Supplementary Materials

Table S1. Landsat satellite imagery.

Date	Path, row	Landsat source	Spatial resolution (m)
1989/7/15	121,40	5 TM	30
1989/2/4	122,40	5 TM	30
2000/9/23	121,40	5 TM	30
2000/10/8	122,40	5 TM	30
2008/8/20	121,40	5 TM	30
2008/12/17	122,40	5 TM	30
2016/7/9	121,40	8 OLI	15
2016/2/7	122,40	8 OLI	15

Table S2 mathematical notation

Notation	Meaning
T	number of time points
Y_t	year at time point t
t	index for a time point
J	number of categories
i	index for a category
j	index for a category
C_{tij}	number of pixels that are category i at time point t and category j at time point t+1
C_{tji}	number of pixels that are category j at time point t and category i at time point t+1
A_t	annual change percentage during time interval $[Y_t, Y_{t+1}]$
U	uniform intensity of annual change percentage during the temporal extent $[Y_1, Y_T]$
G_{tj}	intensity of annual gain of category j during time interval $[Y_t, Y_{t+1}]$ relative to size of category j at time point t+1
L_{ti}	intensity of annual loss of category i during time interval $[Y_t, Y_{t+1}]$ relative to size of category i at time point t
R_{tij}	intensity of annual transition from category i to category j during time interval $[Y_t, Y_{t+1}]$ relative to size of category i at time point t
W_{tj}	uniform intensity of annual transition from all non-j categories to category j during time interval $[Y_t, Y_{t+1}]$ relative to size of all non-j categories at time point t
d_{tj}	Annual difference for category j during interval t
D_t	Annual difference overall during interval t
ε_{tij}	Annual exchange between categories i and j during interval t
e_{tj}	Annual exchange component for category j during interval t
E_t	Annual exchange component overall during interval t
q_{tj}	Annual quantity component for category j during interval t
Q_t	Annual quantity component overall during interval t
S_t	Annual shift component overall during interval t

Text S1 Equations for difference components

Equation 1 gives the annual difference during time interval t for category j. Equation 2 gives the annual quantity component during interval t for category j. The quantity component is the absolute net change in size of the category. Equation 3 gives the annual exchange between categories i and j during time interval t. Categories i and j form exchange when some locations transition from category i to category j while other locations transition from j to i. Equation 4 sums the exchanges for category j to give the exchange component for category j. Equation 5 gives the shift component for category j during interval t. The shift component is the difference minus the quantity component minus the exchange component. Equations 6–8 sum the components for each category to give the components overall during time interval t. Division by 2 is necessary in equations 6–8 because each location of temporal difference involves two categories, i.e. the losing category and the gaining category. Equation 9 shows how the difference overall is the sum of the three components. Equations 10–12 express the intensity of each of the three components of change overall. The three intensities in Equations 10–12 sum to one. Equations 13–15 are for the category level. Equations 13–15 give the three component intensities for each category j by taking the size of the component divided by the size of the change. Equations 13–15 sum to one for each category j.

$$d_{tj} = \frac{\{[\sum_{i=1}^{J}(C_{tij}+C_{tji})]-2\times C_{\mathrm{tjj}}\}100\%}{(Y_{t+1}-Y_t)\sum_{i=1}^{J}\sum_{j=1}^{J}C_{tij}} \quad (1)$$

$$q_{tj} = \frac{\left|\sum_{i=1}^{J}(C_{tij}-C_{tji})100\%\right|}{(Y_{t+1}-Y_t)\sum_{i=1}^{J}\sum_{j=1}^{J}C_{tij}} \quad (2)$$

$$\varepsilon_{tij} = \frac{2\mathrm{MINIMUM}(C_{tij},C_{tji})100\%}{(Y_{t+1}-Y_t)\sum_{i=1}^{J}\sum_{j=1}^{J}C_{tij}} \; for\ i > j\ and\ \varepsilon_{tij} = 0\ for\ i \leq j \quad (3)$$

$$e_{tj} = \sum_{i=1}^{J}(\varepsilon_{tij} + \varepsilon_{tji}) = \frac{2\{[\sum_{i=1}^{J}\mathrm{MINIMUM}(C_{tij},C_{tji})]-C_{\mathrm{tjj}}\}100\%}{(Y_{t+1}-Y_t)\sum_{i=1}^{J}\sum_{j=1}^{J}C_{tij}} \quad (4)$$

$$s_{tj} = d_{tj} - q_{tj} - e_{tj} \quad (5)$$

$$Q_t = \frac{\sum_{j=1}^{J}q_{tj}}{2} \quad (6)$$

$$E_t = \frac{\sum_{j=1}^{J}e_{tj}}{2} \quad (7)$$

$$S_t = \frac{\sum_{j=1}^{J}s_{tj}}{2} \quad (8)$$

$$D_t = \frac{\sum_{j=1}^{J}d_{tj}}{2} = Q_t + E_t + S_t \quad (9)$$

$$Quantity\ overall\ intensity_t = Q_t/D_t \quad (10)$$

$$Exchange\ overall\ intensity_t = E_t/D_t \quad (11)$$

$$Shift\ overall\ intensity_t = S_t/D_t \quad (12)$$

$$Quantity\ intensity_{tj} = Q_{tj}/D_{tj} \quad (13)$$

$$Exchange\ intensity_{tj} = E_{tj}/D_{tj} \quad (14)$$

$$Shift\ intensity_{tj} = S_{tj}/D_{tj} \quad (15)$$

Text S2 The calculation methods for Intensity analysis at three levels

The first level is the time interval level, which addresses the question "In which time intervals is the overall annual rate of change relatively slow or fast?" There are two equations at this level. Equation (16) defines the annual percentage of change in the spatial extent for each time interval thus Equation (16) gives *T−1* rates, meaning one rate per time interval. Equation (17) defines the annual uniform rate of change when we distribute the overall change that occurred during all intervals uniformly from the first time point to the last time point. If $A_t < U$, then A_t is slow, meaning the time interval [Y_t, Y_{t+1}] experiences change slower than if the changes during all time intervals were distributed uniformly during the temporal extent [Y_1, Y_T]. If $A_t > U$, then A_t is fast, meaning the time interval [Y_t, Y_{t+1}] experiences change faster than if the changes during all time intervals were distributed uniformly during the temporal extent [Y_1,Y_T].

$$A_t = \frac{\left\{\sum_{j-1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right)-C_{tij}\right]\right\}100\%}{(Y_{t+1}-Y_t)\sum_{j-1}^{J}\left(\sum_{i=1}^{J} C_{tij}\right)} \tag{16}$$

$$\mathrm{U} = \frac{\left\{\sum_{t=1}^{T-1}\left\{\sum_{j-1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right)-C_{tij}\right]\right\}\right\}100\%}{(Y_T-Y_1)\sum_{j-1}^{J}\left(\sum_{i=1}^{J} C_{tij}\right)} \tag{17}$$

The second level is the category level, which examines how the loss intensity L_{ti} from category *i* and the gain intensity G_{tj} to category *j* compares to a uniform intensity A_t during each time interval [Y_t,Y_{t+1}]. If $L_{ti} < A_t$, then L_{ti} is dormant, meaning category i experiences loss less intensively than if the change during time interval $[Y_t, Y_{t+1}]$ were distributed uniformly across the spatial extent. If $L_{ti} > A_t$, then L_{ti} is active, meaning category i experiences loss more intensively than if the change during time interval $[Y_t, Y_{t+1}]$ were distributed uniformly across the spatial extent. Similarly, if $G_{tj} < A_t$, then G_{tj} is dormant; and if $G_{tj} > A_t$, then G_{tj} is active. Equation 18 gives L_{ti} and Equation 19 gives G_{tj}.

$$L_{ti} = \frac{\left[\left(\sum_{j=1}^{J} C_{tij}\right) - C_{tij}\right] 100\%}{(Y_{t+1} - Y_t) \sum_{j=1}^{J} C_{tij}} \tag{18}$$

$$G_{tj} = \frac{\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tij}\right] 100\%}{(Y_{t+1} - Y_t) \sum_{i=1}^{J} C_{tij}} \tag{19}$$

The third level is the transition level, which examines how the transition intensity R_{tij} from category i to category j compares to a uniform transition intensity W_{tj} given the gain of category j during time interval $[Y_t, Y_{t+1}]$. If $R_{tij} < W_{tj}$, then the gain of j avoids i, meaning the gain of j transitions from i less intensively during time interval $[Y_t, Y_{t+1}]$ than if the gain of j were to have transitioned uniformly from the space that is not j at time Y_t. If $R_{tij} > W_{tj}$, then the gain of j targets i, meaning the gain of j transitions from i more intensively during time interval $[Y_t, Y_{t+1}]$ than if the gain of j were to have transitioned uniformly from the space that is not j at time Y_t. Equation 20 gives R_{tij} and Equation 21 gives W_{tj}. The order of subscripts j and i in C_{tji} in the denominator of Equation 21 is intentional, so that the summation over i subtracts category j at the initial time Y_t.

$$R_{tij} = \frac{C_{tij}\,100\%}{(Y_{t+1} - Y_t)\sum_{j=1}^{J} C_{tij}} \tag{20}$$

$$W_{tj} = \frac{\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right] 100\%}{(Y_{t+1} - Y_t)\sum_{i=1}^{J}\left[\left(\sum_{j=1}^{J} C_{tij}\right) - C_{tji}\right]} \tag{21}$$