Defining SPA Boundaries At Sea

Joint Nature Conservation Committee
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1. Introduction

Unlike on land, there are usually little obvious or distinct physical features in the seascape (other than underwater terrain/topography) which could be of use for defining boundaries of protected areas for birds within the marine environment. Birds are highly mobile species and the sea is a dynamic environment.

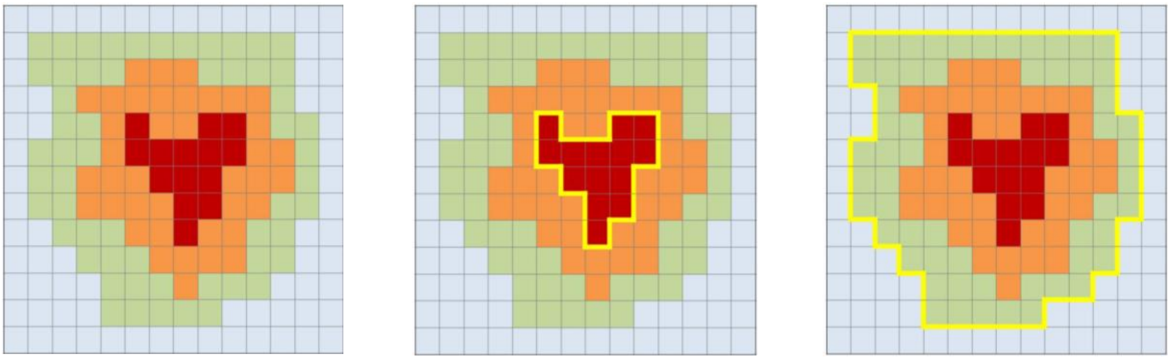
We have developed a method to identify and delineate important bird areas at sea based on some measure of the number of birds using an area (for the purpose of this document we will refer to such measures as density). Different types of analyses have been undertaken as part of our work to identify a suite of marine Special Protection Areas (SPAs) under the EC Birds Directive, resulting in maps showing the relative importance of marine areas for marine birds. These maps illustrate how densities increase or decrease across a defined area. It is these density values that form the basis of boundary setting using 'maximum curvature' analysis as described in this document.

It should be noted that the maximum curvature method is applied to outputs from analysis in the larger terns, breeding red-throated divers, and inshore wintering waterbird analyses. It was not applied too ESAS hotspots or to little tern foraging areas as the analyses for these provide outputs which inherently include possible boundaries and so no further boundary analysis is required.

2. Determining the size of a marine SPA

The sea area containing the species of interest is divided into grid cells for analysis purposes (usually either 500m by 500m or 1km by 1km, depending on the data and species). Each grid cell has a density value based on data collection and analysis. To determine the size of an area which is appropriate to support important bird numbers, a threshold value of density needs to be identified in order to determine where the line should be drawn between protected vs. non-protected areas. Once a threshold density value has been identified, grid cells which have a density value higher than the threshold would be included within the boundary of the protected area.

It is important to avoid subjective judgements, and to make the selection of a density threshold objective, repeatable, and generally applicable. Figure 1 shows the problem: map A) shows a stylised gridded density map with highest density in red, medium density in amber, and low density in green. Blue represents where no birds have been observed. Maps B) and C) show two possible scenarios for drawing a boundary.



A) Density values: red = high, amber = medium, green = low.

B) Boundary option 1: only high density cells are included.

C) Boundary option 2: all cells included where birds were observed.

Figure 1: Density map (A) with two subjectively chosen possible boundary options (B and C).

Both boundary options 1 (map B) and 2 (map C) in Figure 1 are based on subjective judgements of how high a density is required for a grid cell to warrant inclusion within the boundary of a proposed SPA site. Depending on whether one chooses to include only the core distribution (= high density cells; map B) or all birds occurring within the area of search (= high, medium and low density cells; map C), the boundary shape and the size of the area to be protected can look quite different. There are countless boundary possibilities in between these two extremes.

To produce suitable threshold density values which are unbiased by subjective judgement, a technique called maximum curvature (described in detail in O'Brien *et al* 2012) was used throughout JNCC's marine SPA identification work. Maximum curvature identifies the density value below which there would be a clear reduction in the rate of gain in birds if further grid cells were to be added to the SPA. This idea can be equated to the law of diminishing returns within the field of economics.

3. Maximum Curvature Analysis

The maximum curvature process involves ordering the grid cells from high to low bird densities. The analysis starts with the highest density grid cell, and includes this within the protected area. It then adds in the next highest density grid cell, and the next and so on. Each time it adds in a grid cell, the cumulative number of birds within the area as well as the cumulative area is calculated. Initially as the size of the cumulative area increases, we see a rapid increase in the cumulative number of birds due to high bird densities being included first (Figure 2). This slows down as more low bird densities are added.

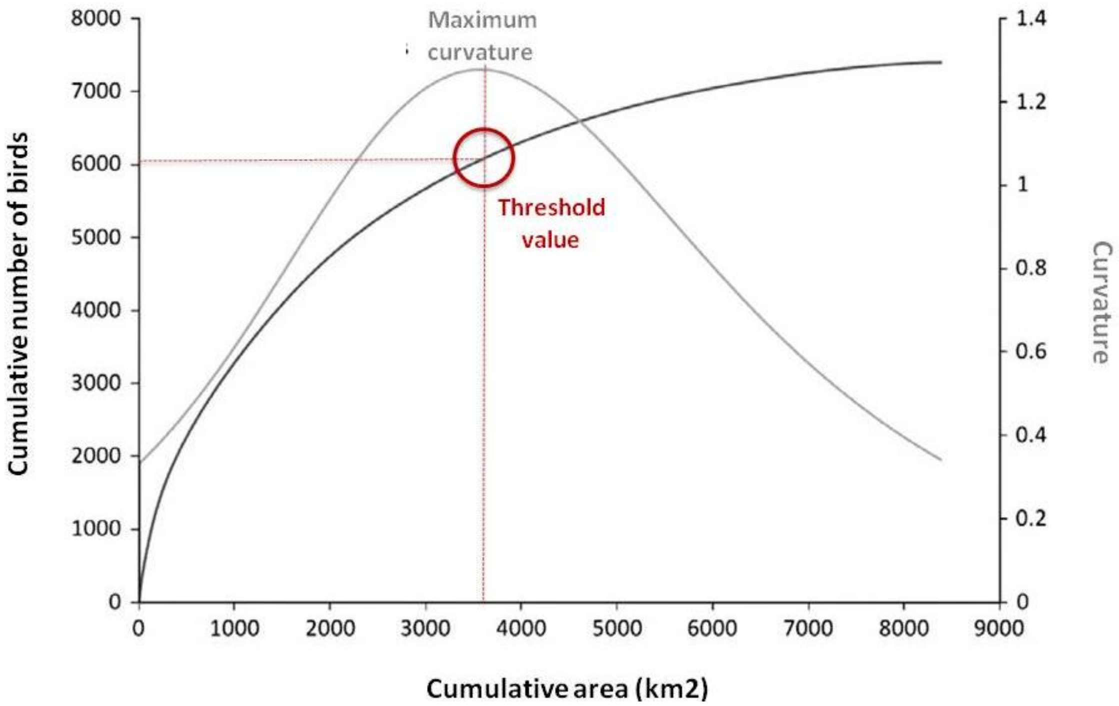
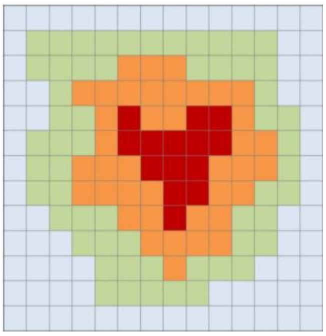


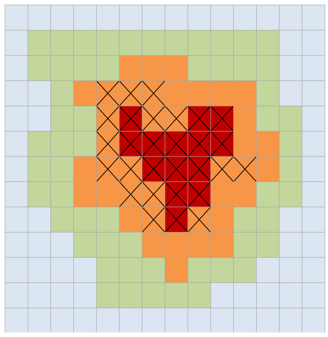
Figure 2: Maximum curvature example, showing the point on the curve of cumulative number of birds against cumulative area, where there is the greatest transition from rapid increase to slower increase in bird numbers as the size of the area increases.

The point of maximum curvature is the point where there is a transition from rapid increase to slower increase in bird numbers (cumulative number of birds per cumulative area) beyond which disproportionately larger areas would be required to encompass further increase in bird numbers. It depicts a trade-off between the "gain" (supporting important bird numbers) and the "cost" (area size). In the example shown in Figure 2, the point of maximum curvature occurs at a cumulative area of 3566 km^2 and with a total of 6059 birds in the area. The density of the last cell added into the analysis at this point can then be read off of the data, and in this example it is 0.618 birds/km^2. This density serves as the threshold value above which a grid cell would be included within the protected area.

To use this when drawing a boundary, following the simplified example shown in map A of Figure 1 above, we would now mark those cells which have a density exceeding the maximum curvature threshold (grid cells with a cross in Figure 3 below) and draw a boundary around all of those (see more details on this in the 'Drawing the boundaries' section below). Using this threshold avoids having to make subjective judgements about where the distinction between high and medium densities, or between medium and low densities, should be, or about which categories of density should be included within a boundary.



A) Density values: red = high, amber = medium, green = low.



B) Grid cells exceeding maximum curvature threshold for density shown with a cross.

Figure 3: Density map (A) and the same map but indicating, with a cross, grid cells which exceed the maximum curvature threshold (B).

It is worth noting: the calculation of maximum curvature is sensitive to the size of the area of search which is included in the analysis. Therefore species-specific distribution and range patterns are used to define an area of search, which is the area used for the analysis. For example it might be all grid cells in which any birds have been observed within a defined region at sea, or it might be all grid cells within the foraging range of a species from a certain breeding colony. More detail on area sizes can be found in separate documents for different types of analysis, e.g. larger tern and little tern marine SPA identification, inshore wintering waterbird aggregations.

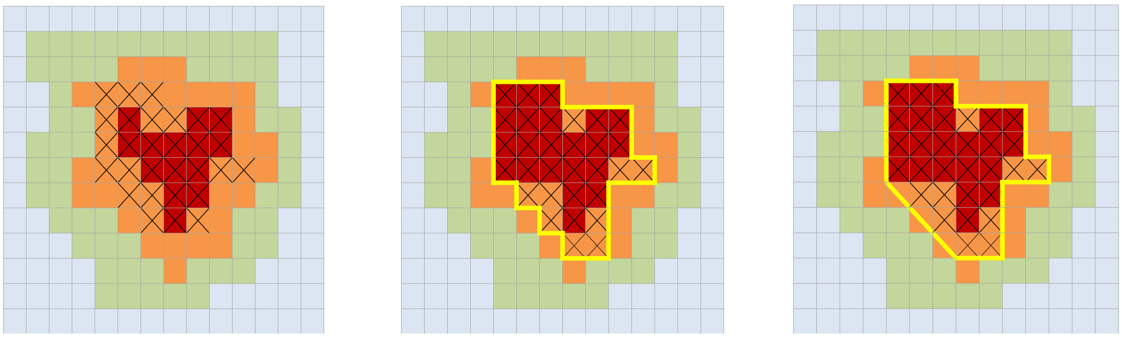
In short, the threshold density to be used for boundary delineation is the estimated bird density that corresponds to the cumulative number of birds at the point of maximum curvature. Thus, all cells in a modelled density surface (gridded map) with a value exceeding the density threshold would be included within a possible SPA boundary.

4. Drawing the boundaries

Drawing a boundary line exactly along the extent of selected grid cells would in many cases result in a fairly complex shape. To facilitate SPA management and the application in marine spatial planning processes, boundaries based on maximum curvature would be drawn as simple and with as few vertices as possible.

Such boundaries follow the lines of latitude and longitude to the nearest 10 seconds (around 0.00028 degrees), or be diagonal lines if appropriate. This implies the inclusion of the occasional grid cell with density estimates below the identified threshold value but is considered acceptable in favour of simplicity.

Figure 4 shows, in B), a boundary drawn precisely around the cells which exceed the maximum curvature threshold. The map in Figure 4 C) shows a simpler boundary which is less complex for management purposes. It includes all of the cells which exceed the maximum curvature threshold, but also includes a few sections of grid cells which do not exceed the maximum curvature boundary (bottom left).



A) Grid cells exceeding maximum curvature density threshold shown with a cross.

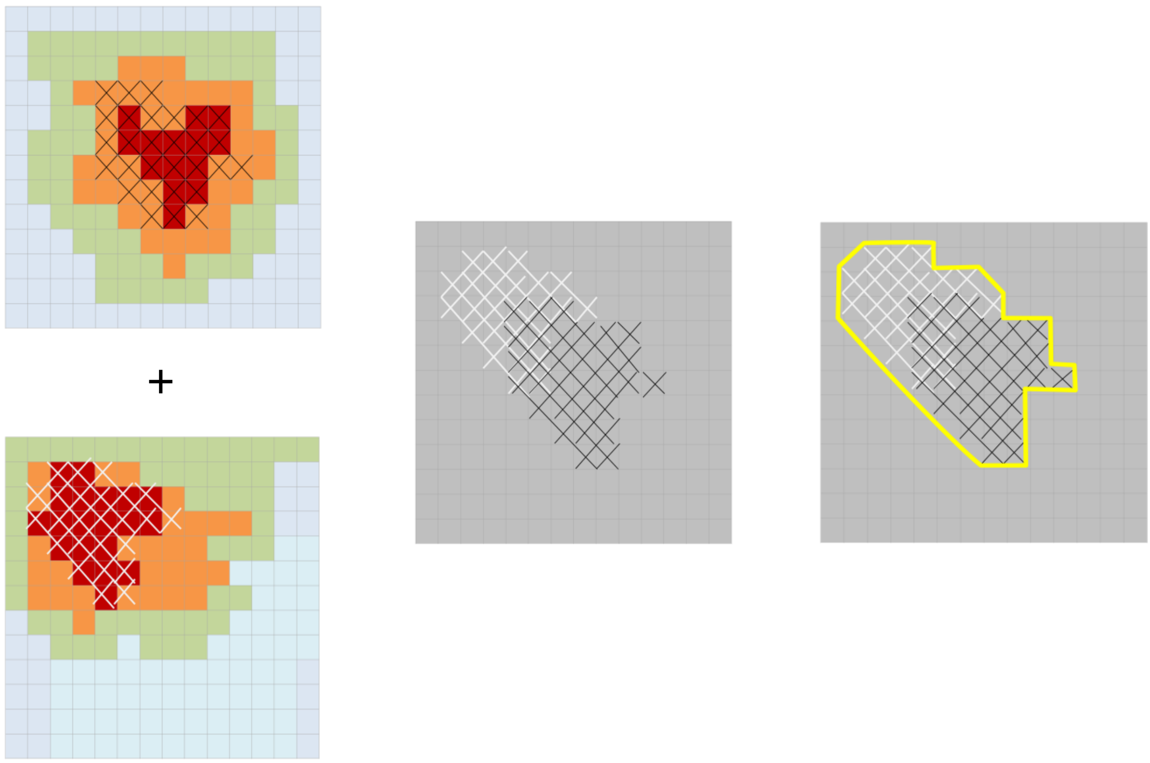
B) Boundary (yellow) drawn tightly around maximum curvature cells.

C) Boundary (yellow) drawn simply with few vertices for ease of management.

Figure 4: Cells exceeding maximum curvature (map A), and a boundary drawn tightly around these cells (B) and more simply to facilitate management (C).

In some areas, where there are several species of interest, the cells exceeding the density threshold for each species are overlaid in a single composite map. A boundary in this case is drawn following the same principles used for single species but would now identify a possible SPA boundary for multiple species. This is show in Figure 5 for an example with two qualifying features with overlapping important areas. The same principle applies even for many overlapping features.

However, the species specific maps of important areas (maximum curvature cells) will be retained in situations where there are multiple partially overlapping features within a possible SPA boundary, in order to be used as appropriate for individual management decisions affecting specific species within the proposed SPA.



A) Grid cells exceeding maximum curvature density threshold, for two different species.

B) Two species maximum curvature cells overlaid.

C) Boundary (yellow) drawn around both species, simply with few vertices, for ease of management.

Figure 5: Cells exceeding maximum curvature for two different species, one in white and one in black (maps in A), with the maximum curvature cells for each of the two species overlaid (B) and with a simplified composite boundary drawn around both of these species (C).

5. Summary

Maximum curvature analysis is used to avoid subjective judgements on SPA boundary placement and to provide an objective and repeatable method. This method finds the threshold bird density below which disproportionately large areas of sea would be required in order to increase the number of birds protected within the SPA. Boundaries are then drawn around grid cells which exceed this threshold, in as simple a way as possible without including excessive amounts of additional grid cells. This process is applied to different types of data which JNCC has analysed as part of the marine SPA work, and is used for boundary definition in many of the sites within the suite of pSPAs being consulted upon.

6. References

O'BRIEN, S.H., WEBB, A., BREWER, M. J. and REID, J. B. 2012 Use of kernel density estimation and maximum curvature to set Marine Protected Area boundaries: Identifying a Special Protection Area for wintering red-throated divers in the UK. *Biological Conservation,* **156,** 15–21.