Notornis, 2016, Vol. 63: 152-166
0029-4470

Changes in the status and distribution of Australasian bittern (*Botaurus poiciloptilus*) in New Zealand, 1800s−2011

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Abstract We collated and reviewed 4179 records of the historic and contemporary distribution of the endangered specialist wetland bird, the Australasian bittern (matuku, *Botaurus poiciloptilus*), in New Zealand, to assess its current status and trends in its distribution across major habitat types. We mapped distribution in 5 time periods (pre-1900, 1900−1949, 1950−1969, 1970−1989, post-1990). We found that Australasian bittern are currently found throughout New Zealand with strongholds in Waikato, Northland and Auckland regions (46% of records) in the North Island, and Canterbury and West Coast (22%) in the South Island. They occur widely in freshwater and brackish riverine, estuarine, palustrine and lacustrine habitats. Australasian bittern were abundant (records of groups >100 birds) in Māori and early European times, but historical maps indicate their range appears to have been reduced by *c.* 50% over the last hundred years, with the most dramatic shrinkage in range occurring post-1970. Marked declines in occupancy began in Otago, Canterbury, Waikato, Wellington and Auckland regions between the 1900-1949 and 1950-1969 periods and reductions in range have been steady since. In comparison, declines in Northland, Southland, West Coast and Tasman/Nelson appear to be more recent and greatest between the 1970-1989 and post-1990 periods. The apparent shrinkage in range is supported by numerous observations in the literature. Australasian bittern distribution is now biased towards coastal areas and lowland wetlands of the North Island. Information indicates that range reductions were paralleled by marked declines in numbers: 34% of pre-1900 records were >1 bittern and 7.3% were >10, whereas post-1990, only 19% of records were >1 and 0.7% >10. The clearance and drainage of wetlands (*c.* 90% loss) and shooting were major causes of declines, but contemporary threats include continued habitat loss and degradation, accidental deaths from a range of causes, and predation by introduced mammals. Current trends in Australasian bittern populations suggest that they should be reclassified as Nationally Critical under the New Zealand threat classification system. Conservation management should focus on restoration of hydrology, water quality and aquatic food supplies, predator control, reedbed management and maintaining regional wetland networks.

O'Donnell, C.F.J.; Robertson, H.A. 2016. Changes in the status and distribution of Australasian bittern (*Botaurus poiciloptilus*) in New Zealand, 1800s-2011. *Notornis 63 (3-4):* 152-166.

Keywords swamp birds; wetlands; habitat use; threatened species; conservation status; distribution; habitat loss; bittern

INTRODUCTION

The Australasian bittern (*Botaurus poiciloptilus*) is a wetland specialist present only in New Zealand, New Caledonia and southern Australia, where it inhabits a variety of fresh and brackish water habitats (Buchanan 2009; O'Donnell 2011; BirdLife International 2015). Bitterns are difficult to study, largely because they are rare, highly cryptic and secretive, and inhabit locations that are difficult to survey (Poulin & Lefebvre 2003; Gilbert *et al.* 2005; O'Donnell *et al.* 2013). As a result, little information has been published on the status, populations, distribution and habits of Australasian bittern (Marchant & Higgins 1990; Heather & Robertson 2000; McKilligan 2005).

Received 29 June 2016; accepted 19 September 2016
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The Australasian bittern is classed as globally Endangered by the IUCN (BirdLife International 2015) and Nationally Endangered in New Zealand (Robertson *et al.* 2013), because numbers are thought to have been drastically reduced through loss and degradation of their wetland habitat. Degradation of the remaining wetlands continues, with fragmentation, water abstraction, pest invasion and habitat modification being major threats (O'Donnell 2000; Ministry for the Environment 2007; Ausseil *et al.* 2008; Ausseil *et al.* 2011). In Australia, recent regional declines in reporting rates of >90% are thought to represent genuine population declines (Buchanan 2009; Pickering 2010) and in New Caledonia there have been just 2 recent records of booming males (BirdLife International 2015). In 2011, the Australasian bittern was listed as Endangered under Australian federal legislation (Department of Environment 2016).

There is no information on rates of decline in New Zealand, but we predict that the distribution of bittern has shrunk at least since Europeans began draining wetlands in the mid-1800s. Approximately 90% of inland palustrine wetlands have been drained, representing a massive loss of potential habitat (Ausseil *et al.* 2008; Ausseil *et al.* 2011). Although the extent of biodiversity loss associated with this clearance has not been measured, it is likely that the decline in abundance and range of species dependent on wetlands has been severe. Wetland loss also continues to occur in some regions of New Zealand (*e.g.,* Ledgard 2013), highlighting that further information is needed to quantify the impacts of land use change on threatened species.

It is important to develop a greater understanding of the distribution and abundance of Australasian bittern in New Zealand. If postulated declines are continuing, then it is important that conservation programmes focus on ways to reverse these declines. Accurate information on distribution and habitat use provides baseline information on potential threats to Australasian bittern populations. These can be used to determine where and at what rates declines may be occurring and to identify important sites for protection and management. Such information is essential for prioritising the timing and location of conservation actions for this species. Actual population counts of Australasian bittern are unavailable, largely because of difficulties in counting them (O'Donnell *et al.* 2013). Thus, in this paper we use distribution records as a surrogate indicator to infer broad population trends and to explore possible range changes (Noss 1990). The aims of this paper are to (1) collate a national database of distribution and habitat records of Australasian bittern, (2) describe regional distribution patterns, (3) report on changes in distribution and reporting rates over time (from the 1800s to 2011) and describe landscape-scale habitat use patterns derived from these data.

METHODS

Collation of records

We collated as many records of Australasian bittern as possible between April 2009 and June 2011. To do this, we undertook computer-based searches of science publication databases and we contacted people in the Department of Conservation (DOC), Fish & Game, Territorial Local Authorities, Te Papa, Auckland, Canterbury and Otago museums, the Ornithological Society of New Zealand (OSNZ) (through its newsletters; *e.g.,* Langlands & O'Donnell 2009) and asked for records. We also searched the on-line listservers BirdingNZ (www.birdingnz.net) and New Zealand eBird (ebird.org). Records included those lodged with the OSNZ Recording Scheme since 1939 and published as Classified Summarised Notes (*e.g.,* Edgar 1972; O'Donnell & West 1996) and the OSNZ Atlas Schemes (1969-1979 and 1999-2004; Bull *et al.* 1985; Robertson *et al.* 2007).

For each record we plotted the locations in ArcGIS (Version 9). Grid references were recorded as New Zealand TM Projection (NZTM) using the WGS 84 Map Datum. Many historical records were in either imperial or New Zealand Map Grid formats. They were converted to the NZTM using the Land Information New Zealand web-based conversion programme (http://apps.linz.govt.nz/coordinate-conversion/).

We scored the accuracy of the location of each record (sighting or calls) on a 4 point reliability scale:

1. *Accurate record*. Exact location point known (*i.e.,* where the bird was sighted).

2. *Specific habitat record*. The location of the habitat was known and it was associated with a small polygon (*e.g.,* somewhere within a small wetland).

3. *General habitat record*. The location of the habitat was known and it was associated with a large polygon (*e.g.,* somewhere within a large wetland such as Lake Ellesmere, *c.* 20,000 ha).

4. *Non-specific record*. Only the general region of the record was known or it was from an unknown location within a 10,000 yard or metre grid square from the successive atlases of bird distribution (Bull *et al.* 1985; Robertson *et al.* 2007).

Any vague or uncertain records were excluded. For example, numerous study skins in museums had no location data or only identified a large provincial

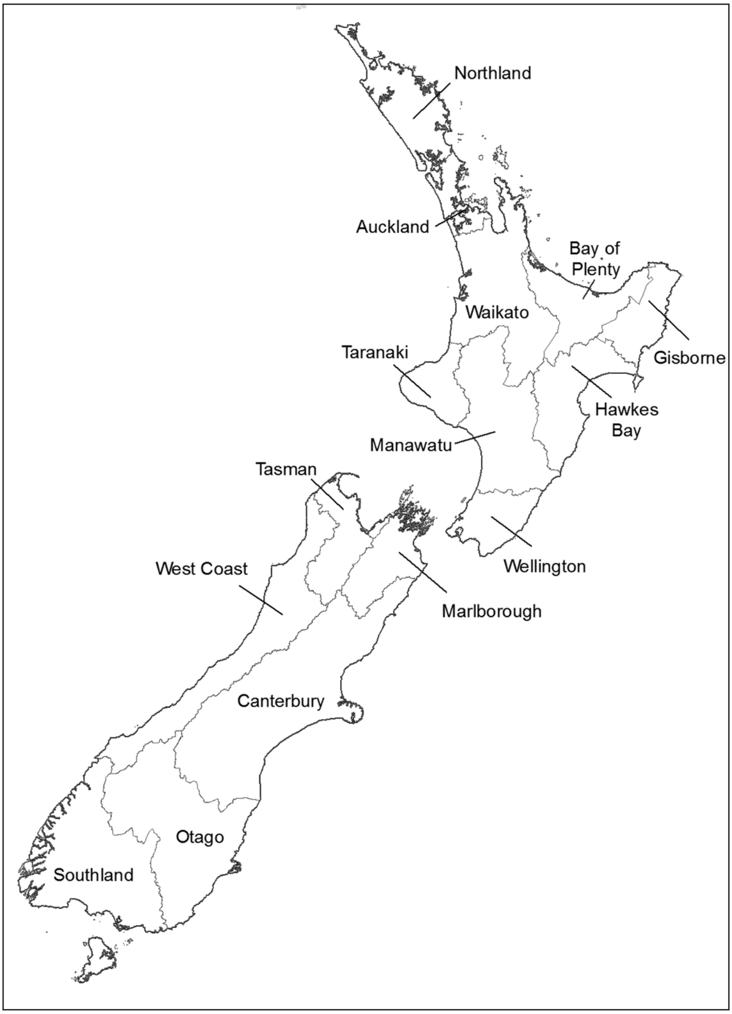


Fig. 1. Regional territorial local authority boundaries used in analyses of Australasian bittern distribution in New Zealand.

region (*e.g.*, Canterbury region). We had no way of verifying that bittern were accurately identified for every record we entered in the database. We assumed records in the published literature were accurate. We believe unpublished records were also reliable because they generally came from ornithologists and people familiar with the species. Modern records frequently came with digital images of the bird and its habitat. In addition, Australasian bittern are large and distinctive when seen and have distinctive booming calls when calling; observers were unlikely to confuse them with other bird species and for many, the observations were rare and memorable.

We recorded the location name, location coordinates, date of record, number of birds observed, altitude (m a.s.l.) and hydrosystem where sufficient information was available. Some records had behavioural observations and cause of death (if a specimen) attached to them. Records were categorised according to broad habitat characteristics if the information was known. In this paper, we describe distribution of records across hydrosystem classes after Johnson & Gerbeaux (2004): (1) estuarine, (2) riverine, (3) lacustrine, (4) palustrine, (5) non-wetland or (6) unknown.

Mapping distribution

All records were mapped and their locations checked for errors using ArcGIS Version 10. Errors were identified where a bittern location was in a highly atypical habitat (*e.g.*, marine zone) as indicated by reference to topographical maps. Such records were rechecked against their original sources and corrected where possible; otherwise they were excluded. Records were collated according to the region they occurred in (Fig. 1) based on territorial local authority boundaries. We sorted records chronologically, generated distribution maps and examined the distribution and frequency of sightings in 5 time periods from *c.* 1800–2011 (pre-1900, 1900–1949, 1950–1969, 1970–1989, post-1990). The period 1970–1989 contains records from the first OSNZ national bird distribution atlas (Bull *et al.* 1985) and post-1990 contains records from the second OSNZ atlas (Robertson *et al*. 2007).

We used these records to construct historic distribution maps. We predicted that the distribution of Australasian bittern had declined since the arrival of humans in New Zealand based on examination of anecdotal historic records (see below) and the fact that wetland cover has been reduced by *c.* 90% (Ausseil *et al.* 2008). Therefore, when building the maps, we assumed that sites where bittern were present in recent times were likely to have been occupied historically. This assumption is supported by general regional descriptions of the distribution of Australasian bittern (*e.g.*, von Hochstetter 1867; Hamilton 1878; Reischek 1885; Buller 1888; Drew 1896; Pycroft 1898; Oliver 1955, 1968). Thus, our baseline historic distribution map (pre-1900) included all locations recorded in the database. Maps for subsequent periods followed the same process: the 1900–1949 map included all records post-1900, 1950–1969 all records post-1950 and so on. We collated summary statistics for these characteristics and classed them by (1) territorial authority boundaries, (2) elevation of records relative to sea level, (3) and occurrence within a conservation park or reserve (protected area). In addition, a grid-based approach was used to assess the area of occupancy of Australasian bittern over the 5 time periods. Within ArcGIS (version 10) a 5 x 5 km grid cell layer was overlain on the New Zealand mainland and the presence of bittern observations recorded for each grid cell for each time period. Only records with an accuracy of 1-3 were selected for the protected area and grid-cell analysis.

Analyses

We tested whether the distribution of records did not simply reflect, or was biased towards, the distribution of observers by comparing the proportion of observations distributed in each region with an expected reporting rate per region. We used the number of OSNZ members living in each region (in 2011) as a surrogate for expected reporting rates and used χ^2 to test whether observed and expected reporting rates differed. We compared the distribution of records in different hydrosystems with the areas (ha) of each hydrosystem nationally, based on Ausseil *et al.* (2008) for wetlands, DOC's REC database for rivers, Freshwater Environments of NZ database (Leathwick *et al.* 2010) for lakes and Hume *et al.* (2007) for estuaries. We tested if the observed distribution of records was different to that expected if records were evenly spread across hydrosystem types using χ^2 and used the Spearman Rank Correlation Coefficient (r_s) to examine whether there was a trend in occupancy of grid cells nationally over the five historical time periods.

RESULTS

Accuracy and origin of records

Location data were available for 4,179 bittern records. Twelve percent of records were classed as accurate locations (n = 501 records), 40% classed as specific habitats (in a small wetland polygon, n = 1,664), 34% were from very large wetlands (where the specific location within the site was not recorded; n = 1,409), and 14% were classed as non-specific records (only general region of the record was known; n = 605).

The largest sources of records were the OSNZ Atlas schemes (35.1%, n = 1,470), scientific journals (16.5%, n = 689), and published records (7.5%, n = 315), unpublished DOC records (10.0%, n = 414), personal communications from individuals (9.3%, n = 389), the Birding-NZ list server (6.2%, n = 261), environmental newsletters (4.9%, n = 204), and museum records (3.5%. n = 146). Records were also obtained from newspapers (2.0%, n = 84), unpublished OSNZ surveys (1.8%, n = 75), university theses (1.2%, n = 50), historic books (0.7%, n = 34), bird rescue centres (0.4%, n = 17), NZ Wildlife Service records (0.4%, n = 15), Ebird (0.2%, n = 8), websites (0.2%, n = 6), and the OSNZ Nest Record Scheme (0.1%, n = 4).

Distribution of Australasian bittern

Australasian bittern records were distributed throughout New Zealand (Fig. 2) including Stewart Island, Great Barrier Island, and historically, Waiheke, Kapiti and Chatham islands. Several island records appear to be of vagrants (Coppermine, Mercury, Mana and Mayor islands). Approximately 45% of records post-1990 were associated with public conservation land.

Most records were from the North Island (66.2%), with the 3 northern regions of Waikato (19%), Northland (17%) and Auckland (11%) appearing to be the main strongholds (46% of records, Fig. 3). The proportions of observations in each region was not biased by number of potential observers, with some regions having more records than expected and some fewer (χ^2 = 5397, d.f. = 13, P < 0.001; Fig. 3). For example, the large number of records from Northland and Waikato were higher than expected based on the number of potential observers, and the numbers in Auckland fewer. In the South Island, most records were from Canterbury (14% of national total), where there was also a large pool of potential observers (Fig. 3). However, there were more records than expected on the West Coast and

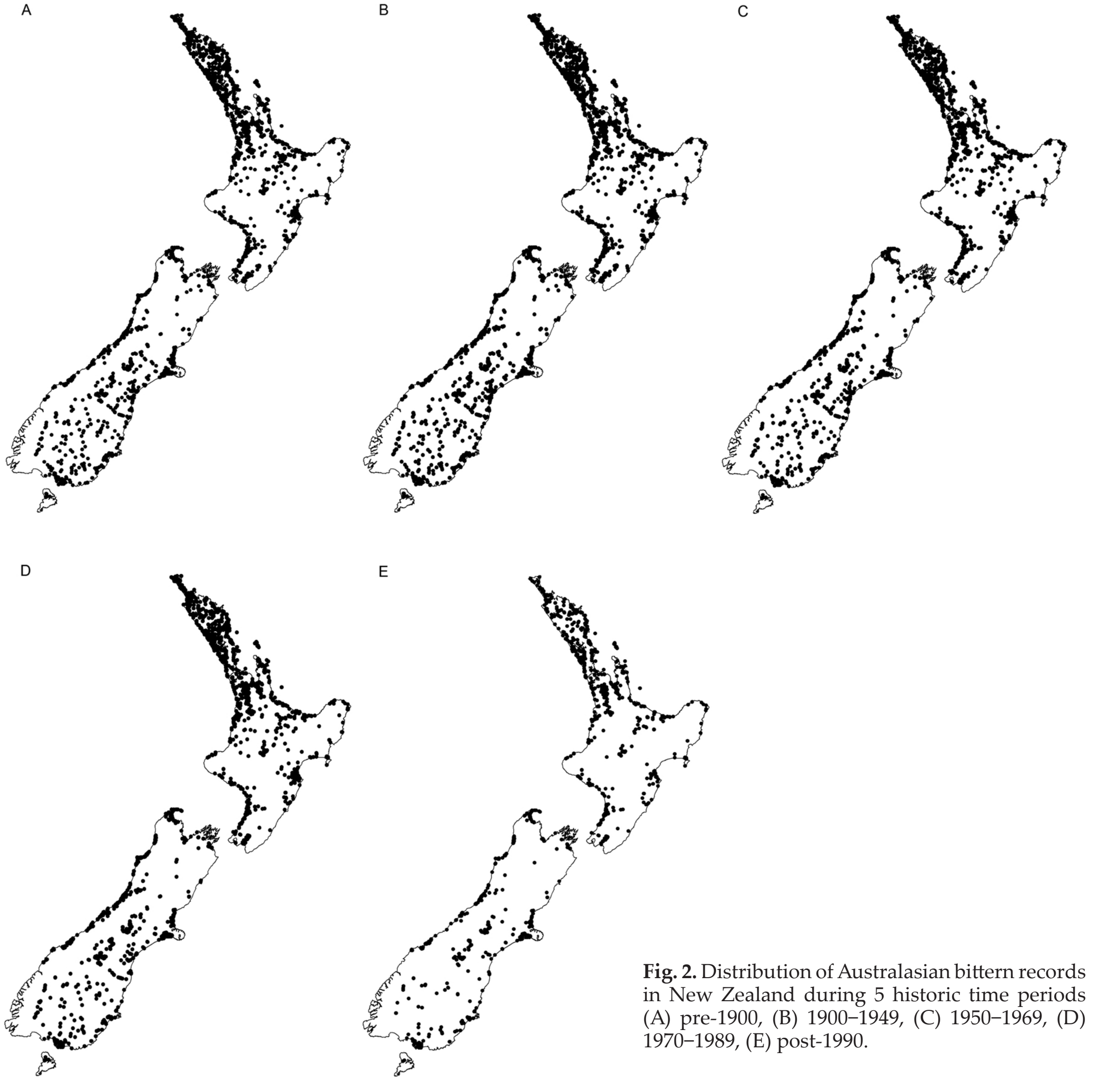


Fig. 2. Distribution of Australasian bittern records in New Zealand during 5 historic time periods (A) pre-1900, (B) 1900–1949, (C) 1950–1969, (D) 1970–1989, (E) post-1990.

Southland and lower reporting rates from Tasman-Nelson, Marlborough and Otago (Fig. 3). Reporting rates were lowest in Taranaki in the North Island and Marlborough in the South Island.

Macro-scale habitat use

Records of Australasian bittern were all from low altitudes; 52.2% were <100 m a.s.l., 96.5% were below 400 m a.s.l., and, although 143 records were above 600 m a.s.l, the highest was at 691 m a.s.l. We could identify the hydrosystem for 70% of bittern records. Australasian bittern were recorded from a wide range of freshwater and brackish wetland sites. Records were spread across the range of hydrosystems with 35.5% in lacustrine habitats (n = 1,037), 23.0% in palustrine habitats (n = 672), 19.5% in estuarine habitats (n = 570) and 13.8 % in riverine habitats (n = 402; Fig. 4). The number of records was different from that expected from the distribution of each hydrosystem nationally, with more records than expected in estuarine systems and fewer in riverine habitats (χ^2 = 370.44, d.f. = 3, P < 0.001; Fig. 4). Only 8.3% of records were not in wetlands (n = 242), most of which were from farmland.

Changes in distribution and abundance with time

Records of Australasian bittern were from the period *c.*1800 to 2011. Records from Māori verbal

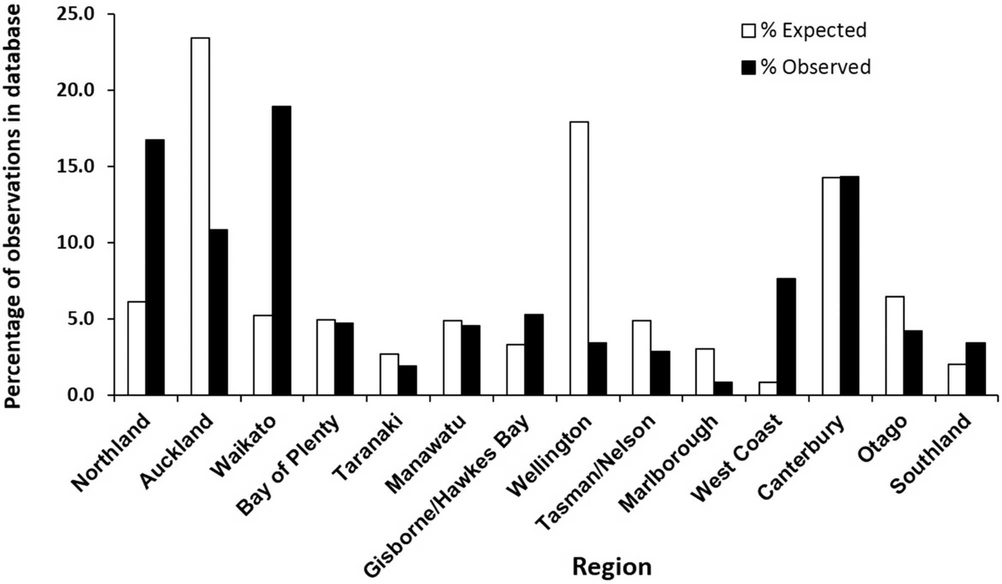


Fig. 3. Observed distribution of Australasian bittern reports (n = 4,179) in territorial local authority regions in New Zealand. Expected values are based on the distribution of bird watchers in each region (n = 1,050 OSNZ members, 2011).

histories (n = 11) were nominally tagged as the year 1800. Data were distributed across the whole chronological sequence (Fig. 2). However, most records were recent; following the initiation of this inquiry, and coinciding with data gathering for the 2 atlases of bird distribution in New Zealand (1969–1979, 1999–2004), with 38% of records pertaining to 1970-1989 and 48% of records were post-1990.

The distribution of Australasian bittern appeared to have declined since European occupation of New Zealand (Fig. 2A – 2E). For example, in regions such as Southland and Otago (Fig. 5), there has been a noticeable contraction of the range of bittern, particularly at inland sites. Records are now concentrated around large wetland complexes such as the Awarua Wetland and Taieri River floodplain. Many old inland records coincided with the locations of historical wetlands that have since been drained. Records in our national bittern database occupied 1,054 of 11,984 5 x 5 km grid cells on the national grid. Occupancy of grid cells declined to 53% of grid cells (n = 560) by the post-1990 period (Fig. 6), which represented an apparent ongoing decline on occupancy ($r_{s\,=}$ -1, p = 0.01). The greatest reduction in occupancy was between the 1970-1989 and post-1990 periods, despite this being the period when most reports were lodged in our database. Apparent declines in distribution occurred across all regions of New Zealand. However, there were some regional-specific patterns of decline detected (Fig. 7). Marked declines in occupancy began in Otago and Canterbury, Waikato, Wellington and Auckland regions between the 1900-1949 and 1950-1969 periods and reductions in range have been steady since (Fig. 7). Declines in occupancy in regions such as Northland, Southland, West Coast and Tasman/Nelson appear to be more recent and greatest between the 1970-1989 and post-1990 periods (Fig. 7). The apparent shrinkage in range is supported by anecdotal observations in the scientific literature (see below).

Pre-European era: Australasian bittern are thought to be relatively recent colonists to New Zealand, based on their apparent absence from the fossil records (Worthy & Holdaway 2002). However, it appears that they were widespread and abundant in Māori times (Waitangi Tribunal 2007; Fig. 2A). Bittern were most commonly known as matuku to Māori, but also as hūrepo, matuku-hūrepo, hūroto, kāka, and kautuku. While there are few formal records of matuku from this period, and fewer that could be identified to a specific location (but see Martin 1884), they were a common food source for Māori (Thomson 1859), including in the southern and eastern South Island (Kaiapoi to Rakiura; Williams 2004) and the central and eastern North Islands (Waitangi Tribunal 2006, 2007). Māori place names referring to bittern in areas with extensive wetlands are widespread (*e.g.*, Kautuku, Te Kautuku, Roto Kautuku, Waimatuku). Matuku also appear in language as part of legends, stories, early pictures and metaphor (*e.g.*, Taylor 1855; White 1890; Drummond 1907a). For example, from one story

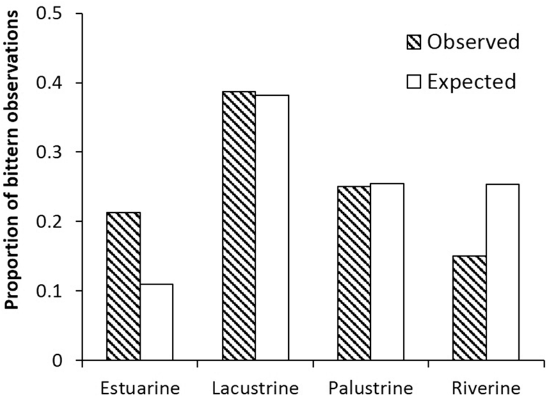


Fig. 4. Distribution of Australasian bittern records across hydrosystems in New Zealand (*n* = 2,681 records). Expected values are based on estimates of the total areas (ha) of these habitats nationally (see text for data sources).

we can deduce there were many swamps filled with bittern in south Taranaki when the Aotea's settlers arrived there (J. Archer, *pers. comm.*, www.maori.org.nz/papa_panui). One painting from the Rangatikei River in 1862 shows a Māori with bittern's wings in a head dress (J. C. Crawford, Alexander Turnbill Library, http://mp.natlib.govt.nz).

European era pre-1900: There are many general references to Australasian bittern in the early European literature, although few could be entered into the database because locations were usually general. When Europeans colonised New Zealand bittern still appeared to be common and widespread throughout most of the country (Yate 1835; Dieffenbach 1843; Power 1849; Taylor 1855; Thomson 1867; Buller 1888; Guthrie-Smith 1895). They were present in wetlands (now drained) within New Zealand's major cities, such as the wetlands of the Te Aro Valley and Basin Reserve in Wellington (Stidolph 1925). Generally, they were described as abundant in the 1800s (Buller 1892), with the most exuberant record talking about them 'abounding in the hundreds' in 1864 at Rangiriri (DOC bittern database). Specific references include being, 'very common' about Christchurch, New Plymouth and in the Taieri Basin (Potts 1869; Drummond 1907b), 'abundant' at Governors Bay (Dawson & Cresswell 1949), 'numerous' in the Marlborough district (Handley 1895), 'not uncommon' in the Lake Brunner district in the 1880s (Smith 1888), 'very common' in coastal swamps in the Wanganui area (Drew 1896) and 'remarkably numerous' in the Hawkes Bay (Hamilton 1885). They appear to be rare or absent in these places today (Robertson *et al.* 2007).

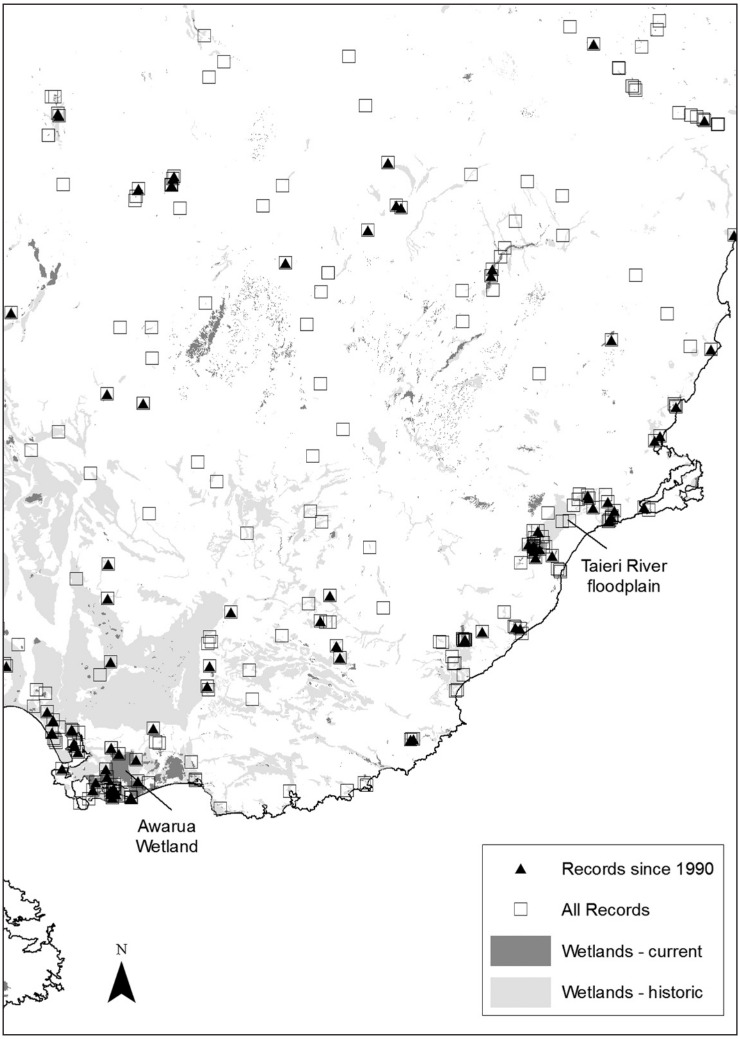
Declines in the range of Australasian bittern, including disappearance from the Chatham Islands (along with other wetland birds), were noted by authors as early as the late 1800s (Travers 1868; Potts 1869; Buller 1892; Oliver 1955) and, at least in the Hawkes Bay, birds were becoming rare by 1900 (Hutchinson 1900). They were common in wetlands on sites that were to become cities (*e.g.*, New Plymouth, Christchurch).

1900–1949: During this period, bittern still appeared to be widespread throughout New Zealand (Fig. 2C). However, authors were beginning to note some declines and disappearances. Fulton (1908) and Hutchison (1900) noted that they were becoming rare where swamps had been drained by the early 1900s and Hope (1927) stated "At one time fairly common; then for some years there was a decided decrease in their numbers". Drummond (1907b) conducted a New Zealand-wide survey of trends in the population trends and causes of decline of native bird species in 1905. Respondents (*n* = 178) sent in observations from throughout New Zealand and 28 mentioned the status of Australasian bittern. All except one (Manganui District, Northland) indicated that Australasian bittern were decreasing significantly by about 1900 (North Cape, Kaitaia, Towai Bay of Islands, Kaipara, Maungatawhiri Valley, Opotiki, Raglan, Waverley, Manawatu, Castle Point, Brightwater, Spring Creek, Christchurch, Hororata, Ashburton, Waitohi, Diamond Lake, Taieri, Inch Clutha, Tautuku). Respondents used such terms as 'seldom seen now', 'almost extinct', 'rare', 'once numerous', 'not seen one for years' and 'decreasing rapidly'. Rigg (1907) reported of bittern swamps in some parts of the Horowhenua: 'during the last two years it has made its disappearance in large numbers'. Nevertheless, rarity was not universal. They were still common in Northland (Drummond 1907b), 'not uncommon' at Lake Wairarapa and other lakes in area (Stidolph 1938), 'fairly common' in swamps adjacent to Kaiangaroa (Weeks 1949), 'plentiful' at Piako (Anon 1907) and 'sometimes seen in pairs' on Stewart Island (Gordon 1938).

1950–1969: Little was written about the distribution and status of Australasian bittern during this period. They were widely distributed, albeit at slightly fewer sites than recorded previously (Fig. 2C, Fig. 6). In more remote areas they were reportedly 'not uncommon' (*e.g.,* Westport in the 1950s, Readman 1950).

1970–1989: Comprehensive data on the distribution of bittern were collected for the first time in this period with the introduction of the OSNZ atlas scheme (Bull *et al.* 1985). Despite this dramatic increase in observation effort, in some regions bittern were not widely recorded (Fig. 2D, Fig. 6). They appeared to be rare or absent from some regions, such as Taranaki and Marlborough (Fig. 2D). Australasian bittern were still widespread in

Fig. 5. Distribution of Australasian bittern records in the Southland/Otago region of New Zealand for 2 time periods; pre-1900 (all records) and post-1990.



many regions, particularly Northland and Waikato. Two studies during this period confirmed that Whangamarino wetland in Waikato was a major stronghold for bittern with *c.* 250 birds present (Ogle & Cheyne 1981; Teal 1989). Ogle (1982) surveyed 218 lakes and swamps and 57 estuaries in Northland. Australasian bittern were recorded in 61 freshwater wetland habitats (27%) and from 10 swamp-estuary complexes (16%). Bittern were also reportedly still common in the Hokianga Harbour in the 1980s with 39 recorded during a 6 month period (Booth 1984), 16 were recorded on the Aupori Peninsula in 1984 (Howell 1985).

Post-1990: Over the last 40 years at least, Australasian bittern have become patchily distributed (Bull *et al.* 1985; Robertson *et al.* 2007; Fig. 2E). Most recent records come from Northland-Auckland, West Coast, and the Waikato. Otherwise they appear to be thinly distributed in some coastal areas in the North and South Islands, inland Southland, around central North Island lakes and in the Canterbury high country (Robertson *et al.* 2007). While most records in this period were of single birds, relatively good numbers were still being recorded in Northland and Waikato (*e.g.,* North Kaipara Lakes 17 in 1991, Onley 1991) and Whangamarino wetland in Waikato (> 50 in 2009, E. Williams, *pers. comm.*) and on the Tongariro Delta, Lake Taupo with numbers estimated 16-22 booming males in 1993 (Cuthbert & Hilton 1993) and 19 booming males remaining in 2005 (Speedy 2005).

Numbers of Australasian bittern

It is difficult to glean much information on specific numbers of bittern from the historical records, the

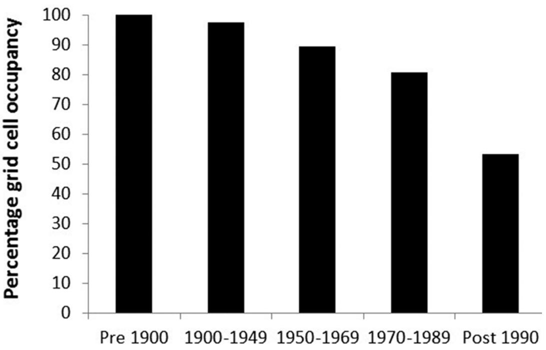


Fig. 6. Changes in the occupancy of 5 x 5 km grid cells across the national grid during 5 time periods: pre-1900 (*n* = 1,054 cells), 1900–1949 (*n* = 1,029 cells), 1950–1969 (*n* = 941 cells), 1970–1989 (*n* = 849 cells), and post-1990 (*n* = 560 cells).

trends in distribution patterns or from the numbers of bittern being observed, especially because the behaviour of this species is so cryptic (Williams 2016). Where the number of birds was recorded in the DOC Bittern Database (*n* = 2,661), the majority were of single birds (80%), although numbers up to 100 were recorded. Nevertheless, 34% of pre-1900 records were of more than 2 bitterns and 7.3% were >10, whereas in the post-1990 period only 19% of records were more than 2 and 0.7% >10.

There is no doubt Australasian bittern were abundant in Māori times, numbering in their hundreds at some sites (Waitangi Tribunal 2007). No long term trend data appear to occur at any sites. However, there are several examples that demonstrate that significant declines have occurred. For example, it was estimated that 60-100 birds were present on just the southern shore of Lake Whakaki, Hawkes Bay in 1963 (Edgar 1972). In comparison, Jonas (2012) estimated only 6 booming males remained at the same location in 2011. Australasian bittern were common at Lake Rotorua with at least 44 being flushed from one patch of raupo in 1937 (Anon 1937). However, the last record at this site in our database was a single bird in 1980 and none have been seen since (Sachtleben *et al.* 2014). Bittern were also still common in the Muruwai Lakes until the 1970s with 18 recorded in 1971 and 34 in 1973 (Edgar 1973), although only 8 were recorded in a similar survey in 1982 (Taylor 1982).

Causes of decline

Authors report a wide range of factors that are likely to threaten Australasian bittern populations. Habitat clearance and wetland drainage would have reduced the distribution of bittern substantially (Ausseil *et al.* 2008). Eleven historic references mention the impacts of wetland clearance on bittern. For example, Barker (1873) describes numerous bittern flying off when the extensive wetlands in the Wairiri Valley, Canterbury were burned. However, declines in wetland bird species have also occurred in areas where habitat has been little modified (Oliver 1955; Bull *et al.* 1985; Robertson *et al.* 2007).

The scale of wetland loss has been dramatic in many regions. For example, virtually the whole extent of 177,000 ha of swampy flats lying between Waikanae and Rangitikei, where once bittern were 'abundant' (Buller 1888), have been cleared (Ausseil *et al.* 2008). Similarly, '20,000 acres around Lake Wairarapa' where bittern were common (Hill 1963) are now almost completely gone and bittern now occur in low numbers on Lake Wairarapa itself (Moore *et al.* 1984; J. Cheyne, *pers. comm.*). Over 80,000 ha of wetlands were drained between Lake Ellesmere and Christchurch after Europeans arrived (O'Donnell 1985). Bittern were very common in this area in the 1800s, but number fewer than 10 booming males today (Potts 1869; Langlands 2013).

Historically Australasian bittern were hunted for sport, food, feathers for trout-fishing flies and novelty clothing (*e.g.*, Allan 1900; Anon 1939). They were also perceived by some as pests because they were thought to prey upon introduced salmonids (Anon 1875). Shooting of Australasian bittern as game birds was legalised in 1867 (Miskelly 2014) and common practice in the 1800s (Potts 1882; Buller 1888; Kirk 1888; Drew 1896) until they were finally fully protected in 1904 (Miskelly 2014). There were 24 records of birds being shot in our database. Most were pre-1900, but 4 were in 1900-1909, 1 in 1918, 1 in 1926, 1 in 1935, 1 in 1941, and 1 contemporary record in 2009. In addition, there are numerous reports of prosecutions for illegally shooting bittern in early New Zealand newspapers until the late 1930s (http://paperspast.natlib.govt.nz). Interestingly, Hope (1927) stated that since bittern were protected, numbers increased again to "fair numbers" in North Canterbury.

Causes of mortality recorded in our database included being killed or badly injured on roads after colliding with vehicles (*n* = 13) or rail (*n* = 2) and flying into power lines (*n* = 8). Other deaths included 1 bird found wedged in tree, 1 found dead on a beach wreck, and 1 flying into a window. Although 9 historic references mentioned the impacts of introduced mammalian predators (stoats *Mustela erminea*, weasels *M. nivalis*, cats *Felis catus*) there was only 2 confirmed records of a bird being killed by feral cats (O'Donnell *et al.* 2015).

Records of injured birds were also frequent. There were 11 records of birds injured from collisions with cars and unknown causes resulting in damaged wings and legs, and injured eyes and beaks. Nationally, injured Australasian bittern are regularly handed into wildlife centres and attempts

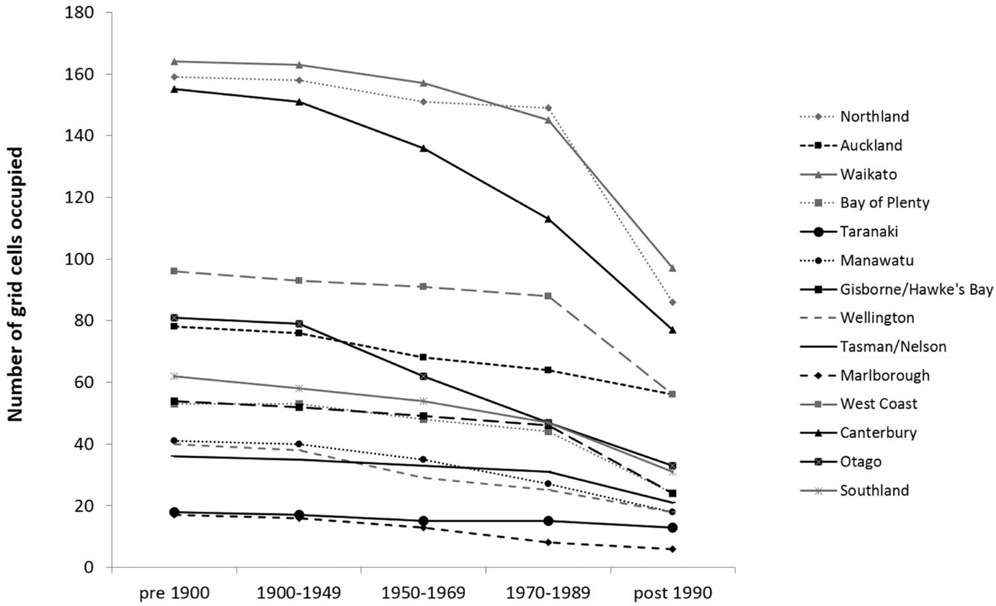


Fig. 7. Changes in the number of 1,054 5 x 5 km grid cells occupied across the national grid within each territorial local authority boundary during five time periods (A) pre-1900, (B) 1900–1949, (C) 1950–1969, (D) 1970–1989, (E) post-1990.

made to rehabilitate them. Of those that receive captive care and are released, there is concern that few survive post-release (Williams & Brady 2014).

DISCUSSION

Biases in records

There are several potential limitations and biases when collating anecdotal records of bird distribution. Sightings were collected opportunistically rather than systematically, so they may be biased regionally, particularly to areas close to population centres. There was also a bias towards recent records, which reflect high levels of reporting following initiation of this inquiry and far fewer observers in historic times. Although it is increasingly important to make use of presence-only data for conservation purposes (Zaniewski *et al.* 2002), caution should be exercised when constructing species distributions using presence-only data where no direct information about absences is available because unstructured sampling can lead to incorrect inferences being drawn (Royle *et al.* 2012).

Absence of records is not evidence of absence of birds, especially when they are as shy, rare and cryptic as Australasian bittern (O'Donnell & Williams 2015). Australasian bitterns' foraging strategy is to sit and wait, usually on the edge of emergent swamp vegetation and open water. Most sightings of birds are of individuals that have been disturbed or are flying purposefully from one area to another. Inconspicuous swamp bird species are under sampled by most standard inventory and monitoring methods applied to birds (Gibbs & Melvin 1997; Bibby *et al.* 2000). A range of methods have been applied to surveying swamp birds overseas, however, most rely on call counts because these birds are rarely seen or flushed. Territorial bittern call rarely, except at times when males are booming during the breeding season (Poulin & Lefebvre 2003; O'Donnell 2011). Thus the patterns and interpretation of records presented in this paper should be viewed with some caution. However, we feel that the broad distribution patterns and trends described in the results are useful, particularly because our sample size (>4000 records) is large and patterns we detected were strongly supported by a large anecdotal literature. Predicted declines in occupancy in areas such as Auckland, Wellington, Tasman/Nelson, Marlborough and Otago appear real, because the large number of active ornithologists in these areas is unlikely to have missed as many birds as might be expected in remote areas of New Zealand.

Causes of decline

Wetland drainage, fragmentation, and declines in quality, shooting, and birds colliding with transmission lines, vehicles and fences, are among a long list of factors that continue to cause mortalities and potentially contribute to ongoing declines in range and abundance of Australasian bittern (records in our database; Martin & Shaw 2010; Weeks *et al.* 2016). Degradation of the remaining wetlands in New Zealand continues, with fragmentation, grazing, water abstraction, pest invasion and habitat modification being major threats that must be managed more effectively (Heather & Robertson 2000; O'Donnell 2000; Ministry for the Environment 2007). Along with habitat loss, increasing frequency of droughts leading to reduced inundation of wetlands is thought to be contributing significantly to declines in Australia over the last 10-20 years (Birdlife International 2015). In addition, predation by introduced mammals has been highlighted as a threat to Australasian bittern and other specialist swamp birds (O'Donnell *et al.* 2015). All introduced mammalian predator species are abundant and/or widespread in New Zealand wetlands and most have been confirmed to prey upon freshwater bird species (O'Donnell *et al.* 2015). While their precise impacts on the long-term viability of threatened bird populations have not been evaluated, evidence suggests that predation is a serious threat, warranting predator control (O'Donnell *et al.* 2015).

We identified a substantial reduction in the frequency, number and distribution of bittern records from the 1970s until present. In the 1970s, wetlands were a focus for agricultural conversion, and it was not until government approved New Zealand's first wetland policy in 1986 that conservation attitudes towards wetland conservation became more acceptable (Keller 1988). This period also coincided with the introduction of the Resource Management Act (1991) and the formation of DOC (1987). While it may be expected that wetland habitat, and the species they support, would have greater levels of protection (Robertson 2016) this is not apparent with respect to Australasian bittern. Although there is no empirical evidence to link the decline of wetland habitat between 1970 and 2011 to changes in the bittern population, it is likely a contributing factor. The regional patterns in reduction in occupancy of 5 x 5 km grid cells reflect early loss of wetlands when areas were drained for agriculture in areas such as Otago, Canterbury and Waikato and later pressure on wetlands in areas such as Northland, Tasman and the West Coast (Aussiell *et al.* 2008). Ultimately, a combination of ecological pressures is likely to explain declines in Australasian bittern.

Conservation status

Several wetland birds, including the New Zealand little bittern (*Ixobrychus novaezelandiae*) became extinct following the colonisation of New Zealand by Polynesian people (Tennyson & Martinson 2006). Declines of some swamp birds, particularly crakes (*Porzana* spp.), rails (*Rallus* spp.) and fernbirds (*Bowdleria* spp.) continued steadily following European settlement (O'Donnell *et al.* 2015) and the decline in extant specialist swamp birds, including Australasian bittern, appears to be ongoing.

The Australasian bittern is currently classed as 'Nationally Endangered' (Robertson *et al.* 2013) using the New Zealand threat classification system (Townsend *et al.* 2008). Recent information on population trends, including the results reported in this paper, suggests that Australasian bittern should be reclassified as 'Nationally Critical'. A taxon is 'Nationally Critical' (Criterion C) when the population has an ongoing trend or predicted decline of > 70% in the total population due to existing threats taken over the next 10 years or 3 generations, whichever is longer and irrespective of population size or number of sub-populations.

Although there are no data on generation time in Australasian bittern, one generation is likely to be in the order of 5–10 years, based on very limited survival data from *Botaurus* bittern overseas. Birdlife International (2012) estimates generation time of *Botaurus stellaris* as 5.5 years based on a small amount of banding data. However, some birds in the overseas datasets are still alive. Longevity records (some birds still alive) for *B. stellaris* and *B. lentiginosus* are >11 years (Clapp *et al.* 1982; Hagemeier & Blair 1997; Fransson *et al*. 2010; Garnett *et al.* 2011; BTO 2016). Thus, for calculations below we use a generation time = 5.5 years (optimistic scenario) and 8.0 years (pessimistic scenario) resulting in 3 generations equalling either 16.5 or 24 years, respectively.

In recent years, numbers of booming males have been monitored at Whangamarino wetland in Waikato. Calling rates are strongly correlated with actual numbers of males (Williams 2016). A decline would need to be >7% per annum to get a >70% decline in three generations (16.5 year scenario) and >5% per annum (24 year scenario). Declines in calling rates of male bittern since 2009 of *c.* 10% per annum have been recorded at Whangamarino (DOC, *unpubl. data*). It is likely that the situation would be worse for adult female bittern because only females incubate and raise young, and are likely to be more vulnerable than males when nesting to predation.

Historical data from Whangamarino seem to support the estimate above. Whangamarino (*c.* 8000 ha) is generally thought to support the largest population of bittern in New Zealand. Ogle & Cheyne (1981) estimated the number of male bittern to be 145 birds based on transect surveys. In 2015, numbers were estimated at 15 males based on monitoring booming (Williams & Cheyne 2016). This is equivalent to an 89% decline over 35 years (*i.e., c.* 7% decline per annum), which, if representative of other wetlands, would trigger a predicted decline > 70 % in three generations. Despite being one of New Zealand's largest wetlands, habitat has degraded dramatically at this site through extensive weed encroachment, sedimentation and significant declines in water quality over the last

35 years. Furthermore, the full range of introduced mammalian predators typical of terrestrial habitats are now known to be abundant throughout. This degradation is predicted to continue unless habitat management solutions are found, and implemented, in the near future. In addition, with failure of food supplies in wetlands emerging as a critical factor based on increased rate of starved bittern being handed in to wildlife clinics and from radio tracking studies (Williams & Brady 2014; E. Williams, *pers. comm.*), there should be considerable concern about the viability of Australasian bittern populations.

In addition, the considerable reductions in range since 1990, strong anecdotal evidence of reductions in numbers from the literature, and measured reductions in both area of wetlands (>90%; Ausseil *et al.* 2008) and wetland quality (Ausseil *et al.* 2011) support the threat classification. We surmise that it is unlikely that bittern have expanded their range significantly in modern times given these factors and the ongoing multitude of pressures on wetland quality (Weeks *et al.* 2016). Reductions in range appear independent of region and habitat (hydrosystem) type. Although it is only possible to infer rates of decline from changes in distribution, if populations have declined by *c.* 50% between the last 2 reporting periods we analysed (1970-89 to 1990-2011) (as inferred by reduction in occupancy Fig. 6), we estimate a minimum 1−3.5% decline in occupancy per annum.

Internationally, Australasian bittern are currently classed as 'Endangered' by the IUCN (Birdlife International 2015), The IUCN uses multiple criteria for assessing threat status of species as a whole across its range and applies the precautionary principle when there is doubt about the rate of decline and the relative contribution of threat processes (Mace & Lande 1991; IUCN 2012). Australasian bittern also occur in Australia, and perhaps New Caledonia where there have been just 2 recent records (Birdlife International 2015). In Australia, regional declines in reporting rates of >90% are thought to represent genuine population declines (Buchanan 2009), and the species was listed as endangered in 2011 (Department of Environment 2016).

Although the world population of Australasian bittern is not known, it is thought to number less than 2500 mature individuals (BirdLife International 2015), with a significant proportion in New Zealand. There have been several population estimates for New Zealand. Ogle & Cheyne (1981) speculated that the population numbered <1000 birds, based on extrapolations of densities from Whangamarino wetland in the Waikato. Teal (1989) estimated numbers at ~ 1280 birds based on extrapolating the reporting rate across wetlands surveyed nationally by the New Zealand Wildlife Service. Heather & Robertson (2000) published an estimate of 580-725 birds, although they did not cite the source of the estimate. Furthermore, although censuses of subpopulations have not been conducted, based on numbers in our database, populations are likely to number in the tens or fewer. However, there has been no research conducted into the long-term demographics of this species, and information on recruitment and age structure of the population is particularly lacking.

If population trends described above also apply in Australia and New Caledonia, Australasian bittern should be reclassified as 'Critically Endangered' by IUCN. The IUCN (2012) criterion for Critically Endangered relevant to Australasian bittern is A2, 'An observed, estimated, inferred or suspected population size reduction of ≥80% over the last 10 years or 3 generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on trends in indices of abundance, decline in area of occupancy and quality of habitat'.

Recovery potential

In comparison to other endangered species, Australasian bittern have relatively large clutches (mean = 4.3 eggs, max = 6; mean = 3.4 chicks, max = 6; O'Donnell 2011). They also still occupy several regional hotspots in numbers likely to exceed 10-20 birds per site (*e.g.*, post-2000 records: Waituna Lagoon, Southland; Whangamarino wetland, Waikato (E. Williams, *pers. comm.*); Cascade wetland, South Westland (J. Lyall, *pers. comm.*); Lake Ellesmere, Canterbury (Langlands 2014); Hawkes Bay wetlands (O'Donnell *et al.* 2013); Tongariro Delta (Speedy 2005) and Kaipara Harbour). Such sites may need to be designated as core areas for the recovery of this species in each region.

Thus, Australasian bittern have the potential to recover from declines if conservation management actions are instigated. Some council authorities now have stricter regulations governing wetland drainage and clearing, but wetland planning rules are not consistent across New Zealand (Myers *et al.* 2013), so strengthening rules for wetland protection is required to ensure habitats are available for Australasian bittern in the future. It is encouraging that large scale predator control is underway at some key strongholds for bittern (Whangamarino wetland; L. Roberts, *pers. comm.*) or in planning phases (Awarua wetland; S. Thorne, *pers. comm.*) but for most wetlands, mammalian predators are not adequately managed (O'Donnell *et al.* 2015). Conservation management should ensure no further loss of wetland habitat and focus on restoration of water regimes, water quality and aquatic food supplies, predator control, reedbed management and maintaining regional wetland networks

(White *et al.* 2006). The development of a national Australasian bittern recovery plan would provide a valuable first step to achieving these aims.

ACKNOWLEDGEMENTS

Thank you to the >600 people who contributed records for inclusion in the DOC Australasian bittern database, Chris Robertson for supplying OSNZ atlas scheme data, Ingrid Hutzler for data on OSNZ membership, Derek Brown for GIS advice, Eva Pomeroy for ArcGIS grid cell analysis, and Jo Sim, Caitlyn Westbrooke, Peter Langlands and Sabrina Luecht for assisting with collating the records. Emma Williams, John Craig, Leigh Bull and an anonymous referee provided helpful comments on drafts of this manuscript. The project was funded by the Department of Conservation Arawai Kākāriki wetland restoration programme.

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