SEA BIRD DISTRIBUTION DATA WITH OBJECT BASED MAPPING OF HIGH SPATIAL RESOLUTION IMAGE DATA

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ABSTRACT:

Wildlife research and management increasing demand information on the numbers and distribution of birds at high spatial resolution. Duck and other sea birds present special possibilities for automated image-based mapping of bird numbers and locations, data which have been gathered with poorer spatial resolution by airborne observers for many decades. In order to address environmental impact assessment demands for data collection at a fine geographical scale, (e.g. in connection with offshore windfarms), improved data collection methods must be considered. Aircraft mounted digital cameras provide very high spatial resolution (10 cm and less) image data and recent advances in object-based image information extraction tools represent significant developments. This paper assesses the representation of Common Eider and Common Scoter in very high spatial resolution image data and the success of both pixel-based and object-based extraction of information from these image data relevant to the counting and mapping of individual birds, using digital airborne images from Danish offshore areas. Results demonstrate the capacity of the 10 cm spatial resolution image data and the object-based methods for sea duck mapping. Certain pixel-based methods can also enable useful information extraction in some cases, but the more flexible and direct bird-individual mapping possibilities of the object-based methods are seen as significant. Initial Danish results from 2007 with sub-10 cm, 24-bit Vexcel UltraCam D image data are also noted. The potential benefits and problems of these technologies compared to standard sea bird census methods are discussed.

1. INTRODUCTION

1.1 General introduction

This paper reports some initial work to directly map bird individuals in Danish coastal waters using very high spatial resolution image data and object based, as well as pixel-based, image mapping methods. The paper describes the background to development of this remote sensing application, the methods used and the results that have been acquired to date. It discusses the longer term prospects and implications for this application arena.

1.2 Applied background

The following factors are driving forwards a need for greater monitoring for coastal and off-shore ecology, including scientific data collection and monitoring of sea bird populations and distributions:

- International directives that require long term monitoring of species, *e.g.* EU Birds Directive and EU Habitats Directive
- The requirements of environmental impact assessments and similar measures for new off-shore installations such as windfarms, transport connections and platforms
- Increasing sophistication in metapopulation, bioenergetics and related biological research work.

Thus, there are major needs for high quality data of breeding and migratory bird population sizes and flyways, flock species and gender composition, geographic locations and bird behaviour. The Danish coastal waters of the Wadden Sea, North Sea and western Baltic Sea are inter-nationally important breeding, migration and over-wintering areas for many sea bird populations, including the sea duck species Common Scoter (*Melanitta nigra*) and Common Eider (*Somateria mollissima*) (Laursen *et al.*, 1997).

1.3 Current Danish sea bird data collection methods

The established method for acquiring data on sea bird populations is human observation from shore, ships and sea platforms. During the past ten years these methods have, for Danish waters, been augmented with human observation from aircraft and a standardised procedure has been developed and adopted for that work (Petersen *et al.*, 2006). Table 1 describes the main operational aspects of the Danish sea bird population air survey method. This procedure is associated with the following less favourable characteristics:

- Disturbance to the birds, causing anxiety and energy expenditure
- No audit-trailing of raw observations data
- Dependence on the skill of each observer
- Low bird position precision, e.g. the far-most lateral angle zone covers distances of 430 – 1000 m from nadir.

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- High risk of danger for the observers and air-crew
- Expensive, requiring typically for one-date coverage of 400 sq.km. 3-4 hours flying and 10+ hours post-mission data processing.

Moreover, no studies have been made to objectively assess the overall accuracy of the method.

1. Demarcation of survey area as a set of 2 km wide tracts with medial flightlines, and waypoint entry to plane navigation system. 2. Survey mission, with 1 observer to record birds to port and 1 observer to record birds to starboard. Observers have watches synchrosised to plane's GPS clock and audio tape recorders with mouthpiece microphones. 3. Tract flightlines are flown at altitude of 70 – 90 m at ca. 120 knots, with observers making vocal recording of time and sea-state. Bird observations consisting of species, gender and behaviour (sitting, flushing, diving) of birds seen perpendicular to the plane are recorded and attributed to one of 3 lateral angle zones. 4. Post-mission, audio tapes are transcribed to paper (for archiving) and observer data are integrated with flightline GPS data to establish GIS model of bird distribution and sea-state.

Table 1. Summary of the main stages in the standard Danish procedure for aircraft based sea bird data collection using human observers.

1.4 Danish digital imaging bird data collection

The perceived need for increasing data on sea bird populations (§1.2) has questioned the feasibility of longer term reliance on just the standard human observer based methods. Advances in aircraft camera digital image acquisition and object-based image mapping methods in the past 10 years are seen as representing possibilities for development of alternative methods for sea bird data collection. Interest in these possibilities enabled trialling of such methods during the years 2000-2004. The segmentation and combined tone, texture and context handling possibilities of object based image mapping were seen as relevant given the low target:background pixel number ratio and the sub-target spatial resolution of the image data. The aims of the work were to:

- Collect airborne digital camera image data of sea birds.
- Make visual assessment of the image data quality.
- Develop, assess and compare the accuracy of pixel based and object based image mapping methods for mapping of birds of different species and genders.

2. METHODS

2.1 Image Acquisition

The imaging equipment used was a Hasselbad camera with a PhaseOne Light Phase H20 digital camera back, fitted to a standard air reconnaissance lens, mounted in the lower fuselage hole for vertical viewing. The H20 provides 4080 x 4076 pixel 24-bit RGB digital image data. The system was flown at ca. 600 m ASL, resulting in image pixels with a ground resolution element size of 10 cm.

During 2000 – 2003 this system was used to collect image data over three Danish coastal areas (Figure 1) : west of Horns Reef (HR), close to Samsø island (S) and in Aalborg Bay. Visual observations during the flights confirmed the presence of mainly eider and scoter. Data for precise georeferencing of the image data were not collected. For the purpose of these initial method assessments it was decided to not correct the image data for observed distortions such as associated with lens vignetting.

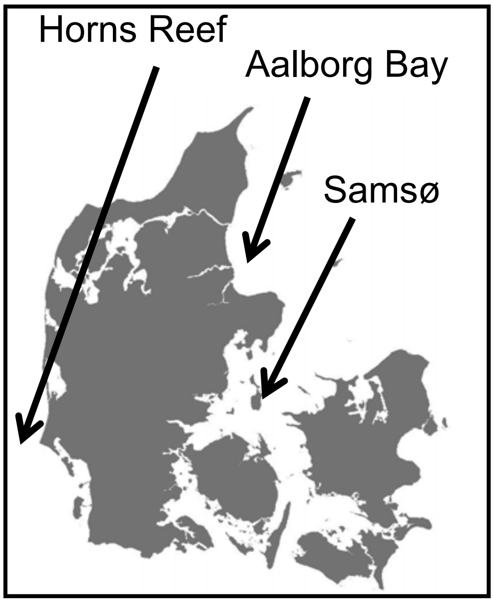

Figure 1. The general locations within Denmark of the acquired image data. (Work with the Aalborg Bay image data is not reported in this paper.)

2.2 Visual Assessment of Image Bird Data

Visual assessment of the image data revealed strong image patterns that could be interpreted as individual birds. Figure 2 shows expressions of eider and scoter individuals in the image data. It is apparent that common scoter are expressed as relatively dark image objects, forming a cluster of c. 3x3 image pixels. Male common eider are expressed as relatively bright objects, forming an rectangular or oval cluster with a major axis c. 7 pixels long and a minor axis of c. 3 pixels long. Female eider are expressed as small, less bright pixel clusters. In these images these patterns, interpreted as scoter and eider were the only image patterns with these tones, sizes and shapes. Thus they represent marked contrast to the image patterns expressed by the sea surface.

2.3 Pixel Based Image Mapping of Birds

Given the relative simplicity of the image data in terms of overall pattern variability and target:background contrast, single band level-slicing was applied as a pixel-based method for automated mapping of birds. Parameters for level-slicing were derived heuristically from the image data.

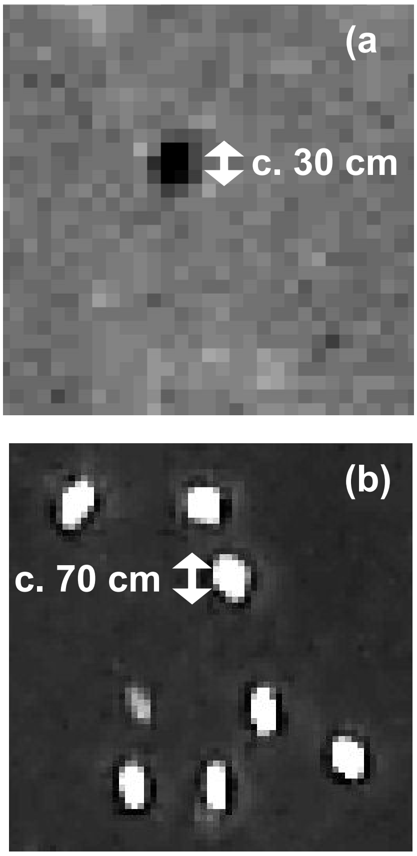

Figure 2. Examples of the image data that was interpreted with high confidence as representing birds; (a) a single common scoter, (b) seven male and one female common eider.

2.4 Object Based Image Mapping of Birds

The approach to object-based image classification that was used in this study follows the paradigm reported by Benz *et al.* (2004). In simple terms this follows a two step approach. The first step is segmentation of the image with parameters set for the scale factor and the relative influence of object shape versus object tone ("colour"). The scale factor is dimensioned ranging from 1 (an object of each pixel) to a factor yielding one whole scene object. Segmentations are made with appropriate parameter settings to derive image objects that relate to the object of mapping interest, or sub-objects or super-objects thereof. Segmentation can, as in this study, proceed heuristically. The second step is one of labelling of image objects as members of target classes, *i.e*. the process of object relationship modelling. Specification of the object environment is the key to the modelling possibilities. The following were characteristics of the object labelling environment possibilities that were used in this study:

- objects' tone, texture, and shape properties
- objects' class-related property features (e.g. objects' spatial proximity to an object of class "x")
- class hierarchy formulation with possibilities for class inheritance, class grouping and class structuring
- class definition in terms of classifier value membership functions
- object class parameterisation by means of supervised training
- object class identification by means of standard nearest neighbour fuzzy classification
- iterative class definition refinement procedures

As with the pixel-based mappings, the object-based mapping worked with just the single band of the image data that visually showed maximum contract between the mapping targets and the sea surface background.

3. RESULTS

3.1 Visual Image Mapping of Birds

On the basis of the expression of birds in the image data (§2.2), the images were systematically screen viewed with a x8 zoom factor and each visual interpretation of image data as a bird was recorded as a point in a GIS dataset. The species and gender interpretations and the confidence of the interpretation (strong, weak) were also recorded for each GIS point. Table 2 summarises the results of the visual mappings.

image scene	bird	total number of birds	number interpreted with high confidence	number inter-preted as male birds
HR0071	c. scoter	254	222	222
S69709	c. eider	294	235	171

Table 2. The results of the visual interpretations of the image data (2 scenes) for common scoter and common eider.

These point data provided the basis of control data for subsequent assessment of the extent of under-mapping of birds by the pixel and object based methods. Rule-based modelling of the image extent of birds provided the means for subsequent assessment of the extent of over-mapping by the pixel and object based methods, *e.g*. a male scoter was modelled as a 5x5 pixel cluster centred on a male scoter data point.

3.2 Pixel Based Image Mapping of Birds

With pixel-based level slicing on scene HR0071 it was possible, with the rule "scoter = pixel value leq 15", to correctly locate as at least a single pixel, 192 out of the 222 scoters that had been mapped visually with a high confidence. The same rule also located 14 out of the 32 scoters that had been mapped visually with a lower confidence level. This rule however also resulted in apparent overmapping of 161 out of the 968 modelled scoter cluster pixels. A more relaxed rule resulted in better representation of each bird, but also an even higher level of apparent overmapping (Figure 3). Overmapping was most prevalent towards the sides and corners of the image scenes, such as could be interpreted as a result of lens vignetting.

The best rule-set derived for mapping eiders in scene S69709 resulted in correct location as a single pixel of all 171 male eiders that had been visually mapped with high confidence. The same rule also located 46 out of the 64 high confidence female eiders and 31 out of the 59 low confidence female eiders (Table 3a). Associated apparent overmapping was less than 2% of the modelled male eider cluster pixels, but far greater for the

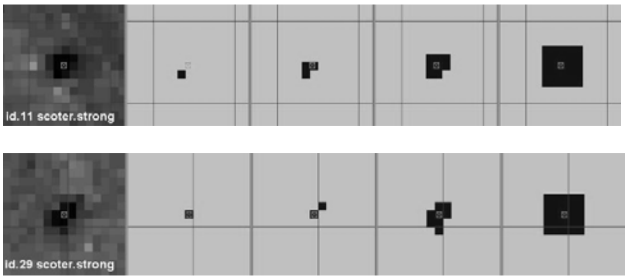

Figure 3. Two examples of the pixel-based mapping of common scoter in scene HR0071. From l-to-r the 2 examples show (1) one band of the image data, (2) result of rule "scoter = pixel value leq 5", (3) leq10 rule result, (4) leq15 rule result, (5) control cluster data.

modelled female eider cluster pixels with "mismapping" of apparent males as females being the main error element (Table 3b). Figure 4 shows some examples of the pixel-based mapping of eider.

(a) Control Level-slice	Not bird	Female low	Male high	Female high
Not bird	16625142	26		11
Male	n/a	2	171	7
Female	n/a	31		46

(b) Control Level-slice	Not bird	Female low	Male high	Female low
Not bird	16610160	n/a	n/a	n/a
Male	18	5	3195	24
Female	86	124	1130	319

Table 3. Summary results of the pixel-based level-slicing on scene S69709 for mapping of male and female common eiders: (a) single pixel co-location results between control (column) and test (row) data; (b) bird pixel cluster results.

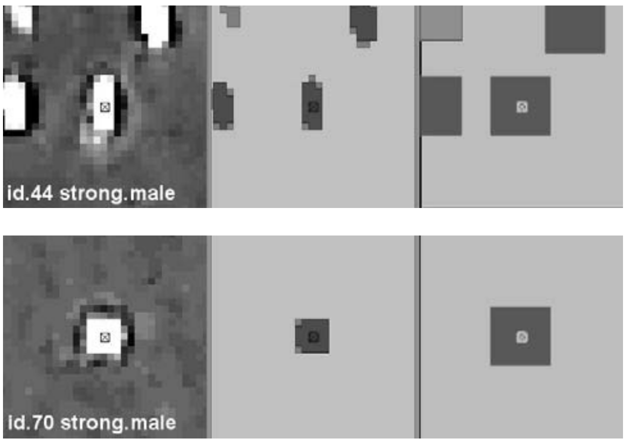

Figure 3. Two examples of the pixel-based mapping of common eider in scene S69709 with the rule "male eider = pixel value gt120, female eider = pixel value 80-119. From l-to-r the 2 examples show (1) the raw image data, (2) the result of the mapping rule, (3) control cluster data. The single pixel control data is shown as an x-marked pixel at the image centres.

3.3 Object Based Image Mapping of Birds

Scene segmentation on the different scenes was able to isolate single pixels or clusters of image pixels representing eider and scoter, as well as mainly far larger pixel clusters representing sea surface without birds (Figure 5).

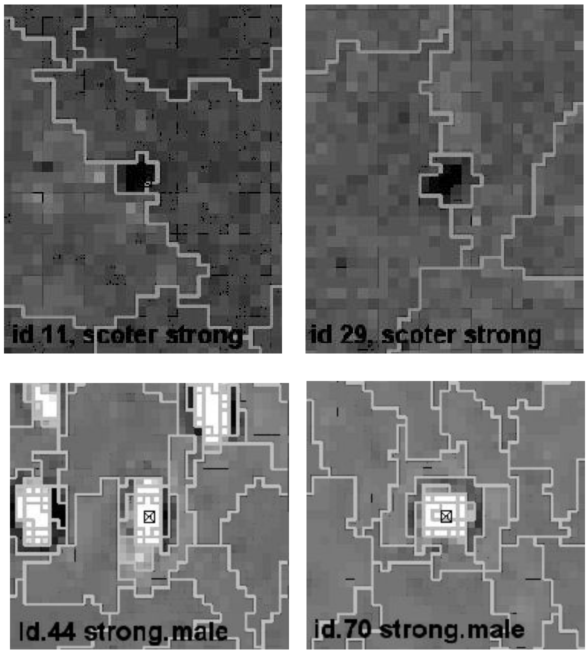

Figure 5. Image scene segmentations used for mapping the two scoter (top) and the two eider (bottom) previously shown in Figure 3 and Figure 4.

Mapping of image objects as scoter used standard nearest neighbour classification on the object features mean pixel value, minimum pixel value, area and compactness with one training class for scoter (5 objects) and 3 training classes for sea (5 objects per class). This was able in scene HR0071 to locate 207 of the 222 high confidence control data scoter and 18 of the 32 low confidence scoter.

Standard nearest neighbour classification on the object features mean pixel value and area, with one training class for male eider (3 objects, one class for female eider (4 objects) and 2 sea classes, together with rules controlling the size and class related context of objects plus post-processing for sub-eider sized objects was able to correctly map in scene S69709 most of the control data birds (Table 4). Undermapping of both male and female eider was very low, representing a major improvement for the female eider over the pixel-based approach (Table 3). Apparent overmapping of male eider is, at under 2% similar to the pixel based result. For the female eider overmapping of apparent "not bird" pixels as female eider is a major error element.

(a) Control Level-slice	Not bird	Female low	Male high	Female high
Not bird	16622189	8		1

Male	n/a		171	1
Female	n/a	51		62

(b) Control Level-slice	Not bird	Female low	Male high	Female low
Not bird	16610160	n/a	n/a	n/a
Male	82		5087	25
Female	1242	563	98	785

Table 4. Summary results of the object-based sementation and object identification on scene S69709 for mapping of male and female common eiders: (a) single pixel co-location results between control (column) and test (row) data; (b) bird pixel cluster results.

4. DISCUSSION

In the studies reports here it was chosen to work with the essentially raw image data in order to get, as an initial trial, "worse case" assessment of the approaches. It is anticipated that effects of lens vignetting that are clearly seen in the full scene image data can be substantially reduced, such as with knowledge of camera system parameters or image data parameters. It is expected that correction for vignetting would reduce the extents of apparent overmapping that are reported here, such as in the pixel-based scoter mapping with higher level-slice thresholds. It will be interesting to assess the sensitivity to vignetting reduction of data segmentation for object-based bird mapping.

The single-pixel control data used in this study for assessment of the pixel based and object based mappings are considered as essentially "ground truth" for the classes they represent. Correspondingly the undermapping results are seen as representing a good indication of the strengths of the mapping methods. The apparent overmapping results are considered as less reliable, since they depend on the control data modelling that was made of bird individuals as rectangular pixel clusters. Whilst this modelling aimed to over-represent the bird in the control data, thus nullifying the apparent undermapping scores but strengthening the apparent overmapping scores, the applied modelling represents a potential source of error in the overmapping control data.

In both the pixel-based and the object-based studies reported here, just single image channels of the RGB image data have been used for the bird mapping. The channels used have been those that visually showed greatest contrast between bird and non-bird image data. When we have viewed the image data as true-colour composites of the RGB channels the brown plumage of female eiders is apparent and it is anticipated that mapping with multi-band image data will in certain cases increase the ability to map different bird genders and species. The mapping analyses made to date have been empirical, but for the longer term development of techniques greater understanding is also needed of the radiometric processes involved in this sensing application. For instance, relatively dark pixels are observed adjacent to the bright pixels of male eiders (see Figure 3); it is necessary to understand more fully the sensor-target reflection relationships in order to increase interpretation capabilities.

The object based mappings assessed here used a single segmentation of the image data, rather than a nested hierarchy of segmentation representing different spatial scales, as is also possible with the multi-scale segmentation / object relationship modelling approach (Benz *et al.*, 2004). Given the marked difference in the sizes of typical male and female eiders, a two-scale segmentation might be required to increase the accuracy of the mapping of female eider.

The positive results that are reported here have stimulated acquisition during spring 2007 of further airborne digital camera image data of sea birds in Danish waters. For this campaign the higher spatial resolution (5 cm), 4-channel (RGB,NIR) Vexcel Ultra-Cam D system has been used. Images have been acquired but work with them has only just begun and it is premature to speculate on the pluses and minuses of these data.

The longer term context and implications of this work are that recent years have seen an increasing need for spatially-explicit abundance data relating to animal abundance. The need to map sea bird densities over large areas of featureless open water in order to support the environmental impact assessment of one of the largest marine infrastructure developments, namely offshore wind farms, has been the impetus for this piece of work, but the technique is of wider utility in removing the error, bias and resource implications of human imagery interpretation associated with counting objects in remote sensing scenes (*e.g.* Anthony *et al*., 1995, Frederick *et al*., 2003). In particular, we see considerable potential improvement in counting colonial birds (such as cliff-nesting seabirds, flamingos in Africa, penguins in Antarctica, waterfowl in Alaska) using this technique over the use of aerial imagery using colony area/density relationships (Woehler and Riddle, 1998) and segmetation/threshold filtering (*e.g.* Trathan, 2004). We also see potential for the techniques for census and monitoring of cetacean species.

It is not anticipated that digital camera image data methods will fully replace the standard human observer based approaches during the foreseeable future. Furthermore, for cost-effectiveness automated digital image mapping methods should be associated with user-intervention time that is less than that associated with manual (visible) mapping of birds from the image data. As a rough estimate, it is reckoned that a skilled interpreter can cover a 2 ha image scene containing 200 – 400 bird individuals in c. 20 minutes. Additionally, it would be significant to develop and demonstrate the added value for bird ecology work of the richer information associated with mapping bird individuals as objects.

5. CONCLUSIONS

1. Digital camera image data with spatial resolution of c. 10 cm provide a basis for mapping of sea bird individuals, including discrimination of different bird species and male and female birds.
2. Both pixel based level slicing and object based methods can provide good mappings of scoter (unspecified gender) and male eider.
3. Object based methods can provide better location mapping of female eider, but with refinement of methods needed to reduce apparent overmappings.
4. The versatility of object based approaches for mapping multi-pixel objects can represent important techniques for controlling the mapping process, such as where the mapping task is demanding.

5. The object based image mapping methods represent a more direct route than pixel based methods to representation of bird individuals as objects.
6. Simultaneous overflying of a human observer based sea bird census campaign with a digital camera imaging system could provide valuable data for much needed accuracy and precision assessment of the former approach.

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