Conclusion

The plant population size, spatial pattern, and the density of mating groups (e.g., Antonovics & Levin 1980; Barrett & Thomson 1982; Feinsinger et al. 1991), and abundance and behaviors of the pollinator fauna (e.g., Motten 1986; Bertin 1982; Snow 1982) are expected to influence plant reproductive success through changes in the quantitative and qualitative patterns of pollination.

Most evolutionary biologists would accept that floral design and display modify the actions of pollen vectors so as to enhance fertility and to minimize limitations related to both pollen load size and donor diversity (Harder & Barrett 1996). Nevertheless, the supposed merits of the adaptation and the effects of pollinator visitation on patterns of both stigmatic pollen load size and donor diversity as well as their reproductive consequences have remained to be poorly understood.

In the present study, the reproductive success at pollination stages and factors affecting it were analyzed for natural populations of a distylous plant species, *Primula sieboldii* E. Morran (Primulaceae).

The present study has demonstrated following points.

1. In Chapter 1, the importance of pollination process in seed production of field plant populations was confirmed. The smaller populations (genets $\leqq 3$) set almost no seeds consistently during the study years presumably due to lack of mating partner. In the larger populations (genets $\geqq 7$), the pollination failure would be the most plausible reason for variation of reproductive success among the populations in some year.
2. In Chapter 2, the effects of population size and pollinator availability on pollination and its relation to seed set of *P. sieboldii* populations were revealed. The number of

compatible pollen grains deposited on the stigmas was significantly lower in the relatively large populations with low pollinator availability than that of the population with sufficient pollinator services. It was likely that small compatible pollen load due to low pollinator availability led to lower seed set in these populations.

3. Seed set varied greatly among the small populations, while that of the large populations with low pollinator availability was moderate. Quality of pollination, i.e., the number of pollen donor within the stigmatic compatible pollen load can be interpreted to be higher in the large populations than in the small populations, because more successful mating is possible with multiple pollen donors.

4. Seed set in the long-styled morph of *P. sieboldii* populations was higher than in the short-styled morph under the naturally pollen-limited condition (Chapter 1). This is supposed to be related to the fact that the stigmas of the long-styled morph received more compatible pollen grains, though partial or cryptic self-compatibility of the long styled morph (Chapter 1) could partly explain the difference.

5. In Chapter 3, I quantified between-morph pollen exchange patterns and pollen carryover in *Primula sieboldii* flowers. From the results of these experiments I can derive the following suggestion. In both morphs, stigmatic pollen load after a single visit by the bee may be insufficient for maximum seed set. Several visits by the pollinators in both morphs would be required for receiving sufficient pollen grains far more than the ovule number, which is a necessary condition for full fertilization of the ovules. The short-styled morph is thought to be more vulnerable to legitimate pollen shortage than the long-styled morph in *P. sieboldii* because of much smaller legitimate pollen load on their stigmas. The extensive pollen carryover suggested that a mixed pollen load would be brought about by a single visit of the bee which carries mixture of pollen from many flowers of different genets on its proboscis in the population which consists

of a number of genets.

6. It is likely that high seed set observed in large population P with sufficient pollinator services was caused by both high pollen load size and donor diversity due to multiple pollinator visits to individual flowers in the population. In large populations J and Q with low pollinator availability, pollen load size was small because individual flowers might have been visited by pollinators once or zero. Moderate seed set in these populations suggests the relatively high diversity of pollen donor, which was sustained due to large population size. Flowers in small populations D,E,F,G, and O might have been limited by both pollen load size and diversity of pollen donor due to smaller number of mating partners, resulting in high variation in seed set among the small populations.

At present, evaluating genetic diversity of stigmatic pollen load is technically difficult, since direct measurement methods for genotype of individual pollen grains in the stigmatic pollen load have not yet developed, except for species with pollinia, such as *Asclepias syriaca* (Asclepiadaceae) (Shore 1993), *Asclepias exaltata* (Broyles & Wyatt 1995), and *Aerangis ellisii* (Orchidaceae) (Nilsson et al. 1992). In most studies which attempted to evaluate pollen donor diversity, genetic diversity of progeny of a fruit has been measured as a surrogate (e.g., Johnson 1993; Karron 1995; Goodell et al. 1997), however, postpollination process such as selective abortion and germination failure can affect the estimation in this method. In the present study, the extent of pollen donor diversity in stigmatic pollen load was inferred through the new technique, i.e., evaluation of the extent of pollen carryover and pollinator visitation rate.

Throughout the present study, the usefulness of parameters, such as, 'relationship between population size or pollinator availability and pollen load size', 'size of pollen load deposited on a single visit by pollinator' and 'the extent of pollen carryover and pollinator visitation rate', in analyzing the reproductive success of the stage of pollination was demonstrated. Although the value of individual parameters may vary depending on the plant and pollinator species, those parameters may be useful also in similar analysis for many other outcross flowering plant species.

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