	803	73	334	552	66	307	374	2
2010	32	52	0	0	0	0	19	0	0
2011	600	663	372	1141	1573	707	329	511	5
2012	4	50	0	4	6	0	8	3	0
2013	365	440	134	3	14	0	63	40	0
2014	0	0	0	0	0	0	0	0	0
2015	939	1200	604	568	819	233	358	392	28
2016	0	0	0	0	0	0	0	0	0
2017	141	99	33	0	3	0	1	0	0
2018	189	344	72	929	1370	479	414	414	66
2019	65	9	0	2	1	0	0	0	0
2020	11	1	0	0	0	0	0	0	0
2021	229	110	112	25	26	13	2	0	0
2022	307	576	123	1169	2656	502	768	1397	36

Note : italic lettering, the FFs at MO in 2004 and RS in 2001 were collected after early October and mid-September, respectively, and thus may be slightly less than the annual production ; nd, no data for analysis because sampling was not conducted.

mature and empty masts were assumed to have not been fully pollinated (Kon et al. 2005a). Fungus-damaged masts had decayed embryos.

The annual mast production was calculated as the sum of the six mast categories for each year at a given site and provided an estimate of the annual production of female flowers. In this data paper, we show the annual production of female flowers (FFs), male inflorescences (MIs), and filled masts (FMs) in each stand (Table 2). The numbers were calculated and rounded off to the nearest whole integer on an area basis (number m^{-2}).

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