APPENDIX S1: Justification of Parameter Estimates

Parameter estimates are derived from well-studied tropical forests, including Barro Colorado Island, Panama (Condit 1998). When estimates were not available from natural systems, agricultural and laboratory studies were used as described below.

Tree, Juveniles, Seedlings, and Seeds. Crown area of 25 m^2 is typical for a 10 cm diameter tropical tree (O'Brien *et al.* 1995; Bohlman & O'Brien 2006; Muller-Landau *et al.* 2006), and 10 cm is a typical size for onset of reproduction in tropical tree species (Condit 1998; Hubbell *et al.* 1999; Hubbell, Condit & Foster 2005). Tropical tree fecundity is estimated to range from 0.0438 to 1764 cm^{-2} of basal area depending on seed size (Clark *et al.* 1999; Muller-Landau *et al.* 2008). Dispersal distance parameters range from 2.3 to 8.75 for 41 species on BCI, which approximates to mean dispersal distances of 5 to 125 m (Muller-Landau *et al.* 2008). The mean and median dispersion parameter of the negative binomial for the same study were estimated as 0.1858 and 0.1015 with a range of 0.024 to 0.909 (Muller-Landau *et al.* 2008). The majority of tropical seeds are not viable for more than one year (Garwood 1983; Sautu *et al.* 2006). Annual seedling survival in Central Panama ranges from 0 to 96% (Howe 1990; Asquith, Wright & Clauss 1997; Webb & Peart 1999; Comita & Hubbell 2009).

Insect Seed Predators. Insect fecundity per female has been shown to range from 30 to 190 eggs in field and laboratory settings (Janzen 1980; Fox 1993; Stillwell *et al.* 2007). The movement ecology of bruchid beetles in natural settings is not well-studied (Lewis & Gripenberg 2008). Wright *et al.* (1983) documented the arrival of beetle eggs on palm seeds at particular distances from an adult tree. Using their distribution data on bruchid eggs around a tree, we fit a Poisson regression to the number of seeds found with eggs at each distance and determined the mean distance of eggs from a tree to be 41 m. The average proportion of bruchid beetle eggs that survived to the larval stage was 0.12 and varied with the number of eggs laid on a seed with a maximum of 0.2 when only one egg is laid (Wright 1983). In a laboratory setting, egg to adult survivorship can be much higher, ranging from 0.6 to 1 (Fox *et al.* 2007; Stillwell *et al.* 2007).

Pathogens. <u>Length of seedling susceptibility</u>. In a field study conducted in Panama, the majority of seedling mortality due to damping-off disease occurred within a five-week interval when seedlings were two to seven weeks old (Augspurger 1983). Seedlings from a variety of agricultural crops are susceptible to damping-off disease until 2-15 days after emergence, after which susceptibility decreases (reviewed in Martin and Loper 1999).

<u>Generation Time</u>**.** The latent period between inoculation and sporulation tends to be short for *Phytophthora*, as short as twenty-four hours, and depends on the plant's susceptibility to infection (Erwin, Bartnicki-Garcia & Tsao 1983; Erwin & Ribeiro 1996). Some *Phytophthora* can sporulate after 2 days on rich media while others sporulate if nutrient limited; the release of zoospores from sporangia and subsequent infection can take only a few hours (Judelson & Blanco 2005). Sporulation of *Phyophthora capsici* occurs at a minimum of three to four days after inoculation (Granke *et al.* 2009). In one week, oospores of *Phyophthora infestans* can produce new oospores that can germinate and form sporulating lesions on a plant (Drenth, Janssen & Govers 1995). In a soil bioassay with leaf baiting, infection of *Phytophthora infestans* of potatoes was observed 5-29 days after soil was inoculated (Fernández-Pavía *et al.* 2004). For another pathogen, *Pythium ultimum*, the first cycle of primary infection was estimated to take

three days, while the secondary cycle of infections was estimated as 7 cm day $^{-1}$ when plants were 8mm apart (Brassett & Gilligan 1988).

Fecundity. Oomycetes can produce many spores during infection, ranging from none to 660 mm^{-2} of lesions in some species (Grove, Madden & Ellis 1985; Drenth, Janssen & Govers 1995; Timmer *et al.* 2000).

Dispersal. Spores are the unit of dispersal (Erwin, Bartnicki-Garcia & Tsao 1983). Spores causing root infections are dispersed within soil, surface water, and water droplets (Ristaino & Gumpertz 2000). The mean dispersal distance (calculated from an exponential model of the rate of spread of disease to infected plants), ranged from 6-15 mm for soil-borne fungi after one week, and from 0.08-13 m for splash-borne fungi (Fitt *et al.* 1987).

Germination. Oospores and sporangia are more likely to germinate when there are chemical stimulants nearby. Seed and root exudates enhance spore germination in the soil surrounding the seed. For example, one species of *Pythium* has been found to germinate within 10 mm of a germinating seed (Stanghellini & Hancock 1971).

Infectivity**.** Infectivity ranges from 0.001 to 0.04, calculated as –log (probability that a host remains susceptible) divided by the number of propagules in a given area or volume and is estimated using published data (Martin & Loper 1999; Widmer 2009). Zoospores are the primary infective agents (Erwin, Bartnicki-Garcia & Tsao 1983).

Annual spore mortality**.** Annual spore viability depends on various factors, including pathogen type, initial oospore concentration, sampling technique, and environmental factors (Erwin & Ribeiro 1996). Viability of spores of *Phyophthora infestans* collected from potato fields in Mexico ranged from 1% (in soil with low oospore concentration) to 60% (in soil with high oospore concentration) 3 months after potato harvest and 16.75 % (in soil with high oospore concentration) after 24 months of winter fallow (Fernández-Pavía *et al.* 2004). After 343 days in two separate years, percent of soil samples with viable *Phytophthora capsici* oospores ranged from 0 - 16.7 % in the first year and 0 - 100% in the second year depending on the sampling technique (French-Monar *et al.* 2007). In another study of *P. capsici*, 9 % of oospores were viable after 27 weeks (Bowers, Papayizas & Johnston 1990).

References

Asquith, N.M., Wright, S.J. & Clauss, M.J. (1997) Does mammal community composition control recruitment in neotropical forests? Evidence from Panama. *Ecology,* **78,** 941-946.

Augspurger, C.K. (1983) Seed dispersal of the tropical tree, *Platypodium elegans*, and the escape of its seedlings from fungal pathogens. *Journal of Ecology,* **71,** 759-771.

Bohlman, S. & O'Brien, S. (2006) Allometry, adult stature and regeneration requirement of 65 tree species on Barro Colorado Island, Panama. *Journal of Tropical Ecology,* **22,** 123-136.

Bowers, J., Papayizas, G. & Johnston, S. (1990) Effect of soil temperature and soil water matric potential on the survival of *Phytopthora capsici* in natural soil. *Plant Disease,* **74,** 771-777.

Brassett, P. & Gilligan, C. (1988) A Discrete Probability Model for Polycyclic Infection by Soil-Borne Plant Parasites. *New Phytologist,* **109,** 183-191.

Clark, J.S., Silman, M., Kern, R., Macklin, E. & Hille Ris Lambers, J. (1999) Seed dispersal near and far: patterns across temperate and tropical forests. *Ecology,* **80,** 1475-1494.

Comita, L. & Hubbell, S.P. (2009) Local neighborhood and species' shade tolerance influence survival in a diverse seedling bank. *Ecology,* **90,** 328-334.

Condit, R. (1998) *Tropical Forest Census Plots*. Springer-Verlag and R. G. Landes Company, Berlin, Germany, and Georgetown, Texas.

Drenth, A., Janssen, E. & Govers, F. (1995) Formation and survival of oospores of Phytophthora-infestans under natural conditions. *Plant Pathology,* **44,** 86-94.

Erwin, D., Bartnicki-Garcia, S. & Tsao, P. (1983) Phytophthora: It's biology, taxonomy, ecology, and pathology. pp. 392. APS Press.

Erwin, D. & Ribeiro, O.K. (1996) *Phytophthora: Diseases worldwide*. APS Press, St. Paul, Minnesota.

Fernández-Pavía, S., Grünwald, N., Díaz-Valasis, M., Cadena-Hinojosa, M. & Fry, W. (2004) Soilborne oospores of *Phytophthora infestans* in central Mexico survive winter fallow and infect potato plants in the field. *Plant Disease,* **88,** 29-33.

Fitt, B.D.L., Gregory, P.H., Todd, A.D., McCartney, H.A. & Macdonald, O.C. (1987) Spore dispersal and plant disease gradients; a comparison between two emperical models. *Journal of Phytopathology,* **118**.

Fox, C. (1993) Multiple Mating, Lifetime Fecundity and Female Mortality of the Bruchid Beetle Callosobruchus maculatus (Coleoptera: Bruchidae). *Functional Ecology,* **7,** 203-208.

Fox, C., Scheibly, K., Smith, B. & Wallin, W. (2007) Inbreeding depression in two seed-feeding beetles, *Callosobruchus maculatus* and *Stator limbatus* (Coleptera: Chrysomelidae). *Bulletin of the Entomoloigical Research,* **97,** 49-54.

French-Monar, R., Jones, J., Ozores-Hampton, M. & Roberts, P. (2007) Survival of Inoculum of *Phtophthora casici* in Soil Through Time Under Different Soil Treatments. *Plant Disease,* **91,** 593-598.

Garwood, N.C. (1983) Seed Germination in a Seasonal Tropical Forest in Panama: A Community Study. *Ecological Monographs,* **53,** 159-181.

Granke, L., Windstam, S., Hoch, H., Smart, C. & Hausbeck, M. (2009) Dispersal and Movement Mechanisms of *Pytopththora capsici* Sporangia. *Phytopathology,* **99,** 1258-1264.

Grove, G., Madden, L. & Ellis, M. (1985) Influence of temperature and wetness duration on sporulation of *Phytophthora cactorum* on infected strawberry fruit. *Phytopathology,* **75,** 700-703.

Howe, H.F. (1990) Survival and growth of juvenile Virola surinamensis in Panama: effects of herbivory and canopy closure. *Journal of Tropical Ecology,* **6,** 259-280.

Hubbell, S.P., Condit, R. & Foster, R.B. (2005) Barro Colorado Forest Census Plot Data. Center for Tropical Forest Science.

Hubbell, S.P., Foster, R.B., O'Brien, S.T., Harms, K.E., Condit, R., Wechsler, B., Wright, S.J. & lao, S.L.d. (1999) Light-gap disturbances, recruitment limitation, and tree diversity in a neotropical forest. *Science,* **283,** 554-496.

Janzen, D. (1980) Specificity of Seed-Attacking Beetles in a Costa Rican Deciduous Forest. *Journal of Ecology,* **68,** 929-952.

Judelson, H.S. & Blanco, F.A. (2005) The spores of *Phytophthora*: weapons of the plant destroyer. *Nature Reviews Microbiology,* **3,** 47-58.

Lewis, O.T. & Gripenberg, S. (2008) Insect seed predators and environmental change. *Journal of Applied Ecology,* **45,** 1593-1599.

Martin, F.N. & Loper, J.E. (1999) Soilborne Plant Diseases Caused by *Pythium* spp.: Ecology, Epidemiology, and Prospected for Biological Control. *Critical Reviews in Plant Sciences,* **18,** 111-181.

Muller-Landau, H.C., Condit, R.S., Chave, J., Thomas, S.C., Bohlman, S.A., Bunyavejchewin, S., Davies, S., Foster, R., Gunatilleke, S., Gunatilleke, N., Harms, K.E., Hart, T., Hubbell, S.P., Itoh, A., Kassim, A.R., LaFrankie, J.V., Lee, H.S., Losos, E., Makana, J.R., Ohkubo, T., Sukumar, R., Sun, I.F., Supardi, N.M.N., Tan, S., Thompson, J., Valencia, R., Munoz, G.V., Wills, C., Yamakura, T., Chuyong, G., Dattaraja, H.S., Esufali, S., Hall, P., Hernandez, C., Kenfack, D., Kiratiprayoon, S., Suresh, H.S., Thomas, D., Vallejo, M.I. & Ashton, P. (2006) Testing metabolic ecology theory for allometric scaling of tree size, growth and mortality in tropical forests. *Ecology Letters,* **9,** 575-588.

Muller-Landau, H.C., Wright, S.J., Calderón, O., Condit, R. & Hubbell, S.P. (2008) Interspecific variation in primary seed dispersal in a tropical forest. *Journal of Ecology,* **96,** 653-667.

O'Brien, S.T., Hubbell, S.P., Spiro, P., Condit, R. & Foster, R.B. (1995) Diameter, height, crown, and age relationships in eight neotropical tree species. *Ecology,* **76,** 1926-1939.

Ristaino, J. & Gumpertz, M. (2000) New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. *Annual Review of Phytopathology,* **38,** 541-576.

Sautu, A., Baskin, J.M., Baskin, C.C. & Condit, R. (2006) Studies on the seed biology of 100 native species of trees in a seasonal moist tropical forest, Panama, Central America. *Forest Ecology and Management*, **234,** 245-263.

Stanghellini, M. & Hancock, J. (1971) The sporangium of *Pythium ultimum* as a survival structure in soil. *Phytopathology*, **61**.

Stillwell, C., Wallin, W., LJ, H. & Fox, C. (2007) Phenotypic plasticity in a complex world: interactive effects of food and temperature on fitness components of a seed beetle. *Oecologia*, **153,** 309-321.

Timmer, L., Zitko, S., Gottwald, T. & Graham, J. (2000) Phytophthora Brown Rot of Citrus: Temperature and Moisture Effects on Infection, Sporangium Production, and Dispersal. *Plant Disease*, **84,** 157-163.

Webb, C.O. & Peart, D.R. (1999) Seedling density dependence promotes coexistence of Bornean rain forest trees. *Ecology*, **80,** 2006-2017.

Widmer, T. (2009) Infective Potential of Sporangia and Zoospores of *Phytophthora ramorum*. *Plant Disease*, **93,** 30-35.

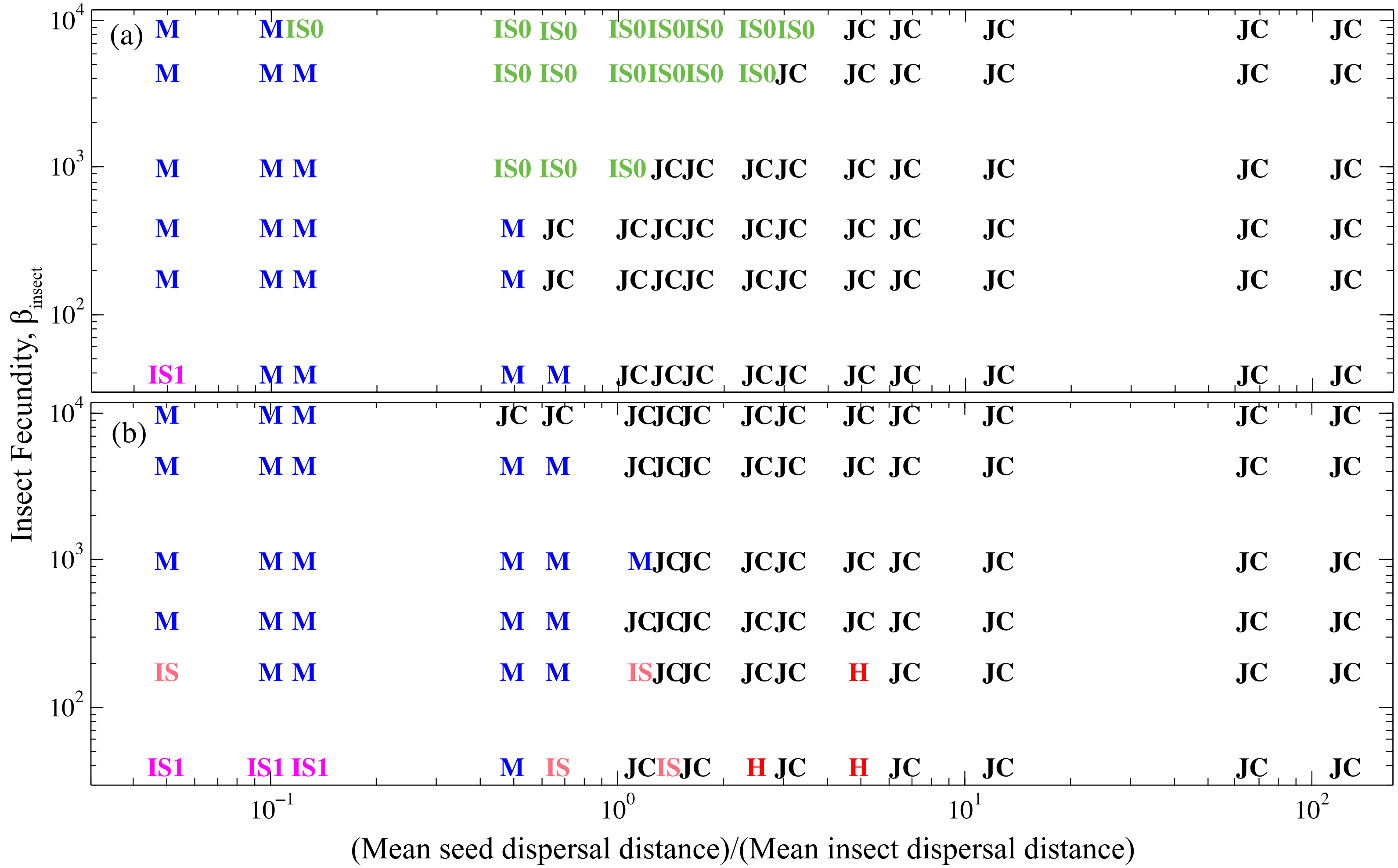

Fig. S1. The recruitment patterns resulting from insect seed predation with (a) even and (b) clumped seed deposition. The recruitment patterns are Janzen-Connell (JC), McCanny (M), Hubbell (H), and Invariant Survival (IS). IS1 indicates an average of at least 99% of seeds survived. IS0 indicates no seedlings emerged.

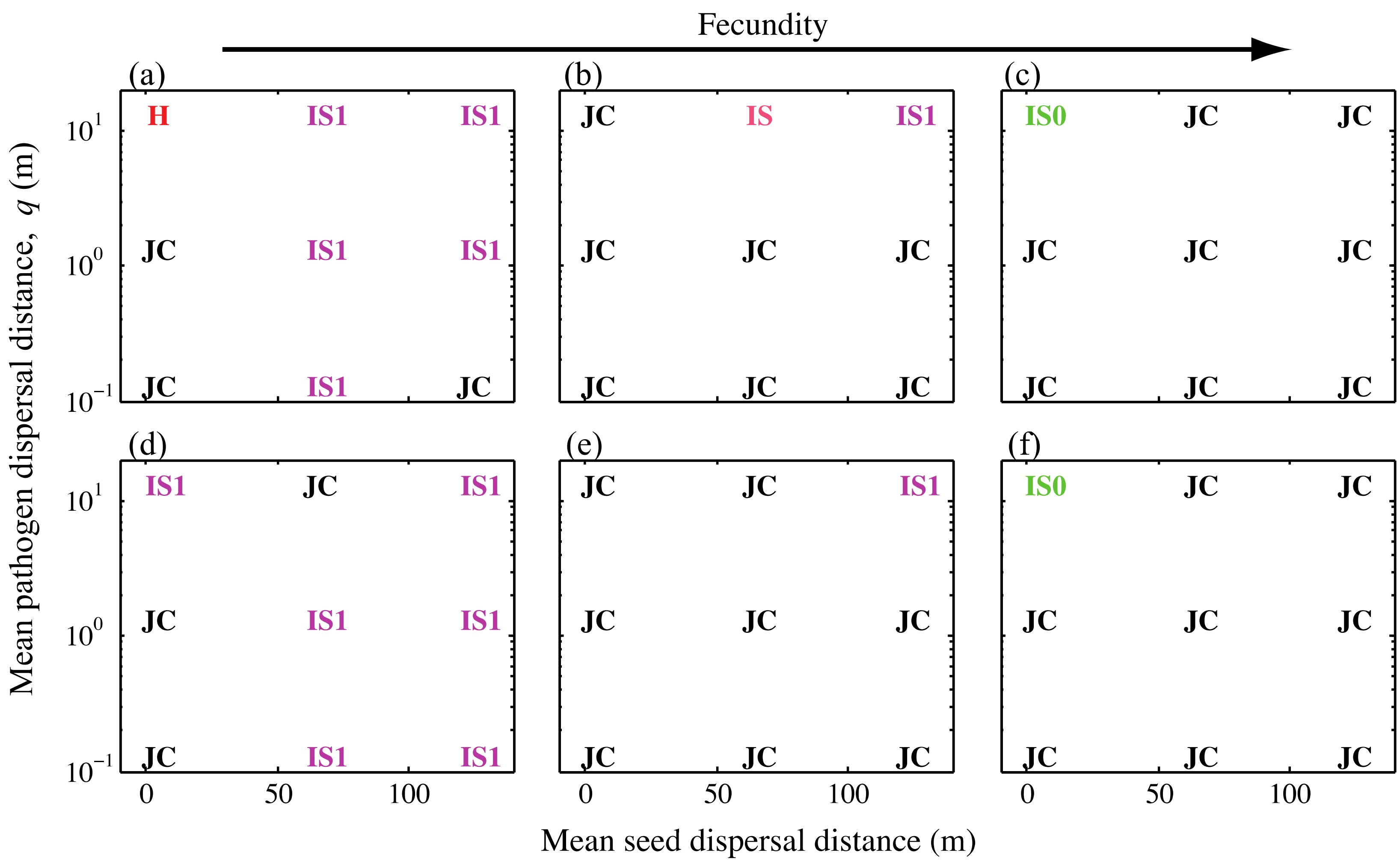

Fig. S2. Recruitment patterns resulting from factorial combinations of parameters for pathogen attack under (a-c) even and (d-f) clumped seed deposition and fecundity equal to (a, d) 1000, (b, e) 10000, (c, f) 100000 and 200000 spores. IS0 indicates no seedlings emerged; IS1 indicates an average of at least 99% of seeds survived.