Electronic Supplementary Material

1. Details of cascading habitat-formation

Cascading habitat-formation is a hierarchically structured process because the secondary habitat-former is dependent on the primary habitat-former (typically physical dependency, either obligate, such as mistletoes or facultative, such as vines) [1]. The secondary habitat-former is generally smaller than the primary habitat-former (but see examples 13-17 in Figure 1 for exceptions). The secondary habitat-former typically has negative effects on the primary habitat-former (e.g., through competition for limited resources or by increasing drag), although positive effects can also occur (e.g., through stress reduction or associated enemy escape). The strength of reciprocal effects between the co-existing habitat-formers and end-users can therefore determine the spatio-temporal stability of the habitat cascade. We suggest that the magnitude of facilitation associated with the secondary habitat-former is great (1) the larger, more abundant and more ecologically/functionally different the secondary habitat-former is compared to the primary habitat-former, (2) at opposite end-points of environmental stress gradients because end-users here are more likely to escape stress and enemies and find resources and friends, and (3) when alternative pathways for end-users to escape stress and enemies and find resources and friends, are weak (= weak dilution/strong concentration-processes), for example if spatio-temporal heterogeneity, food web complexity, or adjacent and interspersed habitats are low and small [1-2]. Thus, cascading habitat-formation is typically density-mediated [1, 3-6], although trait-mediated indirect facilitation can also occur [7].

Facilitation of end-users from cascading habitat-formation can occur autogenically (i.e., within/on the secondary habitat-former) and allogenically (i.e., through ecological subsidy) from either locally (e.g., mistletoe litter fallen to the forest floor [8-10]) or from adjacent ecosystems (e.g., through advection processes, such as when seaweeds fixed in polychaete gardens dislodge and are transported to adjacent salt marshes together with their end-user communities [11]), and across terrestrial, freshwater and marine ecosystems as observed for trophic cascades [12]. Cascading habitat-formation can control species abundances, patterns of diversity and ecosystem functioning across biogeographic, taxonomic and latitudinal realms, in terrestrial (see example 1-5 in Figure S1 below), semi-terrestrial (example 6-8), freshwater (example 9 and 13), and marine (example 10-17) ecosystems. Indirect facilitation
is here described within a habitat-formation framework; however, similar indirect facilitation processes can often be applied to other types of co-existing ‘ecologically important species’ (e.g., keystone resources/species, foundation species, habitat-modifiers, ecosystem engineers, structural species, transformer species, dominants, core species) [13-20].
**Figure S1. Common types of cascading habitat-formation.** Cascading habitat-formation can increase diversity and abundance of end-users: primary habitat-formers (light grey) cause indirect positive effects on end-users by physically controlling secondary habitat-formers (dark grey). **Example 1:** A eucalyptus tree provides habitat for birds (long black arrow) and mistletoes (short black arrow), and mistletoes provide additional habitat for additional birds (short black arrow). The tree has both direct and indirect positive effects on birds, resulting in net facilitation of bird communities (bend arrow). **Examples 2-17:** Examples of co-existing habitat-formers in terrestrial (2-5), semi-terrestrial (6-8), freshwater (9, 13), and marine (10-17) ecosystems. See footnote for details on the interacting habitat-formers, associated end-users, and scientific case-studies. Symbols are courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Footnote: to ease comparison, the fundamental primary habitat-former, the facilitated secondary habitat-former, and the facilitated end-users are emphasized in underlined, bold, and italic type, respectively. Ball-park sizes of habitat-formers are included for comparisons –
actual sizes can, of course, vary by orders of magnitude depending on age of the habitat-formers and environmental conditions. These examples do not represent an exhaustive list; more combinations between these, and other, co-occurring habitat formers are likely to be common.

1*Eucalyptus* trees (c. 10-30 m) provide habitat for *mistletoes* (c. 1 m) to facilitate more *birds* [8, 10, 21] (experimental and correlative evidence).

2*Trees* (c. 10-30 m) provide habitat for *nest epiphytes and orchids* (c. 1 m) to facilitate more *birds and invertebrates* [22-33] (experimental and correlative evidence).

3*Trees* (c. 10-30 m) provide habitat for *lianas* (c. 10-20 m) to facilitate more *invertebrates* [34-36] (correlative evidence).

4*Trees* (c. 10-30 m) provide habitat for *vines* (c. 5-15 m), *ferns* (c. 1 m), *lichens and mosses* (c. 0.02-0.05 m) to facilitate more *invertebrates and birds* [36-41] (correlative evidence).

5*Grasses* (c. 1 m) provide ‘habitat’ for *hemi-parasitic plants* (c. 0.2 m) to facilitate more *invertebrates* [42] (suggestive evidence).

6*Mangroves* (c. 10-50 m) provide habitat for *seaweeds* (c. 0.5 m) to facilitate more *invertebrates* [4, 43-44] (experimental and correlative evidence).

7*Salt marshes* (c. 1 m) provide habitat for *seaweeds* (c. 0.3 m) to facilitate more *invertebrates* [45] (experimental evidence).

8*Salt marshes and seagrasses* (c. 1 m) provide habitat for *mussels* (c. 0.1 m) to facilitate more *invertebrates and seaweeds* [46-48] (experimental and correlative evidence).

9*Freshwater and marine plants* (c. 0.5 m) provide habitat for *colonial diatoms and other microbial biofilms* (c. 0.001 m) to facilitate more *invertebrates* [49-53] (these epiphytes are not habitat-formers *sensu strictu* but rather a trophic subsidy; i.e., these studies show that consumers can have positive indirect effects on primary habitat-formers by preferentially consuming epibionts. This type of ‘keystone consumption’ [1] is thereby a mirror-process of cascading habitat-formation/modification and facilitation).

10*Seagrasses and seaweeds* (c. 0.3-1 m) provide habitat for *epiphytes* (c. 0.02-0.2 m) to facilitate more *invertebrates* [54-57] (experimental and correlative evidence).
11 Seagrasses (c. 0.5 m) provide habitat for seaweeds (c. 0.2 m) to facilitate more invertebrates [3, 58-59] (experimental evidence).

12 Corals (c. 0.5 m) provide habitat for polychaetes, sponges, seaweeds, and other sessile organisms (c. 0.1 m long) [60-62] to facilitate more invertebrates (experimental, correlative and suggestive evidence).

13 Mussels (c. 0.1 m) provide habitat for seaweeds (c. 0.2 m) to facilitate more invertebrates [1, 59, 63] (experimental and correlative evidence).

14 Oysters (c. 0.1 m) provide habitat for seaweeds (c. 0.2 m) to facilitate more invertebrates (suggestive evidence).

15 Cockles (c. 0.02 m) provide habitat for seaweeds (c. 0.1 m) to facilitate more invertebrates [1] (correlative evidence).

16 Gastropods (c. 0.02 m long) provide habitat for seaweeds (c. 0.2 m) to facilitate more invertebrates [1] (correlative evidence).

17 Polychaetes (c. 0.02 m) provide habitat for seaweeds (c. 0.2 m) to facilitate more invertebrates [1, 64] (experimental and correlative evidence).
Table S1. Overview of representative studies on cascading habitat-formation. All studies except [25] manipulated the abundance of primary and/or secondary habitat-formers (HF). Study [25] was included because of its high-impact conclusion in a high-impact journal (doubling rainforest invertebrates by incorporating overlooked cascading habitat-formation; Nature). The first 9 studies (‘a-i’) were highlighted in a review of cascading habitat-formation [1]. Here we add data on sizes of the habitat-formers and experimental extent and grain, and data for study [21] (cf. Table S2 for details). Column headings: Primary and Secondary habitat-formers = the HFs ‘broad habitat-type’, ‘species identity’ and ‘typical length’, respectively. End-users = quantified organisms that can be facilitated by the primary and/or secondary HF. MR = Magnification ratio = end-user value of (Primary HF + Secondary HF)/Primary HF. For example, MR = 2 corresponds to a doubling of end-user metric by including a secondary HF in a system. MR values are shown for end-user abundances first and then taxonomic richness (NA = Not Available). MR values were extracted from [1] and Table S2. Size-ratio = Size ratio between co-existing HFs (Length primary HF/Length secondary HF). Extent = area over which plots are scattered. Grain = the area of a plot.

<table>
<thead>
<tr>
<th>Study</th>
<th>Primary habitat-former</th>
<th>Secondary habitat-former</th>
<th>End-user</th>
<th>MR</th>
<th>Size-ratio</th>
<th>Extent (m²)</th>
<th>Grain (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a[1]</td>
<td>Polychaete garden-Diopatra cuprea-0.05 m</td>
<td>Seaweed bed-Sargassum mimic-0.3 m</td>
<td>Sessile plants-invertebrates</td>
<td>10.5/2.5</td>
<td>0.2</td>
<td>400000000</td>
<td>0.3</td>
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<tr>
<td>b[56]</td>
<td>Sea grass meadow-Thalassia testudinum mimic-0.7 m</td>
<td>Epiphyte-Multiple species-0.05 m</td>
<td>Mobile invertebrates</td>
<td>2.4/NA</td>
<td>6.0</td>
<td>100</td>
<td>0.2</td>
</tr>
<tr>
<td>c[54]</td>
<td>Seagrass meadow-Mimic-0.3 m</td>
<td>Epiphyte-Giffordia mitchelliae mimic-0.02 m</td>
<td>Mobile invertebrates</td>
<td>8.4/NA</td>
<td>35.0</td>
<td>100</td>
<td>0.0001</td>
</tr>
<tr>
<td>d[55]</td>
<td>Seagrass meadow-Mimic-0.3 m</td>
<td>Epiphyte-Multiple species-0.01 m</td>
<td>Mobile invertebrates</td>
<td>1.7/1.2</td>
<td>30.0</td>
<td>25</td>
<td>0.05</td>
</tr>
<tr>
<td>e[57]</td>
<td>Salt marsh-Spartina alterniflora-1.5 m</td>
<td>Epiphyte-Multiple species-0.05 m</td>
<td>Mobile invertebrates</td>
<td>2.0/1.4</td>
<td>16.0</td>
<td>10000</td>
<td>2.3</td>
</tr>
<tr>
<td>f[46]</td>
<td>Salt marsh-Spartina alterniflora-1.5 m</td>
<td>Bivalve-Geukensia demissa-0.2 m</td>
<td>Various plant-invertebrates</td>
<td>2.8/NA</td>
<td>7.5</td>
<td>10000</td>
<td>1.0</td>
</tr>
<tr>
<td>g[48]</td>
<td>Forest-Dipterocarp trees-30 m</td>
<td>Bivalve-Geukensia demissa-0.2 m</td>
<td>Mobile invertebrates</td>
<td>3.0/1.1</td>
<td>7.5</td>
<td>10000</td>
<td>1.0</td>
</tr>
<tr>
<td>h[25]</td>
<td>Forest-Coffee trees (mainly Inga jinicuil)-2.5 m</td>
<td>Epiphyte (nest)-Asplenium nidus-1 m</td>
<td>Mobile invertebrates</td>
<td>2.0/NA</td>
<td>30.0</td>
<td>70000</td>
<td>21</td>
</tr>
<tr>
<td>i[23]</td>
<td></td>
<td>Epiph yte (nest)-multiple species(mainly Tillandsia spp)-0.3 m</td>
<td>Birds</td>
<td>1.5/1.0</td>
<td>8.3</td>
<td>40000000</td>
<td>30000</td>
</tr>
<tr>
<td>[21]</td>
<td>Forest - <em>Eucalyptus</em> trees - 20 m</td>
<td>Epiphyte (mistletoe) - Loranthaceae (mainly <em>Amyema miquelii</em>) - 1 m</td>
<td>Birds</td>
<td>1.3/1.4</td>
<td>20.0</td>
<td>1600000000</td>
<td>10000</td>
</tr>
</tbody>
</table>

We used the length of the sediment protruding tube-cap for *Diopatra* because the seaweeds are only incorporated to this structure. Three nested removal experiments were conducted, spread over an area of ca. 20×20 km.  

b. We assumed the plots were spread out over an area of 10×10 m.  

c. We assumed that the area of individual plots correspond to ca. 1×1 cm seagrass leaves (width × depth) and that these leaves were spread out over an area of 10×10 m.  

d. Individual mimics (=plots) were vacuum sampled – we assumed these mimics were spread out over an area of 5×5 m.  

e. We assumed plots were spread out over an area of 100×100 m.  

Correlative survey samples were collected from a 7 ha forest.  

f. Two nested sites were separated by 2 km – incorporating the size of individual plots we then assumed all plots were spread out over an area of ca. 2×2 km.  

g. We assumed the plots were spread out over an area of c. 40×40 km (as indicated from the online appendix map).
Table S2. Calculation of magnification ratios (MR) from [21]. Data were shown as proportional change from 2003/04 to 2007/08. To calculate MR values for end-users (birds) we assumed that control and mistletoe removal plots had similar mean values at the start of the experiments (e.g., 100 birds for simplicity). We extracted proportional change data from figure 1 and 2 (column ‘Fig.’) in [21] to calculate number of birds/bird-species at the end of the experiment in controls (column ‘Bird 2007/07 Mistletoe+’) and removals (column ‘Bird 2007/08 Mistletoe-‘). Comparing infected (Mistletoe+) vs. removal (Mistletoe-) plots is comparable to the experimental designs for studies listed in Table S1. For simplicity, we did not include comparisons to plots that were not mistletoe infested – corresponding to ‘correlative’ evidence for cascading habitat-formation (these MR were smaller than the experimentally determined MR shown here, unpubl. data).

<table>
<thead>
<tr>
<th>Response; proportional change in...</th>
<th>MR</th>
<th>Fig.</th>
<th>Extracted Mistletoe+</th>
<th>Extracted Mistletoe-</th>
<th>Birds 2007/08 Mistletoe+</th>
<th>Birds 2007/08 Mistletoe-</th>
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</thead>
<tbody>
<tr>
<td>Mistletoe foragers-all bird species</td>
<td>1.07</td>
<td>1a</td>
<td>-2.79</td>
<td>-8.81</td>
<td>97.21</td>
<td>91.19</td>
</tr>
<tr>
<td>Mistletoe foragers-woodland bird species</td>
<td>1.03</td>
<td>1a</td>
<td>-8.01</td>
<td>-10.66</td>
<td>91.99</td>
<td>89.34</td>
</tr>
<tr>
<td>Mistletoe nesters -all bird species</td>
<td>1.15</td>
<td>1b</td>
<td>4.31</td>
<td>-9.45</td>
<td>104.31</td>
<td>90.55</td>
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<tr>
<td>Mistletoe nesters -woodland bird species</td>
<td>1.24</td>
<td>1b</td>
<td>2.44</td>
<td>-17.65</td>
<td>102.44</td>
<td>82.35</td>
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<tr>
<td>Residents-all bird species</td>
<td>1.45</td>
<td>2b</td>
<td>1.67</td>
<td>-29.71</td>
<td>101.67</td>
<td>70.29</td>
</tr>
<tr>
<td>Residents-woodland bird species</td>
<td>1.76</td>
<td>2b</td>
<td>14.69</td>
<td>-34.88</td>
<td>114.69</td>
<td>65.12</td>
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**Average for bird abundance data** 1.3

<table>
<thead>
<tr>
<th>Response; proportional change in...</th>
<th>MR</th>
<th>Fig.</th>
<th>Extracted Mistletoe+</th>
<th>Extracted Mistletoe-</th>
<th>Birds 2007/08 Mistletoe+</th>
<th>Birds 2007/08 Mistletoe-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species richness -all bird species</td>
<td>1.32</td>
<td>2a</td>
<td>4.94</td>
<td>-20.74</td>
<td>104.94</td>
<td>79.26</td>
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<tr>
<td>Species richness -woodland bird species</td>
<td>1.50</td>
<td>2a</td>
<td>10.64</td>
<td>-26.19</td>
<td>110.64</td>
<td>73.81</td>
</tr>
</tbody>
</table>

**Average for bird richness data** 1.4
References


34. Ødegaaard F. 2000 The relative importance of trees versus lianas as hosts for phytophagous beetles (Coleoptera) in tropical forests. *Journal of Biogeography* **27**, 283-296.


