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Taxonomic revision, occurrence, and identification of Intermediate Egret *Ardea intermedia* in North Queensland, Australia

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Abstract. Between May and July 2021, five individual white egrets observed in Cairns, Queensland, Australia, appeared to have the physical characteristics of the nominate Intermediate Egret *Ardea intermedia* in non-breeding plumage, based on the mensurate bill methodology established by Cake *et al.* (2016). We review the taxonomic status of the Intermediate Egret complex, including *A. intermedia* (breeding in Asia), *A. plumifera* (breeding in Australia) and *A. brachyrhyncha* (breeding in Africa), using the species ranking criteria of Tobias *et al.* (2010). We subsequently performed an expanded comparative image-based morphometric analysis of the bills of 110 *A. intermedia* and *A. plumifera* from Asian and Australasian locations, including scaled digital photographic comparisons, and several multivariate and univariate analyses, as a test of taxon identification. In addition, we used Donegan's (2018) universal effect size to determine if the taxa could be separated using only cranial–bill morphometry. The study showed a statistically significant dissimilarity in bill morphometry between the geographic populations, with five of the 55 Australian individuals being similar to *A. intermedia*. These analyses support our initial suspicion that the five birds at Cairns were *A. intermedia*, becoming the first recorded occurrence of *A. intermedia* in North Queensland or the eastern coast of Australia.

Introduction

Field identification of egrets belonging to the Intermediate Egret complex (Intermediate Egret *Ardea intermedia,* Plumed Egret *A. plumifera* and Yellow-billed Egret *A. brachyrhyncha*) can be surprisingly difficult, especially when the bird is isolated or in association with other all-white egrets such as Cattle Egret *Bubulcus ibis* and female Great Egret *A. alba* (Ali & Ripley 1978; Brown *et al.* 1982; Marchant & Higgins 1990; Cake *et al.* 2016). Although the three species are geographically separated, vagrancy can occur, with two taxa from this complex now confirmed to occur on the Australian mainland: the Australian-breeding Plumed Egret and, recently, the migratory Intermediate Egret (BirdLife Australia 2016a; Cake *et al.* 2016; see Figure 1).

Del Hoyo *et al.* (2014) split the Intermediate Egret complex into three taxa using the Tobias *et al*. (2010) criteria. That method applies a points system to defined thresholds in effect size (Cohen's *d*) of various morphological, plumage (note that references to 'plumage' include skin coloration), bioacoustic, behavioural and biogeographic attributes to help determine if similar subspecies might in fact be distinct species. The method was used extensively in del Hoyo *et al.* (2014) and subsequently adopted by BirdLife International as their primary taxonomic tool (HBW & BirdLife International 2021). BirdLife Australia (2019) adopted the split for Australian species and recently the International Ornithological Congress (IOC) has also proposed that the split be accepted (IOC 2021a). The Tobias *et al*. (2010) criteria have been criticised by several authors (e.g. Remsen 2015; Donegan 2018; Rheindt & Ng 2021), though many of the taxonomic splits published in Tobias *et al*. (2010) and del Hoyo *et al.* (2014, 2016) have slowly been adopted by other national and global taxonomies such as Donegan *et al.* (2016), IOC (Gill *et al.* 2021), Clements (Clements *et al.* 2021) and eBird (eBird 2021); see also discussion in Collar *et al.* (2016). Tobias *et al.* (2021) have also shown that the methodology has been adopted by many publications and globally adopted species splits (see also IOC 2021a,b).

The main criteria for splitting the Intermediate Egret complex into three species (del Hoyo *et al.* 2014) were significant differences in breeding plumage, and particularly bill, facial skin and leg colour during courtship and breeding; and bill size and tail size (summarised in Table 1), and vocalisation. Accepting that *A. intermedia* and *A. plumifera* are separate species (BirdLife Australia 2019), we note the recently accepted records of *A. intermedia* in Australia from Western Australia and Christmas Island (Figure 1; BirdLife Australia 2016a,b; Cake *et al.* 2016) and a photographic record from Broome, Western Australia (Jackett 2017). It would also seem likely that, based on the spatial distribution of the two species, there may be a band of overlap between them around the eastern part of the Indonesian archipelago, as illustrated by BirdLife International in their fact sheets distribution maps (BirdLife International 2021a,b). To our knowledge, there are no known published accounts of *A. plumifera* occurring west of Timor-Leste.

In western Asia (Oman, Pakistan, Sri Lanka, India), *A. intermedia* is resident year-round with local nomadic movement in response to wet and dry seasons, with breeding recorded from July to September in the north, November to February in southern India, and December to May in Sri Lanka (Baker 1929; Ali & Ripley 1978). However, in eastern Asia, *A. intermedia* is strongly migratory, breeding (July–September) as far north as south-eastern Siberia, north-eastern China and South Korea, then migrating south in winter (October–May) to Thailand, Cambodia, the Malay Peninsula, Philippines, and Indonesian archipelago, east to at least Bali and Timor-

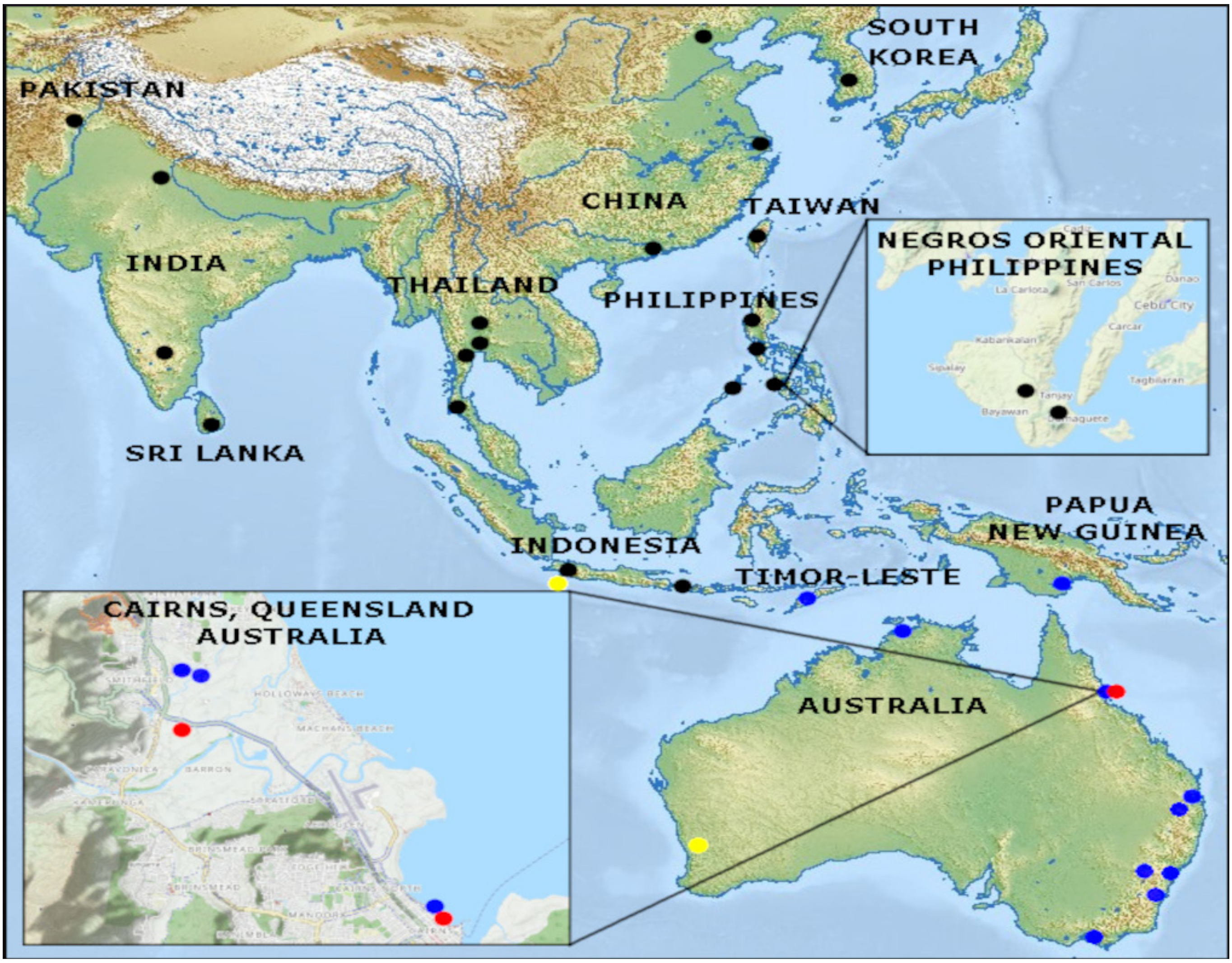

Figure 1. Location of the species samples referenced in this paper: suspect *Ardea intermedia* shown by red dots, *A. plumifera* by blue dots, *A. intermedia* by black dots, and BirdLife Australia Rarities Committee accepted records of vagrant *A. intermedia* (on Christmas Island and on Lake Joondalup, Perth) by yellow dots. Map sourced from https://mapswire.com/world/physical-maps under Creative Commons Attribution 4.0 International License.

Leste (Lekagul & Round 1991; Wells 1999; Kennedy *et al.* 2000; Sheldon *et al.* 2001; Trainor 2005; del Hoyo *et al.* 2014). In April 2011, a breeding colony was unexpectedly found in Perek, Malaysia (Amar-Sing 2012); however, the species has not been recorded breeding in the Philippines, Sabah, Bali or Timor-Leste (Kennedy *et al.* 2000; Sheldon *et al.* 2001; Trainor 2005). Conversely, *A. plumifera* has been described as rather sedentary with localised nomadic movements, though there are long-distance movement records of individuals from Victoria, New South Wales and Queensland in Australia to West Papua and Papua New Guinea, and concentrations at breeding colonies are inevitably followed by wide dispersal. Breeding has been recorded from October to April through eastern and northern Australia (Marchant & Higgins 1990; Geering *et al.* 1998; del Hoyo *et al*. 2020). Given that both species can fly long distances, it is not surprising that either species could occasionally wander outside their usual range in the Australasian region.

From May to July 2021, AW observed several unusual egrets foraging on mudflats at Cairns, Queensland, Australia (16°55′6″S, 145°46′36″E), and it was suspected that they may be *A. intermedia*, notwithstanding the difficulties of separating the two species in non-breeding plumage (see Cake *et al.* 2016). CJC was contacted, and we began investigating if the two species could be easily separated using digital photography and applying the relatively simple post-observation analysis suggested by Cake *et al.* (2016).

In this paper, we begin by reviewing the taxonomic status of the three aforementioned egret species in relation to how the taxa were split using the Tobias *et al*. (2010) criteria by del Hoyo *et al.* (2014). We then investigate and expand the methodology described by Cake *et al.* (2016) to identify *A. plumifera* and *A. intermedia* in the field using digital photography and post-observation analysis within image-processing software. We then examine a digital photographic sample of 55 *A. intermedia* from many parts of Asia and 50 *A. plumifera* from throughout Australia, concentrating on identifying differences in their bill and head morphology, and analyse the results statistically. We then examine the five suspect egrets from Cairns to investigate their taxonomic provenance. Finally, we discuss the non-breeding plumage of *A. plumifera* and *A. intermedia* and recommend a simple methodology that can be used in the field and post-observation environment to determine the probable identity of a suspect individual, such as the birds discovered in Cairns that we suspect to be *A. intermedia*.

Table 1. Plumage details (a) and morphometric data (b) that were used by del Hoyo *et al.* (2014) to justify splitting *Ardea intermedia* into three species, *A. intermedia*, *A. plumifera* and *A. brachyrhyncha*. Additional data from Junge (1948), Hindwood *et al.* (1969), Ali & Ripley (1978), Brown *et al.* (1982), Hancock (1984), Marchant & Higgins (1990), Wells (1999) and this study.

(a) Plumage and colour of legs, feet, soft parts, eyes and bill

Plumage	*Tibia*	*Tarsus*	*Feet*	*Lores + facial skin*	*Eye*	*Bill*
***A. intermedia*, Asia (Oman, through central, eastern, north-eastern and southern Asia to eastern Indonesia)**						
Non-breeding	Variable dark green to brown/black	Variable dark green/brown to dusky black	Black	Pale yellow	Lemon-yellow	Yellow, often tipped black
Breeding	Black	Black	Black	Yellow	Golden yellow to red	Mostly black to completely black
Courtship	Black	Black	Black	Yellow-green to blue-green	Blood red	Black
***A. plumifera*, Australasia (Timor, Aru Islands, West Papua, Papua New Guinea, Australia, New Zealand)**						
Non-breeding	Black	Black	Black	Pale yellow	Yellow	Yellow
Breeding	Black to beige	Black	Black	Yellow to blue-green	Golden yellow	Yellow distal third, turning pinkish red
Courtship	Pink to red	Pink to red	Black	Bright lime-green	Red	Bright orange-red to fleshy red, becoming yellowish towards tip
***A. brachyrhyncha*, Africa (south of Egypt and Sahara Desert)**						
Non-breeding	Variable yellowish to pale brown	Variable dark brown	Black	Yellow	Yellow	Yellow, often with dark tip
Breeding	Yellowish to pinkish crimson	Black with yellow stripe down sides	Black	Yellow turning green	Yellow	Orange-yellow, reddish base
Courtship	Deep pink to red-crimson	Black with pinkish stripe down sides	Black	Bright green	Deep red/ruby	Yellow from tip turning red basal half

(b) Measurements of bill, wing and tarsus: mean and range (mm); *n* in parentheses. Sources: 1. Ali & Ripley (1978), 2. Junge (1948), 3. British Museum of Natural History, 4. Brown *et al.* (1982), 5. Marchant & Higgins (1990).

Taxon	*Bill*	*Wing*	*Tarsus*	*Tail*	*Source*
A. intermedia	72, 66–76 (12)	319, 304–333	131, 122–148	126, 116–135	1
	71, 64–78 (23)	294, 268–317 (23)	111, 102–119 (23)	112, 103–120 (23)	2
A. brachyrhyncha	80, 76–83 (7)	304, 292–315 (7)	111, 104–116 (7)	127, 123–137 (7)	3
	71, 66–78 (8)	311, 305–318 (5)	107,104–110 (7)	125, 118–132 (5)	4
A. plumifera	87, 81–92 (15)	278, 263–294 (7)	103, 98–106 (7)	114, 109–119 (7)	3
	82, 79–83 (4)	299, 295–304 (4)	110, 106–114 (4)	114, 109–118 (4)	5

Study area and methods

Although this study is primarily focused on *A. intermedia* and *A. plumifera,* we included *A. brachyrhyncha* for completeness. First, we examined the degree of phenotypic distinctiveness of each of the three species using published data (Tables 1–2, Figure 2) ascribing Tobias *et al.* (2010) criteria scores for relevant characters as described in del Hoyo *et al.* (2014). The method specifies that only three plumage characters, two vocal characters, two biometric characters (assessed for effect sizes using Cohen's *d*; see below), and one behavioural or ecological character may be counted (Tobias *et al.* 2010, 2021; Collar *et al.* 2015). Taxon pairs are compared this way and if the summed score exceeds a threshold of 7 points, then the two taxa can be recommended for species ranking by taxonomic authorities.

Descriptions of the relevant egrets' plumage and body parts were assessed for three plumage stages as recommended by Hancock (1984): non-breeding, breeding and courtship (Tables 1–2, Figure 2). We also included published biometric data for lengths of bill, tail, wing and tarsus. For biometric data, we tested the effect size (Cohen's *d*) between the three species using the Tobias *et al.* (2010) criteria, where effect size of 0.2–2 is minor (1 point), 2–5 is medium (2 points), 5–10 is major (3 points), and >10 is exceptional (4 points). Additional biometric data were obtained from the British Museum of Natural History, Baker (1929), Junge (1948), Ali & Ripley (1978), Brown *et al.* (1982) and Marchant & Higgins (1990).

The effect size is an important adjunct to statistical hypothesis testing as it measures the biological or taxonomic robustness of the data being analysed (Nakagawa & Cuthill

Table 2. Effect size differences (Cohen's *d* and Donegan's *d*) (a) and Tobias *et al*. (2010) scores (b) for biometric data in Table 1. Welch's paired *t*-test *P* values. Values with * are not used to compute the Donegan's universal effect size (UES) for each paired comparison (see text for details). Tobias *et al*. (2010) criteria scores or each paired species comparison are based on three plumage differences, two effect sizes for biometric data and one vocalisation (see text for details). SD = Standard Deviation (see text).

(a) Effect size difference for published biometrics

	A. plumifera vs *A. intermedia*				*A. plumifera* vs *A. brachyrhyncha*				*A. intermedia* vs *A. brachyrhyncha*			
Metric	*Bill*	*Wing*	*Tarsus*	*Tail*	*Bill*	*Wing*	*Tarsus*	*Tail*	*Bill*	*Wing*	*Tarsus*	*Tail*
Difference (mm)	14.48	17.55	9.23	5.50	10.91	21.16	0.77	13.70	3.57	3.61	8.45	8.20
Pooled SD	3.90	15.69	6.23	6.85	4.37	9.91	3.49	4.38	4.50	14.29	5.45	7.60
Cohen's *d*	3.71	1.12	1.48	0.80	2.50	2.13	0.22	3.13	0.79	0.25	1.55	1.08
Welch's *t*-test *P*	0.0001	0.0003	0.0001	0.0130	0.0001	0.0001	0.0957*	0.0001	0.03	0.4176*	0.0001	0.0002
Donegan's *d*	3.61	1.11	1.47	0.88	2.37	2.07	0.23	3.07	0.76	0.27	1.78	1.07
Tobias criteria points	2	1	1	1	2	2	1	2	1	1	1	1
Donegan's UES	4.14				4.39				2.21			

(b) Tobias *et al*. (2010) scores

	A. plumifera vs *A. intermedia*	*A. plumifera* vs *A. brachyrhyncha*	*A. intermedia* vs *A. brachyrhyncha*
Bill colour	3	1	3
Facial skin colour	2	2	2
Tibia and tarsus colour	2	2	2
Bill length	2	2	1
Tail length	1	2	1
Vocalisation	1	1	1
Total Tobias criteria score	11	10	10

2007; Halsey 2019). For Cohen's *d,* the mean difference between two variables is normalised to SD (Standard Deviation) units. Thus a *d* of 0.5 can be interpreted as 0.5 SD (Maher *et al.* 2013) and the significance of Cohen's *d* was assessed using the original descriptive terms of Cohen (1988) and Sawilowsky (2009) where an effect size of *d* = 0–0.1 is classed 'no difference', *d* ≥0.1–0.2 as 'very small', *d* ≥0.2–0.5 as 'small', *d* ≥0.5–0.8 as 'medium', *d* ≥0.8–1.2 as 'large', *d* ≥1.2–2.0 as 'very large' and *d* ≥2.0 as 'huge'.

Figure 2. Comparison of cranial-bill morphology in breeding (left) and non-breeding (right) plumages using scaled photographs for the three egret species, *Ardea plumifera*, *A. intermedia* and *A. brachyrhyncha*. Photos (from top to bottom): Left: Daniel J. Field, Brisbane, Australia; Satheesh Sankaran, Bangalore, India; Johan van Rensburg, Standerton, South Africa. Right: Adrian Walsh, Cairns, Australia; Chris J. Chafer, Negros Island, Philippines; Dave Montreuil, The Gambia

Table 3. Description of ratio measures used in this study to determine differences between *Ardea plumifera* and *A. intermedia* as measured in pixels within the image-processing software. See Figure 3 for location of each measure.

L/E	Ratio of nares to bill tip vs eye-centre to nares as per Cake *et al.* (2016)
Dm/Db	Ratio of bill depth midway between nares and tip vs bill depth at nares as per Cake *et al.* (2016)
L/Dm	Ratio of bill length from nares to tip vs bill depth midway between nares and tip as per Cake *et al.* (2016)
L/Db	Ratio of bill length from nares to tip vs bill depth at nares
ET/Dm	Ratio of centre of eye socket to bill vs depth midway between nares and tip
NT/Dm	Ratio of bill to nape vs bill depth midway between nares and tip
FT/Dft	Ratio of forehead to bill tip vs bill depth midway between forehead and tip
FT/Fm	Ratio of forehead to bill tip vs bill depth at forehead to base of maxilla
L/Dft	Ratio of length from nares to tip vs bill depth midway between forehead and tip

We also ascribed Tobias *et al.* (2010) criteria to selected plumage and vocal characters where an exceptional difference (a radically different coloration, pattern, or vocalisation) scores 4 points, a major character (pronounced difference in body part, colour, pattern, measurement or vocalisation) 3 points, a medium character (clear difference reflected, e.g. by a distinct hue rather than a different colour) 2 points, and a minor character (weak difference, e.g. a change in shade) scores 1 point. The threshold of 7 points allows species ranking and species ranking cannot be triggered by minor characters alone (Tobias *et al*. 2010, 2021; Collar *et al.* 2015). Plumage data were obtained from Ali & Ripley (1978), Brown *et al.* (1982), Hancock (1984), Marchant & Higgins (1990), del Hoyo *et al.* (2014) and our observations from this study.

Photography treatment

Cake *et al.* (2016) encouraged researchers to review bill differences from actual measurements and ratios, as a basis for multivariate analyses. They describe a methodology of acquiring a suitable digital photograph of the target egret with the head and bill in complete profile relative to the photographer's line of sight. Any obliqueness in the egret profile would result in inaccurate measurements being made. Non-conforming photographs were discarded.

We loaded each individual photograph into digital image-processing software [ImageJ (Rasband 1997–2018), Adobe Photoshop] and rotated it until the base of the maxilla was approximately parallel to the bottom of the image workspace. The head and bill were then cropped, the image coded and saved as a new file. There is a surprisingly large variation within the combination of head and bill details in individual egrets (see results, Appendix 1). This individuality allows the analyst to determine if two pictures taken at the same location on the same/different dates might be the same individual. This was done by reference to several physical markers: nare size and shape; bare skin to the rear of the eye; colour of tarsus and inner and outer tibia; and other indicators such as extent of black on bill tip, bill shape and any unusual markings on the bill. If the same individual was discovered, the best image was retained, and duplicates were discarded. The process was repeated until 55 *A. intermedia* individuals and 50 *A. plumifera* individuals, plus the five suspect egrets from Cairns, were available for analysis.

We chose a sample size of 110 individuals from the two taxa subsequently being considered (*A. intermedia* and *A. plumifera*) from throughout their respective geographic ranges to accurately estimate standard errors of mean shapes or intraspecific variance-covariance structure (Walsh 2000; Cardini *et al.* 2021). This was done to reduce any statistical bias that might have been introduced by sampling individuals from two localised areas where we resided. AW photographed 25 *A. plumifera* individuals and five suspect individuals between May and July 2021 in the Cairns area of North Queensland, Australia, and CJC had photographed 25 *A. intermedia* individuals from two wetland/fishpond sites in Negros Oriental, Philippines, between 2018 and 2021. An additional 25 *A. plumifera* photographs from elsewhere in Australia, Papua New Guinea and Timor-Leste, and 30 *A. intermedia* photographs from other parts of Asia (Figure 1) were downloaded from Flickr (www.Flickr.com) for analysis using the Creative Commons license CC BY-NC-SA 2.0, as per Cake *et al.* (2016) (see Appendix 2 for locations, photographers and sources). The Asian photographs came from a range of countries from Pakistan to South Korea.

Once the database was compiled, various measurements (in pixels) were taken within the image-processing software and the results stored in a digital spreadsheet as the number of pixels recorded by the measuring tool. In addition to the three ratio measures described by Cake *et al.* (2016), we recorded several additional cranial and bill measures (Table 3, Figure 3).

Cake *et al.* (2016) also briefly described a comparative digital photographic scaling method used to measure the comparative shape and length of the bill between the two taxa, *A. intermedia* and *A. plumifera.* By comparing digital photographs of 50 birds, they found that the bill of *A. plumifera* was up to 9% longer than in *A. intermedia.* We likewise scaled and compared the bills of the 110 individuals from Australasia and Asia used in this study. Cake *et al.* (2016) assumed that the distance between the centre of the eye and the nare (measure E in Figure 3) was consistent between individuals. We likewise scaled all birds to a single reference bird so that the distance E was consistent before measuring the length FT (Figure 3) within the ImageJ or Photoshop software. We also used the diameter of the iris as an additional scaling variable during the scaling process.

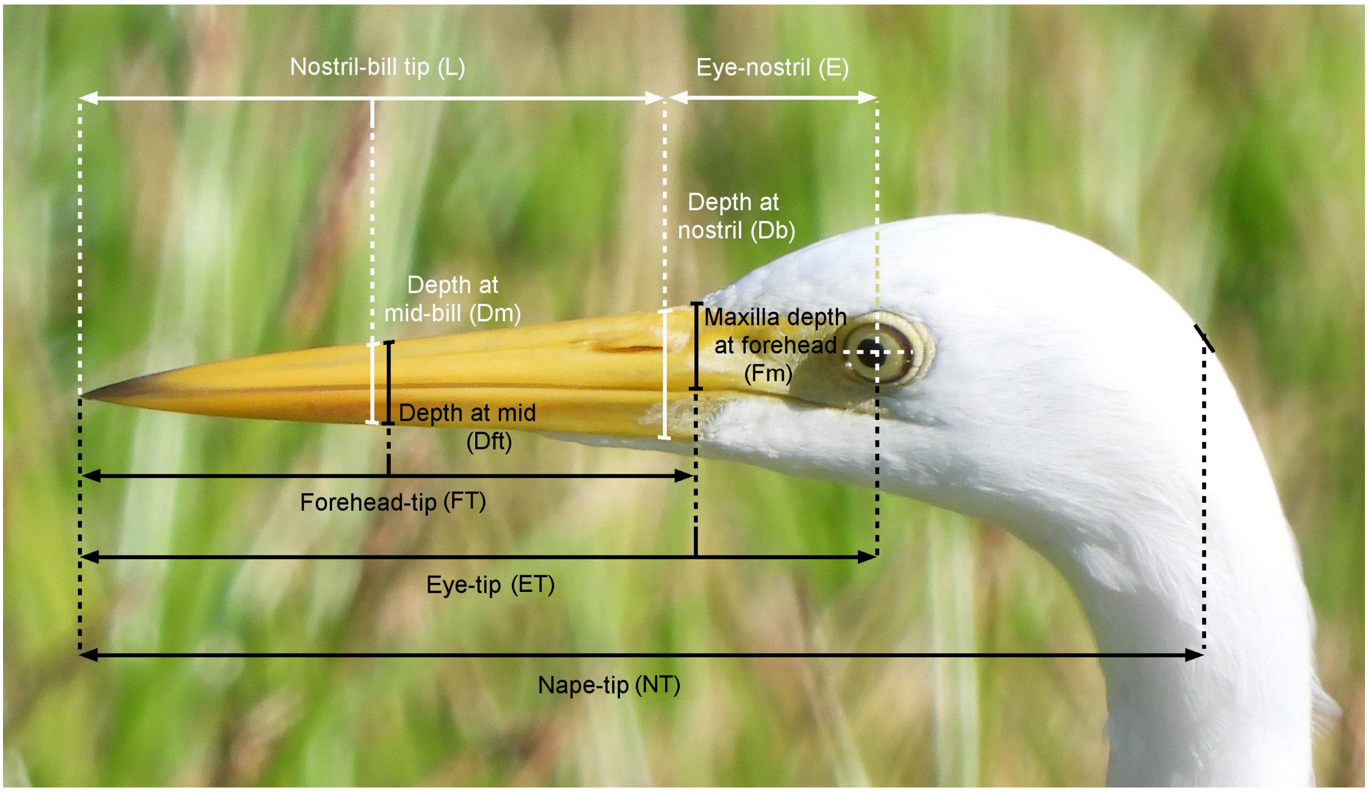

Figure 3. Bill measurements used for the morphometric ratio analysis. Profile image has to be as perpendicular to the camera lens as possible to avoid obliquity distortion errors in the measurements. Image is rotated such that the maxilla/mandible intersection is as horizontal as possible. Eye to bill tip (ET) and eye to caudal end of nare measurements (E) are measured from a cross-hair marking the centre of the eye socket, rather than the centre of the pupil due to eye movement. Nape to bill tip (NT) measurements are via a line through the centre of the eye socket. From where the forehead (F) meets the bill to the bill tip is measured via a straight line (FT). Depth measurements of Dm (midway between nares and tip), Db (at nares), Dft (midway between forehead and tip) and Fm (at forehead to base of maxilla) are perpendicular to the horizontal alignment of the maxilla/mandible intersection. This image is of a Plumed Egret *Ardea plumifera* taken at Dunne Road Swamp, Smithfield, Cairns, in June 2021. Some measures are adapted from Cake *et al*. (2016); see Table 3 for details. Photo: Adrian Walsh

Statistical methods

For each ratio variable, we compared the two taxa using Welch's *t*-test as a preliminary procedure recommended by Patten & Unitt (2002) and Donegan (2018). Variables that were not significantly different at $\alpha = 0.05$ were omitted from further analysis.

Data for the nine measured ratios (Table 3) were analysed in the statistical software program PAST (Hammer *et al.* 2001). We first explored the data set using Non-metric Multidimensional Scaling (NMDS), applying the Bray–Curtis similarity measure (Clarke 1993; Hammer *et al.* 2001) to assess and visualise the multivariate (dis) similarity of the two taxa in two-dimensional space. Stress values and R^2 for the NMDS were reported as a means of evaluating the multivariate representation of species grouping dissimilarity within two-dimensional space: stress values <0.05 are regarded as an excellent representation of the multidimensional reduction, and <0.1 as very good (Clarke 1993; Dexter *et al.* 2018). After examination of the computational stability and stress values in the NMDS, the data were grouped into visually obvious point clouds using the shaded convex hull option in PAST for clearer visualisation of the groupings. We emphasise that this grouping is a *post-hoc* process independent of the data computational process. To test the significance of the difference between group centroids and their variance in the NMDS, we computed Mahalanobis squared distance (D^2) and Rao's *F* statistic with the null hypothesis that there is no significant difference between assigned taxa centroids and their variance. To illustrate the results of each ratio, we show the mean and ± 1 SD interval for each ratio.

The statistical significance of (dis)similarity between taxa was assessed by performing a one-way non-parametric permutation MANOVA (PermANOVA: Anderson 2001; Hammer *et al.* 2001). PermANOVA makes no assumptions about multivariate normality of the data and has been shown to be very robust to deviations of multivariate normality (Hammer *et al.* 2001). A SIMPER (similarity percentage: Clarke 1993) analysis was conducted to identify which variables contributed most to any difference between the identified groups (Clarke 1993; Hammer *et al.* 2001). The most significant variables were further examined using Cohen's *d* effect size (Cohen 1988), which has become the preferred method for testing differences between avian biometrics (Tobias *et al.* 2010; Collar *et al.* 2015; Lenhard & Lenhard 2016; Donegan 2018; Ho *et al*. 2019; Sangster *et al*. 2021). Finally, we included an analysis of the five suspect egrets from Cairns that instigated this study, and attempted to assign them to a specific taxon using the universal effect size (UES) diagnosability test provided by Donegan (2018) and canonical discriminant analysis (CDA, also known as canonical variate analysis).

Tobias *et al.* (2010, 2021) and Donegan (2018) discussed the use of effect sizes as a means of better describing sample distributions in biometric analyses as opposed to using standard statistical tests such as the student *t*-test. Donegan (2018) suggested that Cohen's *d* as used by Tobias *et al.* (2010) is not entirely suitable for biometric assessment as it produces seemingly conservative results. He proposed an alternative method for calculating the effect size by using a controlled, unpooled effect size (Donegan's *d*), for each biometric variable being considered and, subsequently, a Euclidean summing formula that allows the computation of a universal effect size coefficient (UES). As del Hoyo *et al.* (2014) provided an effect size greater than 7 for the difference between *A. plumifera* and *A. intermedia,* we used the Tobias *et al.* (2010) methodology and the UES computational spreadsheet of Donegan (2018) to assess if the two species in this study, *A. plumifera* and *A. intermedia,* could be distinguished on cranial–bill morphometry alone.

We used CDA (Fisher 1936; Legendre & Legendre 1998; Hammer *et al.* 2001) to provide an independent assessment of whether individuals of unknown species could be correctly assigned to the two *a priori* defined species. We used this method to classify the five suspect egrets observed in the Cairns locations by using the CDA to place the egrets into the bivariate feature space based on the same variables used to discriminate the two *a priori* defined egret species. This process is known as 'new data allocation' (Hammer *et al.* 2001; Anderson & Robinson 2003; Rakotomalala 2017). The algorithm within the CDA classifies the data, assigning each new point to the group that gives a minimal Mahalanobis distance to the group mean. The Mahalanobis distance is calculated from the pooled within-group covariance matrix, giving a linear discriminant classifier. The given and estimated group assignments are listed for each point in the output. In this study, we have five suspect egrets that were added to the analysis but not included in the discriminant analysis itself. Thus, they were classified by the comparison routine within the program by comparing their canonical coordinates with the training set coordinates (Hammer *et al.* 2001; Rakotomalala 2017).

Results

Taxonomic review

Although del Hoyo *et al.* (2014) split the three taxa and provided a brief rationale for doing so, a lack of space in that volume possibly prevented a detailed explanation of the split based on the Tobias *et al*. (2010) criteria, and the explanation requires clarity. It should be noted that in non-breeding plumage all three species look very similar, yet in courtship and breeding plumage they are remarkably different (Figure 2, Table 1). Immature birds are indistinguishable from adult non-breeding birds (Ali & Ripley 1978; Marchant & Higgins 1990).

Pairwise comparisons between the three species of the four morphometric characters using both Cohen's *d* and Donegan's *d* (Table 2) show differences between the resulting effect sizes. Donegan's UES implies that, even using just these four characters, *A. plumifera* is taxonomically different from both *A. intermedia* and *A. brachyrhyncha.* From the effect size comparison we chose tail length and bill length as the two characters to consider using the Tobias *et al*. (2010) criteria method.

Thus, using the Tobias *et al*. (2010) criteria with published data for the three plumage stages (non-breeding, courtship, breeding; see Hancock 1984 for rationale and Table 1 for sources), the three allopatric taxa were assessed as follows using three plumage characters (actually relating to bill and leg colour rather than feathers), two biometric characters and one vocal character:

(a) Three plumage characters (points in parentheses). See Figure 2, Table 1.

1. *A. intermedia* differs from *A. plumifera* and *A. brachyrhyncha* in courtship/breeding plumage with an all-black bill vs yellow–orange-tipped to deep reddish-pink-based bill in *A. plumifera* (3 points) and orange–yellow-tipped deep-crimson-red-based bill in *A. brachyrhyncha* (3 points).
2. *A. intermedia* differs from *A. plumifera* and *A. brachyrhyncha* in courtship/breeding plumage with lores and facial skin yellow turning blue-green during courtship vs yellowish turning bright lime-green in courtship in *A. plumifera* (2 points) and green in *A. brachyrhyncha* (2 points).
3. *A. intermedia* differs from *A. plumifera* in courtship plumage, with all-black legs vs pink to red (2 points), and from *A. brachyrhyncha* in courtship and breeding plumage, with all-black legs vs yellowish, turning crimson-pink in breeding plumage (2 points)

(b) Two biometric characters (points in parentheses). See Tables 1–2.

4. *A. plumifera* has a significantly longer bill than either of the other two taxa (2 points).
5. *A. intermedia* has a longer tail than *A. plumifera* (1 point), and *A. brachyrhyncha* has a longer tail than either of the other two taxa (2 points).

(c) One vocal character

6. Vocalisation is uncommon in all three taxa, though *A. brachyrhyncha* appears to be more vocal than the other two taxa, especially at nesting time (Brown *et al*. 1982) (allow 1 point). *A. plumifera* gives *glock* vocalisation vs none in *A. intermedia* (Marchant & Higgins 1990; del Hoyo *et al*. 2014, 2020) (allow 1 point).

In terms of vocalisation, *A. plumifera* is generally silent, except at the nest, and few vocal data are published (Marchant & Higgins 1990). Calls near the nest are described as a soft rasping *grrrrk, grrrrk* and, when disturbed, a soft *glock*, and an alarm call described as *kroo-kroo* (Marchant & Higgins 1990; del Hoyo *et al* 2020). We could find only three spectrogram records for *A. plumifera* from Victoria and Queensland in AVoCet (http://avocet.zoology.msu.edu/), eBird (https://ebird.org/) and Xeno-Canto (http://www.xeno-canto.org/) (Figure 4), which can be described as *grrrrk* lasting almost 0.8 second with 1 second between repeats.

Baker (1929) and Ali & Ripley (1978) did not mention vocalisation in their accounts of *A. intermedia* from India, Pakistan, Sri Lanka and Burma (now Myanmar). Kennedy

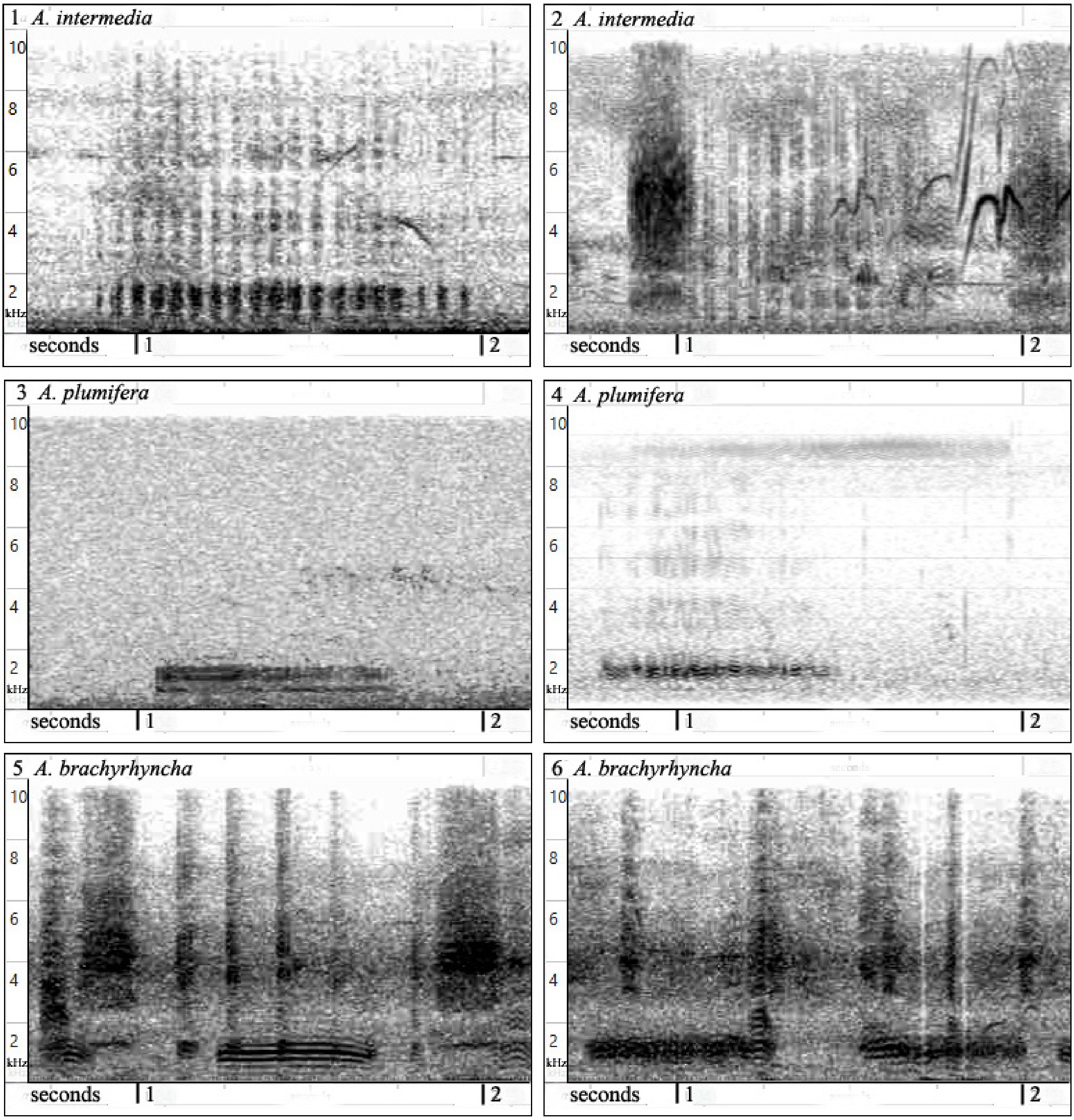

Figure 4. Example spectrograms for the three egret species in this study. The spectrograms show similarity within species from different locations and dissimilarity between species.

1. *A. intermedia* ML363390161; S.J. Koottanad, 22 August 2021, Kerala, India
2. *A. intermedia* ML282224; P. Boesman, 27 March 2016, Bundala National Park, Sri Lanka
3. *A. plumifera* ML179233001; S. Young, 28 September 2019, Tarampa, Queensland, Australia
4. *A. plumifera* XC270400; K. Deoniziak, 18 August 2015, Mareeba, Queensland, Australia
5. *A. brachyrhyncha* ML2241; M.E.W. North, 15 April 1962, Wembere, Tanzania
6. *A. brachyrhyncha* ML2242; M.E.W. North, 15 April 1962, Wembere, Tanzania

et al. (2000) described the only call as a harsh *croak* when disturbed, otherwise silent. Some spectrograms are now published in eBird and Xeno-Canto from India, Sri Lanka, Japan and the Philippines (Figure 4), and from these the call can be described as a repeated short *croak, croak, croak*, lasting nearly 1 second with 0.5 second between repeated calls.

Brown *et al.* (1982) stated that *A. brachyrhyncha* is usually silent away from the nest but can be vocal at the nest. It may utter a grunt *aaah* upon take off and a gargled *ggrow* when threatening, also rasping sounds. Only one spectrogram is published in either AvoCet, eBird or Xeno-Canto, from Tanzania (Figure 4), which can be described as a rapid repeated *cak, cak cak* interspersed with *craw,* repeated several times for 50 seconds.

A basic analysis of the few spectrograms available on eBird and Xeno-Canto (Figure 4) suggests similarity within species and differences in spectral frequency range between species. With this very limited data set, we allocate a nominal score of 1 point for each species

Table 4. Observations of five egrets (all in non-breeding plumage) from the Cairns area, Queensland, June–July 2021, and suspected to be Intermediate Egrets. * = yellow strip observed on upper, inner tibia.

Bird Code	*Tibia*	*Tarsus*	*Feet*	*Lores*	*Eyes*	*Bill*
CE01	Black*	Black	Black	Pale yellow	Yellow	Yellow with black tip on maxilla
CE22	Black*	Black	Black	Pale yellow	Yellow	Yellow with black tip on maxilla
CE36	Black	Black	Black	Pale yellow	Yellow	Yellow with black tip on maxilla
CE39	Black	Black	Black	Pale yellow	Yellow	Yellow with black tip on maxilla
VP01	Black	Black	Black	Pale yellow	Yellow	Yellow with black tip on maxilla and mandible

comparison. Obviously more detailed study and analyses of vocalisation in these taxa would be useful in future.

Therefore, using the six characters described above and in Tables 1–2 and Figures 2 and 4, *A. intermedia* differs from *A. plumifera* by 11 points, *A. intermedia* from *A. brachyrhyncha* by 10 points, and *A. brachyrhyncha* from *A. plumifera* by 10 points (Table 2). Thus, all three taxa combinations exceed the 7-point minimum required for species rank assessment using the Tobias *et al*. (2010) criteria, and our taxonomic analysis concurs with del Hoyo *et al.* (2014), BirdLife Australia (2019) and HBW & BirdLife International (2020).

Observations on the plumage of the five egrets of unknown provenance

On 2 May 2021, AW observed, photographed, and videoed a medium-sized white egret on Cairns Esplanade mudflats at the southernmost end (16°55′6″S, 145°46′36″E). This bird was initially identified as a non-breeding Plumed Egret *A. plumifera* as it showed many of the expected features of that species (compared with other local egrets). The commissural point (commonly referred to as 'gape') did not extend behind the back of the eye; the iris was yellow; the bill was yellow with a small black tip; the lores were pale yellow and did not exhibit any of the green coloration visible in non-breeding Eastern Great Egrets *A. alba modesta*; the toes were fully black and relatively long in comparison with the leg length; the tibia and tarsus were black; the plumage was white without any other coloration; there were no aigrettes visible, and the neck and breast plumes were mostly flattened and not visible; it was smaller than the Eastern Great Egret, and slightly larger than the Australasian Little Egret *Egretta garzetta immaculata,* both of which were visible on the mudflats at the same time. However, several other features attracted attention: it had a long neck, flat crown, lack of gular pouch, and a deep base to the shorter bill, which looked physically different from recently observed Plumed Egrets at local inland wetland habitats. This prompted multiple digital photographs and 4K resolution video to be taken of this particular bird, with the intention of further post-observational analysis. Subsequent research into *A. intermedia* and *A. plumifera*, and observations from May to July 2021 at local Cairns sites frequented by Plumed Egrets (Cairns Esplanade, Cattana Wetlands, Yorkey's Knob and Caravonica) revealed five individuals that appeared to match the physical and morphometric properties of the nominate Intermediate Egret *A. i. intermedia* (Table 4). The particular difference noted during these observations was the shorter, deeper-based bill, which matched earlier analyses of the length to depth ratio of the bills of *A. intermedia*, being 'discriminant between taxa' (Cake *et al*. 2016), and subsequently referenced in accepted BirdLife Australia Rarities Committee (BARC) records of *A. intermedia* from Lake Joondalup, Western Australia (BirdLife Australia 2016a), and Christmas Island (BirdLife Australia 2016b). The tibia and tarsus of these birds were also observed to be black, and there was a black tip to the yellow bill. There were no aigrettes or plumes of note, and the yellow facial colour was consistent with non-breeding *A. intermedia*. A scaled comparison of the five suspect egrets and typical examples of *A. intermedia* and *A. plumifera* is provided in Figure 5.

Two of the five egrets observed in the Cairns area displayed yellow on the upper inner tibiotarsi (Table 4). Although some authors do not reference any yellow on the tibiotarsi of *A. intermedia* (del Hoyo *et al.* 2020), others note for adult non-breeding birds that tibia and hind tarsus colour varies from yellow, brown, green or grey (Marchant & Higgins 1990). During our investigations, we discovered a suspect bird in non-breeding plumage from Darwin, Northern Territory, on the eBird photographic database (Andersson 2017) and measured the cranial profile using the nine ratios established here. The bill morphometrics placed it firmly amongst *A. intermedia*, yet the tibiotarsi of this bird were yellow. Even just using the three Cake *et al.* (2016) ratios alone also placed this bird as *A. intermedia* from the L/Dm measurement of 5.64 and an appraisal of the photograph noted the short bill and lack of domed crown. This 'domed crown' or 'rounded crown' description as typical of *A. plumifera* has also been noted to not be a consistently observed phenomenon, at least with the cohort of birds in this study, nor does it appear to have been objectively measured. It is used as a common diagnostic feature (Marchant & Higgins 1990; Morcombe 2014; Menkhorst *et al.* 2020), and is commonly referenced from Cox (1973), with quote of 'crown is rounded'. Observations and photographic analysis of the 31 *A. plumifera* in the Cairns wetland locations of Smithfield, Yorkey's Knob and Caravonica revealed 17 birds with crowns that could be described as 'rounded', 12 with crowns that were not rounded and two where the category was not clear This is noteworthy, as one of the suspect egrets (CE22: Table 4) appears to have a rounded crown, and yet the bill morphometrics identify it as *A. intermedia*. For the other 25 Australasian individuals in this study, 11 domes were flat, 11 rounded and three indeterminate. For the Philippines data, 19 crowns were flat, nine rounded and two were slightly flatter than rounded. For the other 25 Asian individuals in this study, four appear rounded, 17 were flat and four indeterminate. CJC has noted on several occasions that upon landing next to another egret in a dispute over a food item, the egret's crown feathers are clearly raised briefly,

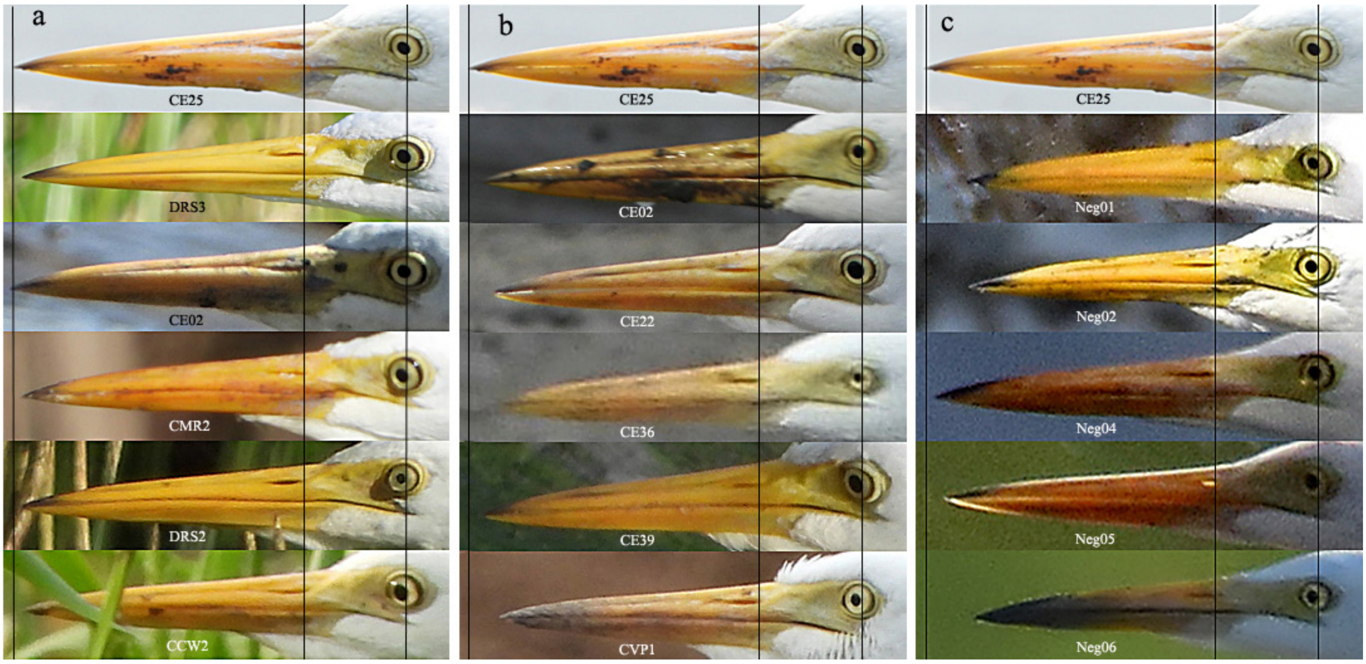

Figure 5. Comparison of scaled bills from *Ardea plumifera* and *A. intermedia* from Cairns, Australia, and Negros Island, Philippines. (a) Six *A. plumifera* from the Cairns waterfront. Top image is the reference egret *A. plumifera* CE25 (see text). (b) CE25 (top) and the five suspect egrets which are the primary subject of this study. (c) CE25 (top) and five *A. intermedia* from Negros Island, Philippines. Vertical lines in each figure define the centre of the eye socket, the nare and the longest bill. Average bill length variation is 2.5% in (a), 9.1% in (b) and 11.7% in (c). Photos: Adrian Walsh & Chris J. Chafer

giving the bird's crown a more rounded appearance for at least 5–10 seconds. We therefore conclude that both *A. plumifera* and *A. intermedia* can show rounded crowns, but the feature is not consistent within or between these species (Appendix 1).

Statistical analysis of cranial–bill ratios

Core results for the nine ratios that we examined (Figure 3, Table 3) show that substantial differences can be found between the two species (*A. intermedia, A. plumifera*) for each of the ratios using Cohen's *d* (Figure 6). We chose the four ratios with the largest effect size to test the null hypothesis that there is no significant difference between the two taxa in cranial–bill morphology (L/Dm: *d* = 2.58, 'huge'; ET/Dm: *d* = 1.87, 'very large'; FT/Dft: *d* = 2.71, 'huge'; FT/Fm: *d* = 1.44, 'very large'). The ratio Dm/Db failed the Welsh's *t*-test for two of the three comparisons and was discarded from further analysis. We did not include L/Dft in subsequent analyses as the measure Dft along the bill length was very close to the point used to measure Dm. The ratio L/Db is likewise similar to FT/Fm and so was not evaluated further. The ratio L/E was deemed to have little morphological value and ET/Dm is preferred. The ratio NT/Dft has some measurement issues when the egret's head is at a particular foraging angle, and so we decided to be conservative and not include it further.

Cohen's *d* was also computed to test if there was any significant effect size difference between the suspect egrets and the two species (Figure 6). Restricting our assessment to the four preferred ratios, in each ratio the effect size difference between the suspect egrets and *A. intermedia* ranges from 'no difference' to 'medium' (L/Dm: *d* = 0.31, 'small'; ET/Dm: *d* = 0.71, 'medium'; FT/Dft: *d* = 0.07, 'no difference'; FT/Fm: *d* = 0.16, 'small'). Conversely, the effect size difference between the suspect egrets and *A. plumifera* ranges from 'large' to 'huge' (L/Dm: *d* = 2.61, 'huge'; ET/Dm: *d* = 2.35, 'huge'; FT/Dft: *d* = 2.59, 'huge'; FT/Fm: *d* = 1.19, 'large'). The effect size difference between *A. intermedia* and *A. plumifera* ranges from 'very large' to 'huge' (L/Dm: *d* = 2.58, 'huge'; ET/Dm: *d* = 1.87, 'very large'; FT/Dft: *d* = 2.71, 'huge'; FT/Fm: *d* = 1.44, 'very large'). This basic analysis suggests that the five suspect egrets are morphologically similar to *A. intermedia,* as their summed effect size is only 1.25 compared with 8.74 for *A. plumifera.* The summed effect size difference between *A. intermedia* and *A. plumifera* is also high at 8.51.

Non-metric multidimensional scaling (NMDS)

The NMDS analysis (Figure 7) shows that the data contain two distinct point clouds in multivariate space that have no spatial overlap and the centroids for the two species data clouds are significantly separated (Stress = 0.0498, R^2 = 0.827, D^2 = 7.78, P <0.0001). A non-parametric PerMANOVA analysis confirms that there is a significant difference between the data clouds for the two species (F = 120.3, Bonferroni-corrected P <0.0001); thus, the null hypothesis of cranial–bill morphological similarity is rejected. The SIMPER analysis (Table 5) shows that these four ratios contribute relatively equally to the multivariate dissimilarity analysis (range 23–29% for each variable).

Canonical discriminant analysis (CDA) and the five egrets of suspect provenance

Next, we analysed the data from the two species using CDA to maximise the distance between species (Figure 8). The two data clouds are clearly separated as

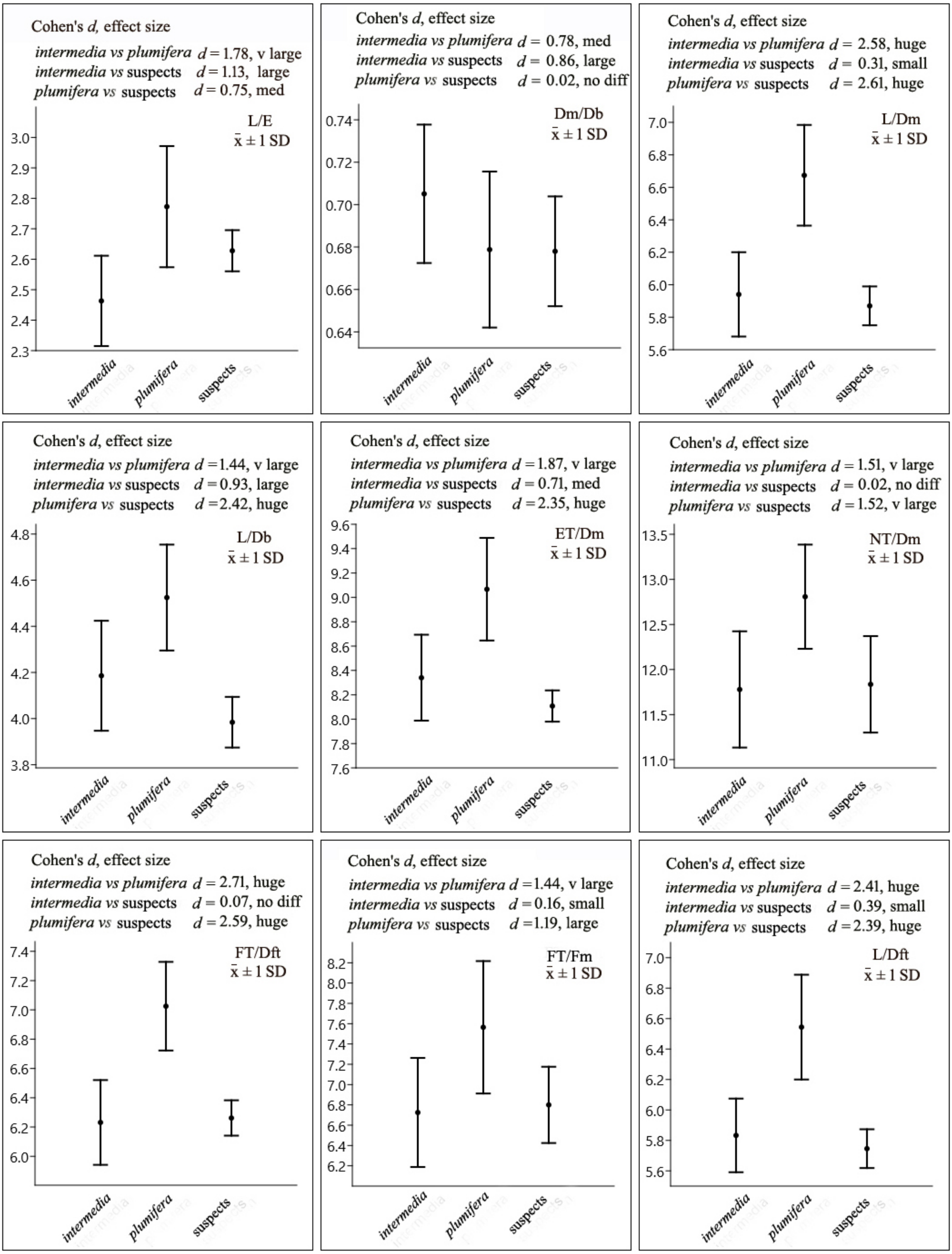

Figure 6. Mean ± 1 Standard Deviation for the nine ratios described in Table 2, representing various ratios measured on the bill and head of two egret species, *Ardea intermedia* (n = 55) and *A. plumifera* (n = 55) and a third group of unknown provenance (n = 5) (labelled as suspects in the graphs below). The specific ratio appears in the top right of each of the nine graphs. Also recorded in each graph is the Cohen's d effect size value and its interpretation according to the Cohen Sawilowsky classification (Cohen 1988; Sawilowsky 2009).

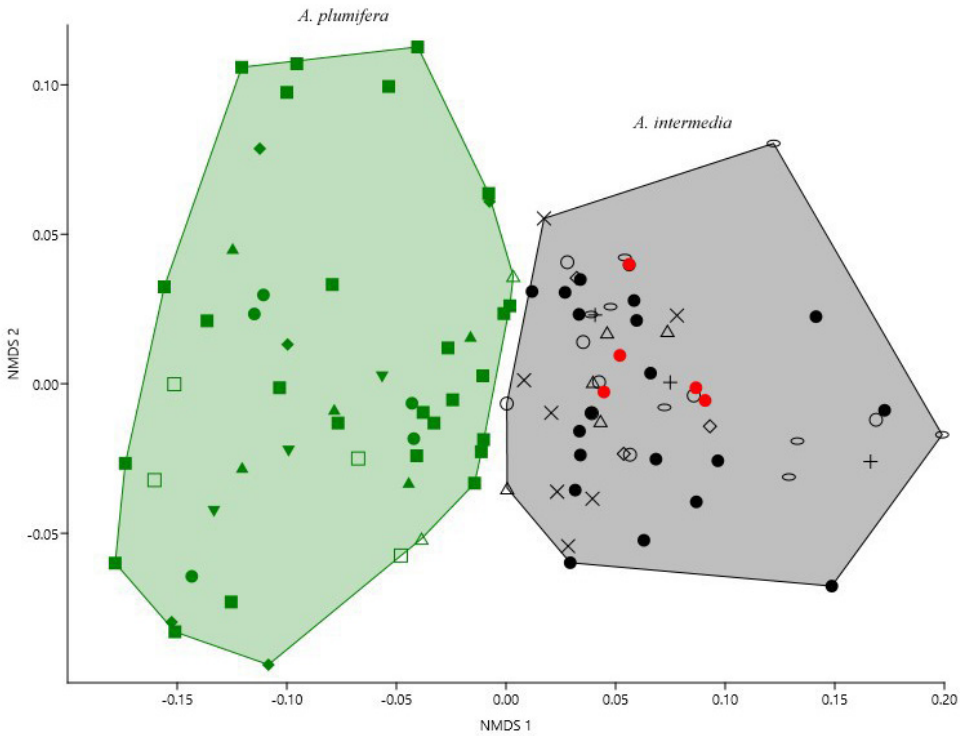

Figure 7. Non-metric multidimensional scaling (NMDS) for four cranial and bill measures used in this study between the 110 birds from *Ardea intermedia* (Asia) and *A. plumifera* (Australasia). Shaded convex hulls around the two point clouds from each taxon show no overlap. The two point clouds are significantly different; Mahalanobis distance between the centroids *A. intermedia* and *A. plumifera* is 10.897, $P < 0.00001$. Symbols are: *A. plumifera*: green solid square, Cairns; open green square, Brisbane area; green solid triangle, Darwin area; green inverted triangle, Papua New Guinea; green circle, Sydney and Newcastle areas; green diamond, Canberra and Ballarat areas; open green triangle, Timor-Leste. *A. intermedia*: black solid circle, Negros Island, Philippines; open black oval, Palawan and Luzon Island, Philippines; open black circle, eastern China, Taiwan and South Korea; +, Sri Lanka; x, India; open black diamond, Bali and Java; open black triangle, Thailand. Red circles show the five egrets of unknown provenance (suspects).

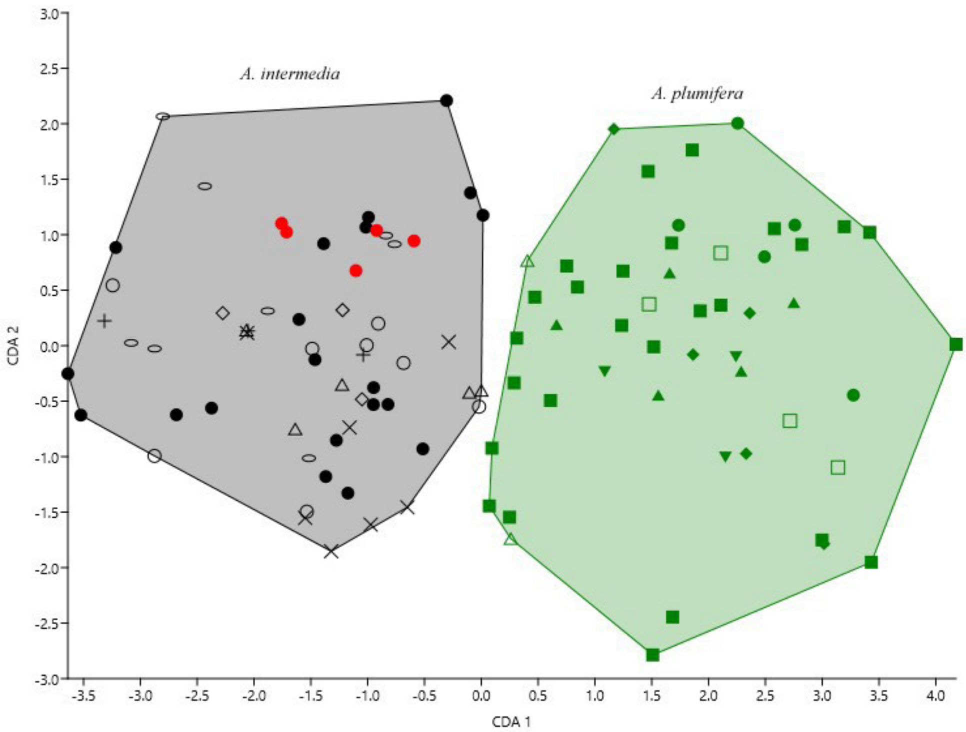

Figure 8. Canonical discriminant analysis (CDA) using four ratios, L/Dm, ET/Dm, FT/Dm and FT/Dft. In this analysis, the 110 egrets assigned to *A. intermedia* and *A. plumifera* are discriminated using canonical variates and become the training set for the five suspect egrets, which were subsequently classified as *A. intermedia* (red circles). Symbols are: *A. plumifera*: green solid square, Cairns; green open square, Brisbane area; green solid triangle, Darwin area; green inverted triangle, Papua New Guinea; green circle, Sydney and Newcastle areas; green diamond, Canberra and Ballarat areas; open green triangle, Timor-Leste. *A. intermedia*: black solid circle, Negros Island, Philippines; open black oval, Palawan and Luzon Island, Philippines; open black circle, eastern China, Taiwan and South Korea; +, Sri Lanka; x, India; open black diamond, Bali and Java; open black triangle, Thailand.

Table 5. SIMPER analysis of dissimilarity from the NMDS for four ratios used in assessing the two egret species [*A. intermedia* (I) and *A. plumifera* (P)].

Ratio	*Average dissimilarity*	*Contribution %*	*Cumulative %*	*Mean I*	*Mean P*
FT/Fm	1.63	29	29	6.73	7.56
FT/Dft	1.4	24.92	53.92	6.23	7.03
ET/Dm	1.31	23.28	77.2	8.34	9.07
L/Dm	1.28	22.8	100	5.94	6.67

Table 6. Confusion matrix from the canonical discriminant analysis CDA (Figure 8) assigning the 110 egrets to their respective categories resulting in 98% accuracy. Only two *A. plumifera* were incorrectly assigned to the *A. intermedia* class.

	intermedia	*plumifera*	Total
intermedia	55	0	55
plumifera	2	53	55
Total	57	53	110

Table 7. Mahalanobis distance D^2 for the three categories of egrets (*A. intermedia*, *A. plumifera*, suspects: three cells lower left) and their statistical significance, Bonferroni corrected *P* (three cells upper right). This is the distance between centroids in the CDA (Figure 8). Suspects and *A. intermedia* are not significantly different in multidimensional canonical space; *A. intermedia* and *A. plumifera* are significantly different, and suspects and *A. plumifera* are significantly different.

	intermedia	*plumifera*	Suspects
intermedia		$P < 0.0001$	$P = 0.87$
plumifera	11.12		$P < 0.0001$
Suspects	1.18	10.31	

expected and the discriminant classifier correctly assigned 98.2% of egrets to their respective species as defined by their geographic distribution and NMDS analysis (Table 6).

We then added the five egrets of unknown provenance to the data table (assigning a '?' in the group column). The CDA was then run again using the original 110 egrets as the training set to classify the five suspect egrets to a species. The CDA classification assigned all five suspect egrets to the *A. intermedia* point cloud (Figure 8). The Mahalanobis D^2 between *A. intermedia* vs *A. plumifera* (D^2 = 11.12, $P < 0.0001$) and *A. plumifera* vs suspects (D^2 = 10.31, $P < 0.0001$) showed that the differences between the groups were highly significant. Concomitantly, *A. intermedia* vs suspects (D^2 = 1.18, $P = 0.87$) showed no significant difference (Table 7).

Donegan's universal effect size coefficient (UES)

Using the spreadsheet and computations from Donegan (2018), we computed Donegan's *d* using the recommended controlled unpooled effect size for *A. intermedia, A. plumifera,* and the five suspect egrets. From those results we computed UES, the Euclidean sum of the four ratios used in this study for each of three comparison pairs: *A. intermedia* vs *A. plumifera, A. intermedia* vs suspects, and *A. plumifera* vs suspects (Table 8). Donegan (2018) suggested that a minimal UES value of 4 should be used to determine taxon rank significance using the Euclidean sum method. On this basis, UES for *A. intermedia* vs *A. plumifera* was 4.36 (different), *A. intermedia* vs suspects was 1.0 (not different) and *A. plumifera* vs suspects was 5.8 (different) (Table 8).

Similarly, we applied the points-based system of Tobias *et al*. (2010) to the four preferred ratios (Figure 6), where *d* = 0–0.2 effect sizes (no point), 0.2–2 (1 point), 2–5 (2 points), 5–10 (3 points) and >10 (4 points). On this basis, the comparison of *A. intermedia* vs suspects was only 2 points, suggesting that there was no taxonomically significant difference between these two groups. Conversely, for both *A. intermedia* vs *A. plumifera* and *A. plumifera* vs suspect egrets, comparisons produced 6 and 7 points, respectively, inferring taxonomically substantial difference between both those group comparisons in cranial–bill measures alone. This is the same result as the basic Cohen's *d* result and the CDA.

Cake *et al.* (2016) also commented that, based on linear measurements from their photographic scaling exercise, the bill of *A. plumifera* was on average ~9% longer than *A. intermedia.* We likewise found in our scaling exercise that the bill length using the measure FT (Figure 3) of *A. plumifera* was on average ~14% longer than *A. intermedia,* and the bill depth at the nares was greater by 7.8% in *A. intermedia.* This implies that *A. intermedia* has a shorter, deeper bill than *A. plumifera.*

Discussion

Donegan (2018) developed a universal effect size (UES) methodology aimed at improving on the species diagnosis work of Tobias *et al.* (2010) using morphometrics and acoustics. Although the methodology appears to work well with passerine species with well-developed songs, it has limitations in non-passerine species with limited vocal output, such as the taxa investigated in our study. Indeed, Donegan (2018) clearly stated that, if significant plumage character differences occur between the target taxa and used in conjunction with continuous variables (morphometrics, acoustics), then the methodology of Tobias *et al.* (2010) is more appropriate. We nevertheless successfully adapted the UES methodology to explore differences in published biometrics for the three egret species, *A. intermedia, A. plumifera* and *A. brachyrhyncha* (Table 2), and in bill morphology (Table 8) for the species and suspect individuals studied here. There was negligible difference between Cohen's *d* and Donegan's *d* in the morphometric analysis, and thus we used the former to complete the Tobias *et al.* (2010) criteria scores. Results

Table 8. Summary table for the computation of Donegan's universal effect size (UES) coefficient using four ratio variables (see Table 3) from *A. intermedia* (n = 55), *A. plumifera* (n = 55) and suspect egrets (n = 5). Donegan's *d* is calculated from the spreadsheet in Donegan (2018); see text for details. Donegan's UES is the Euclidian sum of the four effect size coefficients for each ratio in the three comparisons: $UES = \sqrt{a^2 + b^2 + c^2 + d^2}$ where a = L/Dm, b = ET/Dm, c = FT/Dm, d = FT/Fm.

Ratio	*L/Dm*			*ET/Dm*			*FT/Dm*			*FT/Fm*		
	intermedia	*plumifera*	Suspects	*intermedia*	*plumifera*	Suspects	*intermedia*	*plumifera*	Suspects	*intermedia*	*plumifera*	Suspects
Mean	5.95	6.67	5.87	8.35	9.07	8.11	6.24	7.03	6.26	6.74	7.56	6.81
SD	0.26	0.31	0.12	0.35	0.42	0.13	0.28	0.3	0.12	0.53	0.65	0.38
High value	6.45	7.35	6.03	8.93	10.07	8.28	7.1	7.61	6.46	7.83	9.36	7.36
Low value	5.35	6.15	5.73	7.53	8.27	7.98	5.71	6.38	6.16	5.44	6.6	6.43
Donegan's *d*												
intermedia vs *plumifera*		L/Dm: 2.55			ET/Dm: 1.86			FT/Dm: 2.67			FT/Fm: 1.38	
intermedia vs Suspects		0.36			0.92			0.09			0.11	
plumifera vs Suspects		3.37			3.19			3.23			1.3	
Donegan's UES												
	plumifera	Suspects										
intermedia	4.36	1.00										
plumifera		5.80										

for the bill ratios were very similar to the other statistical and taxonomic diagnosability approaches (NMDS, CDA and species rank diagnosis: Tobias *et al.* 2010, 2021).

Using the Tobias *et al.* (2010) criteria scores for six relevant characters, as used in del Hoyo *et al.* (2014), we showed that there is substantial character difference between the three egret species examined and concur with species rank assessment of del Hoyo *et al.* (2014) (Tables 1–2). Although the three species look remarkably similar in non-breeding plumage, they exhibit clear mensurative differences coupled with visual differences in breeding and courtship plumages. The use of the courtship plumage stage, as suggested by Hancock (1984), is crucial to understanding just how different the species are in their plumage characters, which are probably apparent for at least 8–10 weeks as the birds moult into courtship and breeding plumage and back to non-breeding plumage. There appears to be a gap in knowledge relating to the longevity of coloration changes in the bill, facial skin and legs of all three species. For *A. plumifera*, McKilligan (1991) provided some data indicating that breeding/courtship colours fade once chicks hatch in the nest, and revert to non-breeding colour by the time the young have fledged (i.e. last at least 3–6 weeks). However, it remains unknown how long before nesting the coloration of the bill, facial skin and legs occurs. We could find no information on the longevity of the breeding/courtship colour stage for either *A. intermedia* or *A. brachyrhyncha.* It is also worth mentioning that it is highly unlikely that *A. brachyrhyncha* and *A. plumifera* would ever interbreed as they are biogeographically disjunct, occurring in Africa and Australia, respectively. As already mentioned, it is possible that, although *A. plumifera* and *A. intermedia* may occur together regularly on some islands in the eastern Indonesian archipelago, interbreeding is unlikely as *A. intermedia* is strongly migratory and breeds mainly far to the north in Asia. Nevertheless, the recent establishment of a breeding colony in Perak, Malaysia (Amar-Singh 2012), and the historical suggestion of breeding colonies in Java by Junge (1948), coupled with population estimates of several hundred '*intermedia*' egrets in wetlands on Timor-Leste (Trainor 2005), warrant further investigation of species provenance in that region.

We have shown that there is considerable difference in bill morphology between *A. intermedia, A. brachyrhyncha* and *A. plumifera.* Given the three species' similarity in non-breeding plumage, it is not surprising that they have long been considered a single taxon. There are, however, some examples in non-passerines where the bill morphology is a main character in field and taxonomic discrimination, e.g. Northern *Macronectes halli* and Southern *M. giganteus* Giant-Petrels (Carlos & Voisin 2008), Grey-tailed *Tringa breviceps* and Wandering *T. incana* Tattlers (Hayman *et al.* 1986), Greater *Charadrius leschenaultii* and Lesser *C. mongolus* Sand Plovers (Hirschfeld *et al.* 2000), and Balearic *Puffinus mauretanicus* and Yelkouan *P. yelkouan* Shearwaters (Militão *et al.* 2014).

The initial objective of this study was to try to identify five unusual-looking egrets observed from two Cairns locales (four from Cairns Esplanade, one from the suburb of Caravonica) from May to July 2021. Here we have used several multivariate and univariate analyses to demonstrate that such analysis can be achieved with a high degree of confidence to separate seemingly similarlooking species that might occur in the same area, as has been found with taxa elsewhere (Adams *et al.* 2004; Bright *et al.* 2016). The NMDS and CDA analyses both show that *A. intermedia* and *A. plumifera* can be readily discriminated in multidimensional space using a relatively simple post-field ratio analysis of the cranial–bill morphology using digital photography and image-processing software equipped with a measuring tool. Additionally, from using size effect differences of the ratio data using either Cohen's *d* (Figure 6) or Donegan's UES (Table 8), we conclude that *A. intermedia* differs significantly from *A. plumifera* and that the suspect five egrets are most likely to be *A. intermedia.*

We allocated birds from Timor-Leste to *A. plumifera* in our analyses, based on Mees (1975) and Trainor (2005), who suggested that the taxon was resident and/or a regular migrant from Australia; however, the CDA classifier placed one of two birds that we used from Timor-Leste into the *A. intermedia* class, and visual examination of additional photographs published from West Timor and Timor-Leste (Trainor 2013, 2018, 2019) suggests that both *A. intermedia* and *A. plumifera* occur there. The only other egrets from the eastern Indonesian archipelago that we could find in our internet search that match our photographic quality-control protocols came from Bali. Both these birds were clearly *A. intermedia.* We suggest that birders visiting anywhere in the eastern Indonesian archipelago capture suitable photographs of egrets in cranial profile and analyse them according to methods described in our study before reporting their species rank in databases such as eBird.

This study has demonstrated the value of post-observation analysis using a digital mensurative methodology that can be used by any field ornithologist with a digital camera and telephoto lens. Once the digital photograph is processed within a suitable image-processing software package such as Photoshop or ImageJ, the observer can carefully and quickly obtain several ratios (see Figure 3) and compare them with the plots (Figure 6) to see in which species the ratio results fall. The most useful ratio values are those with the largest effect size, as noted in the statistical analysis: L/Dm <6.4, ET/Dm <8.6, FT/Dft <6.5, FT/Fm <7. If all four of these measured ratio values fall below these minimal values, then the individual is almost certainly *A. intermedia*. Conversely, if all are above those minimal values, the bird is almost certainly *A. plumifera.*

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Appendix 1. Examples of ten *Ardea plumifera* (left) from North Queensland, Australia, and ten *Ardea intermedia* (right) from Negros Island, Philippines. All birds are scaled to a standard egret (see text for details). Note the relative bill length and structure, variation in markings and head curvature between individuals. Photos: Adrian Walsh (*A. plumifera*), Chris J. Chafer (*A. intermedia*)

Appendix 2. Location and photographer of the 110 photographs used to determine the four bill ratios analysed in this study. Abbreviations: ACT = Australian Capital Territory, NSW = New South Wales; NP = National Park.

Code	*Location, date*	*State/country*	*Photographer*
Ardea plumifera			
CDR4	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE11	Cairns, May 2021	Queensland	Adrian Walsh
CE15	Cairns, May 2021	Queensland	Adrian Walsh
CE17	Cairns, May 2021	Queensland	Adrian Walsh
CE18	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE19	Cairns, Jun. 2021	Queensland	Adrian Walsh
CMR3	Cairns, May 2021	Queensland	Adrian Walsh
CMR4	Cairns, Jun. 2021	Queensland	Adrian Walsh
DRS4	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE02	Cairns, May 2021	Queensland	Adrian Walsh
CE14	Cairns, May 2021	Queensland	Adrian Walsh
CE16	Cairns, May 2021	Queensland	Adrian Walsh
DRS1	Cairns, May 2021	Queensland	Adrian Walsh
DRS2	Cairns, Jun. 2021	Queensland	Adrian Walsh
CCL1	Cairns, Jun. 2021	Queensland	Adrian Walsh
CCW1	Cairns, Jun. 2021	Queensland	Adrian Walsh
CCW2	Cairns, Jun. 2021	Queensland	Adrian Walsh
CDR1	Cairns, May 2021	Queensland	Adrian Walsh
CDR2	Cairns, May 2021	Queensland	Adrian Walsh
CDR3	Cairns, Jun. 2021	Queensland	Adrian Walsh
CDR5	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE10	Cairns, May 2021	Queensland	Adrian Walsh
CE25	Cairns, Jun. 2021	Queensland	Adrian Walsh
CMR1	Cairns, May 2021	Queensland	Adrian Walsh
CMR2	Cairns, May 2021	Queensland	Adrian Walsh
DRS3	Cairns, Jun. 2021	Queensland	Adrian Walsh
Dar01	Fogg Dam, Jul. 2017	Northern Territory	M. Barritt
Dar02	Fogg Dam, Mar. 2021	Northern Territory	J. Otto
Dar03	Kakadu NP, Oct. 2013	Northern Territory	G. Pari
Dar04	Fogg Dam, Dec. 2018	Northern Territory	J. Otto
Dar05	Darwin, Jul. 2018	Northern Territory	"Kazredracer"
PNG01	Port Moresby, Aug. 2005	Papua New Guinea	S. Colenutt
PNG02	Port Moresby, Jun. 2018	Papua New Guinea	B. Ryan
PNG03	Port Moresby, Jun. 2011	Papua New Guinea	R. Seifert
NSW02	Sydney, Oct. 2018	NSW	S. Best
NSW03	Sydney, Jan. 2009	NSW	L. Petrucco
NSW04	Orange, May 2015	NSW	I. Sutton
NSW05	Newcastle, Apr. 2016	NSW	A. Delberghe
NSW06	Newcastle, Feb. 2017	NSW	J. Cossill
ACT01	Canberra, Jan. 2009	ACT	J. Robinson
ACT02	Canberra, Jan. 2018	ACT	R. Williams

Appendix 2 continued

Code	Location, date	State/country	Photographer
Ardea plumifera continued			
ACT03	Canberra, Mar. 2016	ACT	“Shortly”
ACT04	Ballarat, Oct. 2011	Victoria	E. Dunens
ACT05	Canberra, Oct. 2008	ACT	T. Hayashi
Tim01	Timor-Leste, Jul. 2018	Timor-Leste	C. Trainor
Tim02	Timor-Leste, Nov. 2015	Timor-Leste	C. Trainor
Bri01	Rocklea, Oct. 2015	Queensland	C. Burns
Bri02	Rocklea, Aug. 2018	Queensland	C. Burns
Bri04	Brisbane, Oct. 2019	Queensland	D. Field
Bri05	Elbow Valley, Nov. 2019	Queensland	M. Head
Suspect egrets			
CE01	Cairns, May 2021	Queensland	Adrian Walsh
CE39	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE36	Cairns, Jun. 2021	Queensland	Adrian Walsh
CE22	Cairns, Jun. 2021	Queensland	Adrian Walsh
VP01	Cairns, Jun. 2021	Queensland	Adrian Walsh
Ardea intermedia			
J01	Joondalup, Jan. 2016	Western Australia	K. Wilcox
Neg01	Tanjay, Mar. 2021	Philippines	Chris Chafer
Neg02	Tanjay, Mar. 2021	Philippines	Chris Chafer
Neg03	Tanjay, Mar. 2021	Philippines	Chris Chafer
Neg04	Sibulan Nov. 2020	Philippines	Chris Chafer
Neg05	Sibulan, Sep. 2020	Philippines	Chris Chafer
Neg06	Sibulan, Sep. 2020	Philippines	Chris Chafer
Neg07	Sibulan, Sep. 2019	Philippines	Chris Chafer
Neg08	Sibulan, May 2021	Philippines	Chris Chafer
Neg09	Sibulan, May 2021	Philippines	Chris Chafer
Neg10	Sibulan, May 2021	Philippines	Chris Chafer
Neg11	Sibulan, May 2021	Philippines	Chris Chafer
Neg12	Sibulan, May 2021	Philippines	Chris Chafer
Neg13	Sibulan, May 2021	Philippines	Chris Chafer
Neg14	Sibulan, May 2021	Philippines	Chris Chafer
Neg15	Sibulan, May 2021	Philippines	Chris Chafer
Neg16	Sibulan, May 2021	Philippines	Chris Chafer
Neg17	Sibulan, May 2021	Philippines	Chris Chafer
Neg18	Sibulan, Sep. 2020	Philippines	Chris Chafer
Neg19	Sibulan, Sep. 2020	Philippines	Chris Chafer
Neg20	Sibulan, Sep. 2020	Philippines	Chris Chafer
P23	Palawan, Jun. 2014	Philippines	R. Brae
P25	Laguna, May 2021	Philippines	B. Thaddeus
P26	Laguna, Mar. 2021	Philippines	B. Thaddeus
P27	Pampanga, Mar. 2021	Philippines	R. Lyengar
P28	Pangasinan, Dec. 2019	Philippines	K. Cancino
P29	Valenzuela, Nov. 2020	Philippines	L. Gocon

Appendix 2 continued

Code	*Location, date*	*State/country*	*Photographer*
Ardea intermedia continued			
P30	Palawan, Mar. 2017	Philippines	P. Hines
P31	Palawan, Jun. 2021	Philippines	C. Hesse
SrL03	Hambantota, Nov. 2012	Sri Lanka	L. Young
SrL04	Udawalawe, Mar. 2019	Sri Lanka	D. Lombard
SrL05	Boralesgamuwa, Apr. 2021	Sri Lanka	C. Cooray
Ind06	Lahore, May 2015	Pakistan	Aasif Latif
Ind09	Keoladeo NP, Nov. 2016	India	Ulrike Wizisk
Ind10	Bangalore, Jan. 2016	India	Satheesh Sankaran
Ind11	Bharatpur, Nov. 2011	India	D. Aggarwal
Ind12	Kabini Lake, Apr. 2012	India	B. Green
Ind13	Bharatpur, Feb. 2017	India	R. Gowan
Ind14	Hyderabad, May 2009	India	Devu
Chn01	Shanghai, Apr. 2017	China	K. Pflug
Chn02	Shanghai, Jul. 2020	China	K. Pflug
Chn03	Shanghai, Jul. 2020	China	K. Pflug
Chn04	Beijing, Sep. 2021	China	J. Shuai
Chin05	Beijing, Sep. 2021	China	J. Shuai
Chin06	Hong Kong, Nov. 2016	China	A. Gillespie
Chin08	South Korea, Nov. 2015	South Korea	B. Davaasuren
Chin09	Taiwan, Apr. 2014	Taiwan	J. Linn
Bali01	Denpasar, Aug. 2014	Bali, Indonesia	G. Faulkner
Bali02	Denpasar, Jun. 2021	Bali, Indonesia	
Jav01	West Java, Mar. 2009	Indonesia	W. Strikland
Thai01	Laem Phakbia, Dec. 2010	Thailand	Somchai Kanchanasut
Thai04	Ao Nang, Nov. 2019	Thailand	N. Cairns
Thai05	Bueng Boraphet, Feb. 2019	Thailand	S. Arena
Thai06	Lumphini Park, Mar. 2020	Thailand	N. Cairns
Thai07	Bang Tuban, Nov. 2019	Thailand	P. Monney