# Supplementary Information

# Define-Investigate-Estimate-Map (DIEM) Framework for Modeling Habitat Threats

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Supplementary Figures S1 through S14 display tree diagrams of the types of threats listed in each study. Diagrams were made for studies that listed a sizeable number of threats. All studies used recognized anthropogenic threats while only four studies note natural threats.

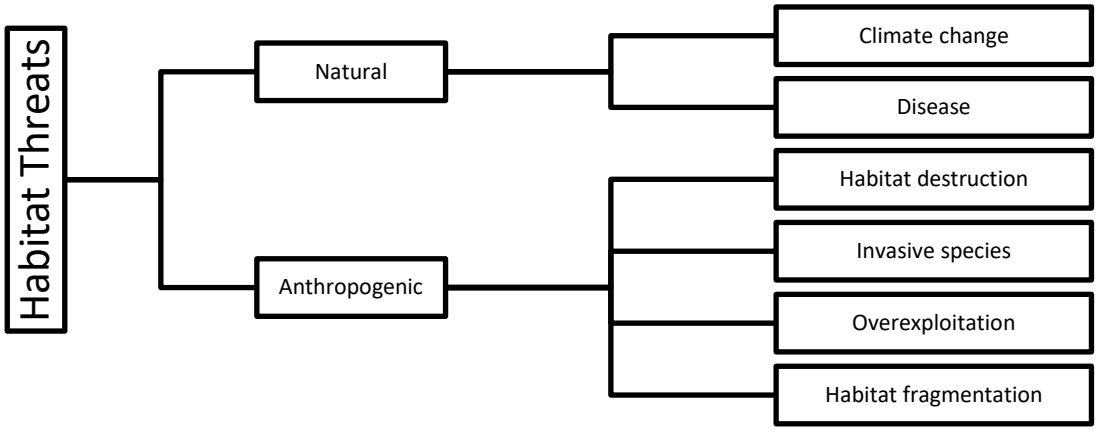



***Figure S1.*** Tree diagram based on Strauss et al. [1].

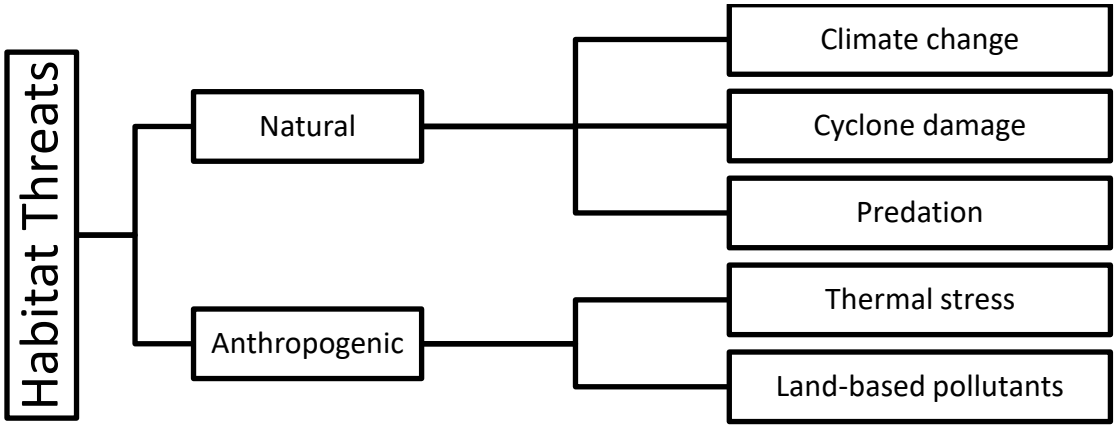



***Figure S2.*** Tree diagram based on Deffense [2].

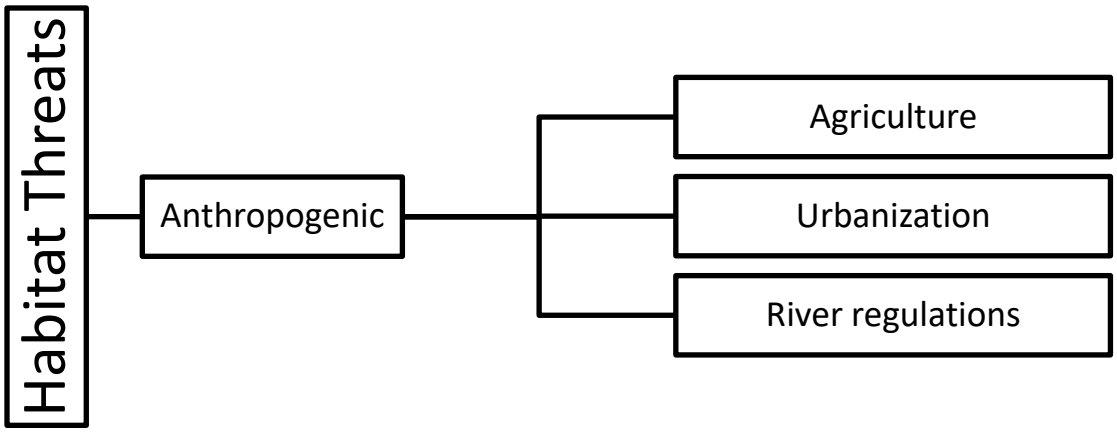



***Figure S3.*** Tree diagram based on Eros et al. [3].

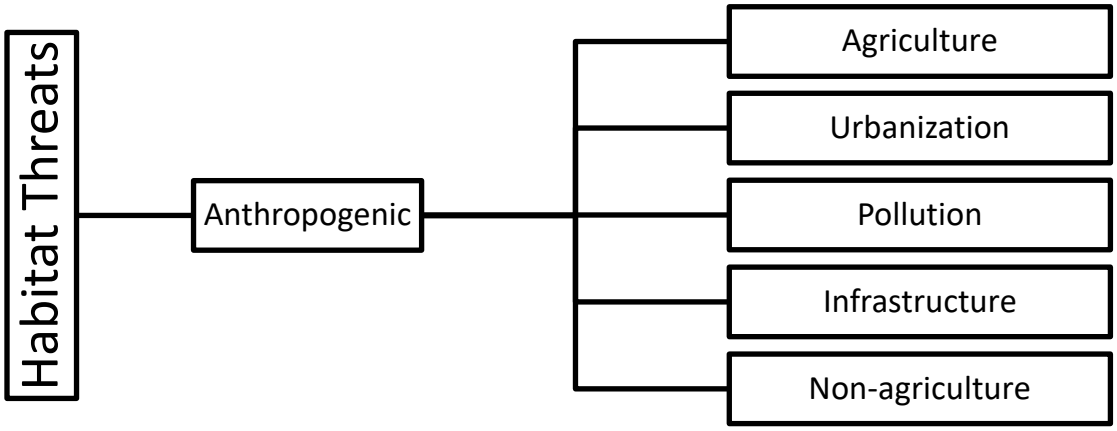



***Figure S4.*** Tree diagram based on Fore et al. [4].

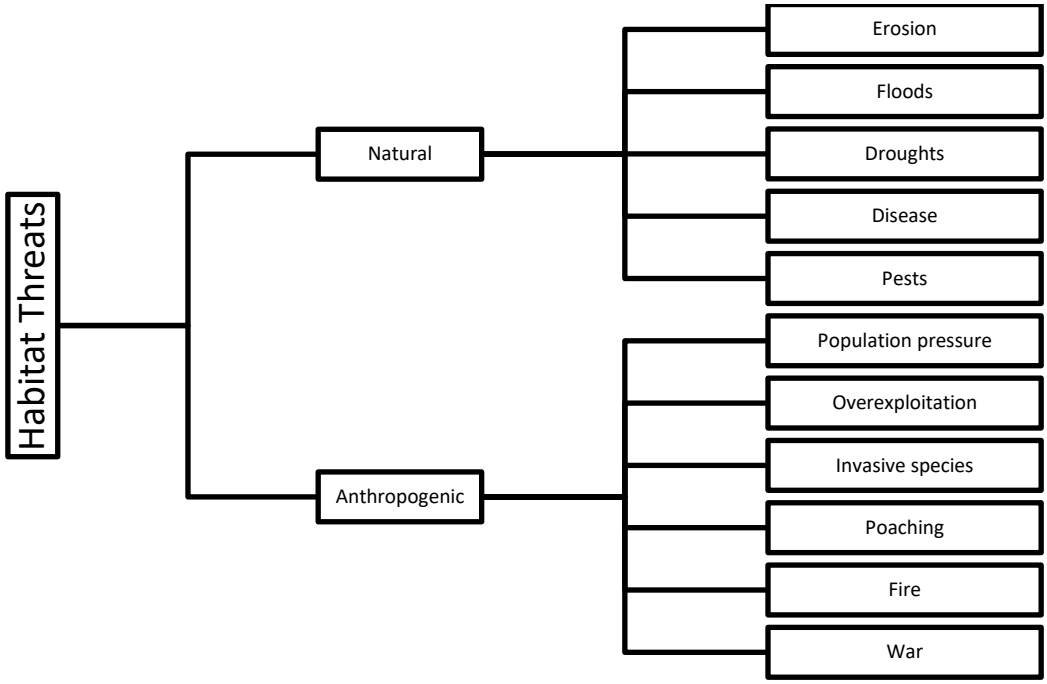


***Figure S5.*** Tree diagram based on Khobe et al. [5].

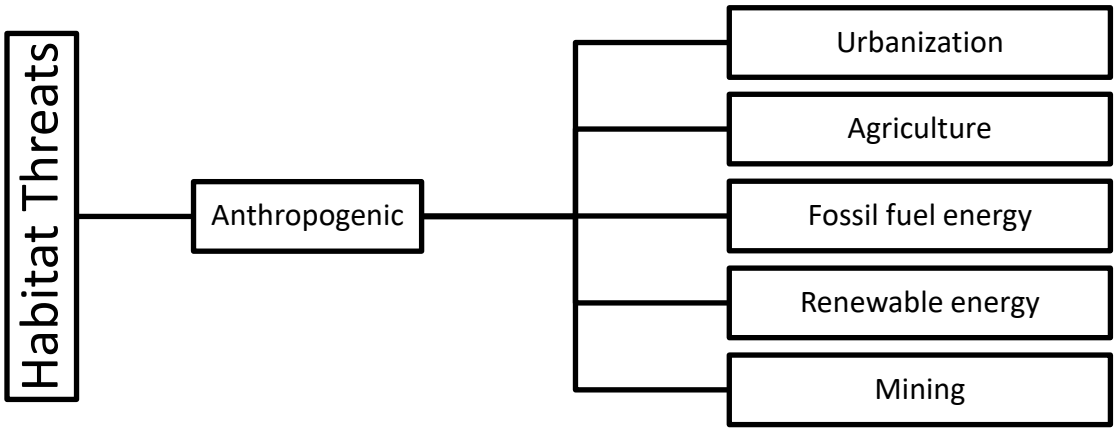



***Figure S6.*** Tree diagram based on Oakleaf et al. [6].

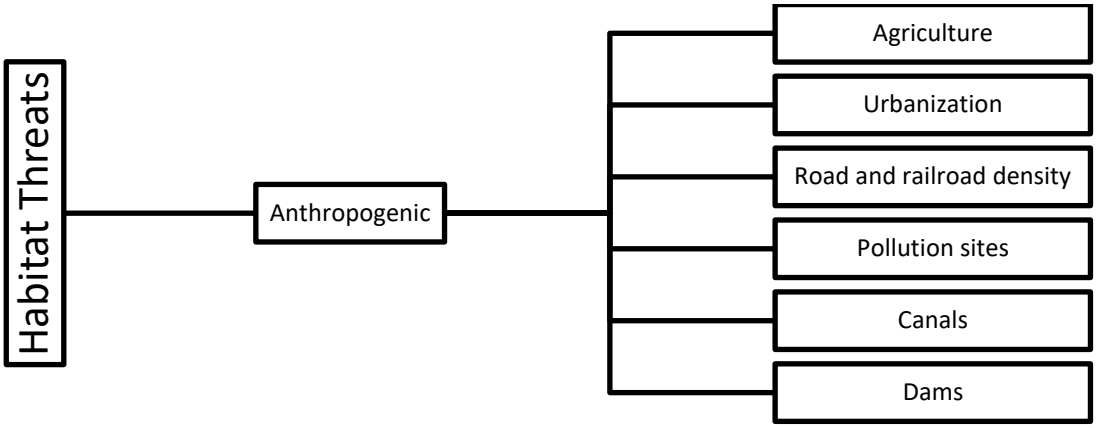



***Figure S7.*** Tree diagram based on Paukert et al. [7].

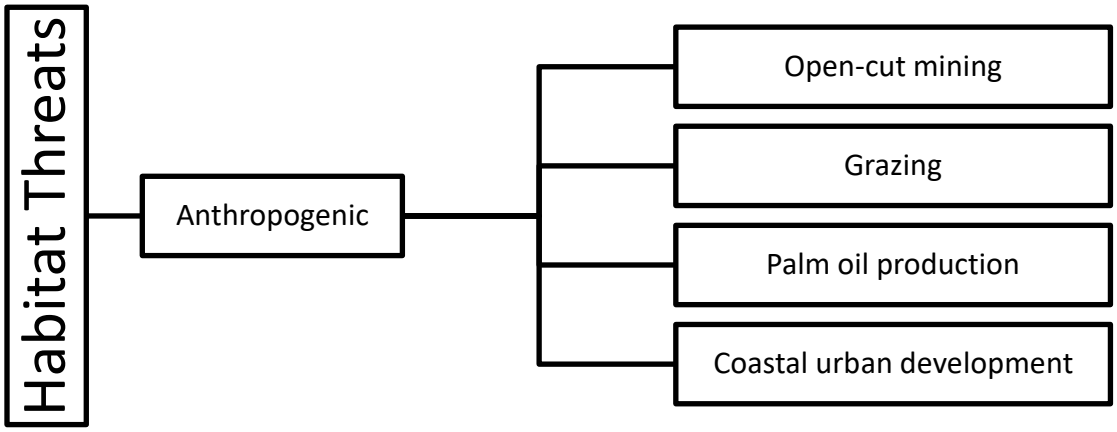



***Figure S8.*** Tree diagram based on Tulloch et al. [8].

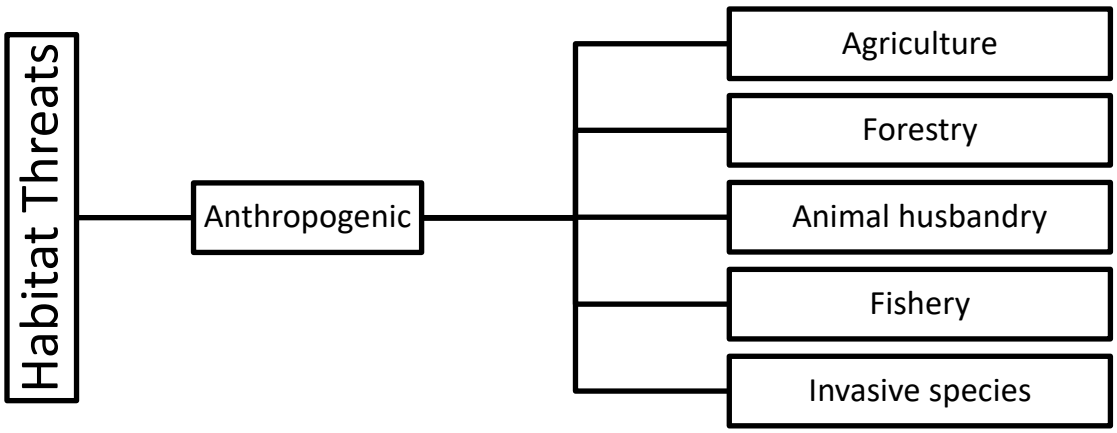



***Figure S9.*** Tree diagram based on Xu et al. [9].

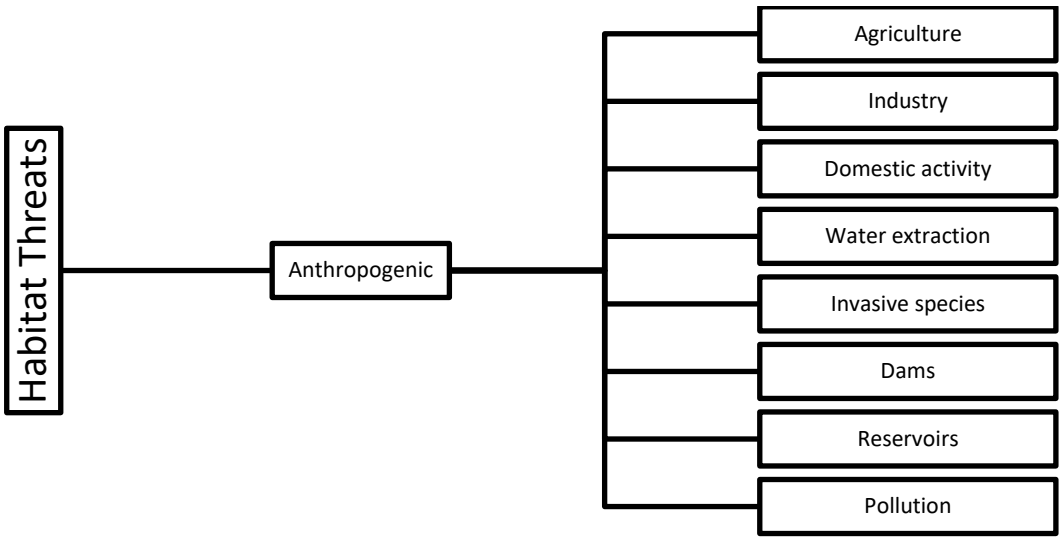



***Figure S10.*** Tree diagram based on Collen et al. [10].

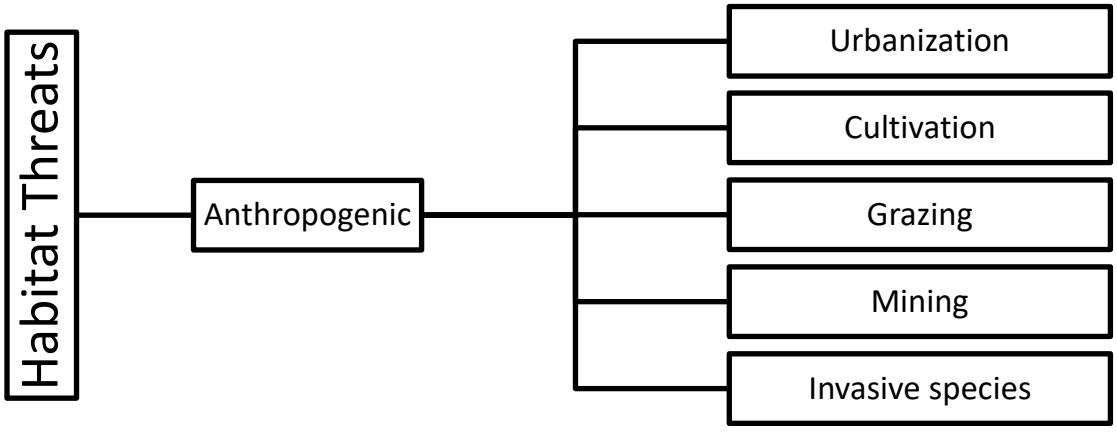



***Figure S11.*** Tree diagram based on Payet et al. [11].

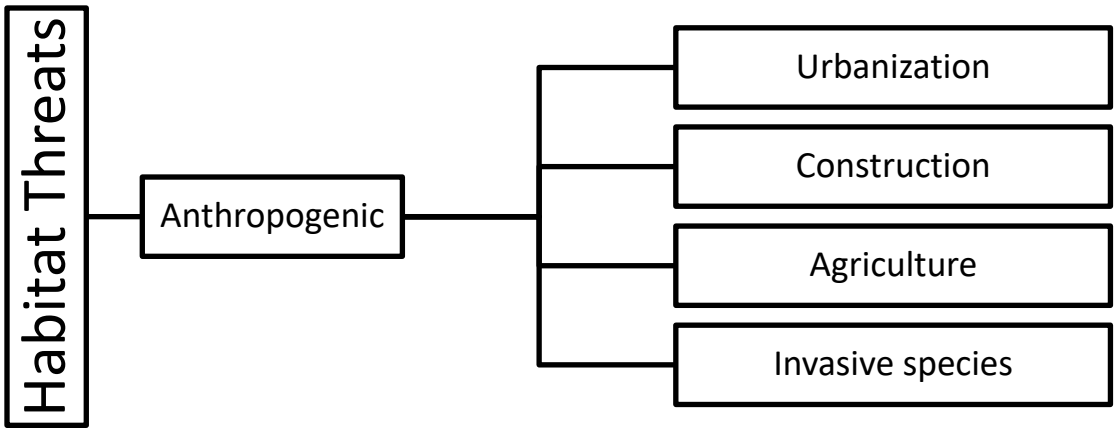



***Figure S12.*** Tree diagram based on Mashizi and Sharafatmandrad [12].

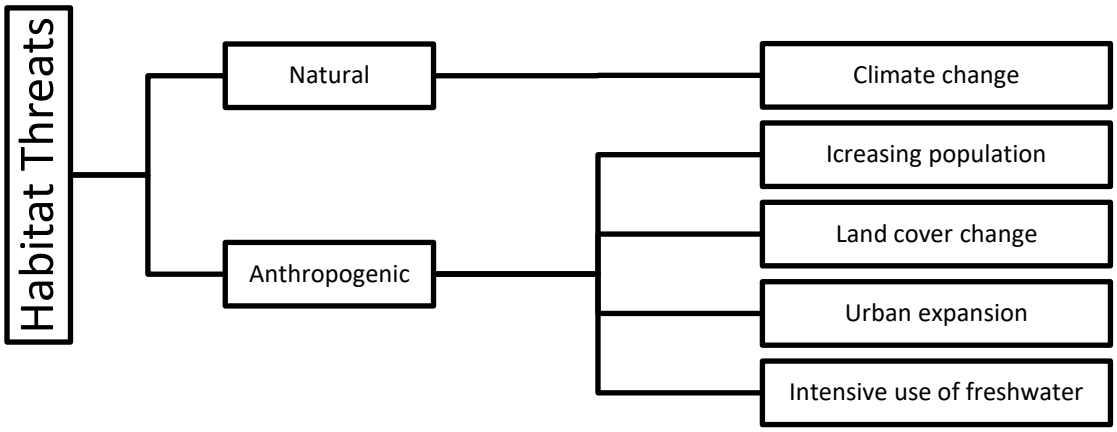



***Figure S13.*** Tree diagram based on Kim et al. [13].

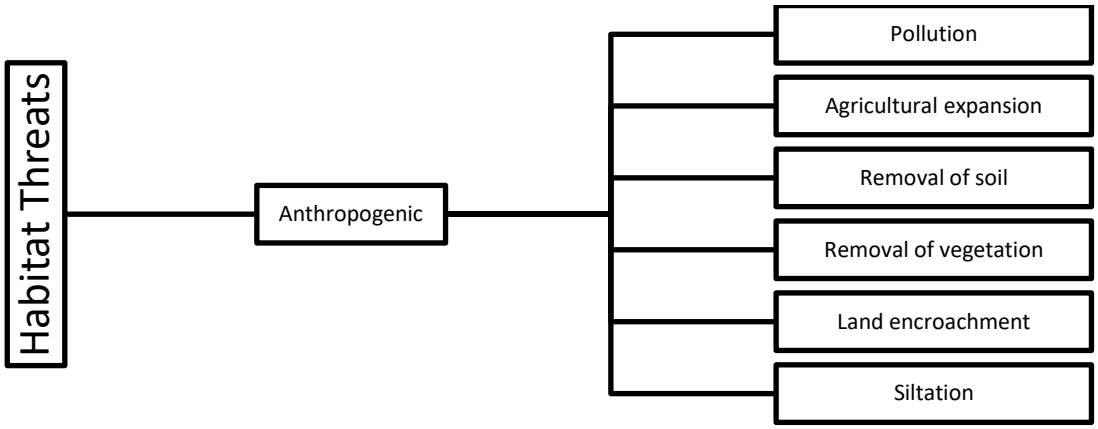



***Figure S14.*** Tree diagram based on Jha and McKinley [14].

Figure S15 shows a timeline in mostly five-year increments. Habitat destruction, invasive species, and urbanization are highlighted as these threats appear in studies the most. Climate change has been recognized since the mid-2000s. Fossil fuels have been noted even more recently. Many of the studies used in this analysis are recent. This explains why 2015-2019 has more threats noted than the other

periods.

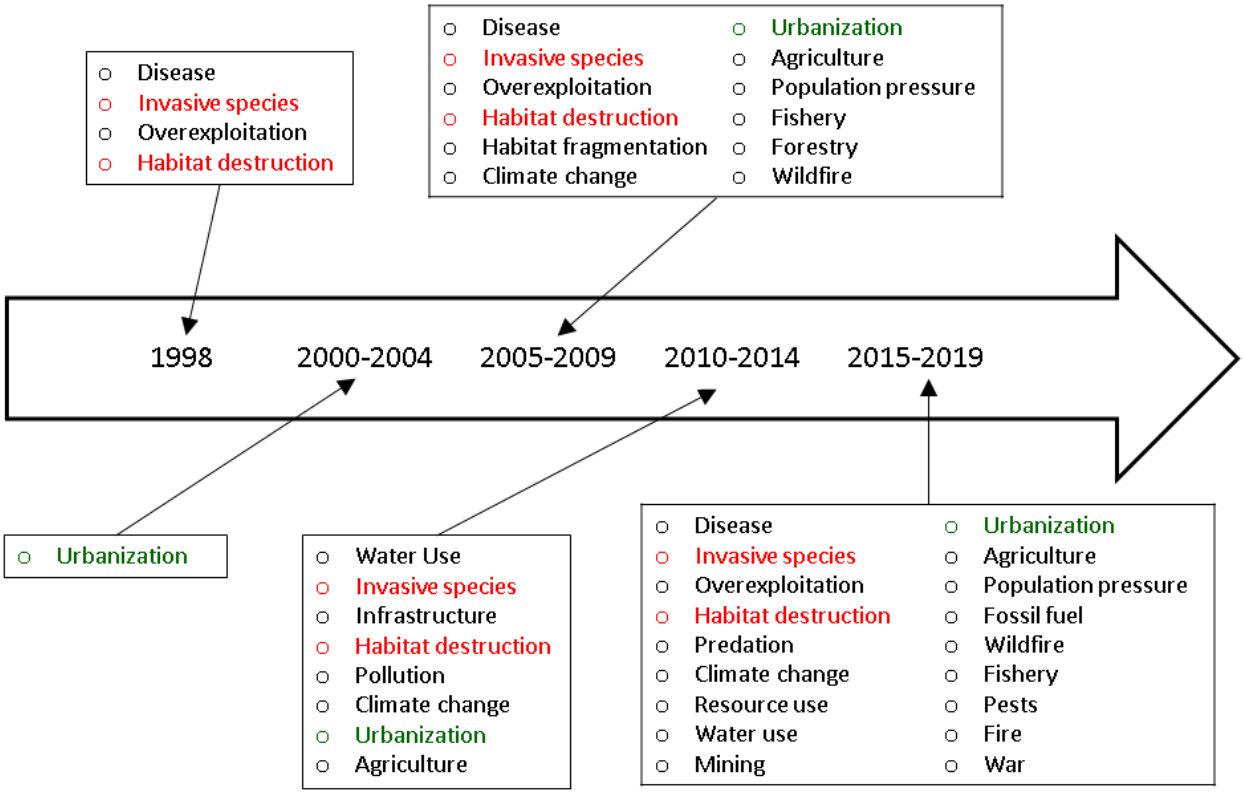



***Figure S15.*** Timeline of habitat threats.

Table S1 is a list of habitat threat characteristics compiled from the literature.

***Table S1.*** Threat Characteristics.

| Reference | Threat factor | $D_{max}$ (km) | Weight | Decay |
|---|---|---|---|---|
| [15] | Transportation | 2 | 0.2 | linear |
| | Water conservancy facilities | 3 | 0.1 | exponential |
| | Town & village | 5 | 0.3 | exponential |
| | Industrial & mining | 4 | 0.15 | exponential |
| | Cultivated land | 1 | 0.1 | linear |
| | Saline land | 1 | 0.02 | linear |
| | Agricultural land | 2 | 0.1 | exponential |
| [16] | Population | 6 | 0.28 | linear |
| | GDP | 7 | 0.31 | linear |
| | Built-up land | 5 | 0.24 | linear |
| | Roads | 2 | 0.17 | linear |
| [17] | Industrial | 3 | 1 | linear |
| | Commercial | 3 | 1 | linear |
| | Recreation | 3 | 1 | linear |
| | Roadhs (60 km/h) | 1.2 | 1 | exponential |
| | Roadms(60~80 km/h) | 0.8 | 0.8 | exponential |

| | | | | |
|---|---|---|---|---|
| | Roadls (80 km/h) | 0.4 | 0.6 | exponential |
| | Public facilities | 3 | 1 | linear |
| [18] | Urban | 10 | 1 | exponential |
| | Rural | 5 | 0.6 | exponential |
| | Industrial and Mining | 6 | 0.5 | exponential |
| | Unutilized land | 8 | 0.7 | linear |
| | Paddy Fields | 8 | 0.6 | linear |
| | Dry Land | 1 | 0.5 | linear |
| | Railway | 5 | 0.7 | linear |
| | Main Roads | 3 | 0.6 | linear |
| | Minor Roads | 2 | 0.5 | linear |
| [19] | Agriculture | 4 | 0.68 | exponential |
| | Streets | 2.9 | 0.71 | exponential |
| | Roads | 2.9 | 0.36 | exponential |
| | Villages | 3.6 | 0.5 | linear |
| | Cities | 7.1 | 1 | linear |
| | Tourism | 3.6 | 0.5 | exponential |
| | Industry | 8 | 1 | linear |
| | Gold mining | 10 | 1 | linear |
| [20] | Population centers | 7-16.18 | 0.34 | linear |
| | Hydroelectric power stations | 1.2 | 0.3 | linear |
| | Grassland | 2-2.2 | 1 | linear |
| | Agriculture | 4.71-5 | 0.29 | linear |
| | Tracks | 1.5 | 0.53 | linear |
| | Lines of transmission | 0.03 | 0.18 | linear |
| [21] | Paved roads | 0.95 | | |
| | Pesticides | 0.1 | | |
| | Urban areas | 0.5 | | |
| [22] | Aquaculture pond | 1 | 0.6 | exponential |
| | River | 3 | 0.4 | linear |
| | Road | 5 | 0.6 | linear |
| | Spartina alterniflora | 3 | 0.8 | exponential |
| [23] | Urbanization | 7.1 | 1 | exponential |
| | Agriculture | 4 | 0.68 | exponential |
| | Roads | 2.9 | 0.71 | exponential |
| | Mining | 5.6 | 0.8 | exponential |
| | Dams | 14 | 0.92 | exponential |
| | WWTP | 6 | 0.83 | exponential |
| | Water abstraction | 13.2 | 0.77 | exponential |
| | Channeling | 0 | 0.76 | exponential |
| | Invasive species | 0 | 0.68 | exponential |
| [24] | Construction | 8 | 1 | exponential |
| | Transportation | 5 | 0.7 | linear |
| | Raw land | 3 | 0.4 | linear |
| | Farmland | 2 | 0.2 | linear |
| [25] | Farmland | 2 | 0.4 | linear |

| | | | |
|---|---|---|---|
| Buildings | 3 | 0.7 | linear |
| Transportation lands | 5 | 1 | linear |
| Green spaces | 1 | 0.2 | linear |

A list of threat index estimation equations is tabulated in Table S2. This list was created by listing index equations that were found directly in the literature or were made based on a calculation methodology from the literature.

**Table S2.** Threat index equations from literature.

| Reference | Location | Habitat | Index Name | Description of Variables | Equation |
|---|---|---|---|---|---|
| [26] | Pacific NW | Coast, lowland, cascades | Conversion threat index | $CP$ - conversion potential<br>$DT^{PA}$ – distance to protected area boundary<br>$CTI$ – conversion threat index | $CPc^{p}_{2000-2100} = \sum LULCc\Delta^{Ps^{1\dots n}}_{y1\dots yn}$<br>$CTI_c = CPc^{p}_{2000-2100} \times DT^{PA}$ |
| [6] | Global | Global | Threat Score | $C_r$ - ranking of target cell<br>$f_i$– number of cells with target cell value<br>$N$ – total number of cells | $C_r = \frac{C_i + 0.5f_i}{N} \times 100$ |
| [27] | California | Coastal | CVI | $a$ - geomorphology<br>$b$ - historical rates of shoreline change<br>$c$ - coastal slope<br>$d$ - relative sea level rise<br>$e$ - wave action<br>$f$ - tidal range | $CVI = \left(\frac{(a*b*c*d*e*f)}{6}\right)^{0.5}$ |
| [1,28] | Rocky Mountains | Mountain range | Indicator Ranking | $Z$ – Z-score assigned to each county<br>$X$ – value of a variable for geographic unit<br>$X_{mean}$ – mean value of the variables for all units in the group<br>$S_x$ – standard deviation of the variables for all units in the group | $Z = \frac{X - X_{mean}}{S_x}$ |
| [29] | Mexico | Freshwater | Corrected Weight Endemism Index | $IE$ – index of endemism<br>$c$ – number of grid cells the species occurs in<br>$n$ – number of species<br>$CWEI$ – corrected weighted endemism index | $IE = \sum_{i=1}^{n} \frac{1}{c_i}$<br>$CWEI = \frac{IE}{n}$ |
| [2] | Queenslan d, Australia | Great Barrier Reef | Habitat Quality Index | $HQI$ - Habitat Quality Index,<br>$TSI$ -Thermal Stress Index, | $HQI_i = TSI_i^{\alpha} \times CDI_i^{\beta} \times COI_i^{\gamma} \times LPI_i^{\delta}$ |

| | | | | | |
|---|---|---|---|---|---|
| | | | | *CDI* - Cyclone Damage Index, *COI* - COTS Outbreak Index, *LPI* - Land-based Pollutants Index, $\alpha,\beta,\gamma,\delta$ - contribution of each threat to be optimized. | |
| [7] | Colorado | Lower Colorado River Basin | Ecological Risk Index | $R$ – ecological risk index<br>$f_i$ – frequency of each threat<br>$s_i$ – severity of each threat | $R = \sum_{i=1}^{n} f_i \times s_i$ |
| [5] | Ghana | Rangelands | Prevalent Threat Index, Rangeland sites Susceptibility Index, Mean Score of Threat Factors Relative Threat Factor Severity Index | $P$ – number of pastoralists mentioning a threat factor<br>$R$ – Range officers of all range sites<br>$T$ – number of threat types occurring<br>$I$ – number of threat types identified<br>$S$ – sum of scores for that threat factor<br>$H$ – total number of respondents<br>$M$ – mean score of a threat factor<br>$F$ – max possible score | $PTI = P/R \times 100/1$<br>$RSSI = T/I \times 100/1$<br>$MSTF = S/H$<br>$RTFSI = M/F$ |
| [30] | California | Various | Index-based and Risk-based Multispecies Conservation Value | $n$ – number of species<br>$S_{ij}$ – habitat suitability for species $i$ at location $j$<br>$E_i$ – endangerment index<br>$P_i$ – probability of extinction<br>$C_{ji}$ – contribution of location $j$ to the viability of species $i$ | $iMCV_j = \frac{\sum_{i=1}^{n}(S_{ij} \times E_i)}{\sum_{i=1}^{n} E_i}$<br>$rMCV_j = \frac{\sum_{i=1}^{n}(S_{ij} \times P_i \times C_{ji})}{\sum_{i=1}^{n} P_i}$ |
| [4] | Missouri River Basin | Prairie, desert, steppe | Threat Index | $Ts_{ijk}$ – threat metric score for every stream segment $i$ in ecoregion $j$ for threat metric score $k$ | $TI_{ij} = \left[\frac{\sum_{k=1}^{n} Ts_{ijk}}{\max\left(\sum_{k=1}^{n} Ts_{ijk}\right)}\right] \times 100$ |
| [31] | Maine, USA | Wetlands | Threat value | $DP$ – development pressure<br>$AHV$ – actual habitat value<br>$PL$ – protection level | Threat value $= \frac{DP \times AHV}{PL}$ |

| | | | | | |
|---|---|---|---|---|---|
| [13] | South Korea | Watershed | Adjusted Threat Index | $\beta x$ – coefficients for the linear regression<br>$S_{i,l}$ – score of selected indicator $l$ ($l$=1,2,…$L$) for grid cell $i$<br>$L$ – number of selected indicators | $\widehat{AT_i} = \beta_0 + \sum_{l=1}^{4} \beta_l S_{i,l}$ |
| [25] | Beijing | Aquatic habitats | Habitat Threat Index | $m$ – number of the grid cells in a land use type<br>$n$ – total number of land uses<br>$Dij$ – impact of grid cell $j$ in land use $i$ | $HTI = \frac{1}{m \times n} \sum_{i=1}^{n} \sum_{j=1}^{m} D_{ij}$ |
| [32] | China | River Ecosystems | Ecological Threat Index | $F_i$ – frequency of threat factor $i$<br>$S_i$ – severity of threat factor $i$ | $gETI = \sum_{i=1}^{n=10} (F_i \times S_i)$ |

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