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COMMENTARY

Improving the estimation of area of occupancy for IUCN Red List assessments by using a circular buffer approach

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Abstract The area of occupancy (AOO) is one of the main measures used by IUCN to quantify range size for species. AOO represents the area of suitable habitat currently occupied by the taxon and is usually quantified by counting the number of occupied cells in a uniform grid that covers the entire range of a taxon. However, this methodology adds uncertainty by the location of the origin of the grid frame. In this communication paper, we tested the influence of the origin of the grid frame used to quantify AOO and found for Swiss bryophytes that 14 species (out of 1089) fall into a different Red List category when the origin of the grid frame was shifted. With this and theoretical examples we show that AOO quantified by circles around the occurrences (a circular buffer approach) would reduce uncertainty significantly because they are independent of the origin of a grid frame. A circular buffer approach to quantify AOO contribute thus to more robust and accurate Red Lists and its usage is in accordance with the IUCN criteria.

Keywords AOO · Bryophytes · Conservation · Extinction risk · Geographic range · Risk assessment · Species distribution · Threatened species

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Red list categories and criteria developed and published by the International Union for Conservation of Nature (IUCN) are frequently used to assess the extinction risk of species at the global and the national scale. These IUCN categories and criteria are intended to be easily understandable, objective, general and thus applicable to all species and regions globally. They are explained in a small booklet (IUCN 2012) and detailed guidelines on how to apply them are regularly updated by the Standards and Petitions Subcommittee of the IUCN Species Survival Commission (IUCN 2017). Software to quantify criteria is easily accessible via GIS tools (downloadable from http://www.iucnredlist.org/technical-documents/red-list-training/iucnspatialresources) and several R packages (Broennimann et al. 2017; Lee and Murray 2017; Moat 2017; Cardoso 2018). One of the criteria used to assess the Red List status of a species is the area of occupancy (AOO), which is defined as the area 'occupied by a taxon, excluding cases of vagrancy' (IUCN 2012) and represents the area of suitable habitat currently occupied by the taxon. IUCN allows several methods for estimating AOO but the most common method involves 'counting the number of occupied cells in a uniform grid that covers the entire range of a taxon' (IUCN 2017). Simulation studies showed that AOO is a very good measure to track loss of species' range size (Breiner et al. 2017) as well as ecosystem collapse (Murray et al. 2017).

Estimating AOO in this way could cause several types of uncertainty: (1) commission and omission errors from false observations; (2) the spatial precision of the coordinates (see Online Resource 1) (3) the grain size of the grid frame (Keith et al. 2017) and (4) the origin of the grid frame which can lead to different values of AOO (Keith et al. 2017). Although, the other errors might be more severe, we focus in this manuscript on (4) the uncertainty caused by the origin of the grid frame. A slight change in the origin of the grid frame could cause changes in the estimated area of occupancy (Fig. 1). Because the assignment of an IUCN Red List category to a species depends on precise thresholds, the method used for the quantification of AOO could directly cause changes in the extinction risk category due to small changes in AOO. A species is classified as vulnerable (VU) for AOO smaller than 2000 km^2, as endangered (EN) for AOO smaller than 500 km^2 and as critically endangered (CR) for AOO smaller than 10 km^2. There is no strict threshold to define a species as near threatened but a threshold of less than 3000 km^2 is recommended and used here as well (IUCN 2012, p. 74f). Additionally to the thresholds, two out of three subcriteria must be met (e.g., whether a species is severely fragmented or whether it is declining continuously or extremely fluctuating); however, these subcriteria are not important for illustrating the uncertainty of using AOO with a grid frame and are thus not considered here.

In extreme cases, four species occurrences could occupy four different cells of a grid even though they are located very close to each other (Fig. 1). The AOO would then be 16 km^2 and the species would be listed as EN. With only a small shift in the location of the grid frame, the four occurrences would fall in a single cell, the AOO would be reduced to 4 km^2 and consequently the species would be listed as CR. It is also possible for four occurrences to be much more distant from each other compared with in the first example but still occupy one cell (Fig. 1). In this case as well, the Red List status would be either EN or CR depending on grid frame location.

The above example demonstrates that small changes in AOO could have large implications for the assessed Red List status of species when grid frames are used and it was already shown that shifts in the origin of the grid frame causes large variation of AOO estimates (Keith et al. 2017). Uncertainty in AOO quantification is however considered in the IUCN guidelines: 'If different grid locations (starting points of the grid) result in different AOO estimates, the minimum estimate should be used' (IUCN 2017, p. 50). Although,

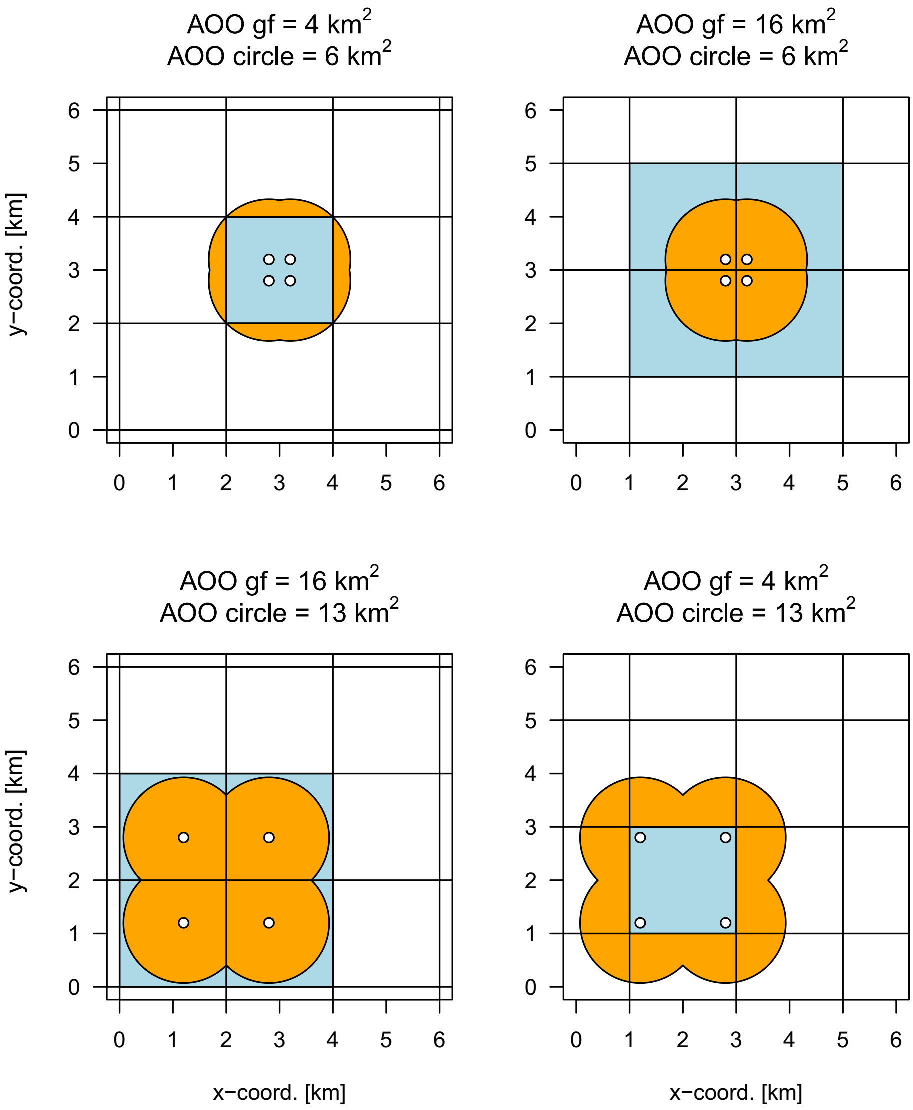

Fig. 1 Quantification of the Area of Occupancy (AOO) using a grid frame (gf) and a circular buffer approach. Upper left: the quantification of AOO of a hypothetical species (occurrences indicated by white points) is similar when a grid frame (4 km^2) or a circular buffer approach (6 km^2) are used and would qualify the species to be listed as critically endangered according to IUCN (2012). Upper right: a shift of the location of the grid frame would result in a much higher AOO when quantification is based on a grid frame (16 km^2) and the species would pass the threshold of 10 km^2 to be listed as critically endangered. Lower left: the hypothetical species would be listed as endangered for AOO when quantification is based on a grid frame as well as on a circular buffer approach. Lower right: the species would pass the threshold to be listed as critically endangered when the grid frame is shifted

recently software was developed to test for such uncertainty (Lee and Murray 2017), it is unknown whether assessors regularly vary grid locations to get a minimum estimate of AOO. It seems obvious that a simpler method, where AOO would have to be calculated only once also in cases where thresholds for AOO are narrowly missed, would lead to more consistent estimates of extinction risk. There is such a simple alternative to the grid frame method which is equally understandable, objective and applicable and would solve the problem completely: using a circular buffer approach around the occurrences would be more robust because it eliminates the risk of not testing for different origins of a grid frame and better reflects the distribution of the occurrences in the landscape (Fig. 1). A circular buffer approach to estimate AOO would also fulfil the IUCN guidelines because it is explicitly mentioned that other ways could be used for its quantification. There is therefore no need to modify the IUCN criteria.

We used point-precise occurrence data (minimum precision 200 m; results for other thresholds can be found in the Online Resource 1) from 1004 bryophyte species and 85 subspecies in Switzerland, provided by the National Data and Information Center for Swiss Bryophytes (www.swissbryophytes.ch), to test the effect of shifting the origin of the grid frame when quantifying AOO. The number of samples per species ranged from 1 to 2356 occurrence points in the database (total number of samples = 158,088; mean number of samples per species = 145 ± 271 SD; Fig. OR1.1 in Online Resource 1). We removed samples with imprecise coordinates (> 200 m precision) and species' aggregates. The database contains data from various sources such as large national monitoring schemes, smaller studies like regional inventories, and casual observations from non-systematic fieldwork and various contributors which did not follow a sampling protocol (www.swissbryophytes.ch). The samples are therefore likely biased geographically and environmentally. Such biases are usually found in species databases and are problematic for estimating the 'true' AOO. However, for illustrating the differences between the methods for quantifying AOO they are not important because the bias affects both measures equally. We oriented the grid frame on the Swiss coordinate system so that the 0/0 coordinate matched the lower right corner of a grid with a resolution of 2 × 2 km. This grid size is recommended by IUCN (IUCN 2017). We then shifted the grid frame by 1 km in the x and y directions (exemplified in Fig. 1) to simulate a different origin. Additionally, we quantified AOO by using circles around the occurrences (circular buffer approach; see Online Resource 2; R code can also be found in the *ecospat* R package, Broennimann et al. 2017; Di Cola et al. 2017); each circle had a radius of $\sqrt{4/\pi}$ to comply with the recommendations for the size of a pixel in the grid frame (4 km^2) by IUCN. We applied IUCN thresholds for both origins of the grid frame and for the circular buffer approach. There was a very high correlation between all values (r = 0.99985 for the two locations of the grid frame, r = 0.99994 for the first grid frame location and the circular buffer approach, and r = 0.99993 for the second grid location and the circular buffer approach). Despite this high correlation AOO values differed for 658 species (60.4%) when the location of the grid frame was shifted. The maximum difference in AOO was 60 km^2. For 14 species (1.3%) the Red List status changed depending on the position of the grid frame (Table 1a) and Keith et al. (2017) found even a change in Red List status for 11 out of 30 simulated distributions. In most cases the value of the AOO according to the circular buffer approach was in between the values of AOO quantified by the two grid frames (444 species; 40.8%) or equal to at least one of the AOO values quantified by a grid frame (338 species; 31.0%). The value of the AOO according to the circular buffer approach was higher for 161 species (14.8%) and lower for 146 species (13.4%) compared with both origins of the grid frame, which resulted in a change in Red List category for three species (Table 1b). We suggest that, in addition to the method currently recommended in the Red List Guidelines (IUCN 2017), an overlay of circles can be an additional method to estimate AOO and might also be a relevant method for assessing red lists of ecosystems. The circular buffer approach introduced here has also the

Table 1 Species for which a change in the method to quantify AOO would cause a shift in the category of the Red List status (without considering any subcriteria), (a) when the position of the grid frame (gf) was shifted, and (b) when a circular buffer approach was used to quantify AOO instead of the grid frames (b). Values in bold are the correct IUCN values for AOO when the location of the grid frame is tested

Species name	AOO gf1	AOO gf2	AOO circle	RL AOO gf1	RL AOO gf2	RL circle
(a)						
Anthelia juratzkana	500	**496**	499	VU	**EN**	EN
Barbilophozia floerkei	508	**496**	509	VU	**EN**	VU
Blepharostoma trichophyllum	2040	**1996**	2010	NT	**VU**	NT
Didymodon verbanus	12	**8**	12	EN	**CR**	EN
Frullania parvistipula	**8**	12	10	**CR**	EN	EN
Lophozia perssonii	**8**	12	11	**CR**	EN	EN
Lophozia ventricosa	508	**484**	506	VU	**EN**	VU
Oreas martiana	12	**8**	8	EN	**CR**	CR
Pohlia nutans subsp. *nutans*	**484**	500	488	**EN**	VU	EN
Schistidium sordidum	**8**	12	9	**CR**	EN	CR
Schistidium strictum	12	**8**	10	EN	**CR**	EN
Seligeria austriaca	**8**	12	9	**CR**	EN	CR
Sphagnum angustifolium	**488**	500	484	**EN**	VU	EN
Zygodon rupestris	508	**480**	488	VU	**EN**	EN
(b)						
Dicranum montanum	**2000**	2004	1996	**NT**	NT	VU
Rhynchostegiella curviseta	8	8	10	CR	CR	EN
Riccia gougetiana	8	8	10	CR	CR	EN

advantage to make testing different origins of a grid frame obsolete. However, assessors should be aware not to simply add the areas of circles around occurrences but to quantify the area received by using the circular buffer approach as described in the Online Resource 2. A disadvantage of our approach is that its usage is limited to point data and, in contrast to a grid-frame approach, cannot be applied to data resulting from species distribution models, ecosystem and range maps, etc. In addition, we stress that any change in the Red List status of a species caused by using a circular buffer approach instead of a grid frame is not a genuine change in status and should be documented as a change of methodology in the Red List.

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