“No moon is an island”...or is it? Investigating the possibility of metacommunity dynamics in the Solar System

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Introduction

The planets, moons, and smaller bodies of the solar system may be perceived as local ‘patches’ embedded in the ‘regional’ matrix of interplanetary space. These mirror the ‘islands’ and ‘oceans’ of the core theory of Island Biogeography (IBT) that models colonization and extinction of species on ecological islands on Earth. The mathematical principles that underpin the movement of biota across islands are fundamental and may therefore also operate on the far larger scale of the whole solar system.

Most existing discussions on this topic are implicitly concerned with single-species dispersal. We propose to expand previous work on the postulated interplanetary transfer of biota by testing the application of existing metacommunity paradigms to the dispersal of entire communities. Given that no exolife has as yet been recognized, such discussions are wholly theoretical. They do, however, help us frame more relevant questions about the origin of life and its possible dispersal.

Biogeography of the Solar System

As in previous work, the planets, moons and small bodies are considered as ‘habitat patches’ whilst the ‘inhospitable matrix’ would be interplanetary space.

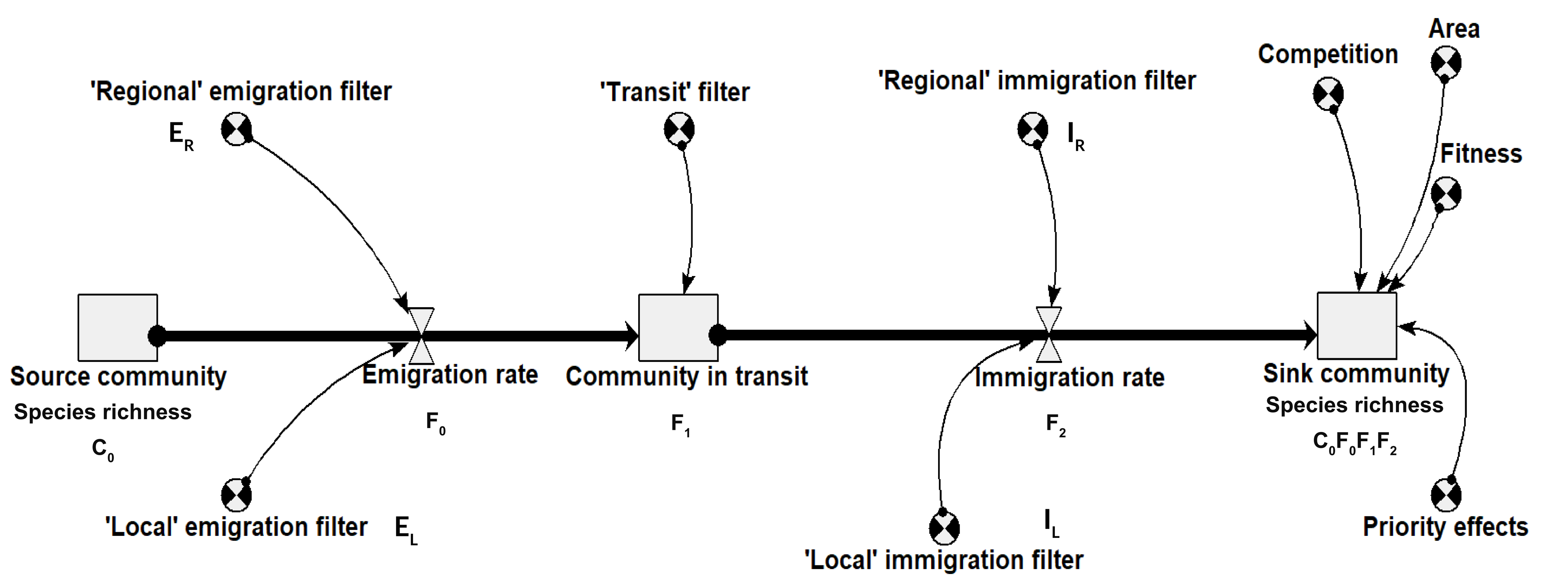
The species-rich ‘mainland’ is currently represented by Earth, the only solar system body that has, to our knowledge, abundant and diverse surficial life. The other planets and moons of the solar system are considered as ecological ‘islands’ and are possible targets for colonisers.

On a ‘local’ within-patch scale, biogeographical dynamics comprise well-characterised processes of dispersal, colonisation and extinction. On a ‘regional’ scale these patches are potentially linked by the same processes.

In this context, dispersal across terrestrial continents would still be considered a ‘local’ event at this scale, and would presumably be subject to natural selection.

On a ‘regional’ scale, successful dispersal-colonisation across patches now represents an extraordinary event that is almost entirely stochastic, passive, and not necessarily subject to natural selection.

A conceptual model for predicting diversity in sink communities



This simple ecological model conceptualises the principal filters in community transfer on ‘Local’ and ‘Regional’ scales. The rectangles are model compartments, the arrows represent flows and the circles are variables that contribute to ecological filtration. The emigration and immigration filters integrate several disparate processes into a single variable. The ‘Regional’ dispersal filters are generally stochastic, infrequent, density-independent and not subject to natural selection. It is assumed that $E_R << E_L$ and $I_R << I_L$

Dispersal is the key filter

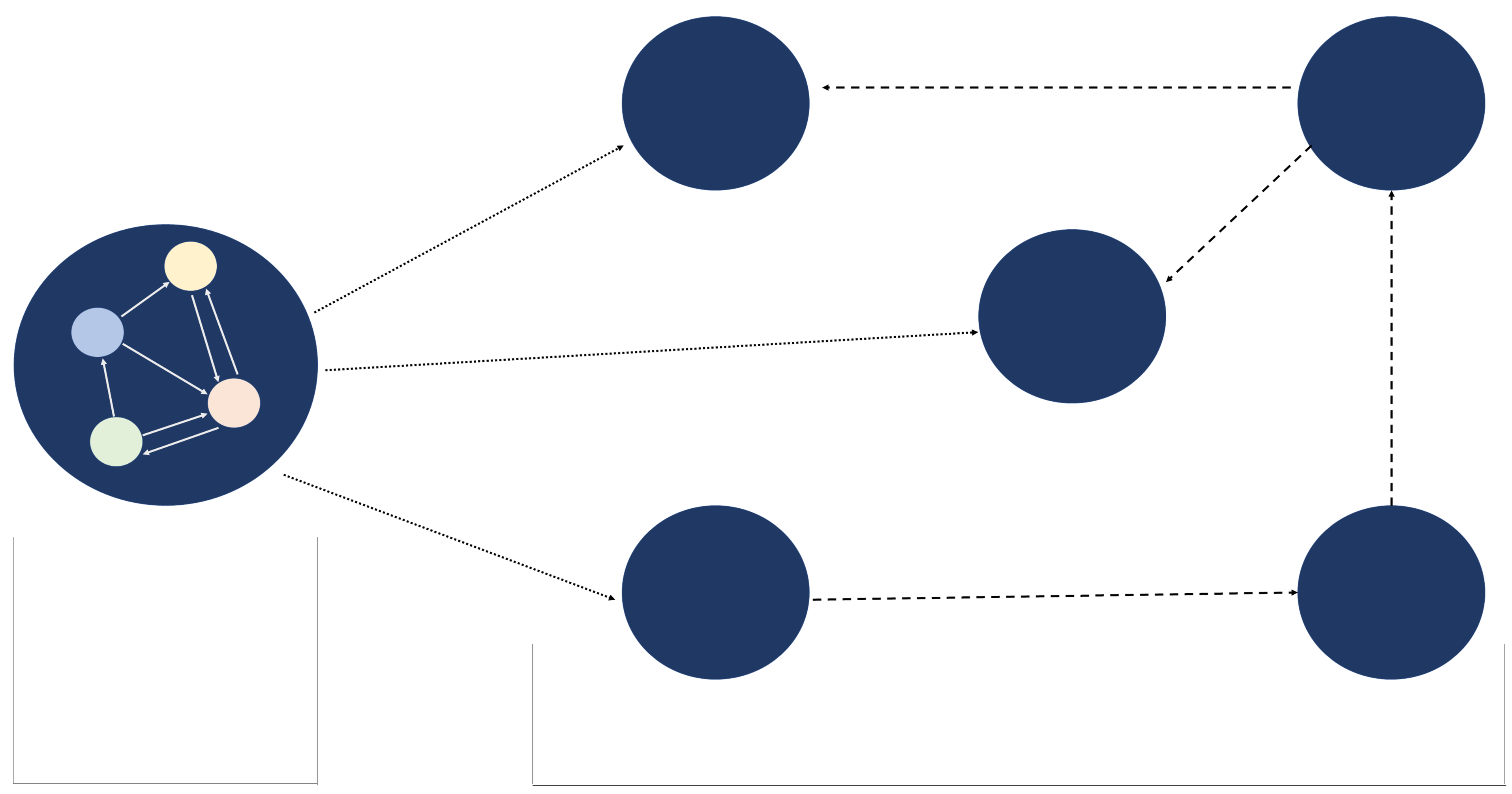
Regional dispersal is dependent on large-scale meteoritic impacts on a solar system body (SSB). This leads to ejection of debris out of the SSB’s sphere of gravitational influence.

Ejecta may harbour a community of microorganisms. The ejecta travel through interplanetary space before colliding with another SSB.

In theory, this vectored community could then be deposited on the host SSB. In practice however:

- The ‘dispersal’ step is expected to constitute a major biological filter, perhaps an insurmountable one for most organisms.
- It requires survival of the pressures and temperatures associated with a large impact and subsequent ejection.
- This would subsequently require tolerance of the high-energy radiation environment in the interplanetary vacuum.
- It would also necessitate survival of an impact on the ‘sink’ SSB.

Which metacommunity paradigms are relevant in this context?



‘Local’ scale
Patches not identical
Strong connections between patches
Environmental gradients relevant
Environmental filtering comparable to physiological tolerances

‘Regional’ scale
Patches considered identical and equally hospitable
Very weak connections between patches
Environmental gradients irrelevant
Environmental filtering exceeds physiological tolerances of most organisms

Each patch is a SSB with Earth as the species-rich ‘mainland’. The expected tolerance values of the dispersal filters are very low, suggesting that, on a regional scale, connections are weak (infrequent and low-volume transfers). The magnitude of the physicochemical stresses during dispersal also suggests that any existing environmental gradients within a sink patch would be irrelevant to immigrants as their physiological tolerance would necessarily far supersede any small-scale variance in environmental conditions. In this context, therefore, all sink patches can be considered as functionally identical - they are equally (in)hospitable.

Metacommunity paradigms

‘Patch-dynamics’ - patches all identical, binomial pattern of occupation, local diversity limited by dispersal. Spatial dynamics controlled by colonisation/extinction.

Potentially applicable to this context as, on a regional scale, patches are likely to present comparable ecological filters.

‘Species sorting’ - patches not identical; resource gradients can control community composition.

Probably inapplicable to this context as no knowledge of extraterrestrial resource gradients is available.

‘Mass effects’ - constant incoming flow of organisms sustains a population in sinks where they would be poor competitors.

Not applicable to this context as connections between patches are likely to be very weak.

‘Neutral’ - all species equal in their competitive ability and dispersal ability, population interactions largely random. Dynamics of species diversity derived from probabilities of species gain and loss.

Potentially applicable to this context as a consequence of the very strong stochastic element.

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