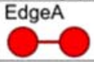
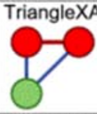
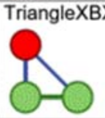
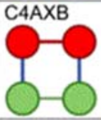
**Appendix 1.**
Fitting a multilevel ERGM

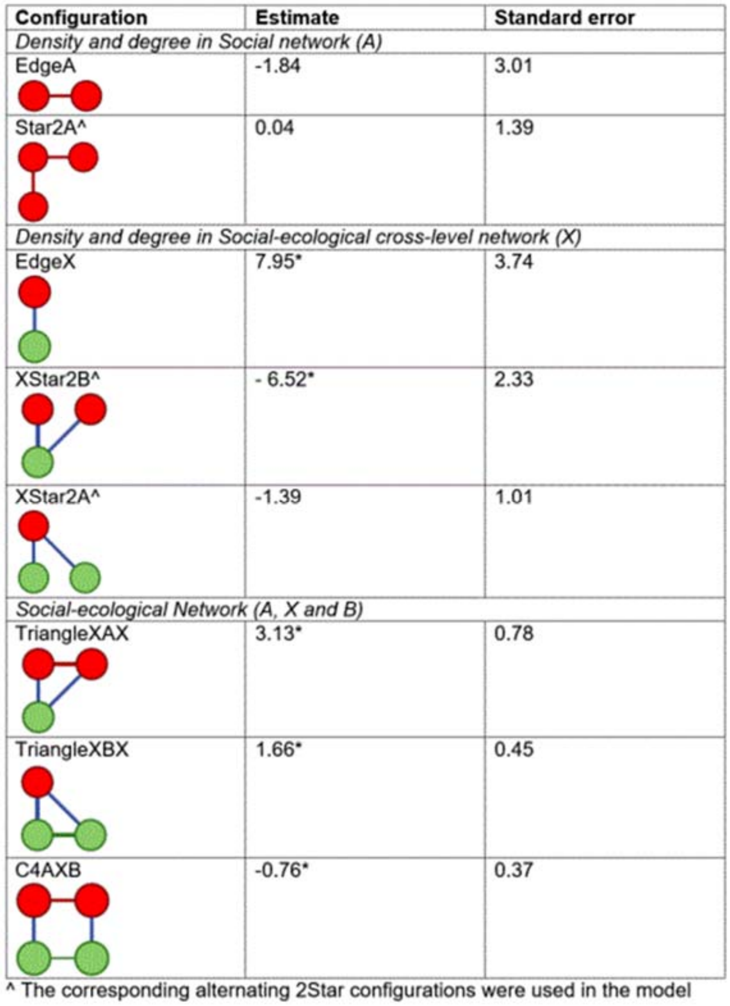
First, the structure of the ecological network was considered exogenous and not liable to change. Thus it was held constant (fixed) in estimating the ERGM. Secondly, no triangles were observed in the social network, so we controlled the estimation so that social triangles were impossible. We then started with a simple model where we only included the favorable building blocks (Main paper, Fig. 2) and edge configurations for both network layers (to control for the density of links in the social network and the cross-level network). The results are presented in Fig. A1.1. We here use the naming convention of configurations (building blocks) as outlined in recent studies (Wang et al. 2013)

***Figure A1.1.*** *A fitted ERGM with a minimal number of tested building blocks. We use the terminology for building blocks commonly used in the ERGM literature. The social network is denoted "A", the ecological network "B", and the cross-level ties as "X". Significant estimates are marked with *.*

| **Configuration** | **Estimate** | **Standard error** |
|---|---|---|
| *Density (Social network A, Social-ecological cross-level network X)* | | |
| EdgeA  | -1.31 | 0.73 |
| EdgeX  | -2.39* | 0.40 |
| *Social-ecological Network (A, X and B)* | | |
| TriangleXAX  | 1.43* | 0.34 |
| TriangleXBX  | 1.40* | 0.37 |
| C4AXB  | -0.46* | 0.20 |

This first model was then extended to account for centralization, i.e. that some nodes in the social and ecological network are more connected than others (Fig. A1.2). These parameters capture an important network feature, controlling for degree distributions. Arguably, network models should always include degree distribution parameters, given the relevance of degree-based effects (Barabási and Albert 1999), and so model 1 should be treated as a simplified version that focusses only on a few theoretically relevant building blocks.

***Figure A1.2.*** *A fitted ERGM (from Fig. A1.1) including centralization parameters (prefixed Star2).*



| Configuration | Estimate | Standard error |
|---|---|---|
| *Density and degree in Social network (A)* | | |
| EdgeA | -1.84 | 3.01 |
| Star2A^ | 0.04 | 1.39 |
| *Density and degree in Social-ecological cross-level network (X)* | | |
| EdgeX | 7.95* | 3.74 |
| XStar2B^ | - 6.52* | 2.33 |
| XStar2A^ | -1.39 | 1.01 |
| *Social-ecological Network (A, X and B)* | | |
| TriangleXAX | 3.13* | 0.78 |
| TriangleXBX | 1.66* | 0.45 |
| C4AXB | -0.76* | 0.37 |

^ The corresponding alternating 2Star configurations were used in the model

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The centralization parameters are prefixed “Star2” in Fig. A1.2. Given the multilevel network structure, there are three degree distributions of interest:

- Centralization among ties in the clan network only (Star2A –*Are there highly central clans in the social network?*)
- Centralization of clans in social-ecological ties (XStar2A – *Are there clans that are highly central in ties to forests?*)
- Centralization of forests in social-ecological ties (XStar2B – *Are there forests that are highly central in links to clans?*)

A fourth possible degree distribution, among ecological ties, cannot be parameterized because as explained above, the ecological network is treated as exogenous.

The centralization parameters are all based on the alternating-star parameters (configurations) for ERGMs as explained in Lusher et al (2013). Without going into the details here, the strongest effect in the alternating star parameter is a so-called *2Star* which is a network path of length two centered on one node (hence its contribution to a centralization parameter – higher order stars are also included in the statistic as set out in p.66 of Lusher et al. 2013). So, the alternating XStar2B configuration can also be interpreted as deriving from the open common pool resource triangle in Fig. 2 (main paper).

In contrast, the configuration XStar2A derives from a configuration centered on a clan connected to two forests.

Note that the inclusion of the centralization parameters substantially changes the estimate of the TriangleXAX. The XStar2B, included in the alternating XStar2B configuration, is a lower order configuration to the triangle (i.e. TriangleXAX contains the XStar2B centered on the forest in the triangle). As explained in (Snijders et al. 2006), the inclusion of lower order effects in triangulation sharpens the inference about the formation of triangles. With the centralization parameters and the triangle parameter present, the model in effect asks the question: *given the presence of an XStar2B, what is the likelihood of a tie between the two social nodes?* Or to put it more substantively: *given that two clans manage the same forest, what is the likelihood that they will be socially linked?* This is a sharper inference than in model 1 (Fig. A1.1) which simply asks about the presence of the triangle in the graph conditional on the density (captured by the edge parameters) and the other cross-level effects.

Although this conditionality in interpretation is often downplayed in ERGMs to simplify the detail (as we have largely done in the main paper), it is an appealing feature of the statistical model when a more fine grained inference about possible processes is required (For a further discussion of inference about likely structural processes from these models, see Lusher et al, 2013, chapter 3). This also represent an important distinction between ERGM and the simpler frequency counting approach. There could very well be cases where lower order effects are strongly positive, whereas higher order effects are weakly negative. In such cases, the frequency of higher order configuration could deviate positively from the expected mean given a random network, but this deviance would be to the result of the strong positive effect of the lower order configuration that overshadows the weaker and negative effect of the higher order configuration.

These issues should not be confused with technical issues such as multicollinearity in regression. The Markov Chain Monte Carlo Maximum Likelihood Estimation (MCMCMLE) used to estimate these models can successfully pick apart highly correlated effects. If there is too much collinearity, the models will not converge. The post-estimation goodness of fit simulation described below can reassure that the models are behaving properly and that the estimates are indeed maximum likelihood in producing distributions with all parameterized network statistics centered on the observed values.

Similarly, the increase in the standard error for TriangleXAX across models reflects the focus on a smaller number of "observations" (i.e. where XStar2B are present).

Conclusively, the TriangleXAX parameter in Model 2 (Fig. A1.2) concentrates the inference on the formation of the social tie in the social-ecological configuration, rather than just the presence of the configuration overall (model 1). Comparison of the estimate in model 2 with the smaller value in model 1 suggests that the tendency for two clans managing the same forest to have a social tie is a strong effect. It is stronger than the effect for just the presence of the triangle "on average" (i.e. in model 1).

The overall fit improved with these additions, as measured by the Mahalanobis distance that decreased from 803 to 263 (the distance captures the level of fit, see e.g Lusher et al. 2013). Note that no other building blocks were included in the model. We tested to include the remaining building blocks in Fig. 2 (main paper) by simulating from the model estimates (the so-called goodness of fit test – see Lusher et al, 2013). A post-estimation simulation can confirm that the model has successfully converged, that the statistics from the fitted parameters are indeed central in the distributions of statistics derived from the graph distribution (i.e. they are maximum likelihood), and that relevant non-fitted observed graph statistics (configurations) are not extreme compared to the distribution of statistics derived from the simulation (i.e., the model is not inconsistent with these additional structural effects).

None of the observed counts of non-fitted building blocks were extreme in the distribution of graph statistics produced from the simulations. The established index of whether a count is extreme is the t-statistic, with a value of less than two in absolute value for non-fitted effects suggesting that the model is plausible in explaining that effect (for fitted effects, it is desirable to have a value less than around 0.2 to confirm convergence – see Lusher et al, 2013.) For the six building blocks in Figure 2, the t-statistics for a simulated sample of 1000 graphs were:

- Fitted effects
    - Closed CPR triangle: -0.01
    - Closed Ecosystem triangle: 0.04
    - Closed four cycle: 0.02
    - Open CPR triangle: -0.12 (alternating XStar2B was fitted)
- Effects not directly fitted
    - Open Ecosystem triangle: -0.3
    - Open four cycle: 0.47

Thus we conclude that the non-fitted effects (i.e. the SE building blocks *open four cycle* and *open ecosystem triangle* in Fig. 2, main paper) are not necessary to explain the network structure over and above the given model parameters. This implies that the open ecosystem triangle and the open four-cycle were neither suppressed nor enhanced.

## Literature Cited


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