**Supplementary information: Spatial divergence in ecological responses to typhoons across a subtropical island**

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**Figure S1.** Ordination biplot for the land cover variables used in this study. We used unsupervised k-means clustering (optimal *k* value = 2 clusters) of a Principal Component Analysis (PCA) of land cover variables (see Methods) to automatically identify clusters of sites with similar land cover. We found a clear distinction between two clusters (red versus blue points and ellipsoids). When examining the variable loadings (land cover classes marked on PCA ordination with names and arrow length showing relative variable weights), we found that the clusters represented a clear distinction along PCA axis 1 (variance explained = 81.2%), where the 10 blue sites were primarily forest sites, while the 14 red sites with either primarily agricultural, urban, or managed grassland sites, herein collectively termed ‘developed’ sites.

**Table S1.** Automatic supervised learning bird species detection classifiers across field sites. We produced automated (supervised machine learning) species vocalisation classifiers in Kaleidoscope Pro (version 5.3.0; Wildlife Acoustics Inc., Concord, MA, USA), using training data from across a variety of sites and dates, and applying trained classifiers to the full dataset of recordings (30 Aug-04 Nov 2018) to automatically identify species detections. We assessed classifier accuracy at each site (Site name, with land use marked in brackets: FOR = forest, DEV = developed site) via visual inspection with a threshold of 15% false positives. We applied the same species-specific classifiers to each site, to prevent site-specific differences in base classifier performance (though given the challenge of applying a single classifier across 24 sites, there were several cases where classifiers did not meet our accuracy threshold (0s in columns 2-4). We achieved accurate classifiers at a range of sites for three species: the large-billed crow (*Corvus macrorhynchos*, 嘴太烏 in Japanese); the Japanese bush warbler (*Horornis diphone*, 鶯); and the Ryukyu scops-owl (*Otus elegans*, 琉球木の葉木菟). Accurate classifiers are marked with 1, indicating that we used data from that site-by-species combination for analysis (see *Analyses on automated species detections*). Note that *O. elegans* is a forest specialist, so is not expected to be found at the developed sites (we did not produce an accurate classifier at any developed sites for this species, in accordance with expectation). Classifiers were produced by S.R.P-J.R. and R.M. and accuracy was visually checked by a single observer (S.R.P-J.R.) for consistency.

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| --- | --- | --- | --- |
| Site name (Land use) | *Corvus macrorhynchos* | *Horornis diphone* | *Otus elegans* |
| Genka (FOR) | 1 | 0 | 0 |
| Hentona (FOR) | 1 | 1 | 1 |
| Katsuudake (FOR) | 1 | 1 | 1 |
| Kemin (FOR) | 1 | 1 | 1 |
| Manabi (FOR) | 1 | 1 | 0 |
| OIST forest (FOR) | 1 | 1 | 1 |
| OIST campus (FOR) | 1 | 1 | 0 |
| Oku (FOR) | 1 | 1 | 1 |
| Takeyanbaru (FOR) | 1 | 1 | 1 |
| Yona (FOR) | 1 | 1 | 1 |
| Chatan (DEV) | 0 | 0 | - |
| Gesashi (DEV) | 1 | 0 | - |
| Heiwa (DEV) | 0 | 1 | - |
| Kurashiki (DEV) | 1 | 1 | - |
| Nago (DEV) | 1 | 0 | - |
| Nakagusuku (DEV) | 1 | 1 | - |
| Oyama (DEV) | 0 | 0 | - |
| Sefa-utaki (DEV) | 1 | 1 | - |
| Senbaru (DEV) | 1 | 1 | - |
| Sueyoshi (DEV) | 1 | 0 | - |
| Tamagusuku (DEV) | 1 | 1 | - |
| Tounan (DEV) | 1 | 1 | - |
| Uehara (DEV) | 1 | 0 | - |
| Yacho (DEV) | 1 | 1 | - |
| Total | 21 | 17 | 7 |



**Figure S2.** **Difference in mean detections of *Horornis diphone* and *Corvus macrorhynchos* under different detection confidence thresholds**. Posterior distributions represent 90,000 post-convergence MCMC draws of the comparison between *Horornis diphone* and *Corvus macrorhynchos* mean daily detections, where values below zero (grey) indicate lower number of detections, and values above zero (blue) a more detections of *H. diphone* relative to *C. macrorhynchos*. Non-zero-spanning credible intervals are marked with \*, while circles indicate zero-spanning credible intervals (no change based on the posterior distribution). Draws are shown per site, ordered from most forested (top) to most developed (bottom) based on principle component axis 1 of the land use dimensionality reduction (Fig. S1). Panels represent results for under three automated detection probability thresholds: 0.5 (a), 0.75 (b), and 0.9 (c). Note that 0.5, which we use throughout, is a conservative filter, as credible intervals more often span zero.



**Figure S3.** Comparison of Biophony (NDSIBio) time series at the Manabi (FOR) field site after detrending using moving average window sizes of **a**) 3 days, **b**) 5 days, and **c**) 7 days. Red dashed lines represent the pre-disturbance baseline value (mean). Grey windows indicate the periods of typhoons Trami (29-30 Sep 2018) and Kong-Rey (04-05 Oct 2018).

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**Figure S4.** Comparison of recovery time values for different recovery window sizes. A change in window size represents a change in the amount of time for which consecutive data points must remain within the pre-typhoon baseline mean ± 1 standard deviation. Relationships between the 24 hr window size used in our analyses (x-axis) and the 12 (top panels) or 48 hr window sizes (bottom panels) are shown for three acoustic indices: NDSI (left), NDSIBio, and NDSIAnthro (right). Note the number of data points differs particularly for the 48 hr window size, since normalised acoustic index values were found not to recover within 30 days of the typhoon when using the 48 hr window size. Results generally show a positive correlation between the chosen 24 hr window size and other window sizes, excepting NDSIAnthro with a 12 hr window size, which recovered quickly in most cases, resulting in a flat relationship.

**Table S2**. Response variables measured in this study, methods of their measurement and interpretation. Response variables were calculated separately for time series of acoustic indices and bird species detections, based largely on methods adapted from Hillebrand *et al.* (2018) and White *et al.* (2020). Following calculation, all stability measures were normalised to 0-1 (see Methods) and then temporal variability and recovery time were taken as 1 values. This was done for ease of interpretation; all stability measures have high values which represent higher stability.

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| --- | --- | --- | --- | --- |
| **Response variable** | **Time window of measurement** | **Method of measurement:**  ***acoustic indices*** | **Method of measurement:**  ***species detections*** | **Interpretation** |
| **Mean state** | 30 days pre- and post-typhoon | Mean acoustic index value across the 30-day detrended time series before or after the typhoons. | Mean number of daily species detections across the 30-day time series before or after the typhoons. | Higher values correspond to higher acoustic index values (a proxy for biodiversity for NDSI and NDSIBio or higher abiotic/anthropogenic noise for NDSIAnthro) or more species detections. |
| **Temporal stability** | 30 days pre- and post-typhoon | 1 coefficient of variation (that is, standard deviation/mean) among acoustic index values across the 30-day detrended time series before or after the typhoons. | 1 coefficient of variation (that is, standard deviation / mean) among daily species detections across the 30-day time series before or after the typhoons. | Higher values correspond to lower variability through time (higher stability). |
| **Resistance** | 2 days post- typhoon | Maximum absolute difference in acoustic index values from pre-typhoon mean in the 48 hours following the 2nd typhoon. | - | Values represent log response ratios, where zero equates to complete resistance (no change), and more extreme positive or negative values represent lower resistance through over- or underperformance, respectively (Hillebrand et al., 2018). |
| **Recovery time** | 30 days post- typhoon | 1 *recovery time*, calculated as the time taken (in hours) for acoustic index values to return to baseline (that is, mean ± 95% confidence interval of 30-day pre-typhoon detrended time series) and stay within this range for 24 consecutive hours, starting from the point of maximum displacement (the resistance point; (Garnier et al., 2017; White et al., 2020). | - | Higher values indicate shorter recovery time (higher stability). |
| **Spatial variability** | One value per recording (indices) or day (Species) across time series | Coefficient of variation (standard deviation/mean) among field sites in half-hourly mean acoustic index values (Donohue et al., 2013). | Coefficient of variation among field sites in daily species detections on each date. | Higher values represent higher variability in space, which is stabilising since spatial variability represents asynchronous biomass fluxes within or among species, in turn providing spatial insurance through patch dynamics (Leibold et al., 2004; Loreau et al., 2003). |

**Table S3**. **Mean, standard deviation (S.D.), and 95% credible intervals of the posterior distribution for parameters included in each best-fitting model.** Error distribution represents the best performing model error distribution for each variable, and the R function within the brms package used to assign each distribution. Only best performing models are reported (model performance was compared using LooIC).

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Data** | **Response variable** | **Error distribution** | **Model Parameter** | **Mean** | **S.D.** | **2.5% C.I.** | **97.5% C.I.** |
| **Acoustic Indices** |  |  |  |  |  |  |
| NDSI | **Mean** | Beta | **Intercept** | **1.45** | **0.23** | **0.99** | **1.92** |
|  |  |  | LandDev | 0.37 | 0.36 | -0.35 | 1.09 |
|  |  |  | **TyphoonPost** | **-0.52** | **0.13** | **-0.78** | **-0.26** |
|  |  |  | LandDev:TyphoonPost | 0.06 | 0.21 | -0.36 | 0.48 |
|  | Temporal Variability | Beta | Intercept | -0.16 | 0.39 | -0.93 | 0.62 |
|  |  | LandDev | 0.36 | 0.59 | -0.80 | 1.53 |
|  |  | TyphoonPost | -0.10 | 0.40 | -0.91 | 0.69 |
|  |  | LandDev:TyphoonPost | -0.22 | 0.80 | -1.82 | 1.38 |
|  | Resistance | Beta | Intercept | 0.66 | 0.48 | -0.29 | 1.63 |
|  |  |  | LandDev | 0.04 | 0.77 | -1.51 | 1.55 |
|  | Recovery Time | Beta | Intercept | 0.94 | 0.52 | -0.08 | 1.97 |
|  |  |  | LandDev | 0.66 | 0.89 | -1.10 | 2.43 |
| NDSIBio | Mean | Beta | Intercept | -0.12 | 0.14 | -0.39 | 0.16 |
|  |  |  | LandDev | 0.16 | 0.22 | -0.26 | 0.59 |
|  |  |  | TyphoonPost | -0.06 | 0.13 | -0.31 | 0.19 |
|  |  |  | LandDev:TyphoonPost | -0.02 | 0.20 | -0.41 | 0.37 |
|  | Temporal Variability | Beta | Intercept | -0.33 | 0.41 | -1.15 | 0.49 |
|  |  | LandDev | 0.26 | 0.61 | -0.96 | 1.46 |
|  |  | TyphoonPost | 0.40 | 0.54 | -0.67 | 1.48 |
|  |  | LandDev:TyphoonPost | -0.10 | 1.00 | -2.09 | 1.89 |
|  | Resistance | Beta | Intercept | 0.10 | 0.55 | -0.98 | 1.20 |
|  |  |  | LandDev | 0.57 | 0.89 | -1.17 | 2.34 |
|  | Recovery Time | Beta | Intercept | 0.91 | 0.59 | -0.26 | 2.08 |
|  |  |  | LandDev | 1.62 | 0.96 | -0.25 | 3.54 |
| NDSIAnthro | **Mean** | Beta | Intercept | -0.51 | 0.26 | -1.01 | 0.00 |
|  |  |  | LandDev | -0.44 | 0.40 | -1.23 | 0.34 |
|  |  |  | **TyphoonPost** | **0.68** | **0.17** | **0.34** | **1.00** |
|  |  |  | LandDev:TyphoonPost | -0.12 | 0.26 | -0.62 | 0.40 |
|  | Temporal Variability | Beta | Intercept | 0.48 | 0.28 | -0.07 | 1.04 |
|  |  | LandDev | -0.98 | 0.72 | -2.42 | 0.46 |
|  |  | TyphoonPost | -0.73 | 0.45 | -1.62 | 0.16 |
|  |  | LandDev:TyphoonPost | 0.34 | 0.95 | -1.55 | 2.24 |
|  | Resistance | Beta | Intercept | 0.20 | 0.48 | -0.73 | 1.15 |
|  |  |  | LandDev | 0.30 | 0.77 | -1.21 | 1.84 |
|  | Recovery Time | Beta | Intercept | 0.04 | 0.53 | -1.01 | 1.07 |
|  |  |  | LandDev | 1.11 | 0.64 | -0.15 | 2.40 |
| **Species detections** |  |  |  |  |  |  |  |
|  | **Mean Daily Detections** | lognormal | **Intercept** | **3.57** | **0.32** | **2.94** | **4.2** |
|  |  |  | LandDev | 0.25 | 0.44 | -0.62 | 1.12 |
|  |  |  | TyphoonPost | -0.18 | 0.32 | -0.81 | 0.45 |
|  |  |  | **SpeciesHoro** | **-1.06** | **0.35** | **-1.76** | **-0.36** |
|  |  |  | SpeciesOtus | -0.46 | 1.43 | -3.25 | 2.34 |
|  |  |  | LandDev:TyphoonPost | -0.41 | 0.38 | -1.17 | 0.35 |
|  |  |  | LandDev:SpeciesHoro | -0.32 | 0.41 | -1.12 | 0.49 |
|  |  |  | LandDev:SpeciesOtus | -0.47 | 1.43 | -3.26 | 2.31 |
|  |  |  | **TyphoonPost:SpeciesHoro** | **-1.25** | **0.39** | **-2.01** | **-0.49** |
|  |  |  | TyphoonPost:SpeciesOtus | -0.13 | 0.55 | -1.2 | 0.95 |
|  | **Temporal Variability** | lognormal | **Intercept** | **0.3** | **0.08** | **0.15** | **0.45** |
|  |  |  | LandDev | 0.06 | 0.11 | -0.15 | 0.27 |
|  |  |  | **TyphoonPost** | **0.4** | **0.09** | **0.22** | **0.58** |
|  |  |  | SpeciesHoro | 0.15 | 0.1 | -0.05 | 0.35 |
|  |  |  | SpeciesOtus | -0.19 | 1.42 | -2.96 | 2.6 |
|  |  |  | LandDev:TyphoonPost | -0.21 | 0.11 | -0.43 | 0.01 |
|  |  |  | LandDev:SpeciesHoro | 0.08 | 0.12 | -0.15 | 0.31 |
|  |  |  | LandDev:SpeciesOtus | -0.19 | 1.42 | -2.98 | 2.58 |
|  |  |  | TyphoonPost:SpeciesHoro | -0.16 | 0.11 | -0.38 | 0.06 |
|  |  |  | TyphoonPost:SpeciesOtus | -0.09 | 0.16 | -0.4 | 0.22 |



**Figure S5. Spatial variability in biophony across sites through time.** Left panels show time series of NDSIBio spatial variability across all sites (a), and across forest (green) and developed (purple) sites separately (b). Dashed lines delineate the pre- and post-typhoon periods. Right panels show the 95% confidence intervals of NDSIBio spatial variability across all sites (a) or separated by land use (b) for the pre-typhoon (circles) and post-typhoon (triangles) periods. Significant pairwise contrasts are denoted with subscript/superscript letters.



**Figure S6. Spatial variability in anthropophony across sites through time.** Left panels show time series of NDSIAnthro spatial variability across all sites (a), and across forest (green) and developed (purple) sites separately (b). Dashed lines delineate the pre- and post-typhoon periods. Right panels show the 95% confidence intervals of NDSIAnthro spatial variability across all sites (a) or separated by land use (b) for the pre-typhoon (circles) and post-typhoon (triangles) periods. Significant pairwise contrasts are denoted with subscript/superscript letters.



**Figure S7.** **Difference from *Corvus macrorhynchos* in mean automated species detections**. Posterior distributions represent 90,000 post-convergence MCMC draws of the comparison between *Horornis diphone* (a) or *Otus elegans* (b) and *Corvus macrorhynchos* mean daily detections, where values below zero (grey) indicate lower number of detections, and values above zero (blue) a more detections of *H. diphone* or *O. elegans* relative to *C. macrorhynchos*. Non-zero-spanning credible intervals are marked with \*, while circles indicate zero-spanning credible intervals (no change based on the posterior distribution). Draws are shown per site, ordered from most forested (top) to most developed (bottom) based on principle component axis 1 of the land use dimensionality reduction (Fig. S1).

**Supplementary references**

Donohue, I., Petchey, O. L., Montoya, J. M., Jackson, A. L., Mcnally, L., Viana, M., Healy, K., Lurgi, M., O’Connor, N. E., & Emmerson, M. C. (2013). On the dimensionality of ecological stability. *Ecology Letters*, *16*, 421–429.

Garnier, A., Pennekamp, F., Lemoine, M., & Petchey, O. L. (2017). Temporal scale dependent interactions between multiple environmental disturbances in microcosm ecosystems. *Global Change Biology*, *23*, 5237–5248.

Hillebrand, H., Langenheder, S., Lebret, K., Lindström, E., Östman, Ö., & Striebel, M. (2018). Decomposing multiple dimensions of stability in global change experiments. *Ecology Letters*, *21*, 21–30.

Leibold, M. A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J. M., Hoopes, M. F., Holt, R. D., Shurin, J. B., Law, R., Tilman, D., Loreau, M., & Gonzalez, A. (2004). The metacommunity concept: A framework for multi-scale community ecology. *Ecology Letters*, *7*, 601–613.

Loreau, M., Mouquet, N., Gonzalez, A., & Mooney, H. A. (2003). *Biodiversity as spatial insurance in heterogeneous landscapes*.

White, L., O’Connor, N. E., Yang, Q., Emmerson, M. C., & Donohue, I. (2020). Individual species provide multifaceted contributions to the stability of ecosystems. *Nature Ecology and Evolution*, *1*.