IndiFrag v2.1 Description of fragmentation and multi-temporal metrics included in IndiFrag software. Categorised in groups: Area and perimeter, shape, aggregation, diversity, contrast and multi-temporal. The group, name, formula, definition, units, reference, and level are reported, where O means object level (e.g.: patch), Cl class level (e.g.: land use) and SO super-object level (e.g.: administrative unit). Acronyms of formulas and complete references are below the table.

Group	Name	Formula	Definition	Unit	Reference	Level
Area and perimeter	Area	$Area$	Area of the object, class or super-object	m^2 | km^2	-	O,Cl,SO
	Perimeter	$Perim$	Perimeter of the object, class or super-object (without boundary duplicity)	m | km	-	O,Cl,SO
	Total perimeter	$PerimT$	Perimeter of the super-object plus the total perimeter of the objects (without boundary duplicity)	km	-	SO
	Class density	$DC = \frac{\sum_{i=1}^{n}(A_i)}{A_T}$	Ratio between a class area and super-object area	%	-	Cl
	Urban density	$DU = \frac{A_u}{A_T}$	Ratio between urban area and super-object area	%	Romano et al., 2006	SO
	Object mean size	$TM = \frac{\sum_{i=1}^{n}(A_i)}{n}$	Equals the average of the size of the objects from a class or super-object	m^2	Irwin y Bockstael, 2007	Cl,SO
	Edge density	$\mathrm{DB} = \frac{\sum_{i=1}^{n}(P_i)}{A_T}$	Equals the sum of the perimeter of the objects from a class or super-object divided by the area of the super-object	m/m^2	Herold et al., 2002; McGarigal et al., 2012	Cl,SO
	Boundary dimension	$\ln(A_i) = \frac{2}{Dim_B} \cdot \ln(P_i) + \ln(C)$	Represents the relationship between the object area and the perimeter, it measures the complexity and randomicity of classes	None	Wu et al, 2013	Cl
	Gross leapfrog	$LPF = \frac{A_{out}}{\sum_{i=1}^{n}(A_i)}$	Ratio between the area of leapfrog or isolated objects from a class located separately at a distance from the rest of the class and the area of the whole class	%	Frenkel and Ashkenazi, 2008	Cl
	Weighted urban fragmentation	$\overline{IFUP}_i = \frac{\sum_{i=1}^{ns}(IFU_i \cdot A_{Ti})}{\sum_{i=1}^{ns}(A_{Ti})}$ $IFU_i = \frac{\sum_{i=1}^{m}(L_{max} \cdot \sum_{i=1}^{n}(A_i) \cdot O_c)}{A_{Ti}}$	Evaluates the habitat fragmentation due to the presence of urban areas, it is weighted by SO area in order to perform comparisons between the fragmentation values	None	Astiaso et al., 2013; Romano 2002; Romano and Tamburini, 2006	SO
Shape	Area-weighted mean fractal dimension	$DFP = \sum_{i=1}^{n}\left[\left(\frac{2 \cdot ln(0.25 \cdot P_i)}{ln(A_i)}\right) \cdot \left(\frac{A_i}{\sum_{i=1}^{n} A_i}\right)\right]$	Equals the average fractal dimension of objects in the class or super-object, weighted by the area of the object	None	Gong et al., 2013; Herold et al., 2002; McGarigal et al., 2012	Cl
	Fractal dimension	$DF = \frac{2 \cdot ln(0.25 \cdot P_i)}{ln(A_i)}$	A normalised shape index based on perimeter-area relationships in which the perimeter and area are transformed with logarithm	None	Frenkel and Ashkenazi, 2008; Gong et al., 2013; Herold et al., 2002; McGarigal et al., 2012	O,Cl,SO
	Shape index	$IF = \frac{0.25 \cdot P_i}{\sqrt{A_i}}$	A normalised ratio of object perimeter to area in which the complexity of object shape is compared to a square of the same size	None	Frenkel and Ashkenazi, 2008; Jiang et al., 2007; McGarigal et al., 2012	O, Cl, SO
	Perimeter-area mean ratio	$RMPA = \frac{\sum_{i=1}^{n}\left(\frac{P_i}{A_i}\right)}{n}$	Describes the relationship between the object area and perimeter, and thus describes how object perimeter increases per unit increase in object area	None	Irwin and Bockstael, 2007, ; McGarigal et al., 2012	O,Cl,SO
Aggregation	Number of Objects	Nob	Number of objects in a class or super-object (except road objects)	nº	-	Cl,SO
	Object density	$DO = \frac{n}{A_T}$	Number of objects divided by the area of the super-object	n^o/km^2	Gong et al., 2013; Herold et al., 2002; Irwin and Bockstael, 2007; McGarigal et al., 2012	Cl,SO
	Weighted standard distance	$DEP = \sqrt{\left(\frac{\sum_{i=1}^{n}(A_i \cdot (x_i - \bar{x})^2)}{A_T}\right) + \left(\frac{\sum_{i=1}^{n}(A_i \cdot (y_i - \bar{y})^2)}{A_T}\right)}$	Degree to which objects are concentrated around their centroid. Equals the average of the distance from objects to the centroid	km	Colaninno et al., 2011	Cl,SO
	Euclidean nearest neighbour mean distance	$DEM = \frac{\sum_{i=1}^{n}(D_{ij})}{n}$	Quantifies object isolation. Equals the average distance between nearest objects from the same class in a super-object	km	Gong et al., 2013; McGarigal et al., 2012	Cl

Aggregation	Effective mesh size	$TEM = \frac{\sum_{i=1}^{n}(A_i^2)}{A_T}$	Size of the objects when the super-object is divided into n areas with the same degree of super-object division	km^2	EEA, 2011; Jaeger, 2000; McGarigal et al., 2012	Cl, SO
	Cohesion	$COHE = \frac{1-\left(\sum_{i=1}^{n}(P_i) / \sum_{i=1}^{n}(P_i \cdot \sqrt{A_i})\right)}{1-\left(1/\sqrt{A_T}\right)}$	Measures the physical connection of the objects	None	Maclean and Congalton, 2013; McGarigal et al., 2012	Cl,SO
	Splitting index	$IS = \frac{{A_T}^2}{\sum_{i=1}^{n}({A_i}^2)}$	Number of objects when dividing the super-object into equal parts, with the same degree of super-object division	None	Jaeger, 2000; McGarigal et al., 2012	Cl,SO
	Coherence degree	$GC = \sum_{i=1}^{n}\left(\frac{A_i}{A_T}\right)^2$	Represents the probability that two points are in the same object in a super-object	%	Jaeger, 2000; McGarigal et al., 2012	Cl,SO
	Urban compactness	$CU = \frac{2 \cdot \sqrt{\pi \cdot A_U}}{P_U}$	Quantifies the degree of spatial aggregation of the urban type objects	%	Zhang et al., 2016	SO
	Class compactness	$C = \frac{2 \cdot \sqrt{\pi \cdot \sum_{i=1}^{n}(A_i)}}{\sum_{i=1}^{n}(P_i)}$	Quantifies the degree of spatial aggregation of the objects of a class	%	Zhang et al., 2016	Cl
	Radius dimension	$\ln A_c(r) = Dim_R \cdot \ln(r) + \ln(C)$	Defined by the total object class area and its radius to depict the density change radiating outward from a centre point. An effective evaluation criterion to assess the centrality of land use patterns	None	Wu et al., 2013	SO
Diversity	Number of classes	NCl	Number of classes in the super-object	nº	-	SO
	Shannon diversity	$DSHAN = -\sum_{i=1}^{m}[P \cdot (ln(P))]$	Equals minus the sum of the proportional abundance of each object class multiplied by that proportion	None	Colaninno et al., 2011, McGarigal et al., 2012	SO
	Shannon's evenness	$USHAN = \frac{-\sum_{i=1}^{m}(P \cdot (ln(P))}{ln(m)}$	Covers the number of classes in a super-object and their relative abundances. It is calculated by dividing DSHAN by its maximum	None	McGarigal et al., 2012, Romano et al., 2010	SO
	Simpson diversity	$SIMP = 1 - \sum_{i=1}^{m}(P^2)$	Probability that two random objects are from different classes	None	McGarigal et al., 2012	SO
	Density-diversity	$DD = \sum_{i=1}^{m}\left(\frac{\sum_{i=1}^{n}(A_i)}{max(\sum_{i=1}^{n}(A_i))}\right)$	Equals the sum of the amount of a class as proportion of its maximum	None	Batty et al., 2003, Escolano, 2009	Cl,SO
	Relative functional fragmentation	$IFFR = \frac{(R_v - m)}{(R_v - 1)}$	Points out the level of functional fragmentation in a super-object by the ratio of the number of classes in the super-object to the number of classes of the whole study area	None	Marinescu and Avram, 2012	SO
	Absolute functional fragmentation	$IFFA = \frac{P_T}{\sum_{i=1}^{m}(\sum_{i=1}^{n}(P_i))}$	Level of functional and structural integration within the perimeter. Ratio between the super-object and the sum of class perimeters	None	Marinescu and Avram, 2012	SO
Contrast	Boundary contrast ratio	$RCB = \frac{l_{i,j}}{P_i}$	Equals the sum of the segment lengths of an object (class or super-object) adjacent to different classes, divided by the perimeter of the object (or the class or super-object depending on the level)	%	Irwin and Bockstael, 2007, McGarigal et al., 2012,	O,Cl,SO
Multi-temp.	Land use change	$LUC = \frac{LUD_{t2} - LUD_{t1}}{LUD_{t1}}$ $LUD = \sum_{i=1}^{n}(E \cdot P) \cdot 100$	It is based on the exploitation degree of classes that are classified into four levels. It is calculated on the basis of the ratio of class area to the super-object area with the consideration of weighted values of each class type level between the two dates	None	Pan et al., 2011	SO
	Change proportion	$CP = \frac{A_{t2} - A_{t1}}{A_T} \cdot 100$	Expansion intensity. Ratio between the change area of a class and the area of the super-object	%	Yin et al., 2011	Cl

Multi-temporal	Landscape expansion index	$LEI = \frac{l_w}{P_w} \cdot 100$	Categorizes new objects in: infilling, edge-expansion, and outlying types by comparing perimeters between new and old objects	%	Liu et al., 2010; Sun et al., 2013; Wilson et al., 2003	O
	Mean expansion index	$MEI = \frac{\sum_{i=1}^{w} LEI_w}{w}$	Equals to the mean of the LEI of all new objects	None	Liu et al., 2010; Sun et al., 2013; Wilson et al., 2003	Cl
	Area-weighted mean expansion index	$AWMEI = \sum_{i=1}^{w} \left(LEI_w \cdot \frac{A_w}{A_{TW}} \right)$	Equals to the sum, across all new objects, previously classified according to LEI, multiplied by the proportional area of the new object	None	Liu et al., 2010; Sun et al., 2013; Wilson et al., 2003	Cl
	Area new	A_{new}	Total area of new objects from a class. It does not take into account lost objects.	km^2	-	Cl
	Area infilling	A_{inf}	Total area of new objects from a class with infilling growth type	km^2	-	Cl
	Area edge-expansion	A_{edg}	Total area of new objects from a class with edge-expansive growth type	km^2	-	Cl
	Area outlying	A_{out}	Total area of new objects from a class with outlying growth type	km^2	-	Cl
	Change rate	$RC = \frac{1}{t_2 - t_1} \cdot ln \left(\frac{A_{t2}}{A_{t1}} \right) \cdot 100$	Annual rate of change calculated as it was not linear	%	Malaviya et al., 2010	Cl
	Change area	$A_c = A_{t2} - A_{t1}$	Equals the difference of the areas of a class in the studied period	km^2	Tian et al., 2014	Cl
	Change area ratio	$A_r = \frac{A_c}{t_2 - t_1}$	Equals the difference of the areas of a class in the studied period divided by the number of years	km^2/year	Tian et al., 2014	Cl
	Centroid coordinates displacement	D	Distance and orientation between the geometric centres of a class (t_1 and t_2)	m	Jing and Jianzhong, 2011	Cl
	Concentric circle	*(graph)*	Quantity and spatial distribution of a class change, it measures areas at different distances (given) with respect to a centre point	km^2	Yin et al., 2011	Cl
	Sector analysis	*(graph)*	Quantity and spatial distribution of a class change, it measures areas at different orientation (22.5 degrees) with respect to a centre point	km^2	Yin et al., 2011	Cl

Acronyms

A_i = area of the object i (m^2)
P_i = perimeter of the object i (m)
A_T= total area of the super-object (m^2 | km^2)
P_T= perimeter of the super-object (m | km)
n= number of objects in a class or super-object
m = number of classes in the super-object
ns = number of super-objects in the study area
L_{max}= maximum length of an object in a class (m)
A_{out}= area of isolated objects in a class (m^2)
x_i, y_i= coordinates of the centroid of an object (m)
$\bar{x}$, $\bar{y}$= mean of the coordinates of the centroid of the objects of a class (m)
O_c= obstruction coefficient (where: 1 industrial, commercial, road, rail networks, airports; const. sites, 0.8 continuous urban fabric; 0.6 discontinuous urban fabric and; 0.4 green urban areas; sport and leisure facilities)
D_{ij}= distance between an object i and its nearest object j (from boundary to boundary) of the same class (m)
A_U= total area of urban objects (m^2)
P_U= total perimeter of urban objects (m)
r = radius from the centre point to the circle (m)
$A_c(r)$ = area of a class inside the circle with radius r (m^2)
C= constant
P= proportion of the super-object occupied by the class i, (A_i/A_T) (%)
R_v= number of classes in the total study area (having into account all the SO)
$l_{i,j}$ = length of the shared edges between two objects from different classes i,j (m). At class or super-object level equals the sum of the total lengths (m)
A_{t1}= area of a class in the first time (m^2)
A_{t2}= area of a class in the second time (m^2)
l_w= length of the edge between a new object and an old object (m)
P_w= perimeter of a new object (m)
A_w= area of a new object (m^2)
A_{Tw} = total area of the new objects from a class (m^2)
w = number of new objects
E = exploitation degree of the class (where: 1 barren/unused land; 2 forest, water, grass; 3 agricultural land; 4 urban, mine, roads, etc.)

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