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Individual identification of Black-throated Divers (*Gavia arctica*)

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The potential to identify individual Black-throated Divers (*Gavia arctica*) on the basis of breeding plumage features was explored using 278 photos, including two paired birds followed during the years 2007–2015 at a specific breeding location. Observations were focused on: 1) white lines on the sides of neck, 2) mantle having rows of sharply contrasting white squares, and 3) small white spots on lesser and median coverts. In photos, the number of white lines on the sides of neck varied from four to seven (mean = 5.0, n = 278), and the second line from the head was the highest in 92.1% of the photos. The number of "white square" rows on the mantle varied from 11 to 14 and the small white spots on coverts from 27 to 67. Identification of individual Black-throated Divers was potentially easiest if the plumage had some special patterns (19.4% of birds, n = 278). Plumage remained the same in the followed pair between years, as was also shown by the discriminant analysis, since the followed pair was correctly classified by sex but not by sides showing that sides are similar. To estimate whether it is possible to separate these two birds from other birds, a second discriminant analysis was accomplished. Thus, 125 other birds were added to analysis as a third group together with the followed pair (female and male, nine years and n = 18 per sex). The linear discriminant analysis yielded a classification rate of 70.8% in original analysis and 69.6% based on the leave-one-out analysis (n = 161). These analyses were based on the relative height of the neck lines, their average relative height and standard deviation. When the number of white spots were added to this discriminant analysis, a correct classification rate of 77.4% in original analysis and 75.7% in the leave-one-out analysis was obtained (n = 115). These analyses suggest that the plumage can be used in identification, especially when following nesting pairs during their breeding seasons in different years. Presumed female and male Black-throated Diver could be distinguished based on the shape of the forehead.

1. Introduction

Individual identification of Black-throated Diver (BTD) (*Gavia arctica*) is a crucial issue for prioritising behavioural studies. It can be used to see whether the same individuals occupy the same territory from year to year when they return to their territories in spring. Identifying birds individually makes it possible to examine their differences in social behaviour e.g. in the company of other

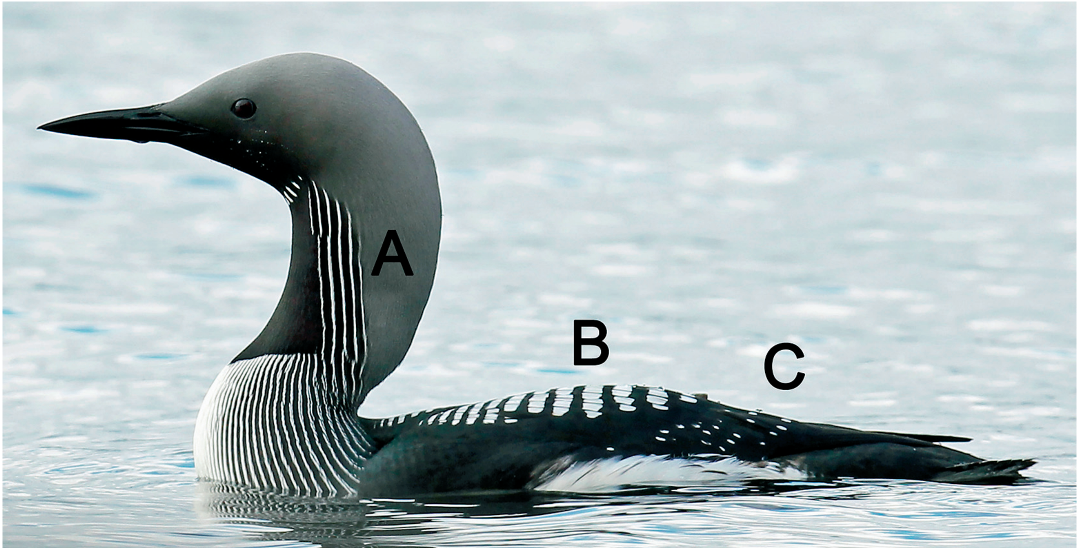

Fig. 1. Points of attention. A: neck lines, B: white squares on mantle, and C: small white spots on lesser and median coverts.

BTDs in flocks where social interaction is important and variable. Individual identification can also be used to estimate the age of the bird by following them in their territories for long periods of time. Gender identification is useful in examining the nesting biology and maternal responsibility in the treatment of juveniles.

Black-throated Diver occurs in northern Europe (north Scotland and Fennoscandia), east through north Asia to River Lena and Transbaikalia (Carboneras & Bonan 2016). Its breeding plumage has several distinct patterns (Fig. 1). Sexes have not been recorded as differing consistently in plumage in any season, but on average males are slightly larger and more heavily-built than females (Lehtonen 1970, Carboneras & Bonan 2016) and may have differently shaped forehead profiles during the breeding season (Lehtonen 1988). The eggs are incubated by both parents; with the female spending longer periods on the nest than the male (Sjölander 1968, Lehtonen 1970).

Studies on individual identification and possible variation based on plumage are very rare in waterbirds. The difference in appearance between female and male is very common in waterbirds (McGregor 2000, Carboneras & Bonan 2016). Very often there is a clear distinction in size and/or in colour. This is not the case in *Gavia* family. For Red-throated Diver (*Gavia stellata*), individual identification is possible by comparing the forms of dark brown-grey and white lines on nape, hindneck and at the base of neck, and by comparing the form of the large rusty patch on foreneck (Eriksson *et al.* 2008). Unfortunately no systematic study has been published about the individual identification of Red-throated Diver. The breeding plumage of Black-throated Diver is completely different from that of Red-throated Diver and therefore the same variables cannot be used for individual identification of these two *Gavia* species.

Vocal individuality has been documented for Black-throated Diver (Gilbert *et al.* 1994). Common loons (*Gavia immer*) have also been reported to be recognizable by their dynamic vocal repertoire (Miller 1988, Vogel 1995, Walcott *et al.* 1999, Mager & Walcott 2007 and 2014, Mager *et al.* 2012). In goshawk (*Accipiter gentilis*), it has been shown genetically that plumage differences are consistent across years and sufficiently different to identify individuals (Hoy *et al.* 2016).

The aim of this study was to evaluate the main features of the summer plumage of BTD and to examine possible changes in plumage in the same territory and possibly the same individuals from year to year. Lehtonen (1974) and Jonsson & Tysse (1992) studied the plumage of BTD but the possible annual changes in the plumage of different individuals or sexes was not studied. Therefore, one of the aims of this paper was also to examine the possibility of individually recognizing BTDs on the basis of differences in plumage, and to compare these with other BTDs. Possible changes in plumage was followed by taking digital photos of BTDs and by comparing these with photos taken elsewhere. The comparison was done by using discriminant analysis to see whether individual discrimination is possible based on plumage.

2. Material and methods

2.1. Plumage of Black-throated Diver pairs

Plumage of Black-throated Diver pairs was studied on Lake Suontee (61°39' N, 26°31' E). Lake Suontee covers an area of 150 km^2, and has 500 islands and islets, supporting about 120 BTD pairs (Virtanen *et al.* 2011, Lehtonen *et al.* 2013, Virtanen 2013). One BTD pair (hereafter "BTD PAIR") was followed by taking 500–1,500 photos per year in May–September to examine possible changes in their summer plumage during the years 2007–2015. The "BTD PAIR" had its territory centred on a 1.5 hectares island where they nested every year.

A Canon EF300mm f/2.8L IS USM lens equipped with 1.4 and 2 times magnifying converters were used in photo shooting. Observations were made using binoculars and a telescope. Attention was focused on neck lines, white squares on the back, and small white spots on lesser and median coverts (Fig. 1). The heights of the neck lines were measured by using digital photos taken exactly adjacent to swimming birds. The top of the black lower part of the throat was extended to the sides using PhotoShop Elements (version 11) drawing tools so that in the photo neck lines were cut horizontally at the same height (Fig. 2). The heights of the lines were measured in pixels of digital photos using PhotoShop Elements. "Number 100" was assigned to the highest second line from head and the heights of all other lines were proportioned to the second line. The number of rows of white squares (B in Fig. 1) and white spots (C in Fig. 1) were counted from the digital photos.

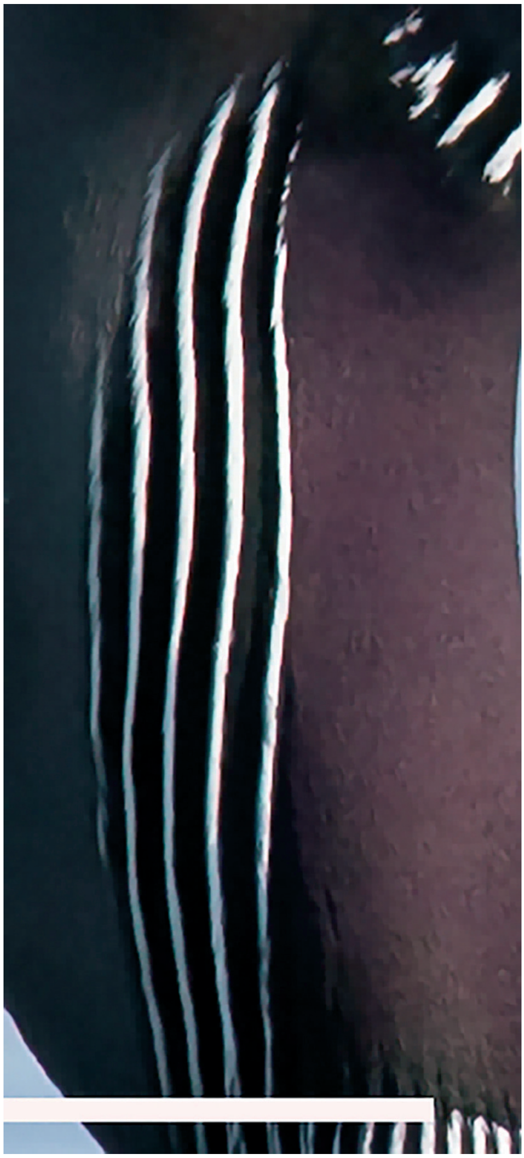

Fig. 2. Relative heights of the white lines on side of neck were measured from digital photos after adding a contributory horizontal line on height of the bottom of the black lower part of throat.

2.2. Plumage of other Black-throated Divers

A database of BTDs was generated by collecting BTD photos from the Lake Suontee and elsewhere from books, web-pages and other sources. These data consisted of 278 photos and they were used to analyse: 1) the height order and 2) the number of white lines on the sides of neck. Only some photos

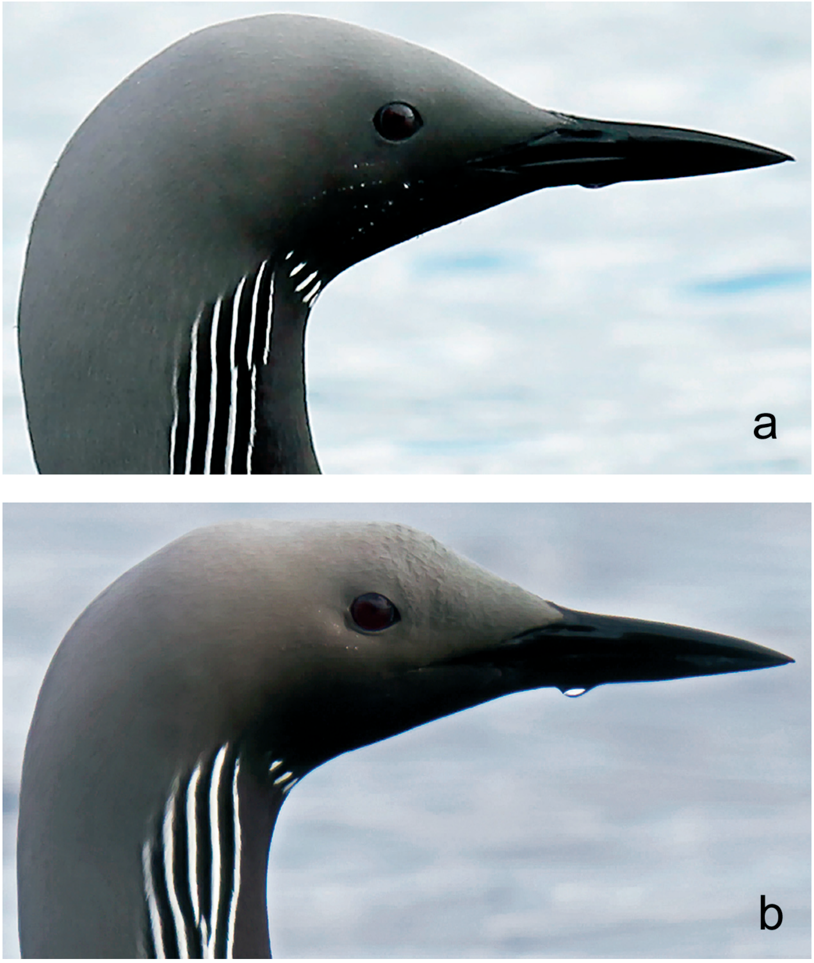

Fig. 3. Seen exactly from the side there is a clear distinction on forehead of female (a) and male (b).

(n = 125) were of the necessary quality to measure 3) the heights of neck lines, and to count 4) the rows of sharply contrasting white squares on mantle and 5) the small white spots on lesser and median coverts of BTDs as described in Section 2.1. These data (”other BTDs”, n = 125) were mainly from Finland (n = 100) and Sweden (n = 25). The BTDs were also sexed when possible based on head shape.

2.3. Statistical analyses

Discriminant analysis was used to evaluate whether it is possible to separate the “BTD PAIR” based on the plumage. The annual data of the “BTD PAIR” was first analysed separately, and after that all the data were analysed together (both the “BTD PAIR” and other BTDs). The latter classification was done in two separate analyses. First, only variables that were found in all BTDs, namely heights of lines 1, 3, 4, and the mean and standard deviation of all lines (in some BTDs 4 or 5) were used. In the second analysis, these variables and the number of white spots on the back were included in the analysis. In the latter analysis, the total number of BTDs was reduced due to fact that it was not always possible to evaluate all plumage patterns based on photos. We used the leave-one-out classification procedure to cross-validate the discriminant function that was generated. In this procedure, each BTD is classified by the functions derived from all BTDs other than that individual bird. All prior group probabilities were kept equal. These analyses were done with IMB SPSS 24 software.

3. Results

3.1. Distinction between female and male in "BTD PAIR"

When the birds of the "BTD PAIR" are seen exactly from the side, it is possible to make a distinction between female and male, as suggested by Lehtonen (1988) and based on information given by Lehtonen (1967, 1970), Sjölander (1968) and Carboneras & Bonan (2016). Forehead shape of females changes smoothly from beak to crown of the head, while males have an angle at the forehead and the crown of the head is even (Fig. 3).

3.2. Plumage of the "BTD PAIR"

In the breeding plumage of the "BTD PAIR", the white lines in the neck of the male were slightly wider and therefore the figure seemed to be stronger than that of the female. In both sexes, the second line from head was the highest on both sides. The figure of the first five lines was very similar from year to year and the relative height of a certain line did not change much during these years (Fig. 4). Standard deviations of the heights of neck lines in nine consecutive years were small and varied from 0.9 to 5.4% (Fig. 4). Standard deviation for the first line was 3.97% (n = 36, both sides of female and male in all years), for third line 1.34% (n = 36), for fourth line 3.22% (n = 36), and for the fifth line 6.71% (n = 36). Uncertainty of measured heights of the lines was determined by the heights from several photos of the same bird taken within a few days. In some years, female had the sixth and even the seventh neck line on the left side (Fig. 5). In 2013, female had a short sixth line on the right side. Male had five lines on both sides in all years.

The female of the "BTD PAIR" had a lower part of the first line from head missing in four of

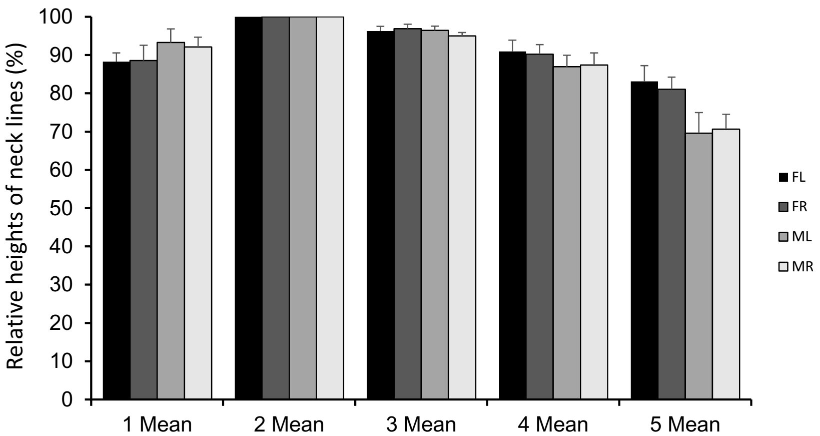

Fig. 4. Means of relative heights (% of line 2) of neck lines 1 to 5 of the "BTD PAIR" in the years 2007–2015. Numbers on x-axis present the order of white neck line from head. FL = female, left side; FR = female right side; ML = male left side; MR = male right side. Error bars are +1 SD of relative heights.

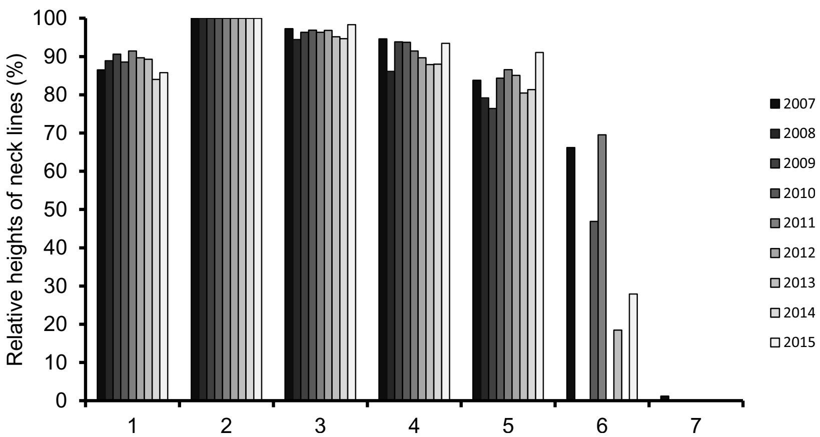

Fig. 5. Relative heights of neck lines (% of line 2) on the left side of female of the "BTD PAIR" in years 2007–2015. Numbers on x-axis present the order of white neck line from head.

Table 1. Distribution of heights of the seven neck lines from head.

Height order of necklines								
Line	Highest	Second highest	Third highest	Fourth highest	Fifth highest	Sixth highest	Seventh highest	Total *n*
1	5	142	94	26	11	0	0	278
2	256	16	6	0	0	0	0	278
3	16	119	142	1	0	0	0	278
4	1	1	36	240	0	0	0	278
5	0	0	0	11	234	0	0	245
6	0	0	0	0	0	32	0	32
7	0	0	0	0	0	0	3	3
Total *n*	278	278	278	278	245	32	3	–

the nine years on the left side and once on the right. The corresponding numbers for the male were two on the left side and one on the right side. These special features remained the same from May to September when observed.

The number of rows of the "BTD PAIR" were either 13 or 14 for the female and 12 for the male on both sides in 2007 to 2015. The female's outer pattern on the left side of the fourth row from behind was a little different from the other patterns and looked exactly the same every year. The white spots of the "BTD PAIR" remained the same from year to year (Fig. 6). Female had on average 27.1 (± 2.7 SD) white spots on the left side and 27.2 (± 2.7 SD) on the right side. Male had 43.1 (± 1.4 SD) and 43.3 (± 2.2 SD) white spots on the left and right side, respectively.

3.3. Plumage of other Black-throated Divers

The number of white lines in neck varied from four (*n* = 33) to seven (*n* = 3) in 278 photos taken from one side of BTD. In most of the photos, BTD had five lines (*n* = 210), while six lines was found from 30 photos (11.5%). Generally, the second line from head was the highest (Table 1). There were also deviations (*n* = 54) from the normal patterns (total *n* = 278).

These included a missing part beneath the first neck line (*n* = 34), a short line or a white spot before the first line (*n* = 8), split first line (*n* = 6), missing part above the first line (*n* = 4) or missing part beneath the fifth line (*n* = 2). Sometimes a line looked like it formed a Y-pattern or one line was split into two vertical lines. In these cases, feathers were temporarily out of order.

Number of rows (B in Fig. 1) ranged between 11 and 14 with a mean of 12.4 (± 0.6 SD, *n* = 98). Number and shape of individual squares on each row varied considerably. Sometimes the outer edges of rows formed an even shape and sometimes it was ragged. When swimming, BTDs show a number of white spots at the back on the both sides (C at Fig. 1). These white spots belong to

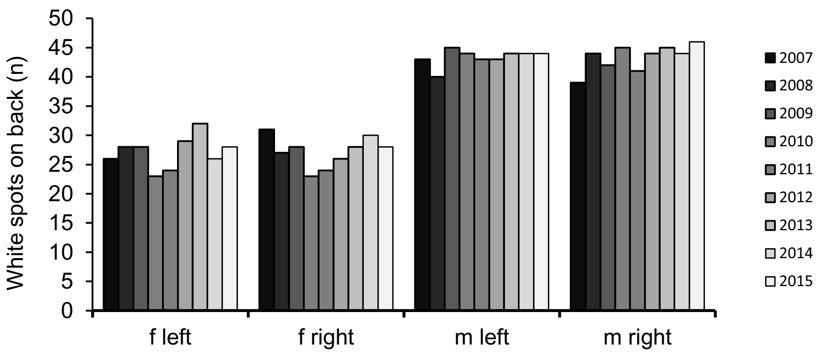

Fig. 6. Number of white spots on back of female and male of the "BTD PAIR" from year to year. f left = female left, f right = female right; m left = male left, m right = male right.

Table 2. Classification results using both sides of "BTD PAIR" based on the number of white spots on back of female and male. Cross-validation is based on leave-one-out analysis. FL = female left side, FR = female right side, ML = male left side, MR = male right side.

	Predicted Group Membership				
	FL	FR	ML	MR	Total *n*
Original					
FL	4 (44.4%)	5 (55.6%)	0 (0%)	0 (0%)	9
FR	4 (44.4%)	5 (55.6%)	0 (0%)	0 (0%)	9
ML	0 (0%)	0 (0%)	9 (100%)	0 (0%)	9
MR	0 (0%)	0 (0%)	9 (100%)	0 (0%)	9
Cross-validated					
FL	0 (0%)	9 (100%)	0 (0%)	0 (0%)	9
FR	6 (66.7%)	3 (33.3%)	0 (0%)	0 (0%)	9
ML	0 (0%)	0 (0%)	0 (0%)	9 (100%)	9
MR	0 (0%)	0 (0%)	9 (100%)	0 (0%)	9

Table 3. Classification results of "BTD PAIR" and other BTDs based on variables: line height 1, 3 and 4, means and standard deviation of lines 1 to 5. Cross-validation is based on leave-one-out analysis. F = "BTD PAIR" female both sides; M = "BTD PAIR" male, both sides; O = other BTDs.

	Predicted Group Membership			
	F	M	O	Total *n*
Original				
F	17 (94.4%)	1 (5.6%)	0 (0%)	18
M	2 (11.1%)	12 (66.7%)	4 (12.2%)	18
O	16 (12.8%)	24 (19.2%)	85 (68.0%)	125
Cross-validated				
F	17 (94.4%)	1 (5.6%)	0 (0%)	18
M	3 (16.7%)	11 (61.1%)	4 (22.2%)	18
O	16 (12.8%)	25 (20.0%)	84 (67.2%)	125

wings. The number of spots ranged between 27 and 67 with a mean of 42.4 (± 9.4 SD, *n* = 92).

3.4. Discrimination based on plumage

In the "BTD PAIR", female and male could be discriminated based on the number of white spots on the back (Fig. 6) (classification 100%), but not between the different sides (Table 2), since the patterns were so similar (Fig. 4). Based on the leave-one-out classification when both sides were included in analysis, the correctly classified female and male sides were only 8.3% (correct classification = 3, total *n* = 36). The highest classification rate in the "BTD PAIR" was obtained with discrimination based on heights of lines 1, 3, 4, and 5, and the standard deviation of lines 1 to 5, and the number of white spots on the back. Here the leave-one-out classification showed correct classification of 58.3% (*n* =21, total *n* = 36). However, both sides were kept in following analyses to include all variation in "BTD PAIR" data, and because data from other BTDs come from one side only and not from the same side.

The discrimination analysis between the "BTD PAIR" and other BTDs was examined to estimate if other BTDs could be mixed with the followed pair. Thus, we had here three groups; female and male (and both their sides) (*n* = 36) and other

Table 4. Classification results of "BTD PAIR" and other BTDs based on variables: line height 1, 3 and 4, means and standard deviation of lines 1 to 5, and number of white spots on back. Cross-validation is based on leave-one-out analysis. F = "BTD PAIR" female both sides; M = "BTD PAIR" male, both sides; O = other BTDs.

	Predicted Group Membership			
	F	M	O	Total *n*
Original				
F	18 (100%)	0 (0%)	0 (0%)	18
M	0 (0%)	13 (72.2%)	5 (27.8%)	18
O	2 (2.5%)	19 (24.1%)	58 (73.4%)	79
Cross-validated				
F	18 (100%)	0 (0%)	0 (0%)	18
M	0 (0%)	13 (72.2%)	5 (27.8%)	18
O	4 (5.1%)	19 (24.1%)	56 (70.9%)	79

BTDs ($n = 125$). Variables in discrimination analysis were heights of the first, third and fourth line from head, and mean and standard deviation of lines. The means and standard deviations of lines were based on either four or five lines. This discrimination resulted in a classification rate of 70.8% in original data, and 69.6% based on cross-validation (n = 161) (Table 3, Fig. 7). When the number of white spots on the back were added to analysis, the number of other BTDs reduced (n = 79), but the classification rate was higher both in original data (77.4%) and in cross-validation (75.7%) (Table 4, Fig. 8).

4. Discussion

Individual identification of BTDs' is a crucial issue for prioritising the behavioural studies and other aspects given in the introduction. Individual identification requires multiple approaches. In this study, we used white lines on the sides of neck starting on the side of the necklace and running over its length, the mantle having rows of sharply contrasting white squares, and small white spots on lesser and median coverts. The discrimination analysis showed that the "BTD PAIR" could be classified correctly based on white spots, but not using different sides suggesting that the sides do not differ in characteristics that were analysed.

BTDs are fast-moving birds and therefore some details cannot be normally registered by using binoculars or a telescope. To make reliable observations, the only effective way is to take photos with a long photographic lens. It is very difficult to get close enough to BTDs. Generally, they keep a distance of at least 20–50 metres or more. Therefore, the focal length of the lens should be more than 300 mm and a high quality camera body is necessary. Concerning the sharply contrasting rows of white squares on the mantle, it would be advisable to photograph them from a short distance and from the highest possible elevation so that they all feature as best as possible in the photo. In photos taken from long distance, only the outermost squares are well separated and only the form of the edge of the rows can be examined.

4.1. Distinction between female and male

The sexes differ very little in structure, but on average males are slightly larger and more heavily-built than females. Sexes do not differ in plumage in any season. Measurements overlap and therefore this cannot be used to distinguish males and females (Carboneras & Bonan 2016). A way to distinguish the sexes of BTD was reported in Finland (Lehtonen 1988). When a BTD having a smooth forehead was captured in 2015 in Finland to implant satellite telemetry it was recognised to be a female by Finnish veterinary surgeon Einar Eriksson (pers. comm.). According to Sjölander (1968) and Lehtonen (1988), the female incubates

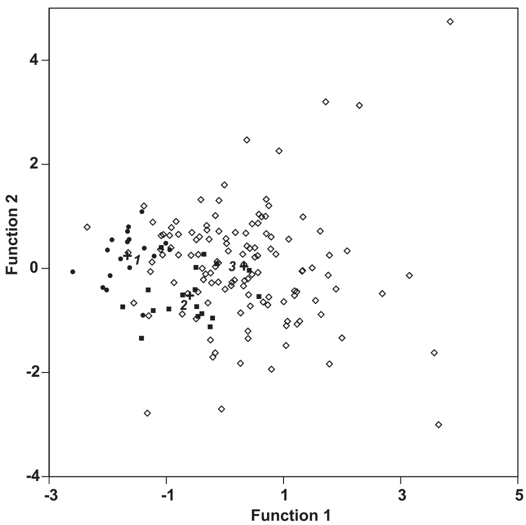

Fig. 7. BTDs on axes representing the first two linear discriminant functions with group centroids 1 to 3 marked with "+". Variables used in analysis were: line heights of 1, 3 and 4, means and standard deviation of lines 1 to 5. Black dots and 1 = female, both sides (*n* = 18); black squares and 2 = male, both sides (*n* = 18); open diamonds and 3 = other BTDs (*n* = 125).

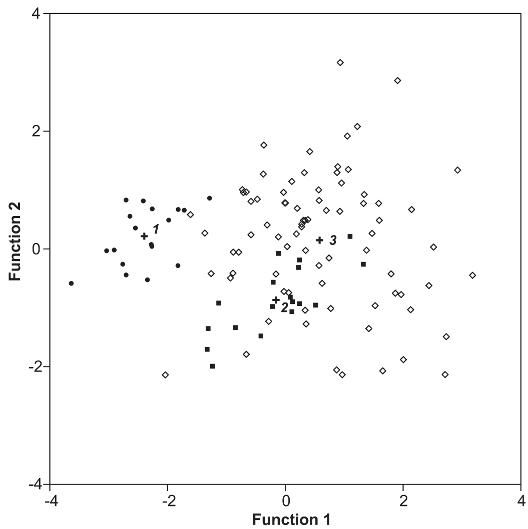

Fig. 8. BTDs on axes representing the first two linear discriminant functions with group centroids 1 to 3 marked with "+". Variables used were: line heights of 1, 3 and 4, means and standard deviation of lines 1 to 5 and number of white spots on back. Black dots and 1 = female, both sides (*n* = 18); black squares and 2 = male, both sides (*n* = 18); open diamonds and 3 = other BTDs (*n* = 79).

84% and 90%–95% of the time, respectively. Males incubate the eggs only for 20 min in the morning and late evening (Lehtonen 1967). Lehtonen (1988) followed the nesting BTDs and noted that the incubating BTD had a smooth change of forehead shape. The other BTD had a strong angle on the forehead. This was the one giving a loud, rhythmic, whistling song; assumed to have been made by the male (Carboneras & Bonan 2016) when guarding the nest and behaving aggressively by driving away other BTDs that come too close to the nest. We have observed the same and, in addition, noted that in spring birds in pairs have a forehead shaped differently from each other. We presumed, therefore, that the sexes differ with respect to the shape of the forehead.

The angle at the forehead of male can be observed only when it is viewed exactly from the side and when the head is in horizontal position or the beak is directed slightly upward (Lehtonen 1988). When using a telescope, the distinctions in the forehead can be observed from a distance of hundreds of metres. BTDs have these distinct patterns in foreheads in photos taken in Finland and in Sweden.

4.2. Breeding plumage

BTD usually has five long parallel white lines on both sides of black neck, starting on the side of the necklace and running over its length. If BTD has these five conventional lines and there are no other special features, these cannot be used for individual identification. However, in 42% of the photos there was something special in this pattern. Either there were only 4 lines, or 6 or even 7 lines, or a part of line was missing, usually from the bottom of the first, the second or the fifth white line. Occasionally there was one or two white spots in the front of the first line. These specialities can be used for individual identification and the missing part was always different from bird to bird. Observations with the "BTD PAIR" indicate that these specialities lasted from May to September. In the following year, these might have disappeared or changed to something else.

Neck lines of the "BTD PAIR" did not change from year to year. Taking into account the estimated uncertainty of measurement, the heights remained the same from year to year. This indicates that they did not change, despite the fact that new summer plumage featured every year after winter plumage. Additional lines and abrupt lines were observed in some years. The possible sixth and seventh lines were always more obscured than the first five lines from head. Sometimes they were difficult to see depending on the brightness and direction of light. Standard deviations of the relative heights of these five lines were in range of 1%–5% in nine consecutive years, being the lowest for the third line and highest for the fifth line.

BTD has small white spots on median coverts behind and below rows of sharply contrasting white squares on the mantle. Due to the large number of spots it is easiest to count them from photos taken from the side or partly from the rear side of the bird in water. The shape and exact location of white squares on the mantle varied considerably between individual BTDs. Sometimes the shape of the outer edge was very even in form and sometimes it formed a ragged figure. White squares on rows were often angular and their length and shape varied. The number of rows on back of the male of the "BTD PAIR" remained 12 on both sides every year during 2007–2015 and the rows of the female varied from 13 to 14 on both sides in these years. Generally, the number of rows remained the same from May to September. However, it was obvious that the shape of the rows and certain squares could slightly change in different years.

There was only one special square which remained exactly the same every year. This was the outermost white square of the fourth row from the back of the female on the left side. This square was not exactly in line with the other squares of this row and the shape was special. Similar pattern was not found from other BTDs indicating that this certain square can be used for identification of the female of the "BTD PAIR".

4.3. Individual identification of BTD

Publications detailing individual identification and possible changes in plumage are very rare in waterbirds. However, individual identification of BTD is possible based on the features of plumage analysed and discussed here. The most effective way to examine and analyse these features is to take photos of the birds. Our results showed that identification of a pair is possible over one breeding season and even over several years. The data collected here give a general pattern of features in plumage that can be used in identification, what kind of changes are possible, and which features are useful in identification. Individual identification is the easiest if the plumage shows something out of the ordinary, but as the followed pair showed, these special features are usually visible only during one season.

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Kuikkien yksilöllinen tunnistaminen

Kuikkien kesäpukuja tutkittiin tarkastelemalla 278 yksilön pukuja ja tutkimalla saman kuikkaparin kesäpukuja yhdeksänä peräkkäisenä vuotena 2007–2015. Huomiota kiinnitettiin 1) kaulan sivun valkeisiin juoviin, 2) selän valkoisia neliöitä sisältäviin riveihin ja 3) peräpään sivujen valkoisiin pilkkuihin. Kaulan sivun valkeiden juovien määrä vaihteli neljästä seitsemään keskiarvon ollessa 5,0 ($n = 278$). Toinen juova edestä oli korkein 92,1 %:lla kuikista. Selän valkoisia neliöitä sisältävien rivien määrä vaihteli välillä 11–14 keskiarvon ollessa 12,4 ($n = 165$). Peräpään sivujen pilkkujen määrä vaihteli molemmilla sivuilla välillä 27–67 keskiarvon ollessa 40,1 ($n = 93$).

Kaikkia kolmea tutkittua piirrettä voidaan käyttää kuikkien yksilölliseen tunnistamiseen. Varsinkin kaulan sivujen valkoisia juovia ja peräpään pilkkuja voidaan käyttää tunnistamiseen jopa vuodesta toiseen, sillä ne pysyivät samanlaisina koko yhdeksän vuoden tutkimusjakson ajan. Helpointa yksilöllinen tunnistaminen on jos puvussa on jotain tavallisuudesta poikkeavaa (19,4 %, $n = 278$).

Erotteluanalyysi osoitti, että seurattu kuikkapari voitiin erottaa toisistaan. Kun analyysiin lisättiin tiedot 125 kuikasta, päästiin oikeaan luokitteluun 70,8 % kuikista ja 69,6 % analyysissä, jossa kukin kuikka arvioitiin erikseen. Näissä analyysissä käytettiin kaulan juovien suhteellisia korkeuksia, niiden keskipituutta ja keskivaihtelua. Kun peräpään pilkkujen lukumäärä lisättiin analyysiin, oikeaan luokitteluun päästiin 77,4 % kuikista, ja yksittäin arvioidussa analyysissä 75,7 % linnuista (n = 115). Naaras- ja koiraskuikka voitiin erottaa toisistaan otsan muodon perusteella.

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