

1 **A global threats overview for Numeniini populations: synthesising expert knowledge for a group of**
2 **declining migratory birds**

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18 **Summary**

19 The Numeniini is a tribe of thirteen wader species (Scolopacidae, Charadriiformes) of which seven
20 are near-threatened or globally threatened, including two critically endangered. To help inform
21 conservation management and policy responses, we present the results of an expert assessment of
22 the threats that members of this taxonomic group face across migratory flyways. Most threats are
23 increasing in intensity, particularly in non-breeding areas, where habitat loss resulting from
24 residential and commercial development, aquaculture, mining, transport, disturbance, problematic
25 invasive species, pollution and climate change were regarded as having the greatest detrimental
26 impact. Fewer threats (mining, disturbance, problematic native species and climate change) were
27 identified as widely affecting breeding areas. Numeniini populations face the greatest number of
28 non-breeding threats in the East Asian-Australasian Flyway, especially those associated with coastal
29 reclamation; related threats were also identified across the Central and Atlantic Americas, and East
30 Atlantic flyways. Threats on the breeding grounds were greatest in Central and Atlantic Americas,
31 East Atlantic and West Asian flyways. Three priority actions were associated with monitoring and
32 research: to monitor breeding population trends (which for species breeding in remote areas may
33 best be achieved through surveys at key non-breeding sites), to deploy tracking technologies to
34 identify migratory connectivity, and to monitor land-cover change across breeding and non-breeding
35 areas. Two priority actions were focused on conservation and policy responses: to identify and
36 effectively protect key non-breeding sites across all flyways (particularly in the East Asian -
37 Australasian Flyway), and to implement successful conservation interventions at a sufficient scale
38 across human-dominated landscapes for species' recovery to be achieved. If implemented urgently,
39 these measures in combination have the potential to alter the current population declines of many
40 Numeniini species and provide a template for the conservation of other groups of threatened
41 species.

42

43 Introduction

44 Globally, biodiversity faces growing pressure, leading to increased extinction risk across taxa
45 (Butchart *et al.* 2010). For birds, 13% of species are regarded as globally threatened with extinction,
46 whilst a further 9% are listed as near-threatened (BirdLife International 2015b). Habitat loss, over-
47 exploitation and invasive non-native species are considered the main threats facing these species,
48 although the impacts of these threats vary between populations, and are often poorly documented
49 or understood (BirdLife International 2010). Identifying the principal drivers of population declines is
50 an essential precursor to any conservation action (Gibbons *et al.* 2011), but is often challenging due
51 to a lack of resources, ecological information, monitoring data and published research. Determining
52 how threats affect populations can be particularly problematic for migratory species, as they face
53 multiple threats at different stages of their annual cycle. Long-distance migrants are in particular
54 decline globally (Robbins *et al.* 1989, Sanderson *et al.* 2006, Yamamura *et al.* 2009); yet 91% are
55 inadequately protected across their annual cycle (Runge *et al.* 2015).

56 Here, we suggest how some of the challenges that make assessing the threats facing migratory
57 species difficult, can be overcome using an expert-based assessment of the global threats to
58 Numeniini as an example. The Numeniini is a highly threatened paraphyletic tribe of waders or
59 shorebirds (hereafter waders) within the suborder Scolopaci (Gibson & Baker 2012). The tribe occurs
60 on all continents except Antarctica, although their breeding ranges are restricted to the Northern
61 Hemisphere (Piersma *et al.* 1996, Colwell 2010). Most species within the tribe are large-bodied with
62 a relatively delayed age of maturity, low fecundity and high survival rates (Piersma & Baker 2000).
63 The tribe includes seven species of conservation concern (BirdLife International 2015b); two are
64 listed as critically endangered (Eskimo curlew *Numenius borealis* and slender-billed curlew *Numenius*
65 *tenuirostris*) of which at least the Eskimo curlew is considered likely to be extinct (Roberts & Jarić
66 2016), one as endangered (Far Eastern curlew *Numenius madagascariensis*), one as vulnerable
67 (bristle-thighed curlew *Numenius tahitiensis*), and three as near-threatened (Eurasian curlew

68 *Numenius arquata*, bar-tailed godwit *Limosa lapponica* and black-tailed godwit *Limosa limosa*).

69 Populations of 6 species can be further divided into 30 separate populations or subspecies (Table 1),

70 many of which have different requirements and migratory strategies, increasing the challenge of

71 conservation at the species' level. Populations of the same species may also be subject to

72 contrasting pressures, and some, such as steppe whimbrel *N. phaeopus alboaxillaris*, are therefore

73 highly threatened even if the species as a whole is not (Brown *et al.* 2014). Many populations are

74 long-distance migrants, including the bar-tailed godwit *Limosa lapponica baueri* which undertakes

75 the longest non-stop migration of any landbird (Gill *et al.* 2009). Given that half of this tribe is of

76 conservation concern, the main aim of this work is to understand the threats that they face around

77 the world, taking advantage of the fact that a number of species occur in discrete populations across

78 different flyways, in order to reduce the likelihood of future extinctions amongst the remaining

79 species. The results of this assessment are likely to be relevant to other threatened wader and

80 migratory species (Faaborg *et al.* 2010a, b, Galbraith *et al.* 2014).

81 We undertook a systematic collation of expert opinion, a process increasingly used to inform

82 ecological analyses and conservation decision-making (O'Neill *et al.* 2008, Kuhnert *et al.* 2010,

83 Sutherland *et al.* 2012). Whilst threat assessments have previously been conducted for some flyways

84 and regional Numeniini populations (e.g. Boere *et al.* 2006, Gill *et al.* 2007, Conklin *et al.* 2014, Hua

85 *et al.* 2015), we have extended these approaches to produce a global assessment for the group.

86 Specifically, we combined questionnaire responses from a wide-range of international experts with a

87 subsequent workshop discussion including representatives from five continents, to identify: (1) key

88 threats acting upon the Numeniini tribe as a whole; (2) how these threats vary between

89 biogeographic populations and flyways; (3) critical knowledge gaps and priorities for future research;

90 and (4) priority conservation actions.

91 **Methods**

92 The Numeniini tribe is not taxonomically monophyletic, but contains ecologically similar species
93 from two clades likely to face similar threats, and hence are considered together. The *Numenius*
94 clade is basal to all other Scolopacidae (except Jacanas and allies), while *Limosa* is a younger group
95 and basal to the sandpipers and allies (Gibson & Baker 2012). Although there remains some
96 uncertainty over the taxonomic identity of some populations and subspecies, we used the most
97 recent research and/or expert opinion to identify a total of 37 taxonomically distinct subspecies and
98 biogeographic populations for assessment as part of our review (Table 1).

99 Assessments were conducted for each population as follows. First, a questionnaire was devised and
100 circulated electronically to experts from around the world from July to September 2013, requesting
101 information about the threats acting upon different populations. Threats were listed on the
102 questionnaire in accordance with the IUCN – CMP Unified Classification of Direct Threats Version
103 3.2., and based on Salafsky *et al.* (2008), adopting a spread of first- to third-order threats as
104 appropriate for the species group (Table 2). This ensured that all contributors considered threats in a
105 consistent manner and that consideration was given to all potential threats. Experts were asked to
106 separately score changes in both the scale and intensity of the threats over the last 25 years on a
107 five point scale (-2 = strong decrease, -1 = decrease, 0 = no change, 1 = increase, 2 = strong increase),
108 as well as the likelihood of each threat being linked to population change (0 = unlikely, 1 = possibly, 2
109 = strongly) and the evidence to support this assessment (1 = poor - based on expert opinion, 2 =
110 moderate - based on correlative studies, 3 = good - based on experimental studies). Separate
111 assessments were requested for the breeding and non-breeding stages of each population's annual
112 cycle. In some instances where populations are dependent on more than one geographical
113 location/region during the non-breeding period (including on migration), assessments were provided
114 separately for each. In total, 115 assessments were received.

115 The second stage was to review and discuss these scores at a one-day workshop attended by over 50
116 experts from around the world at the International Wader Study Group's annual conference in

117 Wilhelmshaven, Germany, on 30th September 2013. Prior to this event, the scores from the
118 questionnaire were collated separately for breeding and non-breeding populations by JWPH, DJB &
119 DJTD; where multiple responses were received for the same population, scores were averaged. At
120 the workshop, the summarised population responses were presented and refined in plenary by one
121 of three working groups focussed on populations confined to flyways in either the Americas; Europe,
122 Africa and West Asia; or Asia and Oceania. In the few cases where populations spend part of their
123 life cycles across more than one of the designated groups (e.g. bar-tailed godwit *Limosa lapponica*
124 *baueri*, which breeds in Alaska, overwinters in Australia and New Zealand, then stages for a month in
125 the Yellow Sea) the assessments were refined by both relevant groups. Each group comprised 10-20
126 people with expertise in each region.

127 The focus of these working groups was to collate the threat scores for each breeding and non-
128 breeding population separately. At this stage, the process was simplified so that scores were
129 obtained for the change in the threat (combining estimates of change in both scale and intensity,
130 which respondents to the questionnaires had difficulty separating), the impact of that change upon
131 the population of interest (-2 = strong negative impact, -1 = likely negative impact, 0 = no impact, 1 =
132 likely positive impact, 2 = strong positive impact), and the evidence to support the impact of a
133 threat. Scores were subsequently circulated to additional experts who were unable to attend the
134 workshop to address any gaps and uncertainties identified. This resulted in a final set of scores for
135 the CHANGE in the threat (-2 = strong decrease, -1 = decrease, 0 = no change, 1 = increase, 2 =
136 strong increase), IMPACT of the change in the threat (-2 = strong negative impact, -1 = likely negative
137 impact, 0 = no impact, 1 = likely positive impact, 2 = strong positive impact) and EVIDENCE to
138 support the impact of the threat (1 = poor based on expert opinion, 2 = moderate based on
139 correlative studies, 3 = good based on experimental studies) for each population and stage in the life
140 cycle (breeding and non-breeding). Populations were assigned to one of the world's nine major
141 flyways (Figure 1), except for a small number of populations that span two flyways during migration,
142 in which case two non-breeding scores were produced. We were unable to make any assessments

143 with respect to non-breeding populations in the Central Asian Flyway; a significant knowledge gap
144 requiring further attention (although see Szabo & Mundkur in press). When we summarised the
145 results by flyway and life cycle stage, we used our collective knowledge to identify instances where
146 threats were known to either primarily impact final non-breeding areas, where birds spend the
147 majority of the Northern Hemisphere winter, or stop-over and staging locations during migration.

148 *Analysis*

149 We first examined global patterns across all species and populations, to show how CHANGE, IMPACT
150 and EVIDENCE scores, as response variables in separate models, varied between threats. Second, we
151 tested evidence for consistent variation in threats between breeding and non-breeding populations,
152 and among flyways. Third, we examined the extent to which CHANGE in, and IMPACT of, threats
153 showed consistent seasonal variation across flyways, by testing the significance of the interaction
154 between season and flyway.

155 We analysed scores for CHANGE, IMPACT and EVIDENCE using a binomial structure, which allowed
156 estimates to be constrained by the upper and lower bounds of the scores provided. To facilitate this,
157 we rescaled our CHANGE and IMPACT scores to vary from 0 to 8 (accounting for the small number of
158 half-scores provided by experts), with 0 equivalent to -2, 4 to 0, and 8 to +2, and transformed our
159 EVIDENCE scores so that they varied from 0 to 2. Each score was then modelled as a proportion of
160 the maximum using a binomial error structure and logit link function. At the end of this process,
161 modelled probabilities were back-transformed to reflect their original values. We used Generalised
162 Linear Mixed Models (GLMMs) with species as a random effect to reflect the potential non-
163 independence of scores from different populations of the same species. However, in the third
164 analysis of flyway*season interactions, estimates of covariance attributed to random effects were
165 very small, due to the lack of replication within combinations of flyway and season. As a result, the
166 models failed to converge as GLMMs, so we instead used Generalised Linear Models (GLMs) without
167 any random effects. All analysis was conducted in SAS v.9.4.

168 **Results**

169 *Global patterns*

170 There was significant variation in the degree of change in threats across all populations (CHANGE,
171 $F_{19, 1280} = 14.64, P < 0.0001$; Figure 2a). Most threats were regarded as showing statistically significant
172 increases in scale and/or intensity, with the exceptions being non-timber crops, livestock, hunting,
173 hunting side-effects and disease. Across all populations, the impact of these threats also varied
174 significantly (IMPACT, $F_{19, 1280} = 5.06, P < 0.0001$; Figure 2b), with strong negative (IMPACT < -0.5)
175 scores for development, mining, transport, disturbance, pollution and climate change. At this level,
176 there was a strong negative correlation between the change associated with threats, and the
177 impacts of those threats (IMPACT versus CHANGE, $r = -0.83, n = 20, P < 0.0001$), suggesting that
178 threats which were scored as increasing most in magnitude were also scored as having the greatest
179 impact. There were no overall significant differences in the degree of evidence attributed to threats
180 ($F_{1, 19} = 0.62, P = 0.78$). In most cases, the amount of evidence scored was poor (mean EVID scores
181 range from 1.33 to 1.47 across different threats), and therefore this assessment is largely based
182 upon expert opinion rather than published studies (see Appendix 1 for exceptions).

183 *Variation between seasons*

184 The direction and severity of trends in threats varied significantly between breeding and non-
185 breeding seasons (CHANGE, threat*season interaction, $F_{19, 1260} = 6.46, P < 0.0001$). Development,
186 aquaculture, renewables, transport, fishing, disturbance, dams, drainage, problematic invasive
187 species and pollution were regarded as having increased significantly more in non-breeding than
188 breeding areas (Figure 3a). Conversely, threats of hunting and problematic native species increased
189 on the breeding grounds by significantly more than non-breeding areas, although breeding season
190 trends for hunting did not differ significantly from zero (Figure 3a). The effect of these threats upon
191 populations also differed significantly with season (IMPACT, $F_{19, 1260} = 3.48, P < 0.0001$). The threats

192 most strongly regarded as impacting breeding populations (mean IMPACT score < -0.5) were mining,
193 disturbance, problematic native species and climate change. A greater number of strong impacts
194 were identified on the non-breeding grounds (Figure 3b): development, aquaculture, mining,
195 transport, disturbance, problematic invasive species, pollution and climate change.

196 *Variation between flyways*

197 Scored trends in threats varied among flyways (CHANGE, threat*flyway interaction, $F_{152, 1140} = 1.68$, P
198 < 0.0001) and did not vary consistently with season among flyways (threat*season*flyway
199 interaction, $F_{140, 980} = 1.34$, $P = 0.0082$). Threats were not scored as having impacts that differed
200 among flyways (IMPACT threat*flyway interaction, $F_{152, 1138} = 1.03$, $P = 0.40$), or with strong
201 differences in the seasonal effects among flyways (threat*season*flyway interaction, $F_{140, 980} = 1.13$,
202 $P = 0.15$). As the CHANGE scores varied among flyways, and to reflect specific differences between
203 them, we summarised the main threats, and their impacts on populations, separately by flyway and
204 season. This enabled us to describe the differences that occurred, and demonstrate which threats
205 were regarded as more important for particular flyways (Table 3). Severe threats were those whose
206 IMPACT < -0.5, whilst moderate threats had a consistent negative impact, as shown by a score that
207 differed significantly from zero. Threats with an impact score that did not differ significantly from
208 zero were regarded as unimportant.

209 Breeding populations in the East Atlantic Flyway faced the greatest number of severe threats
210 (seven); this was the only flyway where non-timber crops, plantations and dams threatened
211 breeding populations. Species breeding in the Central Americas, Atlantic Americas and West Asian
212 flyways were exposed to five severe threats (Table 3). Mining, hunting, disturbance, problematic
213 native species and climate change were all regarded as severe threats across the breeding
214 populations of at least three flyways.

215 More severe threats were assigned to non-breeding populations than breeding populations. Over
216 half of the threats (eleven) were scored as severe across the East Asian - Australasian Flyway (EAAF),
217 whilst populations using the Central Americas, Atlantic Americas and East Atlantic flyways were also
218 scored as being exposed to a large number of threats (seven to eight). Development, aquaculture,
219 mining, transport, fishing, disturbance, problematic invasive species and pollution were severe
220 threats across at least five flyways. Severe negative impacts of disturbance were almost ubiquitous
221 for non-breeding populations. Threats across the EAAF were thought to primarily affect migratory
222 stop-over locations in East and South-east Asia, whilst the distribution of threats across other
223 flyways was more mixed (Table 3).

224 **Discussion**

225 Over half of the Numeniini tribe species have been classified as threatened or near-threatened, with
226 two possibly extinct (BirdLife International 2015b), and a number of biogeographic populations and
227 subspecies are considered highly threatened (Brown *et al.* 2014). Previous work has shown that
228 global extinction risk in birds is greatest in large species with slow generation time (Gaston &
229 Blackburn 1995, Owens & Bennett 2000). More detailed analyses of population trends in well-
230 studied European populations suggests that habitat-specialists, ground-nesting species and long-
231 distance migrants are among the species with the most negative population trends (Julliard *et al.*
232 2003, Thaxter *et al.* 2010, Sullivan *et al.* 2015). Numeniini exhibit all of these traits: many are
233 relatively large-bodied with delayed maturity and low fecundity; specialists of open, often semi-
234 natural habitats during the breeding season and coastal habitats at other times; ground-nesting; and
235 highly migratory. These traits must at least partially account for why so many Numeniini species are
236 currently of conservation concern.

237 The small size and fragmentation of some subspecies and populations (Brown *et al.* 2014) also adds
238 to their threat status; some populations are more threatened than the corresponding species.

239 Furthermore, threats may vary widely among different populations of the same species, but overlap

240 with other populations or subspecies sharing a migratory flyway (Table 3). For example, *orientalis*
241 Eurasian curlew populations and *variegatus* whimbrel populations using the EAAF are particularly
242 threatened by coastal development, whilst *arquata* Eurasian curlew and *phaeopus* whimbrel are less
243 affected. Given that populations of some Numeniini species occupy a wide range of geographical
244 locations, flyways and migratory strategies, conservation efforts should be targeted at improving the
245 status of each separate population, rather than simply considering the overall status of the species.
246 This strategy would also be resilient to any future changes in Numeniini taxonomy that may split
247 some of the current subspecies and populations into separate species.

248 In an effort to identify key threats and knowledge gaps pertaining to the conservation of these
249 species, we created an expert-based assessment that collated and scored threats acting upon
250 individual species and populations across flyways. Globally, this assessment identified residential
251 and commercial development, mining, transport, disturbance, pollution and climate change as
252 having the greatest impacts overall, although the primary threats differed considerably between
253 breeding and non-breeding areas, and among flyways. These seasonal differences likely relate to the
254 long distances between breeding and non-breeding areas, or differences in the habitat associations
255 of Numeniini during the breeding and non-breeding seasons. Many Numeniini breed across large
256 areas of less-intensively managed wetland, upland or tundra habitats, while they often spend the
257 non-breeding period concentrated in coastal areas in temperate and tropical zones that are subject
258 to very different pressures. Some non-breeding threats also differed between migratory stop-over
259 locations and final non-breeding locations, largely in relation to the amount of geographical
260 separation between them. This was most apparent within the EAAF flyway where many populations
261 winter in Australia and New Zealand but stage in the Yellow Sea during their spring migration (e.g.
262 little curlew, Far Eastern curlew, *baueri* bar-tailed godwit), whilst in other flyways, such as the East
263 Atlantic, staging and non-breeding locations tended to be less discrete (Table 1).

264 Populations occupying American and Afro-Eurasia flyways are threatened by a mix of breeding and
265 non-breeding season threats which are likely to affect both breeding success and mortality.
266 Populations using the EAAF and West Pacific flyways are threatened largely by non-breeding threats
267 most likely to alter mortality, although these pressures may also influence breeding success through
268 carry-over effects (Gunnarsson *et al.* 2005, Alves *et al.* 2013 but see also Senner *et al.* 2014, 2015).
269 Given that Numeniini species generally have delayed maturity, high survival and low fecundity
270 (Piersma & Baker 2000), populations are likely most sensitive to variation in mortality rates (Sæther
271 & Bakke 2000), although they may also be sensitive to reductions in fecundity that limit their ability
272 to recover from mortality-driven declines (Robinson *et al.* 2014). To illustrate this, the 46% decline in
273 Eurasian curlew populations in the UK (Harris *et al.* 2015) has occurred despite high and increased
274 adult survival rates resulting from a cessation of hunting (Taylor & Dodd 2013). Similarly, the
275 ongoing decline of the Continental black-tailed godwit populations is due to recruitment failure as a
276 consequence of the intensification of grassland management leading to increased egg losses (Kentie
277 *et al.* 2015) and chick mortality (Kentie *et al.* 2013).

278 Whilst important differences in threats between flyways were identified, a greater number of
279 similarities were apparent, which are discussed below. When doing so, we recognize that the
280 evidence base underpinning this expert assessment is limited. For instance, despite considerable
281 effort to include participants from across the globe, we were unable to report on threats to non-
282 breeding populations using the Central Asian flyway (where declines of Numeniini and other waders
283 are thought to be occurring due to rapid coastal development, e.g. Balachandran 2006, Szabo &
284 Mundkur, in press), and we received greater input for some flyways (e.g. the three Americas flyways
285 and the East Atlantic flyway) than others. We cannot therefore exclude the possibility that some of
286 the geographic variation in our assessment may reflect limitations in our own knowledge. As a result,
287 we have also provided a *post-hoc* assessment of the peer-reviewed scientific evidence in support of
288 the threats identified. This has helped us to identify subsequent research priorities.

289 Many of the published studies examined only individual threats. Studies that quantify the relative
290 magnitude of the impact of different threats upon population trends have been published for only a
291 limited number of populations (e.g. Gill *et al.* 2007, Schroeder *et al.* 2012, Douglas *et al.* 2014, Kentie
292 *et al.* 2014, Duijns *et al.* 2015). Although individual populations of a number of species are the
293 subject of detailed and long-term study (e.g. Gill *et al.* 2001b, Kleijn *et al.* 2010), and the deployment
294 of tracking devices has revolutionised our understanding of the seasonal distribution and habitat
295 requirements of a range of species (e.g. Ueta *et al.* 2002, Battley *et al.* 2012, Hooijmeijer *et al.* 2013,
296 Senner *et al.* 2014), there is an urgent need for quantitative assessments of the relative importance
297 of different drivers of population change for as many populations as possible.

298 *Disturbance*

299 Combined across all populations, human intrusion and disturbance was regarded as the most severe
300 threat, particularly for non-breeding populations. Whilst there is evidence that disturbance can have
301 localised impacts on the distribution of breeding birds (Pearce-Higgins *et al.* 2006, Holm & Laursen
302 2009), the scale of such disturbance in the breeding season currently appears unlikely to be
303 extensive enough to have population-level impacts. Many Numeniini populations have large and
304 remote breeding ranges that are likely to be subject to little or no disturbance. However, for species
305 such as Eurasian curlew and black-tailed godwit that extensively use farmed landscapes, or for
306 populations that rely on a small number of key pre- or post-breeding sites, disturbance could
307 potentially have a population-level impact.

308 Although it can be difficult to study, disturbance can affect the behaviour and distribution of
309 individuals at staging and non-breeding sites, but there is so far little evidence it is having strong
310 negative impacts on populations (e.g. Gill *et al.* 2001a, Finn *et al.* 2007, Peters & Otis 2007, Yasué *et*
311 *al.* 2008). Despite having a high IMPACT score for non-breeding habitats, published evidence
312 suggests that disturbance will affect wader populations only if it significantly reduces the utility of a
313 high proportion of potential sites or affects a large number of individuals by preventing them from

314 accessing undisturbed locations (Peters & Otis 2007), thereby reducing food intake (Gill *et al.* 2001a),
315 increasing energetic costs (Rogers *et al.* 2006) or predation risk (Liley & Sutherland 2007). Whilst
316 disturbance is widely regarded as a potential threat, the majority of published peer-reviewed studies
317 do not appear to support this judgement. Either we have over-estimated the importance of
318 disturbance or an insufficient number of studies have been conducted in parts of the world where
319 key sites are heavily disturbed. Reassuringly, our expert assessment did recognise the tension
320 between our categorisation and the peer-reviewed literature, and acknowledged the evidence
321 regarding the impact of disturbance is 'poor' in all cases (Appendix 1). Nonetheless, given the rapid
322 and widespread increase in the level of disturbance, there is an urgent need to resolve this
323 uncertainty.

324 *Development*

325 Residential and commercial development, drilling, mining and quarrying, and the construction of
326 transportation and service corridors were regarded as having widespread and severe impacts on
327 populations, especially in coastal non-breeding areas where they can result in significant changes in
328 land use. In addition to the direct effects on habitat availability, roads can reduce the local density of
329 breeding waders in surrounding fields (Reijnen & Foppen 1997, Melman *et al.* 2008, Fikenscher *et al.*
330 2015) leading to population level impacts when a high proportion of a population's breeding range is
331 intersected by roads. Similarly, construction activity, whether associated with coastal development
332 (Burton *et al.* 2002) or renewable energy (Pearce-Higgins *et al.* 2012), can have a localised impact on
333 both breeding and non-breeding populations, with displaced birds likely to suffer increased mortality
334 when they settle elsewhere (Burton *et al.* 2006). Furthermore, these studies suggest that where
335 there is significant overlap between disturbance, habitat loss and habitat conversion, there is the
336 potential for significant population-level impacts to occur.

337 The potential severity of these impacts is illustrated by recent trends in the Yellow Sea where 28% of
338 intertidal habitats have been lost since the 1980s (Yang *et al.* 2011, Murray *et al.* 2014, Ma *et al.*

339 2014), likely leading to population declines in 22 of 25 migratory shorebird species using the EAAF
340 (Hua *et al.* 2015). The remaining tidal flats are increasingly degraded (Melville *et al.* 2016),
341 potentially preceding further loss and population decline (Conklin *et al.* 2016, Piersma *et al.* 2016).
342 The high rate of change in the Yellow Sea, coupled with the fact that these threats were regarded as
343 strongly increasing across the Pacific Americas, Central Americas and West Asian flyways, and during
344 the non-breeding period in the Central Asian flyway (Szabo & Mundkur in press), means that
345 residential and commercial development must be regarded as one of the strongest and most severe
346 threats facing Numeniini, with negative impacts on adult survival having now been documented
347 (Piersma *et al.* 2016, Conklin *et al.* 2016).

348 *Pollution*

349 Although there is little evidence (and few studies) of the direct effects of pollution on wader species
350 (Currie & Valkama 1998), increasing levels of pollution is one of the threats contributing to the
351 deterioration of the environment in the Yellow Sea (Barter 2002, Murray *et al.* 2015, Hua *et al.* 2015,
352 Melville *et al.* 2016). Pollution has already resulted in algal blooms and the de-oxygenation of parts
353 of the region, likely impacting the prey base for waders *en route* to their Arctic breeding grounds
354 (Lopez *et al.* 2000). Increases in pollution frequently occur in conjunction with a number of land-use
355 practices (e.g., land reclamation, development, transport, mining, agriculture and aquaculture) that
356 contribute to a general deterioration of habitat availability and quality. Industrial activity along
357 highly developed parts of the Yellow Sea coastline makes pollution a component of the suite of
358 threats facing birds in the region (Barter 2002, Yang *et al.* 2011, Melville 2015). Elsewhere, where
359 populations rely heavily on agricultural habitats, such as rice fields in Europe, Africa and the
360 Americas, Numeniini may also be exposed to chemical contamination with uncertain impacts (Strum
361 *et al.* 2010, Odino 2014, Dias *et al.* 2014).

362 *Terrestrial land-use change and predation*

363 The effects of agricultural and forestry intensification and expansion appeared to be less important
364 than other development pressures, with some notable exceptions: across Europe, a large number of
365 studies have identified negative impacts resulting from agricultural intensification on black-tailed
366 godwit and Eurasian curlew populations. For instance, the increased frequency of mowing and
367 introduction of high stocking densities in agricultural grasslands increase both nest and chick
368 mortality, whilst practices employed to enhance grass growth (drainage, reseeding, high levels of
369 fertiliser inputs, rolling) reduce the quality of breeding habitats and diminish the growth rates of pre-
370 fledging chicks. Combined, these effects have led to population declines (Berg 1992, 1994, Kruk *et al.*
371 1997, Schekkerman *et al.* 2008, 2009, Kentie *et al.* 2013, 2014). Similarly, the transition across much
372 of Europe from hay meadows with a single cut, to silage with multiple cuts in a season, has turned
373 many previously suitable grassland habitats into population sinks (Schekkerman *et al.* 2008, 2009).
374 Large declines in breeding waders in Russia and northern Kazakhstan since the mid-20th Century
375 have also likely been driven by the conversion of virgin steppe into agriculture habitats (Morozov
376 2000, Soloviev 2005, 2012). Similar increases in the intensity of grazing and burning management in
377 North America may also affect breeding populations there (Cochran & Anderson 1987, Sandercock
378 *et al.* 2015). It is worth noting, however, that extensive grazing management can be an important
379 tool to maintain appropriate condition for some Numeniini species by maintaining heterogeneous
380 semi-natural open habitats (e.g. Pearce-Higgins & Grant 2006, Sandercock *et al.* 2015). Determining
381 the proper balance between the need to actively manage these habitats and the economic
382 considerations of local landowners is a key conservation goal for the conservation of temperate
383 breeding Numeniini.

384 Woodland or plantation forestry may have direct negative impacts through the loss and
385 fragmentation of open breeding habitats (Ratcliffe 2007). It is also indirectly associated with
386 population declines by driving increases in the abundance of avian and mammalian predators, which
387 lead to a reduction in nesting success and local breeding population declines (Valkama *et al.* 1999,
388 Pearce-Higgins *et al.* 2009a, Douglas *et al.* 2014). More broadly, there is strong evidence that high

389 populations of generalist predators, in particular red foxes *Vulpes vulpes* (Berg 1992, Grant 1997,
390 Valkama & Currie 1999, Grant *et al.* 1999) and ravens *Corvus corax* (Ballantyne & Nol 2011) may limit
391 populations, although in the UK, raven population increases were not strongly associated with
392 wader population declines (Amar *et al.* 2010). Although much of this evidence is from Europe, the
393 loss of open habitats and agricultural intensification may also impact some North American breeding
394 populations (Cochran & Anderson 1987). The loss of open breeding habitats thus appears to be the
395 main threat facing temperate breeding populations across Europe and North America. These threats
396 do not appear to be affecting other flyway populations to the same extent, potentially as the
397 breeding populations of other species overlap less with areas of significant land-use change, or are
398 more remote, and thus have a weaker evidence base (but see Senner *et al.* 2016).

399 *Climate change impacts and mitigation*

400 Climate change is regarded as being an increasing threat and having a significant impact across
401 Central Americas, Atlantic Americas and East Atlantic flyways, and to be moderately increasing
402 across the two Pacific flyways. For instance, Numeniini may be especially sensitive to alterations to
403 the phenology and abundance of food resources during the breeding season (Pearce-Higgins 2010,
404 Leito *et al.* 2014, Senner *et al.* 2016), although as yet, few breeding population changes having been
405 quantitatively linked to climate change through these mechanisms (Senner 2012, Senner *et al.*
406 2016). Nevertheless, changes in woody plant distribution in the Arctic may already account for some
407 localised population displacement in Arctic-nesting whimbrel (Ballantyne and Nol 2015) and could
408 potentially impact the southerly limit of populations more broadly in the future (Miller *et al.* 2014).
409 An upwards shift in the altitudinal distribution of Eurasian curlew breeding in the UK has also been
410 documented (Massimino *et al.* 2015). There is evidence from the Netherlands that the impacts of
411 climate change on breeding black-tailed godwits may be manifest through the combined impacts of
412 temperature and agricultural management upon sward height and the timing of mowing (Kleijn *et al.*
413 2010).

414 Away from the breeding grounds, habitat loss due to sea-level rise may have a significant impact on
415 the availability of suitable non-breeding stop-over locations, particularly for species dependent on
416 intertidal mudflats or other low-lying areas (Mustin *et al.* 2007, Galbraith *et al.* 2014, Iwamura *et al.*
417 2014). The impact of rising sea-level is likely to be highly site-dependent, as a result of fine-scale
418 variation in topography and the human approach to coastal defence (Galbraith *et al.* 2002), and may
419 have varied and relatively subtle impacts on different Numeniini species depending upon the
420 resulting changes in estuary sediment-type and productivity (Austin & Rehfish 2003). For example,
421 it is likely that the seawall constructed along much of the Chinese coast will reduce the resilience of
422 coastal habitats in the Yellow Sea to sea-level rise (Ma *et al.* 2014).

423 During migration, changes in wind patterns and climatic conditions may also affect the phenology of
424 individuals within populations. For example, individual *baueri* bar-tailed godwits are reliant on
425 favourable wind conditions for successful migration. This population may therefore be highly
426 vulnerable to changes in global weather patterns resulting from climate change (Gill *et al.* 2014).
427 There is also evidence that recent climatic changes during migration may be constraining the ability
428 of Hudsonian godwits to return to their breeding grounds at Churchill, Manitoba (Senner 2012),
429 causing them to mistime their breeding relative to local environmental phenology (Senner *et al.*
430 2016). Although this has not been demonstrated yet in other species, given the importance of
431 breeding phenology as a mechanism for driving a cascade of population-level responses in some
432 species (Gill *et al.* 2014), such impacts may affect many populations.

433 Increasing renewable energy development, such as wind farms, may also be a potential threat
434 throughout the annual cycle, particularly for the East Atlantic and EAAF flyways. There is evidence
435 for impacts of onshore wind farms on breeding Eurasian curlew populations (Pearce-Higgins *et al.*
436 2009b, 2012), and potential for tidal barrages to affect passage or wintering wader populations
437 (Clark 2006). However, as with other human developments, unless these overlap with a significant
438 proportion of flyway populations, they are unlikely to have a significant, population-level impact

439 (Pearce-Higgins & Green 2014). Given the importance of individual estuaries for particular
440 populations (e.g. 42% of the *baueri* bar-tailed godwit and 20 % of the Far Eastern curlew population
441 occurring at a single site in the Yellow Sea (Choi *et al.* 2015, Bai *et al.* 2015)), the deployment of tidal
442 barrages or large wind farms for renewable energy generation could have significant impacts upon
443 particular populations. For example, the Dongsha Shoals off the Jiangsu coast, China, could support
444 40,000 turbines and pose a risk to these species through potential collisions and barrier effects
445 (Melville *et al.* 2016).

446 *Hunting and harvesting*

447 As a group, Numeniini have long been affected by hunting (Gerasimov *et al.* 1997, Barbosa 2001,
448 Graves 2010) and adult survival increases when hunting bans are implemented (Taylor & Dodd 2013,
449 Watts *et al.* 2015). In the present study, hunting was regarded as a threat to some North American
450 and Asian breeding populations, although there was considerable uncertainty about its severity and
451 continued consequences (Page & Gill 1994). Hunting is still permitted in some European countries
452 and can be significant; in France an estimated 10-15,000 black-tailed godwits were hunted per
453 annum until a recent moratorium (Trolliet 2014). As hunting can still significantly impact wader
454 populations (Zöckler *et al.* 2010), the need to quantify its potential impact for Numeniini, and to
455 introduce and enforce control measures where evidence of sustainable take cannot be
456 demonstrated, is likely to be urgent.

457 Along the Chinese coast, there is a significant amount of wader by-catch in fishing nets which may be
458 killing tens of thousands of waders per year (Melville *et al.* 2016). In addition, unregulated
459 harvesting of shellfish and expansion of the aquaculture industry is likely to further reduce non-
460 breeding survival rates there. Certainly, excessive harvesting of shellfish in the UK and The
461 Netherlands has been associated with reductions in Eurasian curlew survival rates (Taylor & Dodd
462 2013), as well as impacts on other wader species (Atkinson *et al.* 2005, van Gils *et al.* 2006).

463 *Conclusions*

464 We have provided a summary of the best available knowledge of the threats to this group of
465 declining migratory waders. By collating expert assessments from across the world, we have
466 identified some important patterns and contrasts among flyways and life-stages to help shape future
467 conservation action. We have also explicitly acknowledged key knowledge gaps to prioritise future
468 research and monitoring needs. This approach could be usefully adopted for other groups of
469 declining species, such as other shorebirds and long-distance migratory passerines, in order to gain
470 further insights into the causes of their decline.

471 Globally, the greatest threats facing Numeniini populations appear to be large-scale development of
472 key passage and non-breeding sites in coastal areas across East Asia, Europe and the Americas.

473 Although there is some evidence that population trends of some species across these flyways have
474 been in decline for many decades (Department of the Environment 2015), these threats have
475 recently been identified as affecting a wide range of wader species, and require urgent action,
476 particularly in the EAAF (Sutherland *et al.* 2012, Murray *et al.* 2014, Hua *et al.* 2015, Piersma *et al.*
477 2016). Similar rates of rapid development could occur at important stop-over and non-breeding sites
478 outside of the EAAF and could be assessed using a combination of remote sensing techniques and
479 field-surveillance (Murray *et al.* 2014). In the face of such rapid land-use change, the long-term
480 persistence of threatened populations using these areas may critically depend upon the remaining
481 key sites being identified, protected and managed. Additionally, in poorly surveyed or inaccessible
482 regions, key sites could be identified through the large-scale deployment of new technologies, such
483 as satellite tracking (e.g. Battley *et al.* 2012). Identifying and protecting key non-breeding sites from
484 unsustainable development around the world is the highest priority action identified by this
485 assessment.

486 Significant land-use change on the breeding grounds, particularly through agricultural intensification,
487 which is being exacerbated by increasing populations of generalist predators, appears to be the main

488 threat identified in Europe, and may also affect some North American species. These impacts are
489 probably not so widespread as on the non-breeding grounds, because many Numeniini breed across
490 less-intensively managed wetland, upland or tundra habitats. However, there is the potential for
491 significant impacts to increase across these breeding habitats if they are drained or developed
492 further, or if human expansion into these areas results in significant increases in generalist predator
493 populations. Given the relatively restricted range of some sub-arctic breeding Numeniini to areas
494 close to the treeline, shrub and tree encroachment and subsequent increases in predator
495 populations could also be a major threat, even in more remote regions. Population monitoring
496 should be prioritised if these threats are to be identified in a timely manner. This will be challenging
497 for species that occupy extensive or remote regions at low densities, and may be best achieved
498 where individuals are concentrated at key non-breeding locations (e.g. Clark *et al.* 2004, Beale *et al.*
499 2006, Senner & Angulo-Pratalongo 2013). In many such instances, in order to effectively link winter
500 and breeding areas, remote tracking of individuals will be required (e.g. Johnson *et al.* 2016). This
501 could be particularly useful for the West Asian flyway, where there is a high degree of uncertainty in
502 our assessment of threats to the region's breeding populations, and other particularly poorly known
503 populations, such as *alboaxillaris* whimbrel and Asian populations of *limosa* black-tailed godwit.

504 The open availability of satellite imagery provides valuable opportunities to identify environmental
505 change across extensive breeding areas (Turner *et al.* 2015). For many Numeniini, it will probably be
506 necessary to combine multiple monitoring efforts including censuses at non-breeding sites, satellite
507 tracking to establish migratory connectivity, and remote sensing of habitat change, to generate a
508 complete picture of their conservation status. Where possible, more detailed demographic
509 monitoring of sample populations could complement such surveillance, enabling population vital
510 rates to be identified, and highlighting where and when in the annual cycle bottlenecks occur (e.g.
511 Robinson *et al.* 2014, Rakhimberdiev *et al.* 2015, Piersma *et al.* 2016).

512 In addition to site-protection and monitoring needs, this study has also emphasised that where
513 species still occur in heavily modified landscapes, such as across much of Europe, many wader
514 populations are declining (BirdLife International 2015a), and may require significant conservation
515 management to persist. This could include the control of predators or non-lethal management of
516 predation risk (Fletcher *et al.* 2010) and the adoption of relevant agri-environment scheme
517 measures (Smart *et al.* 2014). While the evidence for agri-environment schemes benefiting waders is
518 mixed (O'Brien & Wilson 2011, Kentie *et al.* 2015), there is an urgent need to identify and implement
519 the most effective actions more widely. Achieving tangible conservation success at the national or
520 international scale will likely require dedicated programmes targeting species at risk. For example,
521 the Eurasian curlew is now considered the UK's highest conservation priority bird species by some,
522 and the subject of a major recovery programme bringing together research, advocacy and
523 conservation delivery (Brown *et al.* 2015). Robust monitoring of populations would help to measure
524 the success of any conservation interventions.

525 A combination of site protection, active management, population monitoring and individual tracking,
526 which could be facilitated through specific recovery programmes, should reduce the likelihood of
527 extinction of the remaining Numeniini populations and species . Given the multitude of threats
528 most populations face across large geographic regions, this will probably best be achieved by
529 coordination through intergovernmental treaties such as the Convention on Migratory Species
530 (CMS) and Ramsar, or flyway-specific treaties such as the Agreement on the Conservation of African-
531 Eurasian Migratory Waterbirds (AEWA), Western Hemisphere Shorebird Reserve Network (WSHRN)
532 and the East Asian – Australasian Flyway Partnership (EAAFP) to generate the political will,
533 international collaboration and conservation resourcing required to be effective. The long-term
534 future of these populations may ultimately depend upon whether sufficient international efforts can
535 be focussed to enable the necessary monitoring, research and conservation actions to be
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561 None

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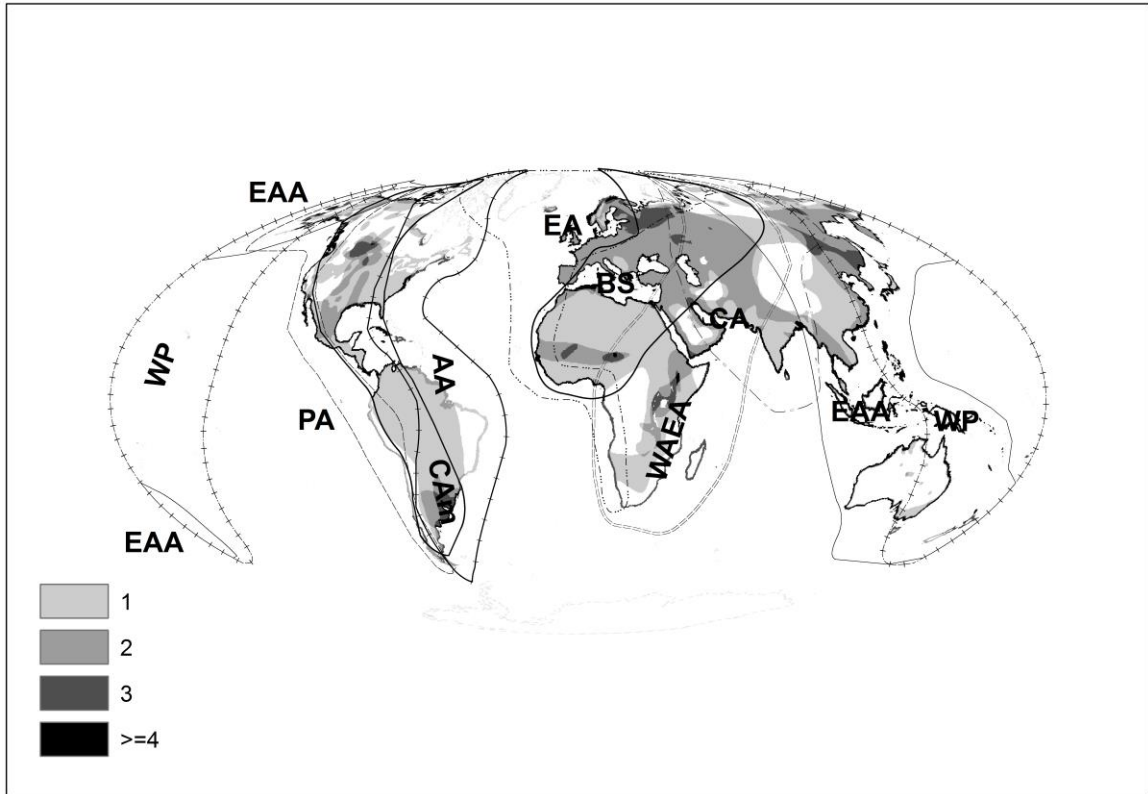
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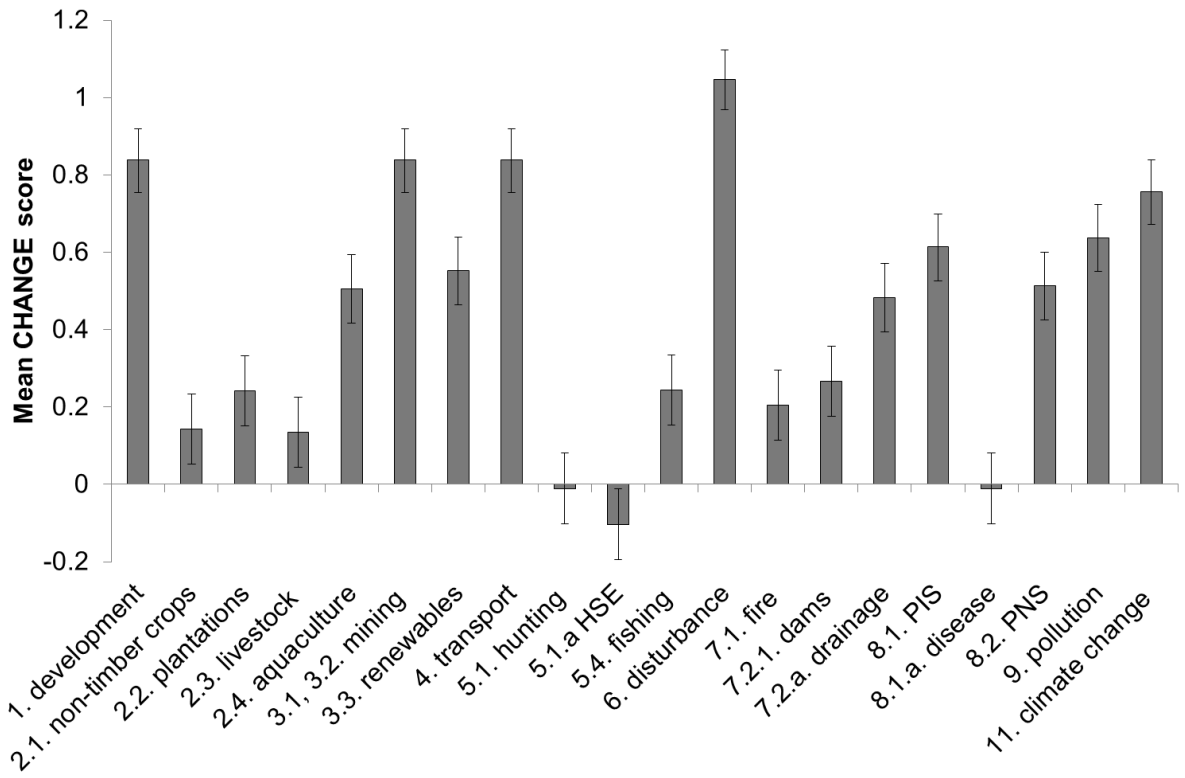
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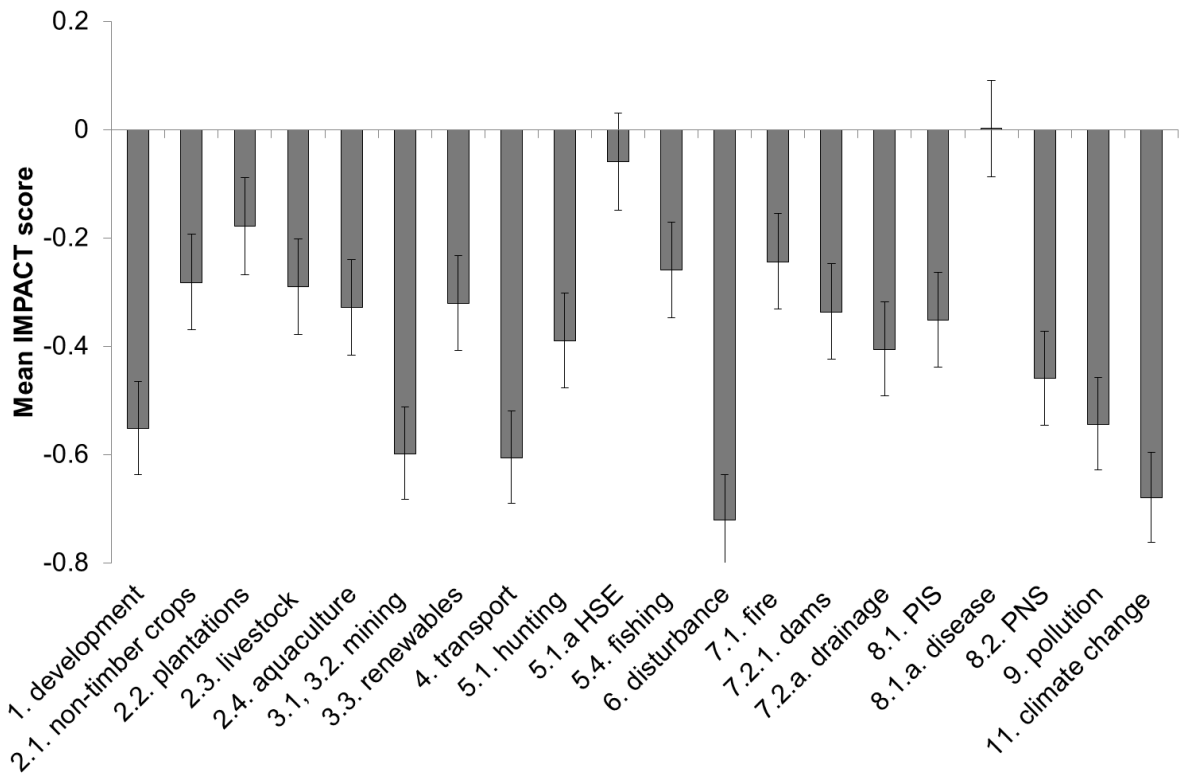
1042 Figure 1. Global flyways (Wetlands International 2014) overlaid on Numeniini species richness
 1043 (numbers in legend) derived from BirdLife International range polygons. White areas are outside the
 1044 global range of Numeniini species. Flyways are abbreviated as follows (PA, Pacific Americas; CA, Central
 1045 Americas; AA, Atlantic Americas; EA, East Atlantic; BS, Black Sea; WAEA, West Asian; CA, Central
 1046 Asian; EAA, East Asian-Australasian; WP, West Pacific).

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1049 b)

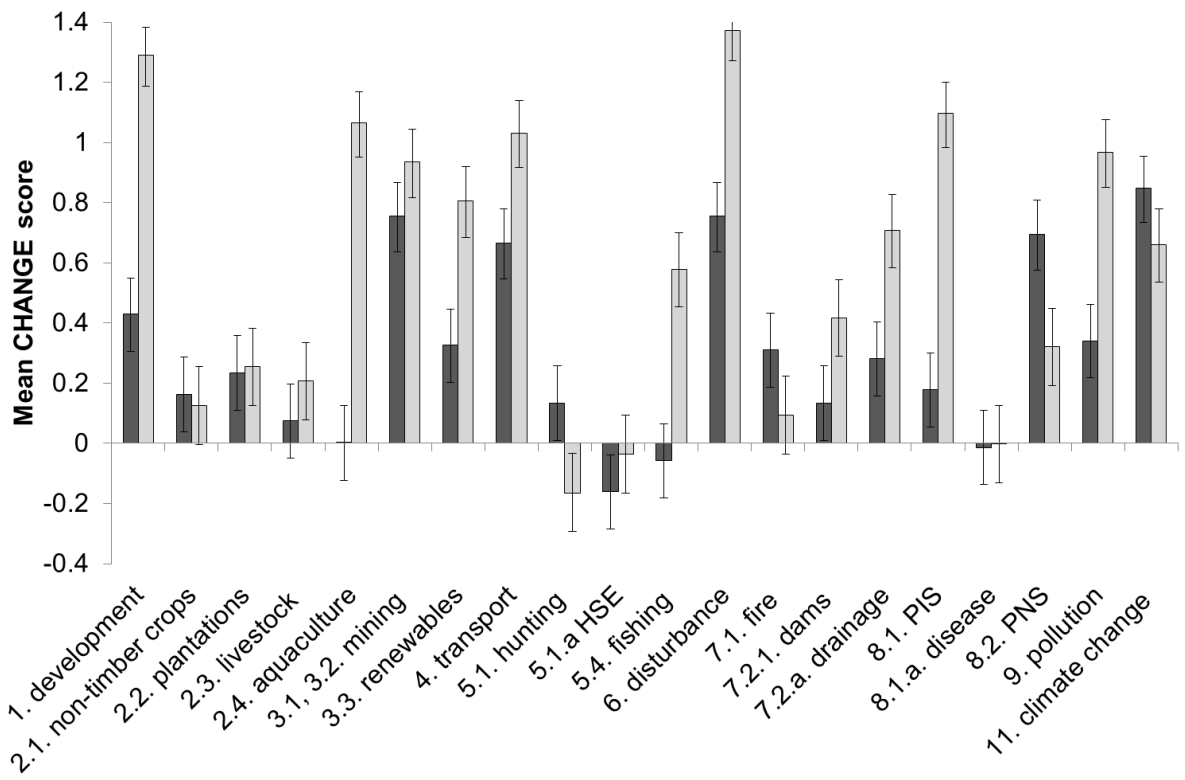


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1051 Figure 2. Mean (\pm SE) CHANGE (a) and IMPACT (b) scores across all populations. Scores represent
1052 least-square mean estimates from a GLMM model with species as a random effect. HSE - Hunting
1053 side-effects, PIS - Problematic invasive species, PNS - Problematic native species

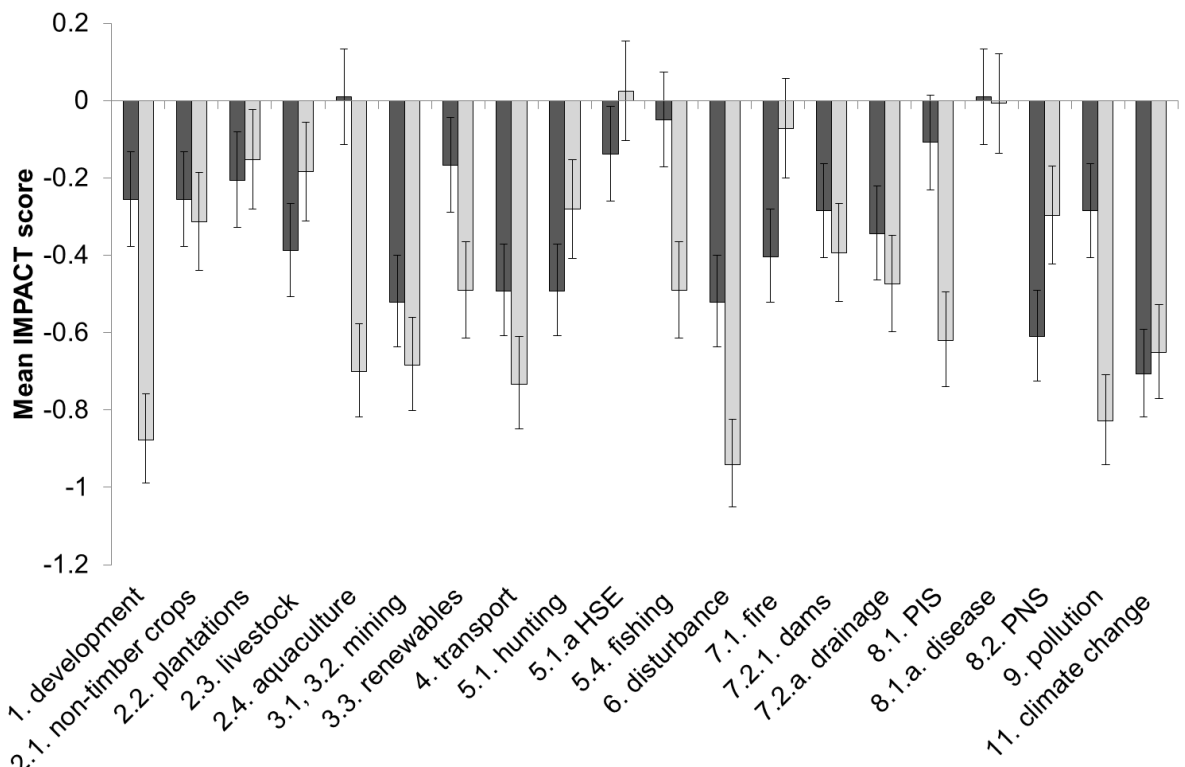
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1060 Figure 3. Mean (\pm SE) CHANGE (a) and IMPACT (b) scores differ between breeding (dark grey) and
1061 non-breeding (light grey) areas. Estimates are from least-square means with species as a random
1062 effect. HSE - Hunting side-effects, PIS - Problematic invasive species, PNS - Problematic native
1063 species

1064 Table 1. Populations used as the basis for this analysis, based upon Wetlands International (2012).

Population no.	Taxon	Population name / distribution	IUCN status of species	Flyway	
1	Upland sandpiper <i>Bartramia longicauda</i>	Americas	Least Concern	Central Americas	
2	Bristle-thighed curlew <i>Numenius tahitiensis</i>	W Alaska (breeding)	Vulnerable	Pacific Americas	
3	Whimbrel <i>Numenius phaeopus hudsonicus</i>	<i>hudsonicus</i>	Least concern	Atlantic Americas	
4	Whimbrel <i>Numenius phaeopus hudsonicus</i>	<i>rufiventris</i>			Pacific Americas
5	Whimbrel <i>Numenius phaeopus alboaxillaris</i>	<i>alboaxillaris</i> , South-west Asia/Eastern Africa			Central Asian
6	Whimbrel <i>Numenius phaeopus islandicus</i>	<i>islandicus</i> , Iceland Faeroes & Scotland/West Africa		East Atlantic	
7	Whimbrel <i>Numenius phaeopus phaeopus</i>	<i>phaeopus</i> , Northern Europe/West Africa		East Atlantic	
8	Whimbrel <i>Numenius phaeopus phaeopus</i>	<i>phaeopus</i> , West Siberia/Southern & Eastern Africa		Black Sea	

9	Whimbrel <i>Numenius phaeopus rogachevae</i>	Not listed in Wetlands International (2012)		Unknown
10	Whimbrel <i>Numenius phaeopus variegatus</i>	<i>variegatus</i> , S Asia (non-breeding)		Central Asian
11	Whimbrel <i>Numenius phaeopus variegatus</i>	<i>variegatus</i> , E & SE Asia (non-breeding)		EAAF
12	Little curlew <i>Numenius minutus</i>	N Siberia (breeding)	Least Concern	EAAF
13	Eskimo curlew <i>Numenius borealis</i>	N Canada (breeding)	Critically Endangered (Possibly Extinct)	Atlantic Americas / Central Americas
14	Slender-billed curlew <i>Numenius tenuirostris</i>	Central Siberia/Mediterranean & SW Asia	Critically Endangered	Black Sea
15	Long-billed curlew <i>Numenius americanus</i>	<i>americanus</i> / <i>parvus</i> ¹	Least concern	Central Americas
16	Eurasian curlew <i>Numenius arquata</i>	<i>arquata</i> , Europe/Europe North & West Africa	Near-threatened	East Atlantic
17	Eurasian curlew <i>Numenius arquata orientalis</i>	<i>orientalis</i> , Western Siberia/SW Asia E & S Africa		West Asian

18	Eurasian curlew <i>Numenius arquata orientalis</i>	<i>orientalis</i> , S Asia (non-breeding)		Central Asian
19	Eurasian curlew <i>Numenius arquata orientalis</i>	<i>orientalis</i> , E & SE Asia (non-breeding)		EAAF
20	Eurasian curlew <i>Numenius arquata suschkini</i>	<i>suschkini</i> , South-east Europe & South-west Asia (breeding)		West Asian
21	Far Eastern curlew <i>Numenius madagascariensis</i>	C & E Asia (breeding)	Vulnerable	EAAF
22	Bar-tailed godwit <i>Limosa lapponica baueri</i>	<i>baueri</i>	Near threatened	EAAF
23	Bar-tailed godwit <i>Limosa lapponica lapponica</i>	<i>lapponica</i> , Northern Europe/Western Europe		East Atlantic
24	Bar-tailed godwit <i>Limosa lapponica taymyrensis</i>	<i>taymyrensis</i> , Western Siberia/West & South-west Africa		West Asian
25	Bar-tailed godwit <i>Limosa lapponica taymyrensis</i>	<i>taymyrensis</i> , Central Siberia/South & SW Asia & Eastern Africa		Black Sea
26	Bar-tailed godwit	<i>menzbieri</i> (& <i>anadyrensis</i>)		EAAF

	<i>Limosa lapponica menzbieri</i> and <i>Limosa lapponica anadyrensis</i>			
27	Marbled godwit <i>Limosa fedoa fedoa</i>	<i>fedoa</i> , SC Canada & NC USA (breeding)	Least Concern	Pacific Americas / Central Americas
28	Marbled godwit <i>Limosa fedoa fedoa</i>	<i>fedoa</i> , James Bay (breeding)		Atlantic Americas
29	Marbled godwit <i>Limosa fedoa beringiae</i>	<i>beringiae</i>		Pacific Americas
30	Hudsonian godwit <i>Limosa haemastica</i>	Alaska (breeding)	Least Concern	Atlantic Americas
31	Hudsonian godwit <i>Limosa haemastica</i>	Hudson Bay (breeding)		Atlantic Americas / Central Americas
32	Black-tailed godwit <i>Limosa limosa limosa</i>	<i>limosa</i> , Western Europe/NW & West Africa	Near threatened	East Atlantic
33	Black-tailed godwit <i>Limosa limosa limosa</i>	<i>limosa</i> , Eastern Europe/Central & Eastern Africa		Black Sea

34	Black-tailed godwit <i>Limosa limosa</i> <i>limosa</i>	<i>limosa</i> , West-central Asia/SW Asia & Eastern Africa	West Asian
35	Black-tailed godwit <i>Limosa limosa</i> <i>limosa</i>	<i>limosa</i> , S Asia (non- breeding)	Central Asian
36	Black-tailed godwit <i>Limosa limosa</i> <i>islandica</i>	<i>islandica</i> , Iceland/Western Europe	East Atlantic
37	Black-tailed godwit <i>Limosa limosa</i> <i>melanuroides</i>	<i>melanuroides</i>	EAAF

1065 ¹Although previously considered as separate subspecies or populations (Wetlands International
1066 2012), for the purposes of this review, we considered that any differences were insufficient for them
1067 to be assessed other than as a single population.

1068 Table 2. Classification of threats and their definition used in the assessment, adapted from Salafsky *et al.* (2008).

Adapted Salafsky <i>et al.</i> (2008) classification	Simplified title	Definition
1. residential & commercial development	Development	Threats from human settlements or other non-agricultural land uses
2.1. annual and perennial non-timber crops	Non-timber crops	Threats from crops planted for food, fodder, fibre, fuel, or other uses
2.2. wood and pulp plantations	Plantations	Threats from stands of trees planted for timber or fibre outside of natural forests
2.3. livestock farming and ranching	Livestock	Threats from domestic terrestrial animals raised in one location on farmed or nonlocal resources (farming); or domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (ranching)
2.4. marine and freshwater aquaculture	Aquaculture	Threats from aquatic animals raised in one location on farmed or nonlocal resources; also hatchery fish allowed to roam in the wild
3.1, 3.2. oil and gas drilling, mining and quarrying	Mining	Threats from exploring, developing and producing non-biological resources, excluding renewables
3.3. renewable energy development	Renewables	Threats from exploring, developing, and producing renewable energy
4. transportation and service corridors	Transport	Threats from long, narrow transport corridors and the vehicles that use them including associated wildlife mortality

5.1. hunting and collecting of target species	Hunting	Threats from killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research or cultural purposes, or for control/persecution reasons; includes accidental mortality/by-catch
5.1.a management to support the hunting and collecting of target species	Hunting side-effects (HSE)	Side-effects of killing or trapping terrestrial wild animals, including the impacts of management to support hunting, such as predator control.
5.4. fishing and harvesting aquatic resources	Fishing	Threats from harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/by-catch
6. human intrusions and disturbance	Disturbance	Threats from human activities associated with non-consumptive uses of biological resources that alter, destroy and disturb habitats and species ¹
7.1. fire and fire suppression	Fire	Impacts of suppression or increase in fire frequency and/or intensity outside of its natural range of variation
7.2.1. dams and water management	Dams	Impacts of slowing water flow through dams and other water managements outside of natural range of variation, to raise water levels
7.2.a. drainage	Drainage	Impacts of increasing flow of water from wetland or waterlogged terrestrial areas through drainage, to reduce water levels.

8.1. invasive non-native/alien species	Problematic invasive species (PIS)	Threats from harmful plants and animals not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities
8.1.a. disease	Disease	Threats from pathogens / microbes that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance
8.2. problematic native species	Problematic native species (PNS)	Threats from harmful plants, animals, or pathogens and other microbes that are originally found within the ecosystem(s) in question, but have become “out of balance” or “released” directly or indirectly due to human activities
9. pollution	Pollution	Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources
11. climate change and severe weather	Climate change	Threats from long-term climatic changes and other severe climatic or weather events outside the natural range of variation

1069 ¹ Whilst this definition was used in the questionnaire, it was highlighted in our workshop that some could have been interpreted this to have included the
1070 effects of widespread habitat destruction. As a result, we ensured that our final workshop scoring was focussed specifically on the direct effects of human
1071 disturbance upon individuals, rather than effects of habitat destruction.

1072 Table 3. The mean CHANGE score (arrows), indicating changes in the scale and intensity of each threat, and IMPACT score (shading), indicating the likely
 1073 impact of that threat being linked to population change, associated with threats (rows) for the breeding season and non-breeding periods. Diagonal arrows
 1074 and amber cells indicate combinations with statistically significant CHANGE and IMPACT scores respectively, regarded as moderate. Up arrows and dark red
 1075 cells indicate where CHANGE > 0.5 or IMPACT < -0.5 respectively, and may therefore be regarded as severe. Light green cells and horizontal arrows indicate
 1076 that IMPACT and CHANGE scores respectively did not differ significantly from zero. We were unable to make a non-breeding assessment for the Central
 1077 Asian flyway. EAAF, East Asian - Australasian Flyway; PIS, problematic invasive species; PNS, problematic native species. Where we are aware of a clear
 1078 separation in the non-breeding threats between migratory stop-over locations and final non-breeding locations, these are denoted by ^M and ^F respectively.

Breeding	Pacific Americas	Central Americas	Atlantic Americas	East Atlantic	Black Sea	West Asian	Central Asian	EAAF	West Pacific
Development	→	→	→	↑	→	→	→	→	→
Non-timber crops	→	→	→	↑	→	→	→	→	→
Plantations	→	→	→	↑	→	→	→	→	→
Livestock	→	→	→	↑	→	→	→	→	→
Aquaculture	→	→	→	→	→	→	→	→	→
Mining	↑	↑	↑	→	→	→	→	→	↗
Renewables	→	→	→	↑	→	→	→	→	→
Transport	→	→	→	→	→	↑	↑	→	↗

Hunting	→	→	→	→	→	↑	→	→	→
Hunting side-effects	→	→	→	→	→	→	→	→	→
Fishing	→	→	→	→	→	→	→	→	→
Disturbance	→	↑	↑	→	→	↑	→	→	→
Fire	→	→	→	→	→	↑	→	↑	→
Dams	→	→	→	↗	→	→	→	→	→
Drainage	→	↗	→	↑	→	→	→	→	→
PIS	→	→	→	→	→	→	→	→	→
Disease	→	→	→	→	→	→	→	→	→
PNS	→	↑	↑	↑	→	→	→	→	→
Pollution	→	→	→	→	→	↑	→	→	↗
Climate change	→	↑	↑	↑	→	→	→	→	→
Non-breeding	Pacific Americas	Central Americas	Atlantic Americas	East Atlantic	Black Sea	West Asian	Central Asian	EAAF ¹	West Pacific
Development	↑	↑	↗	→	→	↑ ^M		↑ ^M	↗
Non-timber crops	→	→	→	↑	→	→		→	→
Plantations	→	→	→	→	→	→		→	↗
Livestock	→	→	→	→	→	→		→	↗

Aquaculture	→	→	↗	↑	→	→		↑	→
Mining	→	↑ ^M	→	→	→	↑		↑ ^M	→
Renewables	↗ ^M	→	→	↑	→	→		↑ ^M	↗
Transport	↑	↑	↑	↑	→	→		↑ ^M	↗
Hunting	→ ^M	→	→ ^M	→	→	→		→	↗
Hunting side-effects	→	→	→	→	→	→		→	→
Fishing	→	→	↑	↑	→	→		↑	→
Disturbance	↑	↑ ^F	↗	↑	↑	↑		↑	↗
Fire	→	→	→	→	→	→		→	→
Dams	→	→	→	→	→	→		↑ ^M	→
Drainage	→	↑	→	↑	→	→		↑ ^M	→
PIS	↑ ^F	→	↑	→	→	→		↑ ^M	↗
Disease	→	→	→	→	→	→		→	→
PNS	↗	↗	→	→	→	→		→	→
Pollution	↗	↑	↑	→	→	→		↑	↗
Climate change	↗ ^F	↑ ^M	→	↑	→	→		→	↗

1079 ¹Threats primarily affecting migratory stop-over locations in East and South-east Asia and are coded as ^M, but may also affect populations for which these

1080 locations are also final non-breeding locations. The majority of populations overwinter in Australia and New Zealand, where they face fewer threats.