

# Appendix 1: Detailed explanation of the ecosystem model

## 1. Plants

### 1-1. Plant traits

Even small oceanic islands are inhabited by diverse plant species. To appropriately address issues of diversity, our model must handle plants at the level of species. However, ecological data required by the model are not available for all plant species. For the purpose of modeling, virtual parameters must instead be set. In doing so, care must be taken not to give advantages to particular species. Otherwise, species with advantageous traits will quickly outcompete other species, leaving the model unable to reproduce the natural ecosystem with many coexisting species. For this study, to express multiple trade-offs based on a single rule, a method was adopted that sets data for individual plant species by applying the concept of Grime's triangle (Grime, 1974, 1979; Grime *et al.*, 1988).

Grime proposed that plant life histories consist of three strategies: competitive (C), stress-tolerant (S), and ruderal (R). Competitive plants, under good environmental conditions, tend to grow rapidly by consuming a large amount of resources. Stress-tolerant plants are able to survive under poor environmental conditions, for example, nutrient deficiency or light limitation due to shading by other plants. Ruderal plants grow quickly on bare ground exposed by environmental disturbance. Unique, species-specific life history strategies combine the three strategies in different proportions. In this study, all plant species are given 100 points, which are allocated across the three strategies. Ecological traits of plant species are determined based on these values.

Our model deals with many species, including invasive species (such as white popinac, beefwood, and bamboo), grasses (bamboo grass), and Japanese lawn grass (which is a main constituent species of grassland), and native woody and herbaceous plant species, for which ecological data are not available. For white popinac and beefwood, which are pioneer woody plant species and grow rapidly under good nutritional conditions (Grime, 1974, 1979; Grime *et al.*, 1988), more points are allocated to C and R than to S (App.1-Table 1). Bamboos, bamboo grass, and Japanese lawn grass are not competitive, but, with their subterranean stems, tend to retain colonized space, so their strategy is predominantly S. In addition, because they grow quickly on bare ground (R strategy), more points are allocated to S and R for these species than to C (App.1-Table 1). The standard values of C, S, and R for the known species were determined after consultation with Drs. Kenji Hata, Takeshi Osawa, and Naoki Kachi, who are specialist of plant ecology and co-authors of this manuscript. In each simulation,

1 these values were determined by adding a Gaussian random number, of which mean value is  
2 0 and standard deviation is 5, to the standard values. In order to keep the sum of values of C,  
3 S, R equal to 100 points, values of C and S were set by this manner, and R is set by subtracting  
4 (C + S) from 100. For native woody and herbaceous plant species whose traits are not known,  
5 C, S, and R points are determined using random numbers (App.1-Table 1).

6 Each plant species is given a height. The height of plants influences the upper limit of  
7 biomass they can retain and their competitiveness (see below, section 1-4 in Appendix 1.  
8 Competition among plant species). The heights of dominant plant species, such as white  
9 popinac and beefwood, are set for the model as shown in App.1-Table 1. For other plants,  
10 heights between 0.1 and 1.0 m for herbaceous species and between 2.0 and 10 m for woody  
11 species are set using uniformly distributed random numbers, so that grass species are not  
12 taller than tree species.

13 In our model, which incorporates area, each plant species has an exclusive habitat area  
14 (occupied area). In proportion to their occupied area, each species is given an upper limit of  
15 biomass that it could achieve. For the purpose of our study, it is assumed that the upper limit  
16 of biomass for each plant species is determined by multiplication of current occupied area  
17 and plant height. If the biomass of species exceeds the upper limit, the excess biomass withers  
18 and dies, turning into litter. It is assumed that plants cannot increase the area they occupy  
19 unless the biomass sufficiency rates (the ratio of the current amount of biomass to the upper  
20 limit of biomass) of them are equal to or larger than a threshold (area increase threshold;  
21 Table 1 in the main text, see below, section 1-3 in Appendix 1). It is also assumed that the  
22 rate of increase of area increases in proportion to the biomass sufficiency rate, because the  
23 high biomass means the plant is under good environmental conditions and growing smoothly.  
24 When the biomass sufficiency rate is 100%, area increases twice as fast as when the biomass  
25 sufficiency rate is 50%. The biomass of a plant species may decrease under poor  
26 environmental conditions. Then, it is assumed that the area a species occupies decreases when  
27 the species cannot maintain its “keep area threshold” (Table 1 in the main text) biomass as  
28 the biomass sufficient rate of the species becomes equal to this threshold. The area no longer  
29 occupied becomes bare ground.

30 Interspecific competition is described by the rule that taller species take occupied space  
31 away from shorter species. Shorter plants lose less occupied area if the difference in height  
32 between competitors is smaller and if the shorter plants are more resistant to competition (for  
33 details, see below, section 1-4 in Appendix 1. Competition among plant species). Herbaceous  
34 plants are shorter and thus less competitive than woody plants. For woody plants, grassland  
35 plays the same role as bare ground and disruption-dependent woody plants have a higher rate  
36 of area increase.

1 It is assumed that a tree species becomes extinct when its biomass decreases below the  
2 biomass of an individual tree. The biomass of an individual tree ( $W$ , kg) is calculated using  
3 the following equation (Koshimizu, 1985):

$$W = k\pi(d/2)^2Hw(1+p), \quad (1)$$

4  
5  
6  
7 where,  $d$  is a diameter at height of human eye (m),  $H$  is a height (m),  $k$  is a coefficient of  
8 stem morphology (approximately 0.5),  $w$  is weight per unit volume of stem (1,300 kg/m<sup>3</sup> on  
9 average), and  $p$  is a coefficient of the amount of branches and leaves (approximately 1.2).  
10 Using the equation, the biomass of a tree with  $H = 10.0$  m (the maximum native tree height  
11 in this model) and  $d = 0.15$  m [diameter at height of human eye of 10-m height of tree—  
12 roughly estimated from Sato & Ueno (1996)] is 137.8 kg. Thus, we simply assumed that the  
13 biomass of an individual tree is height  $\times$  10 kg. The biomass of an individual herb cannot be  
14 calculated using this equation, because herbs do not have lignified stems. However, for  
15 simplicity, we assumed that herbaceous species became extinct under the same condition.

16 White popinac and beefwood are known to be able to fix nitrogen, and this model assumed  
17 that only these species could fix nitrogen. Indeed, white popinacs have been shown to obtain  
18 60% to 80% of their nitrogen requirements through biological nitrogen fixation (Jayasundara  
19 *et al.* 1997). Our model uses nitrogen as the only nutrient and, if we incorporate these nitrogen  
20 fixation rates, white popinac can grow almost freely without any supplemental nutrient. In  
21 reality, of course, plants require many other nutrients besides nitrogen, such as phosphorus,  
22 for growth, and it is therefore assumed that plants can secure 30% of their nitrogen  
23 requirements by biological fixation. If future work allows this model to be updated to  
24 incorporate other nutrient, these previously reported figures for nitrogen will be used.

## 25 26 **1-2. Plant growth**

27  
28 In general, plants grow more if they absorb more nutrient. The absorption rate of nutrient  
29 increases with nutrient density but does not increase infinitely. Growth parameters are  
30 determined by the predominance of the C strategy. If nutrient density is high, C-strategy  
31 species absorb nutrient quickly and grow quickly (the rate of increase in biomass increases).  
32 At low nutrient densities, however, they cannot absorb nutrient and cannot grow. In a natural  
33 setting, a C strategy may be advantageous or disadvantageous depending on environmental  
34 conditions, but in our model, parameters are set based on rules that do not give potential  
35 advantages or disadvantages to particular species. In addition, because faster-growing plants  
36 tend to drop old leaves more quickly, it is assumed that the rate of biomass loss increases and

1 decreases as growth rate does. Plant traits are set as follows:

2 Because C-strategy plants grow quickly under good environmental conditions (Grime,  
3 1974, 1979; Grime *et al.*, 1988), the maximum growth rate per time step of a woody plant is  
4 determined by the following equation:

$$5 \quad (\text{max. growth rate}) = (\text{base growth rate for tree}) / 30 * (\text{C-value}). \quad (2)$$

7  
8 Because the C-value of an average plant species is approximately 30, the average per time  
9 step maximum growth rate is equal to the base growth rate. A species with a C-value of 60  
10 has double the maximum growth rate per time step of a species whose C-value is 30. The  
11 lower limit of maximum growth rate per time step is the minimum growth rate ( $0.1 * \text{base}$   
12  $\text{growth rate for tree}$ ). Because herbaceous plants grow more quickly than woody plants, the  
13 maximum growth rate per time step of herbaceous plants is calculated by multiplying the  
14 value obtained from (1) with a grass coefficient (Table 2 in the main text).

15 C-strategy plants grow quickly when sufficient nutrient is available (Grime, 1974, 1979;  
16 Grime *et al.*, 1988). In contrast, S-strategy (stress tolerant) plants can survive in an  
17 environment deficient in nutrient but do not grow quickly even if sufficient nutrient is  
18 available (Grime, 1974, 1979; Grime *et al.*, 1988). To incorporate this tendency, a species'  
19 (sp1) nutrient absorption rate at one point in time is calculated by the following equation (see  
20 App.1-Fig. 1):

$$21 \quad (\text{absorption rate of sp1}) = x * (\text{nutrient density}) + b, \quad (3)$$

23  
24 where nutrient density is defined as the amount of total nutrient available on an island divided  
25 by the area of the islands,  $x$  is the slope of a line connecting points A and B in App.1-Fig. 1,  
26 and  $b$  is the Y-intercept of the line ( $b$  is not shown in App.1-Fig. 1, because it is smaller than  
27 0.). The C value is utilized to determine the slope as follows:

28 Point A is at coordinates  $(T_1, 0)$ , where  $T_1$  is the density at which nutrient becomes  
29 available to absorb.  $T_1$  increases with the species' C-value and is calculated as  $\text{C-value} \times$   
30  $0.001$ . This means that plant species that predominantly use the C strategy require a higher  
31 nutrient density than plants relying on other strategies. If the nutrient density of the ecosystem  
32 is lower than  $T_1$ , the nutrient absorption rate is the minimum absorption rate ( $0.00001$ , Table  
33 1 in the main text). Point B is at coordinates (H. threshold ND,  $ma1$ ). "H. threshold ND" is  
34 the higher threshold of nutrient density: nutrient are absorbed faster at high nutrient densities,  
35 but because absorption rate does not increase infinitely, it is assumed that absorption rate  
36 stops increasing when nutrient density exceeds "H. threshold ND". For simplicity, all species

1 use the same value for “H. threshold ND”. The y-coordinate,  $ma_1$ , is  $s_1$ 's highest possible  
2 nutrient absorption rate. If  $C = 100$ , then  $ma_1 =$  maximum absorption rate (Table 1 in the  
3 main text and App.1-Fig. 1), and  $ma_1$  is defined so that the area of the ABE triangle equals  
4 the area of the A'B'E triangle. This removes potential advantages and disadvantages in  
5 nutrient absorption rate related to the dominance of the C strategy. In our model, nutrient is  
6 absorbed first by plant species with a higher S-value. This means that S-strategy plant species  
7 gain more competitive advantages in the low nutrient condition.

8 Biomass loss rate for plant species is assumed to increase and decrease in proportion to  
9 growth rate and is calculated by the following equation:

10  
11 biomass loss rate for plant species = base plant biomass loss \* (max. growth rate / base  
12 growth rate for tree). (4)

### 14 **1-3. Increase in area occupied by plant species**

15  
16 Our model incorporates area by considering increases in occupied area as well as increases  
17 in biomass. The rates of increase in area per time step are determined using uniformly  
18 distributed random numbers (see below). White popinac and beefwood, which are known to  
19 rapidly spread and increase their occupied area, are assumed to have the highest rate of area  
20 increase rate among woody plants. Herbaceous plants have a higher rate of area increase than  
21 woody plants. Where bare ground is available, plant species that rely more on the R strategy  
22 increase their occupied area faster. Where bare ground is not available, plants push out shorter  
23 competitors from suitable areas. For woody plants, grassland plays the same role as bare  
24 ground.

25 The area of an island is limited, and the area occupied by plants cannot exceed the area of  
26 the island. If the total occupied area by plants exceeds the area of the island, the occupied  
27 areas of herbaceous plants are equally compressed, because herbaceous plants are less  
28 competitive than woody plants. If the occupied area above the size of the island is greater  
29 than the occupied area of herbaceous plants, all herbaceous plants are wiped out first. For any  
30 remaining occupied area above the size of the island, the areas occupied by woody plant  
31 species are equally compressed so that the total area occupied by plants is equal to the area  
32 of the island.

33 The rate of area increase per time step of native woody plants is given by uniformly  
34 distributed random numbers between the minimum and the maximum values of the rate of  
35 area increase per time step of native woody plant (Tables 1 and 2 in the main text). In this  
36 study, simulations assume that woody plants on bare ground on average expand their

1 occupied area by approximately 10% in one year (Table 1 in the main text). In addition,  
2 because white popinac and beefwood (major introduced tree species) can increase their  
3 numbers quickly, these species' rates of area increase are set as the maximum rate of area  
4 increase. To calculate the rate of area increase of herbaceous plants, which expand faster than  
5 woody plants, the aforementioned random numbers were multiplied by a grass coefficient  
6 (Table 2 in the main text).

7 For plants to increase the area they occupy, they must have sufficient nutritional resources  
8 to produce new plants (including genets). In this study, plants can only increase their area  
9 when the biomass sufficiency rate is higher than the minimum, 50% (area increase threshold,  
10 Table 1 in the main text). As an example, the biomass sufficiency rate of a plant species 1 is  
11 defined as follows:

$$12 \text{ (biomass sufficiency rate)} = \text{biomass of species 1} / ((\text{current occupied area of species 1}) * \text{height of species 1}). \quad (5)$$

15  
16 A species is expected to increase its occupied area faster as its nutritional condition  
17 improves. Therefore, the area increase rate of species 1 is assumed to change with the biomass  
18 sufficiency rate of the species:

$$19 \text{ (current area increase rate)} = (\text{area increase rate specific to species 1}) * (\text{biomass sufficiency} \\ 20 \text{ rate of species 1} / \text{minimum sufficiency rate}). \quad (6)$$

22  
23 At a sufficiency rate of 0.5, the rate of area increase is a value unique to the species, and at  
24 a sufficiency rate of 1.0, the rate of area increases doubles.

25 If bare ground is available on the islands, plants grow faster than normal. Plant species that  
26 predominantly use the R strategy increase their area especially faster. This area increase  
27 coefficient is calculated as follows:

$$28 \text{ (Area increase coefficient)} = 1/30 * R + 1.0. \quad (7)$$

30  
31 If the R-value is zero, the species' rate of area increase is unaffected by available bare  
32 ground and the species always increases its occupied area at the same species-specific rate.  
33 This means that average plants ( $R = 30$ ) double their rate of area increase compared to plants  
34 with an R-value of 0. To calculate area increases of a species, the unique, species-specific  
35 rate of area increase is multiplied with the coefficient obtained here.

#### 1-4. Competition among plant species

Plants try to expand their occupied area even if bare ground is not available and compete for habitat. For the purpose of this study, competition among plant species is defined as a scramble for habitat. In plants, in essence, taller individuals remove their competitors by shading them out. Therefore, competition between species is represented by the process of taller species encroaching into the habitat of shorter species. As an example, consider a case where species 1 encroaches into the habitat of species 2, which is shorter than species 1. When the virtual traits of species 2 lie within a certain part of the attacking range of species 1 (App.1-Fig. 2, for details, see below (section 3-2 in Appendix 1)), the area encroached upon is proportional to the rate of area increase of species 1. If the attacking range of a species is wide, the species competes with many species. The attacking ranges of invasive woody plant species (white popinac and beefwood) are set to large (0.45), because invasive woody plants are widely distributed in various places on the island (Osawa *et al.*, 2016), and then, they would compete with many species. As mentioned above, this is related to the biomass sufficiency rate of species 1. However, if the height difference between the two species is small or if species 2 is highly resistant to stress, it is difficult for species 1 to encroach into the habitat of species 2. In this study, therefore, the area of species 2's habitat encroached upon by species 1 is calculated using a simple Lotka-Volterra equation:

$$\begin{aligned} \text{(area encroached upon)} &= \text{(rate of area increase of species 1)} * \text{(occupied area of species 1)} \\ &* \text{(occupied area of species 2)} * \text{(height difference coefficient)} * \text{(S coefficient)}. \end{aligned} \quad (8)$$

The height difference coefficient is defined by the following equation:

$$\text{(height difference coefficient)} = \text{(height of species 1)} / \text{(height of species 2)} - 1.0. \quad (9)$$

Here, the maximum height coefficient is set at 1. This equation means that if two species do not differ in height, species 1 cannot encroach into the habitat of species 2 (the rate of area increase) and that if species 1 is more than twice as tall as species 2, species 1 can encroach into the habitat of species 2 regardless of the status of species 2 (species 1's rate of area increase is adopted as is).

Species that predominantly rely on the S strategy can reduce competitive pressure. The higher the S-value, the smaller the S coefficient, a measure of a plant's ability to reduce competitive pressure. The S coefficient is set between zero and one and is calculated by the following equation:

1  
2 
$$(S \text{ coefficient}) = (-1) * s\_slope * S\text{-value} + s\_intercept, \quad (10)$$

3

4 where

5  $s\_slope = (1 - 0.5) / 30$

6 and

7  $s\_intercept = s\_slope * 30 + 1.0$

8

9 This equation means that plant species with an average S coefficient (S-value = 30) cannot  
10 reduce competitive pressure (S coefficient = 1), whereas plant species with an S-value of 60  
11 can reduce it to a level of 0.5. When the S-value is 90, the S coefficient is zero, i.e.,  
12 competitive pressure is negated when the S-value is 90 or higher.

13 If bare ground is available, it is more efficient for plant species to expand their occupied  
14 area on to the bare ground than to encroach into areas occupied by other species. It is therefore  
15 assumed that the presence of bare ground reduces competitive pressure (a competition  
16 coefficient is proportional to the coverage of the entire area).

17 Even for tall plant species, if the density of plants is low, sunlight reaches the forest floor,  
18 enabling shorter species to invade and deprive the tall species of habitat. In this study,  
19 therefore, when the biomass sufficiency rate of a plant species falls below a “keep area  
20 threshold”, its occupied area decreases (the occupied area of the species is reduced so that the  
21 biomass sufficiency rate matches the “keep area threshold”).

22

## 23 **2. Traits of animal species**

24

25 Each animal species is given a maximum growth rate, which is defined as the population-  
26 level biomass increase rate when food is sufficient. A biomass increase at the population level  
27 represents offspring being born and growing. For goats, the maximum growth rate is  
28 estimated assuming that two parent goats produce one offspring that matures in one year.  
29 Because black rats have a very high reproductive rate, a biomass increase rate 10 times that  
30 of goats is set for black rats. Many seabird species are known that two parent birds produce  
31 one offspring during one nesting period (Del Hoyo *et al.*, 1992). On the Nakoudojima Island,  
32 the clutch size of black-footed albatross and Bulwer's petrel is 1. That of brown booby is 2,  
33 but only one juvenile leaves the nest because of sibling murder. Then, in the model, all seabird  
34 species have a common maximum growth rate that is estimated assuming that two parent  
35 birds produce one offspring during one nesting period (200 time steps). Invertebrate animals  
36 generally reproduce quickly, but their accurate values are almost unknown. Then, in this study,



1 maximum reproductive rate for invertebrates were chosen from 500 parameter sets (Table 2  
2 in the main text, Appendix 2), and the potential reproductive rate for each invertebrate species  
3 is determined by using a random number (Table 1 in the main text). The biomass decrease  
4 rate per time step is set for animal species as described below (Table 1 in the main text).  
5 Because goats have a lifespan of eight years (Watts & Conley, 1984), the biomass reduction  
6 rate per time step of goats is set assuming that the biomass of the entire population would  
7 decrease to one hundredth of its original size after eight years. For black rats, lifespan is set  
8 at three years (Gaillard *et al.*, 1989) and their biomass reduction rate is set accordingly (Table  
9 1 in the main text). Because seabirds have a mortality rate of approximately 5% per 100 time  
10 steps (Kawakami, unpubl. data), their rate of biomass reduction per time step is set at 0.0005.  
11 For invertebrates, it is assumed that species with a higher reproductive rate have a higher  
12 biomass reduction rate, and the biomass reduction rate per time step is determined by the  
13 following equation:

14  
15 biomass reduction rate per time step = maximum biomass loss for invertebrates \* (potential  
16 reproductive rate of the species / maximum reproductive rate for invertebrates) (11)

17  
18 for terms in the above equation, see Tables 1 and 2 in the main text.

19 Metabolism efficiency ( $T$ ) is estimated using the following equation (Yodiz & Innes,  
20 1992):

21 
$$T = aM^{0.25},$$
 (12)

22  
23 where  $M$  is weight and “ $a$ ” is a coefficient. For  $a$ , the values used by Yodiz & Innes (1992)  
24 are adopted (54.9, 2.3, and 0.5 kg<sup>0.25</sup>/year or 0.1504, 0.002740, and 0.001370 kg<sup>0.25</sup>/time step  
25 for endothermic vertebrates, ectothermic vertebrates, and invertebrates, respectively.  
26 Ectothermic vertebrates are not incorporated in the current Nakoudojima-model with nutrient  
27 cycle). In our model, endothermic vertebrates include goats, rats, and birds, and invertebrates  
28 include multiple species. Each species is likely to have a unique value, but as it is not possible  
29 to obtain data for all species, rough values used by Yodiz & Innes (1992) are adopted for our  
30 model.

31 Animal species included in our model are given different body weights (Table 1 in the  
32 main text). Because goats have an approximate adult weight of 50 kg, the weight is set at 30  
33 kg assuming that the population contains a certain proportion of young goats. The weight of  
34 black rat is set at 0.2kg. The weights of seabirds are determined using uniformly distributed  
35 random numbers between 0.05 kg and 4 kg. The minimum and maximum values are based  
36 on the weight of the smallest and the largest seabird found on the Ogasawara Islands, bulwer's

1 petrel (*Bulweria bulwerii*) and the black-footed albatross (*Diomedea nigripes*), respectively.  
2 The weights of invertebrate species are determined using randomly distributed random  
3 numbers between 0.001 kg and 0.05 kg. This weight range is set arbitrarily. Because predators  
4 are generally larger in size than their prey (Vézina, 1985; Warren & Lawton, 1987; Cohen *et*  
5 *al.*, 1993; Pahl-Wostl, 1997; Neubert *et al.*, 2000; Jennings *et al.*, 2001), the weights of  
6 carnivorous invertebrates are determined using uniformly distributed random numbers  
7 between 0.025 kg and 0.05 kg. The model uses weights in tons.

### 9 **3. Grazing food chain**

#### 11 **3-1. Outline**

13 The species combinations for which predator-prey relationship has been confirmed (Fig.  
14 1) are reproduced in our model. The species combinations for which predator-prey  
15 relationships have not been confirmed, especially relationships involving invertebrates, are  
16 established virtually based on the Niche Model proposed by Williams & Martinez (2000) (see  
17 the former half of section 3-2 in Appendix 1). A predator allocates more predation effort to  
18 prey species with characteristics closer to its preferences (see the latter half of section 3-2 in  
19 Appendix 1). Once the species has filled its requirements for nutrient (becomes satiated), it  
20 stops eating for the time step. Predatory animals prey on animals smaller than them (Vézina,  
21 1985; Warren & Lawton, 1987; Cohen *et al.*, 1993; Pahl-Wostl, 1997; Neubert *et al.*, 2000;  
22 Jennings *et al.*, 2001; Brose *et al.*, 2005). Because homoiothermic animals are highly mobile,  
23 they can spend more effort on eating (the total of their interaction coefficients is high). The  
24 totals of interaction coefficients for individual animal species are shown in Table 2 in the  
25 main text. Black rats feed on all species in the ecosystem including seabird, however, they  
26 cannot feed on seabirds larger than a certain size (Jones *et al.*, 2008, for details, see below,  
27 section 6). Goats feed on all plant species. Korean lawn grass grows from low down the stem  
28 and so is not fatally damaged by goats' feeding (Kachi, pers. obs.). Seabirds do not forage on  
29 the islands but feed on fish out at sea, absorbing necessary nutrient there. Interaction  
30 coefficients for fish are set as constant (Table 1 in the main text). In this model, invertebrate  
31 is divided into carnivore, herbivore, dung feeder, litter feeder, and scavenger. Herbivore is  
32 divided into two groups; one grazes tree and the other grazes grass. Resources and animals  
33 consuming them are listed in App.1-Table 2.

34 Seabirds concentrate their feeding effort on fish out at sea. Litter feeders, dung feeders,  
35 and scavengers concentrate their feeding effort on their own resources. Herbivores (including  
36 goat) and carnivores usually feed on two or more species. In this case, interaction coefficients

1 of consumers (herbivores and carnivores) to each prey species are determined via two steps:  
2 (1) the relative values of interaction coefficient are set by the manner shown in section 3-2,  
3 (2) according to the relative values obtained in step 1, consumers distributed their feeding  
4 effort (the total of their interaction coefficients). As mentioned above, black rats feed on all  
5 species. Moreover, they also feed on animal carcasses. For the manner how to determine  
6 interaction coefficients of black rats, see below (section 6).

7 The amount of biomass which species 1 intakes from species 2 is calculated by using the  
8 following Holling Type III function (Yamamura *et al.*, 1978);

$$\frac{dM_1}{dt} = \frac{kM_1M_2^2}{h+M_2^2}, \quad (13)$$

11 where  $M_1$  and  $M_2$  are the amount of species 1 (predator) and 2 (prey), respectively,  $k$  is an  
12 interaction coefficient when species 1 (predator) feeds on species 2 (prey),  $h$  is a constant  
13 representing handling time (Holling, 1959). Species 1 assimilates a certain rate of the biomass  
14 intake.  
15

16 The assimilation rate varies according to a combination of species 1 and 2 or resource type  
17 (App.1-Table 2). The details are as follows.

18 Assimilation rates are defined mainly based on Begon *et al.* (1996) and are listed in App.1-  
19 Table 2. When an animal species eats another animal species or carcasses, the assimilation  
20 rate is set to 80%. When an animal species eats plants, the assimilation rate differs according  
21 to the parts of the plant eaten. When an animal eats leaves or grasses, the assimilation rate is  
22 set to 50%. When an animal species eats seeds or fruits, the assimilation rate is set between  
23 60 and 70%.

24 For setting assimilation rates for herbivorous invertebrates, we refer to the measured value  
25 (64.67-75.72%: Li *et al.*, 2003). Then in the model, the assimilation rates of herbivorous  
26 invertebrates are set by using a random number uniformly distributed between 0.65 and 0.75.  
27 As the assimilation rates of carnivores and scavengers are higher than those of herbivores  
28 (Begon *et al.*, 1996), those of carnivorous or scavenging invertebrates are set by using a  
29 random number uniformly distributed between 0.75 and 0.85. There is no data for the  
30 assimilation rates of litter and dung feeding invertebrates. Because the litter and dung of goats  
31 are terminal forms of plants, the assimilation rates of litter and dung feeding invertebrates are  
32 set in the same manner as that for herbivorous invertebrates.

### 34 **3-2. Setting interspecific interactions**

1 Predator-prey relationships based on the niche model are determined as follows. All  
2 species are given a virtual trait and a feeding preference. These are determined using  
3 uniformly distributed random numbers between 0 and 1. In addition, individual animal  
4 species are given a range of feeding preference (Table 1 in the main text, App.1-Fig. 2). An  
5 animal species (sp *i* in App.1-Fig. 2) feeds on prey species whose virtual traits lie within a  
6 certain part of its feeding preference range (App.1-Fig. 2). Carnivores do not feed on plants  
7 and herbivores do not feed on other animals. The original niche model has one undesirable  
8 characteristic: if a species' feeding preference is close to the ends of the range (0 or 1), its  
9 range of feeding preference falls partly outside the trait range, reducing the number of its  
10 potential prey species. In our model, therefore, the ends of the trait range are connected to  
11 make it circular (App.1-Fig. 2). This improvement reduces potential advantages or  
12 disadvantages caused by feeding preference value.

13 In our model, animals are given a higher interaction coefficient for prey species with trait  
14 values closer to their own feeding preference (they allocate more predation effort to these  
15 species). Specifically, the interaction coefficient for predators consuming a prey species with  
16 a trait value that is 0.5 (the upper limit of the feeding preference range) higher or lower than  
17 its own feeding preference is set at one-tenth of the interaction coefficient of the predator that  
18 consumes species with the same trait value as its own feeding preference. Relative values of  
19 interaction coefficient are adjusted by using the following linear function:

$$20 \quad 21 \quad 22 \quad 23 \quad 24 \quad 25 \quad 26 \quad 27 \quad 28 \quad 29 \quad 30 \quad 31 \quad 32 \quad 33 \quad 34 \quad 35 \quad 36 \quad RV = -1.8 \times DIFF + 1.0, \quad (14)$$

where RV is a relative value of interaction coefficient, DIFF is an absolute value of the  
difference between values of the feeding preference of a predatory species and the virtual trait  
of a prey species (App.1-Fig. 3). Specific values are adjusted so that the total sum of feeding-  
related interaction coefficients is equal to the upper limit given to each species (Table 2 in the  
main text). In this manner, specialists and generalists are incorporated. Species with a narrow  
range of feeding preference allocates high predation effort to a few species of which virtual  
traits fall in a narrow range (shaded area in App.1-Fig. 3). Such a species is regarded as a  
specialist.

Moreover, each animal species feeds first on species with a trait value close to its own  
feeding preference and then stops feeding once it has ingested its nutrient requirement. The  
nutrient requirement (NR) of plant species is calculated by the following equation:

$$NR = PIR * NC, \quad (15)$$

1 where PIR is a potential increase rate of biomass of the species per unit time, and NC is a  
2 nitrogen content for the species. The unit time is 0.1 time step.

3 NR of animal species is calculated by the following equation:

$$4 \quad \quad \quad 5 \quad \quad \quad \text{NR} = (\text{PIR} + \text{T}) * \text{NC}, \quad \quad \quad (16)$$

6  
7 where T is an amount of biomass lost by metabolism per unit time.

8 In this model, several types of interference are considered. Taller plant species encroach  
9 into the habitat of shorter species. Goats and seabirds stomp plant species. Goats stomp nests  
10 of seabirds. Whether a species interferes with other species is decided by using the frame  
11 work of the niche model (App.1-Fig. 2). In this frame work, the formers correspond to  
12 predator, and the latter correspond to prey. In this case, attacking range feeding preference  
13 and virtual trait of attacker are utilized instead of range of feeding preference and feeding  
14 preference of predator, respectively. Coefficients of interference between plant species are  
15 shown in section 1-4, for other cases of interference, see Table 1 in the main text.

#### 16 17 **4. Detritus food chain**

18  
19 Our model also considers the detritus-based food chain, which includes invertebrates that  
20 use plant litter, animal droppings, and animal carcasses. The only animal droppings available  
21 are goat droppings; on the Ogasawara Islands, no animals have been observed to use  
22 droppings other than those of goats. Plant litter, droppings, and carcasses are decomposed  
23 into nutrient over given periods of time (see below); however, the model does not consider  
24 the age of detritus when ingested by animals (detritus is ingested equally regardless of when  
25 it was deposited). Ingestion efforts spent on different types of detritus are defined by the  
26 maximum sum of interaction coefficients given to each species.

#### 27 28 **5. Optimal foraging**

29  
30 Our model considers optimal foraging so that predation efforts change according to  
31 changes in the amount of prey available. For simplicity, the same learning period (10 time  
32 steps, Table 1 in the main text) is used for all species. During a learning period, all animal  
33 species learn how much nutrient they obtained from each prey species. The data are then  
34 compared with the last learning period. The interaction coefficient for the next learning period  
35 is calculated as x times the current interaction coefficient, where x is the relative amount of  
36 nutrient obtained from a species during a learning period compared to the last learning period.

## 6. Interactions involving black rats

Rats are omnivorous animals, feeding on both animals and plants (including white popinacs; Hashimoto, 2009). Therefore, in this study, most animal and plant species included in the model are subject to predation pressure by rats. Rats are known to be important predators of seabirds and have caused extinctions of several seabird species worldwide (Jones *et al.*, 2008; Scofield, 2009; Yabe *et al.*, 2009; Croxall *et al.*, 2012; Ringler *et al.*, 2015). Moreover, they also feed on animal carcasses. Then, the manner of setting interaction for black rats is complicated, but the fundamental frame work is the same as other cases; (1) setting the relative values of interaction coefficient, (2) distributing the feeding effort of black rat according to the relative values obtained in step 1. In the case of black rat, step (1) is divided into 3 sub-steps;

(1)-1: for invertebrate prey, the relative values of interaction coefficient are set by the manner shown in section 3-2,

(1)-2: for seabirds, the relative values of interaction coefficient are set by the manner explained later (see below),

(1)-3: the ratio of depending on animal carcasses is set by using a random number uniformly distributed from 0.1 to 0.3 (see below).

Step (2) is divided into two sub-steps;

(2)-1: a part of the feeding effort of black rat (the total of its interaction coefficients) is assigned to feeding animal carcasses according to the ratio obtained in the step (1)-3,

(2)-2: the remainder of the feeding effort is distributed according to the relative values obtained by steps (1)-1 and (1)-2.

Small seabirds are especially vulnerable to predation by rats (Seto & Conant, 1996; Jones *et al.*, 2008). It is well known that rats eat also large seabirds (Caut *et al.*, 2008; Grant-Hoffman *et al.*, 2010). According to Jones *et al.* (2008, Fig. 2b), the effect of rats on seabirds of which body size are over 900g is very small. Then, in this study, we simply assumed that rats do not eat seabirds of which body size are over 1kg, and the relative strength of the rats' predation pressure on seabirds is defined in this study as:

$$PP = - max.P * Mb + max.P, \quad (17)$$

where  $PP$  is relative predation pressure,  $max.P$  is a maximum predation pressure given as initial value, and  $Mb$  is an adult weight of a seabird species.

Rats are also scavengers and thus a component of the aforementioned detritus food chain,

1 feeding on animal carcasses. In this study, due to a lack of detailed data on the extent to which  
2 rats feed on animal carrion, it is assumed that carrion makes up between 10% and 30% of the  
3 rats' diet at the beginning of a simulation. This initial value is determined using uniformly  
4 distributed random numbers and is allowed to fluctuate during the simulation according to  
5 the amount of carrion in a given ecosystem (see Appendix 1. section 5). Specifically, the  
6 proportion of carrion in the diet increases two-fold of the initial value if the amount of animal  
7 carrion in the ecosystem doubles.

8 The rats' assimilation efficiency is defined based on Begon *et al.* (1996). Assimilation  
9 efficiency is 80% when the rats eat animals (including carrion) and 60–70% when they eat  
10 plants, assuming they predominantly eat seeds and fruits (actual values are determined using  
11 uniformly distributed random numbers). Therefore, when rats feed on plants, it is assumed  
12 that only part of the plant species' biomass is subject to herbivory pressure. This ratio can be  
13 determined by measuring the proportion of seeds and fruits relative to the plant body.  
14 However, since rats are known also to eat plant bodies (e.g., the bark of white popinacs) in  
15 addition to their seeds and fruits (Hashimoto, 2009), in this study, the ratio of plant biomass  
16 when the plant species is fed on by rats is arbitrary set at 0.3. In the actual calculations,  
17 predation effort (interaction coefficient) of rats on a plant species is multiplied by 0.3.

## 18 19 **7. Interactions involving goats**

20  
21 Because goats are herbivores, eating a wide variety of plant species including introduced  
22 species. On the Nakoudojima Island, feral goats grazed on white popinac (Osawa *et al.*, 2016).  
23 It is assumed that they feed on all plants used in the model. Lawn grasses are not critically  
24 damaged through herbivory by goats as their growth points are so close to the ground, and so  
25 it is assumed here that herbivory by goats does not decrease the biomass of lawn grasses  
26 below the “keep area threshold” (Table 1 in the main text, section 1-1 in Appendix 1). When  
27 the biomass of lawn grasses reaches this threshold, goats stop feeding on lawn grasses and  
28 consequently the area occupied by lawn grasses does not decrease by goats grazing.

29 Goats are known to disrupt ecosystems not only through what they eat but also by  
30 physically damaging plants (e.g., trampling) and interfering with seabirds' nesting activity,  
31 among other things (Coblentz, 1978; Stone & Loope, 1987; de la Luz *et al.*, 2003). In this  
32 study, it is assumed that goats negatively affect all plants in the ecosystem through feeding,  
33 and the impact of trampling is thus not additionally considered. In this model, whether a bird  
34 species' nesting is interfered by goats is determined by using the same framework shown in  
35 the former half of section 3-2 in Appendix 1. In this case, goats and birds correspond to  
36 predator and prey, respectively. The value of interaction coefficients between goats and birds

1 are constant (Table 1 in the main text).

## 3 **8. Interactions involving seabirds**

5 Our ecosystem model includes seabirds. Seabirds do not eat other organisms on an island,  
6 as they do not forage there, but rather feed on fish at sea. In this study, fish biomass is set to  
7 a constant 1.0. The amount of fish eaten by seabirds is defined by the following Holling III  
8 equation:

$$10 \text{ Amount of fish eaten} = dt * M_{SB} * C_{SBF} * M_{fish}^2 / (h_{SBF} + M_{fish}^2), \quad (18)$$

11  
12 where  $dt$  is time,  $M_{SB}$  and  $M_{fish}$  are the biomasses of seabirds and fish around an island,  
13 respectively,  $C_{SBF}$  is the interaction coefficient between seabirds and fish, and  $h_{SBF}$  is a  
14 constant measuring the cost of handling (Table 1 in the main text).

15 In this study, seabirds are classified as forest-nesting or grassland-nesting, and seabirds  
16 belonging to the same nesting type compete for nesting sites. Scrambling for nest sites occurs  
17 between seabirds with similar traits, i.e., similar nest site preferences. Further, scrambling for  
18 nest sites is one-sided, not interactive interference competition, such that larger birds chase  
19 away smaller birds. Whether scrambling for nest sites occurs is determined by using the same  
20 framework shown in the former half of section 3-2 in Appendix 1. In this case, bigger and  
21 smaller birds correspond to predator and prey, respectively. The values of interaction  
22 coefficients between birds are determined by a uniformly distributed random number (Table  
23 1 in the main text). It is assumed that seabirds of the same size avoid each other and do not  
24 compete for nest sites.

25 Seabirds do not walk far but are known to trample plants around their nests. Whether  
26 trampling of plants by seabirds occurs is determined by using the same framework shown in  
27 the former half of section 3-2 in Appendix 1. In this case, birds and plants correspond to  
28 predator and prey, respectively. Grassland-nesting seabirds trample herbaceous plants and  
29 forest-nesting seabirds trample woody plants. The degree of trampling (values of interaction  
30 coefficients between seabird and plant) is constant (Table 2 in the main text).

## 32 **9. Decomposition and weathering**

33  
34 Our ecosystem model includes detritus (animal feces/carcasses/litter) and its  
35 decomposition is modeled as follows.

36 Carcasses and litter contain the same nutrient as their producers (because carcasses and



1 litter are the same biological material as what produces them). Animals excrete as feces the  
2 food that they could not assimilate. For simplicity, it is assumed animals excrete as feces the  
3 food that they could not assimilate. Then, the nutrient content of feces is the same as that of  
4 the ingested food.

5 Detritus is decomposed over a given time and reverts to nutrient. It is known that animal  
6 detritus tends to decompose more quickly than plant detritus (Briggs, 1995; Sansom *et al.*,  
7 2010; Hata *et al.*, 2012; Klompmaker *et al.*, 2017). In this study, it is assumed that animal  
8 carcasses/feces and litter decompose fully in 10 and 100 time steps, respectively (Table 1 in  
9 the main text).

10 Detritus produced on a given time step is stored in detritus pools, which are defined  
11 separately for goat feces, feces of other animals (including seabirds), animal carcasses, and  
12 animal litter. The proportion of nutrient contained in the detritus pools is re-calculated each  
13 time more detritus is added.

14 Detritus in each pool, excluding feces of invertebrates and seabirds, is used by detritus-  
15 feeding animals every time step, and thus the size of the pools decreases (see above for more  
16 details on the detritus food chain).

17 Detritus is lost not only through use by organisms but also through leaching out of the  
18 system due to rainfall and wind. Litter outflow per time step is set to allow that the loss of  
19 25% of litter over 100 time steps, according to the experiment of Hata *et al.* (2012) conducted  
20 on the Ogasawara Islands using beefwood litter. Similar data on animal detritus is lacking, so  
21 the rate is set to 25% over 10 time steps.

22 After a set period has passed since detritus production (100 time steps for litter and 10 time  
23 steps for animal carcasses and feces), nutrient contained in the remaining detritus move to the  
24 ecosystem-level nutrient pools.

25 Actual decomposition comprises complex biological and chemical processes involving  
26 microorganisms such as soil bacteria. However, since the bacterial ecosystem is largely  
27 unknown and the main objective of this study is to characterize the ecosystem of large  
28 terrestrial organisms, a very simple decomposition process is adopted for the model in order  
29 to avoid using excessively complicated models.

## 31 **10. Target islands**

32  
33 This study targets the ecosystems of Nakoudojima Island, Higashijima Island, and  
34 Nishijima Island of Ogasawara Islands, which are small islands with areas of 1.38 km<sup>2</sup>, 0.28  
35 km<sup>2</sup> and 0.49 km<sup>2</sup>, respectively. Small islands are suitable for this study because the model  
36 does not contain an explicit spatial structure. The bigger an island, the greater the role of

1 environmental heterogeneity, as well as migration and dispersion of organisms, making it  
2 difficult to treat the island as a single ecosystem.

3 These islands have interesting characteristics. It is believed that Higashijima Island has a  
4 relatively undisturbed ecosystem, as goats were eradicated from the island a long time ago  
5 (Kanto Regional Environment Office of Japan *et al.*, 2010). Nakoudojima Island, on the other  
6 hand, has been heavily impacted by goats, and vegetation is disappearing from the whole  
7 island. Nishijima Island is unique in its history. According to Abe *et al.* (2011), the major  
8 vegetation of Nishi-jima was plantations of luchu pines (*Pinus luchuensis*) and beefwood  
9 until the 1970s. But pinewood nematodes were introduced to the island, eliminating the pines  
10 and stripping the island of vegetation (Shimizu, 1986). Consequently, beefwood quickly  
11 expanded its distribution to the now-bare areas and formed beefwood forests.

12 This study first explores a set of parameters capable of reproducing the ecosystem of  
13 Nakoudojima Island. This study is supported by a project based primarily on Nakoudojima  
14 Island, so field data are readily available. Based on this parameter set, the study then examines  
15 whether the ecosystems of Higashijima Island and Nishijima Island can also be reproduced.  
16 As Higashijima and Nishijima Islands are much smaller than Nakoudojima Island, initial rates  
17 of area increase for individual plant species were too low, such that calculations for small  
18 time-steps returned very little change in vegetation from the initial state. Therefore, for the  
19 simulations of Higashijima and Nishijima Islands, area increase rates for all plant species are  
20 twice as high as those of Nakoudojima Island.

21 To confirm whether an island ecosystem has been successfully modeled, surveys should  
22 ideally be conducted on all species in the ecosystem to demonstrate that those species coexist  
23 in the modeled ecosystem at the surveyed biomasses. However, in reality it is very difficult  
24 to identify all constituent species of an ecosystem and almost impossible to measure their  
25 biomasses. This study aims to show that the main constituent species (goats, rats, white  
26 popinacs, [beefwood], Korean lawn grass, and sufficient numbers of endemic woody plant  
27 species, herbaceous plant species, seabird species, and invertebrate species) coexist and to  
28 reproduce the proportional areas of forests, grassland and bare ground found on the target  
29 islands. Actual areas of forests, grassland, and bare ground can be measured using maps  
30 created based on aerial photographs and other means. Vegetation proportion data for  
31 Nakoudojima Island were collected immediately before the eradication of goats (Hata *et al.*,  
32 2007). Vegetation proportion data for Higashijima Island and Nishijima Island are calculated  
33 from the Ogasawara Islands Ecosystem Conservation Action Plan (Kanto Regional  
34 Environment Office of Japan *et al.*, 2010).

35 Species that constitute the ecosystems of these three islands and interspecies interactions  
36 are determined based on the information included in the Ogasawara Islands Ecosystem

1 Conservation Action Plan (Kanto Regional Environment Office of Japan *et al.*, 2010) (Table  
2 A.1 in the main text). Because definitive information is lacking, the invertebrate species were  
3 allocated in equal numbers to different foraging guilds except for herbivores. If the number  
4 of herbivorous invertebrate species is smaller than the number of plant species, it is likely  
5 that some plants are initially not consumed at all. Such plants would enjoy extreme  
6 advantages in the ecosystem. To avoid this, the number of herbivorous invertebrate species  
7 is set at 40 (twice the number of any other feeding habit type) so that the number of  
8 herbivorous invertebrate species exceeds the total number of plant species.

## 11. Other assumptions

13 The model assumes nitrogen contents of approximately 2% for plants, 11% for  
14 invertebrates (insects: Schoonhoven *et al.*, 1998), and 12% for mammals (goats and rats:  
15 Takahashi, 1984) and, by analogy, for seabirds. To address expected variation between  
16 species in nitrogen content, the precise values are determined using uniformly distributed  
17 random numbers ( $-10\% \leq \text{standard nitrogen content} \leq 10\%$ ).

18 Seabird species commonly nest on more than one island. If a seabird population becomes  
19 locally extinct on one island, individuals of the same species are able to recolonize from other  
20 islands. In this study, it is assumed that if any of an island's seabird species becomes locally  
21 extinct, one pair of the species migrates from another island.

22 If this rule is adopted, however, seabirds will never become extinct, which would preclude  
23 considerations of diversity in the model. Therefore, it is assumed that seabirds cannot be  
24 observed unless there are at least 10 nesting pairs.

25 Our model offers special considerations to the following introduced species: goats, rats,  
26 white popinacs, beefwood, and Korean lawn grass (an endemic dominant grassland species).  
27 Presence or absence of each of these species on each island is determined based on the current  
28 status of each island (Table A.1 in the main text).

29 Simulation run time is 10,000 time steps, and after this period, the status of the modeled  
30 ecosystem is analyzed. Simulations are run 1,000 times for each island.

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1 App.1-Table 1. Properties of plant species.

Name or type of plants	C	S	R	height	rate of area increase
white popinac ( <i>Leucaena</i> )	30	10	60	6	0.001
beefwood ( <i>Casuarina</i> )	40	10	50	15	0.001
bamboo	20	40	40	8	[0.0001-0.0005]
lawn grass	20	40	40	0.1	[0.0005-0.0025]
bamboo grass	20	40	40	1	[0.0001-0.0005]
native trees	[0-100.0]	[0-100.0]	[0-100.0]	[2.0-10.0]	[0.0001-0.0005]
native grasses	[0-100.0]	[0-100.0]	[0-100.0]	[0.1-1.0]	[0.0005-0.0025]

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C, S, and R represent parameters of Grime's triangle. For details, see section 1-1 in Appendix 1. Pairs of numbers in square brackets represent the maximum and minimum values of random numbers uniformly distributed, for example, [0-100.0] represents a random number uniformly distributed between 0 and 100.0.



1 App.1-Table 2. List of resources and values of assimilation rate.

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	tree	grass	seabird	invertebrate	plant litter	droppings of goat	animal carcasses	fish
goat	0.5	0.5	–	–	–	–	–	–
rat	[0.6-0.7]	[0.6-0.7]	0.8	0.8	–	–	0.8	–
seabird	–	–	–	–	–	–	–	0.8
invertebrate								
herbivore (eating tree)	[0.65-0.75]	–	–	–	–	–	–	–
herbivore (eating grass)	–	[0.65-0.75]	–	–	–	–	–	–
carnivore	–	–	–	[0.75-0.85]	–	–	–	–
litter feeder	–	–	–	–	[0.65-0.75]	–	–	–
dung feeder	–	–	–	–	–	[0.65-0.75]	–	–
scavenger	–	–	–	–	–	–	[0.75-0.85]	–

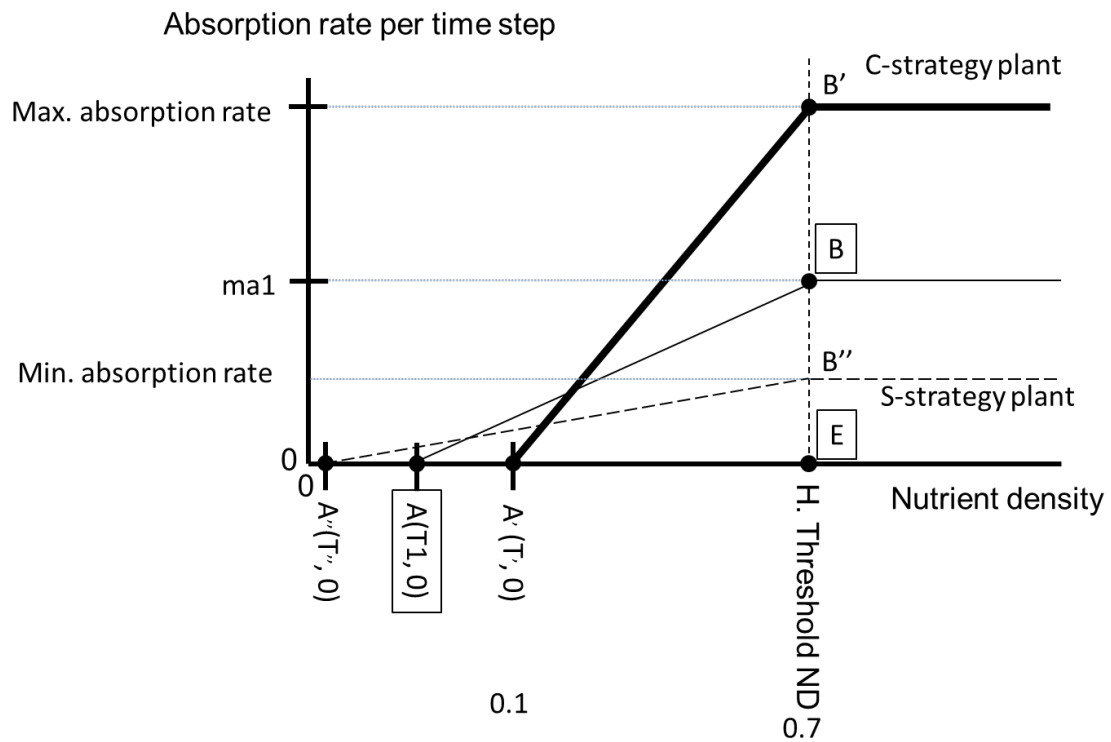
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5 The left column shows the types of animal species. The upper row shows the types of  
 6 resources. The mark “-” means that this type of animal does not eat this resource. Numbers  
 7 represent assimilation rates when animal species eat each resource. Pairs of numbers in square  
 8 brackets mean that the assimilation rate when the species eats the resource is set by using a  
 9 random number uniformly distributed between these numbers.

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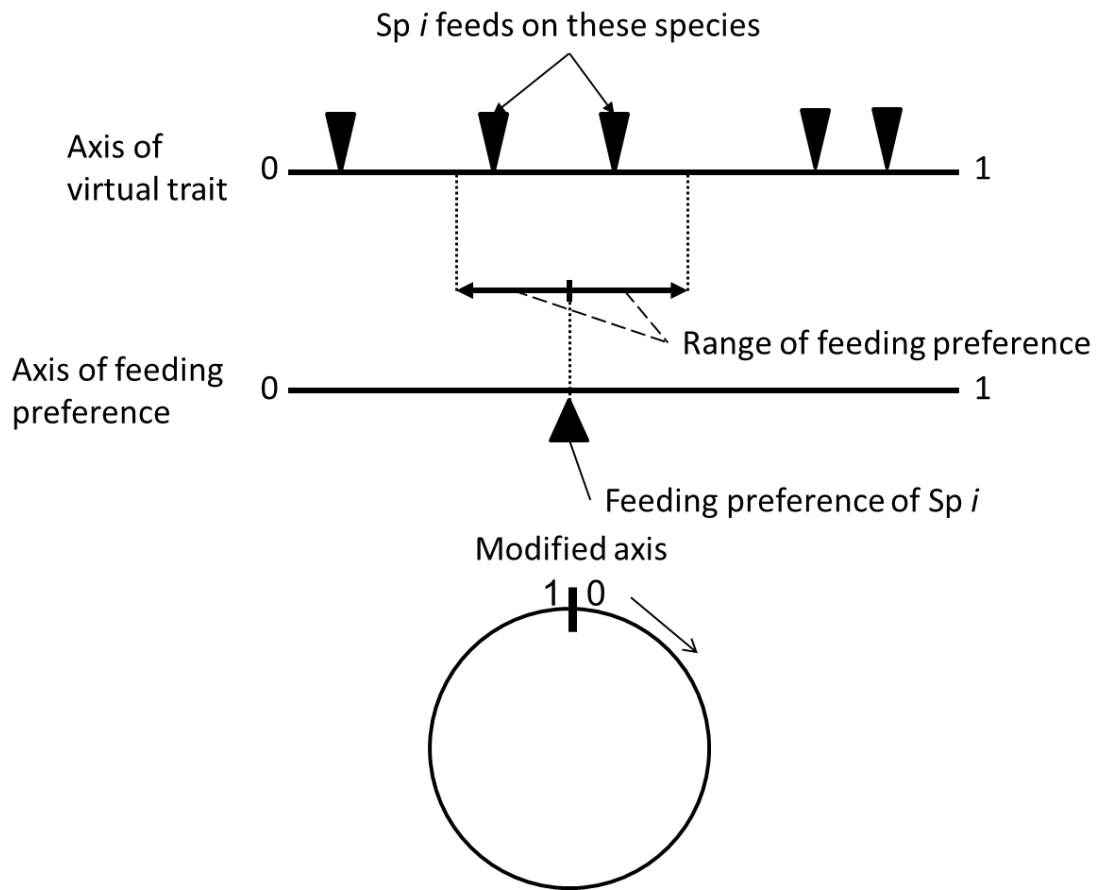
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App.1-Figure 1. Relationship between nutrient density and absorption rate.

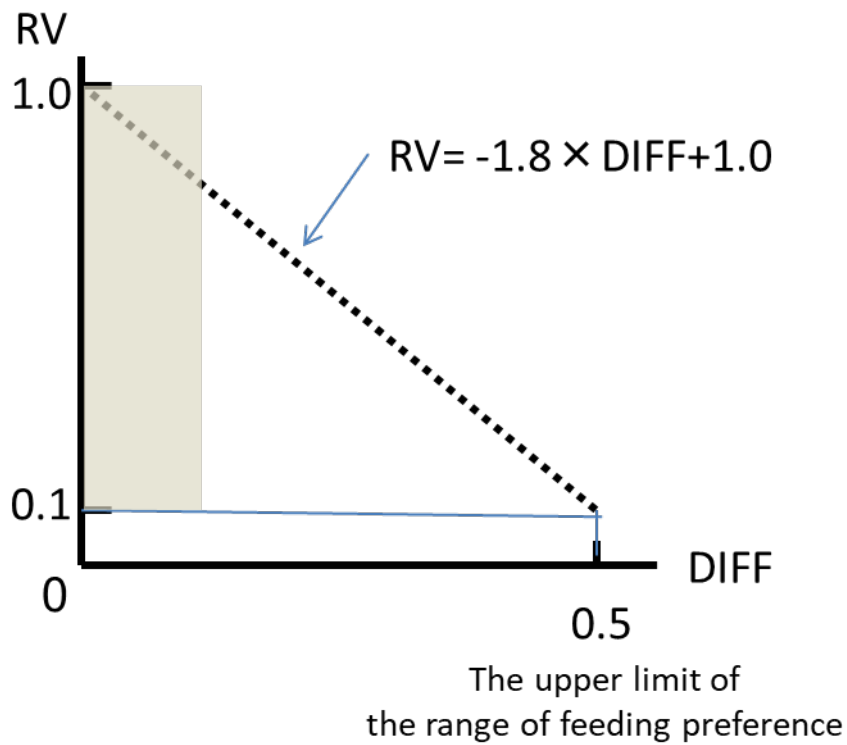
Solid, bold, and dotted lines represent the profiles of the nutrient absorption rates for moderate, C-strategy, and S-strategy plant species, respectively. A, A', and A'' represent the minimum nutrient density at which nutrients become available to absorb for moderate, C-strategy, and S-strategy plant species, respectively. B, B', and B'' represent the maximum nutrient density for moderate, C-strategy, and S-strategy plant species, respectively. "H. Threshold ND" represents the higher threshold of the nutrient density. Nutrients are absorbed faster at high nutrient densities, but because absorption rates do not increase infinitely, it is assumed that the absorption rate stops increasing when nutrient density exceeds "H. threshold ND".



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App.1-Figure 2. Schematic figure of the modified Niche-Model

Species *i* (Sp *i*) feeds on species that have virtual traits that fall within the range of the feeding preferences of species *i*. To reduce the disadvantage of a predatory species, which has a value of feeding preference close to the ends of the range (0 or 1), the ends of the trait range are connected to make it circular. Interspecific competition is set by the same manner. For details, see section 3-2 of Appendix 1.



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App.1-Figure 3. Schematic figure showing how to determine the allocation of predation effort.

This figure shows that the allocation of predation effort is determined by the linear function (the dotted line). RV: a relative value of interaction coefficient, DIFF: an absolute value of the difference between values of the feeding preference of a predatory species and the virtual traits of a prey species. Specialists, which have a narrow range of feeding preference, allocate a high predation effort to a few species, of which virtual traits fall in a narrow range (shaded area). For details, see section 3-2 of Appendix 1.