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Estimating the distribution, population status, and trends of New Zealand scaup (*Aythya novaeseelandiae*)

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Abstract: New Zealand scaup (*Aythya novaeseelandiae*) counts are collated from a total of 12,145 site visits nationally between 1888 and 2018 to estimate their distribution, population status, and trends. Based on systematic counts of large flocks on lakes between 1984–2018, there are about 11,000 New Zealand scaup nationally. This estimate must be interpreted with caution, as if birds are highly mobile the risk of overestimating the population is high. The distribution of New Zealand scaup strongholds (>50 adults) is compared to historical descriptions and trends in water quality. As lakes become more eutrophic over time, the birds move and the population declines. Research should focus on aerial vs ground counts, telemetry/satellite and/or banding studies of bird movement, gender, diet, predation, and littoral zone quantity and quality (<10 m deep). To achieve this, it is recommended that a national waterbird management and monitoring plan be developed.

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INTRODUCTION

The New Zealand scaup (*Aythya novaeseelandiae*), also known as the black teal or pāpango, is an endemic diving duck (Heather & Robertson 2015). Globally, it is the smallest (40 cm, 650 g) of a widespread genus of 12 species comprising the lesser scaup (*A. affinis*), redhead (*A. americana*), hardhead (*A. australis*), Baer's pochard (*A. baeri*), ring-necked duck (*A. collaris*), common pochard (*A. farina*), tufted duck (*A. fuligula*), Madagascar pochard (*A. innotata*), greater scaup (*A. marila*), ferruginous duck or white-eyed pochard (*A. nyroca*), and canvasback (*A. vallisineria*). New Zealand scaup have a conservation status of Least Concern in the IUCN Red List of Endangered Species (IUCN 2016) and Not Threatened in the New Zealand Threat Classification System (Robertson *et al*. 2017).

Male New Zealand scaup are shiny black with subtle maroon on the flanks and a brownish belly. The bill is blue-grey with a dark tip and the eyes are yellow (Heather & Robertson 2015). Females are a brownish black, with brown eyes, and a faint, black-tipped grey bill. In flight, birds have a trailing band of white above their wings and the under wings are fully white. Birds are often silent; however, females quack and males have a 3–4 note high-pitched whistle (Heather & Robertson 2015). Adult males are easily identified but juveniles up to 6 weeks in age may be easily mistaken for adult females. Adult females usually have a vertical white band at the base of the bill, whereas juveniles do not.

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Based on the known age of breeding and life expectancy of other waterbirds, New Zealand scaup may live to 4–5 years and breed at 1–2 years (M. Williams *pers. comm.*). During early spring (September–November), pairs disperse and occupy small home ranges with territories on the margins of wetlands. Birds build a nest close to water and females incubate and care for young alone (Heather & Robertson 1996, 2015). Median clutch size is 7–8 eggs and the incubation period is about 30 days (Stokes 1991). During late spring (November), birds flock and are often found together in pairs or groups of four or five on, or roosting near, lakes, tarns, ponds, and small streams. By early autumn (March), flocks are large, coinciding with the autumnal increase in wetland water levels. As rainfall increases during winter (May–June), birds may remain in flocks or disperse back to wetlands.

Like other Anatidae and *Aythya* species (e.g. Camphuysen 1998), New Zealand scaup are likely to disperse from day roosts and feed elsewhere at night, however no nocturnal studies have been undertaken. New Zealand scaup dive when disturbed or to feed on submerged aquatic vegetation, small fish, and invertebrates (Marchant & Higgins 1990). Most dives last 30 seconds but can occur for over a minute to a depth of 3–4 m (Stewart & Ward 1990).

Food availability and accessibility affects time and energy budgets, bird movement and therefore condition and breeding success (Laughlin 1974, Hohman 1986; Stephenson 1994; Jeske & Percival 1995; de Leeuw *et al*. 1999). If disturbance is high, for example, birds may feed more frequently for shorter periods or fly longer distances away, or feed more frequently at night (Marsden 2000). Additionally, if food is only available on a lakebed, then birds will dive deeper and for longer periods of time than if food is available within the littoral zone.

There has been one study on New Zealand scaup diet. The gizzards of 19 birds from Lake Pouarua and Woodend lagoon in Canterbury, Lake McLaren in the Bay of Plenty, and Westmere Lake in Whanganui North, were studied during 2001 and 2002, after they were unavoidably drowned in nets set to eradicate pest fish (Wakelin 2004). Vegetation and gastropods (snails) were common at all locations and benthic chironomid larvae were common at the Woodend lagoon. Studies of other *Aythya* species showed that as the quantity and diversity of vegetation and associated fish and invertebrates declined, there was a corresponding increase in the proportions of benthic (bottom dwelling) invertebrates in the diet (Quinn *et al*. 1996; Herring & Collazo 2005).

In windy weather or when disturbed, New Zealand scaups flock in sheltered bays or riparian vegetation (Heather & Robertson 2015). There have been a few studies of the impact of disturbance on the dive frequency of New Zealand scaup (Ward & Stewart 1989; Montgomery 1991; Walls 1999). Dogs, high speed vehicles, and boats were the most common disturbances of other *Aythya* species, and the impact on dive frequency depended on the time of year, frequency, and magnitude of disturbance (Carbone & Owen 1995; Keller 1996; Knapton *et al* 2000; Marsden 2000; Evans 2001; Mori *et al*. 2001; Herring & Collazo 2005; Borgmann 2010; Fouzari *et al*. 2015). Disturbance was higher in waterbodies with high recreational use, such as in the Bay of Plenty and Canterbury (Ministry for the Environment 2004).

Some introduced freshwater fish, e.g. koi (*Cyprinus carpio*), perch (*Perca fluviatilis*), and rudd (*Scardinium erthropthalmus*), decrease water quality and indirectly impact New Zealand scaup (Chadderton 2001; Burns *et al*. 2013). Studies in the Northern hemisphere show that in the decade before pest fish removal, water quality and the littoral zone biodiversity was low, and the waterbird population was negligible (Hanson & Butler 1994). In the first three years following pest fish control, water clarity, and littoral zone biodiversity increased, and the waterbird population, including *Aytha* species, increased.

Introduced mammalian predators, e.g. rodents (*Rattus* spp.) and mustelids (*Mustela* spp.), are known to prey upon New Zealand scaup (and other waterbirds) (Stokes 1991; O'Donnell *et al*. 2014). Harriers (*Circus* spp.) are known to prey on *Aythya* species (Houhamdi & Samraoui 2008); however, swamp harrier (*Circus approximans*) predation of New Zealand scaup has not been recorded.

Disease and toxins are known to cause widespread impacts on *Aythya* species (Phillips 1991; Lebedeva & Markitan 2001; Keller *et al*. 2009; Giemesi *et al*. 2012; Folliot *et al*. 2017); however, there have been few impacts of disease on waterbirds (Stanislawek et. al 2002). Water quality is the result of a complex relationship between physical factors (e.g. biogeography, light, altitude, temperature, catchment size, bathymetry, water quantity, and flow), chemical factors (e.g. pH, oxygen concentration, nutrient concentration) and biological factors (e.g. predators, littoral zone area, and food accessibility) (Braithwaite & Frith 1969; Rutledge 1970; Young & Smith 1990; Phillips 1991; Stokes 1991; Winfield & Winfield 1994; Lindeman & Clark 1999; Evans & Day 2001; Austin *et al*. 2002, 2006; Koons & Rotella 2003; Fast *et al*. 2004; Herring & Collazo 2005; Torrence & Butler 2006; Walsh *et al*. 2006; Keller *et al*. 2009; Nõges 2009; Drake *et al*. 2010; Cervencl & Fernandez 2012; Giemesi *et al*. 2012; Wang *et al*. 2012; Heam & Hilton 2013; Finger 2014; Bamford *et al*. 2015; Cherkaoui *et al*. 2016; Marchowski *et al*. 2016; Folliot *et al*. 2017;

Pringle & Burton 2017). Of these factors, the most important appears to be littoral zone area. As water quality and the littoral zone area declines, *Aythya* populations decline (Rutledge 1970; Salmon 1988; Austin *et. al*. 2006).

New Zealand's temperate climate means that altitude and temperature are not as important compared to continental climates, where these factors trigger *Aythya* migration. As the freshwater aquatic invertebrate diversity in New Zealand is naturally low, New Zealand scaup may be a more sensitive indicator to land use change and consequent impacts on water quality and littoral zone area than its congenerics (Burns 1991; Monks *et al*. 2013).

Distribution, population status, and trends

Historically, New Zealand scaup were widespread on rivers and lagoons but not open seashores (Buller 1888). Midden evidence shows that birds occurred on the Chatham Islands, where they are now absent (Heather & Robertson 1996). New Zealand scaup appear to have always been absent from Stewart Island (Williams 1963). During 1800–1900, due to hunting, habitat loss, and predation by introduced mammals, the distribution and population status of New Zealand scaup declined. In response, the birds were removed from the game list, partially protected in 1921, and fully protected in 1934 (Williams 1963). Subsequently, their distribution and population status increased (Williams 1963).

There was no change in the distribution of New Zealand scaup recorded in the OSNZ New Zealand Bird Atlas between September 1969 – December 1979 and December 1999 – November 2004 (Bell *et al*. 1985; Robertson *et al*. 2007; Scofield *et al*. 2012; Walker & Monks 2018). The long time-frame and large scale (approx. 10 km x 10 km grid) of Atlas surveys and/or spatial differences in count effort, however, may have masked trends.

The most recent New Zealand scaup population estimates range from 5,000–10,000 birds (Marchant & Higgins 1990; IUCN 2016) to more than 20,000 birds (Heather & Robertson 2015). The large discrepancy may reflect that these estimates are not based on counts. Other factors include the inherent variability of New Zealand scaup populations and/or changes in environmental factors.

Online databases, the published and grey literature provide decades of observational and systematic count data that provide an opportunity to estimate changes more accurately in the distribution and population status of New Zealand scaup. Before databases of bird counts such as CSN, e-Bird, iNaturalist and the OSNZ can be interpreted, data must be collated, cleaned, and a literature search undertaken to determine sampling biases and major physical, chemical and biological population drivers. The aims of this paper are therefore to collate count data, identify sampling biases and environmental factors that affect the precision and accuracy of distributional and population trends, and to recommend any research and/or changes to count methods that will improve monitoring the effectiveness of conservation action.

MATERIALS AND METHODS

Data

Data were sourced from as many counts as possible between 1888–2018. Sources included eBird (eBird.org), the published and grey-literature, and sightings recorded by individuals. Grey literature records were sourced from offices of the Department of Conservation, Regional Councils, the Ornithological Society of New Zealand (OSNZ) (now Birds NZ) newsletters, OSNZ Classified Summarised Notes (CSN), Local Authorities, Fish & Game New Zealand, and Landcare Research Manaaki Whenua. For each count, the location (if known), source, habitat, weather, gender, time spent counting, distance travelled, time counting started, area counted, and number of observers were entered into an MS Excel spreadsheet and analysed (Microsoft Office Professional Plus 2016). The following data were excluded as locations and/or dates and or/counts were unclear or not recorded: SSWI (Sites of Special Wildlife Importance), PNA (Protected Natural Areas) Programme, SSBI (Sites of Biological Significance), Archives New Zealand and Regional Councils unpublished data, iNaturalist (www.inaturalist.org), OSNZ New Zealand Bird Atlas, Classified Summarised Notes (CSN).

Data accuracy

Data were grouped as systematic, opportunistic, surveillance or count and scored on a 4-point reliability scale (O'Donnell & Robertson 2016). Opportunistic data were recorded at locations and times chosen by the observer. Systematic data were collated using repeatable methods. Some data were partly systematic (e.g. repeated at the same time of the year) and partly opportunistic (e.g. repeated at different times of the day). Surveillance data were simply a record of the presence/absence of a bird. A count was a record of the number of adult birds.

Reliability was determined by location, accuracy, specificity and number of site visits. A site visit was a count at a location and included repeated counts. A location had a New Zealand Gazetteer or New Zealand Geographic Board place name (LINZ 2020). As locations were typically given many different local, rather than an official place names, site visits were grouped by region, which limited data accuracy. Accurate data recorded the GPS coordinates (latitude and longitude) of (a) location(s) from which birds were counted. Specificity was determined by scale and data scored as specific, general and non-specific. Specific data were recorded within a small area e.g. 100 ha. General data were recorded within a large area e.g. 1,000 ha. Non-specific data were recorded within an even larger area, e.g. 10,000 ha.

Count biases

Count data were assessed or tested for the sampling biases outlined below: spatial, observer, detection, observer elevation, count effort, species, bird movement, species, habitat, time of day, weather, season, bird movement and sex ratio.

Spatial

Locations that are chosen, rather than systematically or randomly sampled, have an unintentional spatial bias. As regions within New Zealand are based on water catchments, spatial bias was determined by comparing opportunistic and systematic site visits within regions per annum.

Observer

As there is no national count method, observer bias could not be tested; however, it is assumed to be randomly variable.

Detection

Detection bias is the probability of detecting that a bird is present. The larger and more widespread the species, the higher the probability of detecting a bird. The smaller or rarer or more secretive a bird, or the further away or the denser the vegetation the lower the probability of detection. As New Zealand scaup are widespread, detection bias is low. Detection bias due to habitat or weather is discussed below.

Observer elevation

The majority of New Zealand scaup counts were from land or boats and from a low elevation relative to the water surface. As no aerial counts were undertaken, observer elevation vs counts could not be tested.

Count effort

The number of birds counted may increase (or decrease), even if the distribution and abundance of birds remains the same, as the number of site visits/time spent counting/distance walked/ area counted increases (or decreases). To test this, the total number of birds vs the number of site visits, the time spent counting (minutes), distance travelled (km) was graphed per decade in MS Excel.

Species

Species bias occurs when some bird species are seen but not counted. As the "no count" number was low in most systematic counts, opportunistic data were tested for species bias.

Habitat

The number of counts within each broad habitat type: estuarine, riverine, lacustrine (lakes), palustrine (wetland) (after Johnson & Gerbeaux 2004) per decade was determined. Detection bias due to habitat will be low on open water such as lakes and high in vegetation such as wetlands.

Time of day

To determine any time of day bias, the time counts started was plotted on a MS Excel graph.

Weather

Birds are more likely to be detected when visibility and contrast are good, and wind conditions are light so that birds are not sheltering amongst vegetation. To test this, weather records were summarised as "fine" or "cloudy" or "raining" and tallied.

Season

During early spring/summer (September to March), nesting females will not be counted, and counts will underestimate the effective (breeding) population. During late summer (February to March), fledged chicks may be mistakenly counted as adults, which will overestimate the effective population. To test for seasonal bias, the total number of counts per season were tallied.

Bird movement

If birds move large distances within short periods of time, the likelihood of double counts will be high. As there is no research on New Zealand scaup movement, the probability of double counts or missed birds could not be tested.

Sex ratio

Given a sex ratio of 1:1 at hatching, a sex ratio that significantly favours males may indicate a decreasing population (e.g. Brides *et. al.* 2017). As there were few winter records of the gender of New Zealand scaup, the number of males and females recorded was tallied for all seasons.

Distribution trends
A stronghold is defined as a location where >50 birds flock. Historical descriptions of the distribution of New Zealand scaup strongholds (>50 birds) are compared to counts per decade.

Population status and trends
To provide an index of the population status and trends, systematic and opportunistic counts per decade were tallied and compared to trends in water quality.

RESULTS
Data
Major data sources of opportunistic and systematic data were summarised in Table 1. A total of 12,145 site visits were recorded between 1888–2018. Systematic counts were more accurate than observational counts. The following published and grey literature data sources were collated but not specifically mentioned in this paper: Stidolph (1950, 1951, 1952, 1955); McKenzie (1953, 1980); Sibson (1956–1959, 1960 a,b, 1961, 1978, 1981); Edgar (1972, 1974, 1975, 1976, 1977); Bell (1977); Coker & Imboden (1980); Pierce (1980); Morse (1981); Booth (1982, 1984); Howell & Gaze (1985–1988); O'Donnell (1985, 1995, 2001, 2002); The Amokura 1987–1997 (Newsletter of the Northland Region of OSNZ); Keeley & Gaze (1988); Keeley *et al*. (1989); Taylor & Parrish (1991, 1992); Tennyson & Lock (1998, 2000); Parrish (2000, 2002, 2003, 2006 a,b,c); O'Donnell & Schmechel (2001); O'Donnell & West (2001); Wood & Garden (2010); Champion & Wells (2017).

Count method biases
Spatial
Prior to 2008, few regions were counted and spatial bias was high. During 2008–2018, most opportunistic counts (per annum) were undertaken in the following regions: Canterbury (28–55%), Wellington (5–18%), Otago (8–20%), Bay of Plenty (2–11%), Waikato, Southland and the West Coast (4–14%). Counts were undertaken less often in other regions (0–13%). Site visits generally reflect the extent of freshwater habitat within each region, however Northland, Wellington, the West Coast and Southland were under-represented. Overall, spatial bias of opportunistic counts was moderate to low. Most systematic counts (per annum) were undertaken in Auckland (6–80%), Canterbury (12–50%) and the Bay of Plenty (0–67%).

Count effort
Prior to 1985, there were few records of count effort. During 1985–2018, the maximum time spent counting was five hours, the maximum distance travelled was 10 km and the maximum area counted was 350 ha per day. Of 2,033 opportunistic winter site visits, 1,010 (49%) recorded 10 or fewer birds and 429 (21%) recorded flocks of more than 50 birds. There were insufficient data to determine a correlation between counts and area (ha). Per decade, there was a strong correlation between systematic counts and count effort ($R^2 = 0.7178$) and a weak correlation between opportunistic counts and count effort ($R^2 = 0.5196$) (Figs. 1&2).

Species
A total of 48 (n = 66) systematic site visits recorded all species (73%). A total of 7,085 (n = 8,585) opportunistic site visits recorded all species (82%). Overall, there is no species bias.

Habitat
Of 5,091 opportunistic counts where habitat was recorded, most were on lakes, rivers (creeks, streams etc) and wetlands (Fig. 3).

Time of day
Of 8,657 opportunistic site visits where time of day was recorded (eBird), most counts (93%) were recorded in daylight between 0700 h and 1700 h with a slight decrease between 1200 h and 1400 h (Fig. 4).

Weather
Of 3,336 opportunistic site visits, trip comments (38% of all counts) in eBird, 2,614 (30%) recorded a description of the weather. Conditions ranged from very hot to snow, no wind to very strong wind, drizzle to rain, fine to cloudy. Weather conditions were seldom recorded in the published or grey literature. Temperature was occasionally recorded in eBird as Fahrenheit and Celsius, but more frequently described e.g. fine, cold, hot. Wind conditions were sometimes described, e.g. light breeze (never in knots) and occasionally its direction. Rain was frequently described, e.g. drizzle, heavy (never mm). Cloud cover was commonly described, e.g. cloudy, fine. Count method (e.g. scope used), tidal conditions, lake level, events (e.g. 1st day duck shooting season), riparian vegetation were sometimes described.

Season
Monthly counts by the same observer on Lake Alexandrina and Lake McGregor (1987–1994) and Lake Grasmere (1988–1990) (DOC *unpubl. data*) showed that the highest number of New Zealand

scaup and the least variable counts were during autumn and winter (Fig. 5). Of 396,091 opportunistic site visits, 49,754 (13%) did not record the month. Of counts where month was recorded, most were during autumn (n = 120,750), winter (n = 100,618), summer (n = 71,618), then spring (n = 53,351). Of 288 systematic site visits, the majority were during winter (n = 105), autumn (n = 63), summer (n = 62), then spring (n = 58).

Sex ratio
There was a slight sex ratio bias towards males of 1.7:1.0 (n = 367).

Distribution trends
1960s
During the 1960s, New Zealand scaup were seldom seen in the south west of the North Island, nor the east or south east of the South Island (Williams 1963). By the 2010s, birds were seldom seen in the south west of the North Island but were recorded in the east and south east of the South Island probably due to increased count effort and/or bird movement.

1970s
The New Zealand scaup population was thought to have increased following the construction of hydro-electric lakes in the upper Waikato region during the 1970s (Kear & Williams 1978; Heather & Robertson 2015), but there is no evidence to support this. Of the few hydro-electric lakes that had frequent site visits, e.g. Taylor Dam (2004–2018) in the Marlborough region, fewer than five birds were recorded during winter and fewer than 30 birds during other seasons.

1980s
During the 1980s, birds were observed on large, open, freshwater lakes of high clarity but not on brackish coastal lakes or lagoons (Neilson 1987). There is, however, no evidence that birds tend to be on large, open freshwater lakes of high clarity. The glacier lakes of the South Island, e.g. Lake Poteriteri, represent some of New Zealand's largest, clearest lakes, of which the steep sides and limited littoral zones of these lakes support few New Zealand scaup. The absence of birds on lagoons and brackish coastal lakes during the 1980s is likely to be due to low count effort and/or bird movement, as numerous New Zealand scaup have been counted on lagoons since the 2000s.

1990s
During the 1990s, population strongholds of scaup were on Northland dune lakes, hydro-electric lakes in the upper Waikato, on the lakes of Rotorua District, Taupo, Hawke's Bay, West Coast, North Canterbury, Otago and Southland and on high country lakes and tarns of the Southern Alps (Heather & Robertson 2015). As discussed above, hydro-electric lakes in the upper Waikato are not strongholds. Horseshoe Lake and Lake Tūtira in the Hawkes Bay, Lake Brunner and Lake Moeraki on the West Coast, Lakes in North Canterbury, Otago, Southland and the high country were strongholds.

2000s
During the 2000s, New Zealand scaup strongholds were the dune lakes of Northland, the Rotorua Lakes, Lake Taupo, and the lakes of the South Island West Coast and North Canterbury (Heather & Robertson 1996, 2015). Apart from the Rotorua Lakes, low count effort precludes evidence that the other locations were strongholds.

2010s
Winter strongholds include the dune lakes of Lake Humuhumu and Lake Rototuna in Northland, Lake Ratapiko in Tauranga, Lake Mangamahoe and Stratford Oxidation ponds in Taranaki, various areas around Lake Taupo, the Rotorua Lakes in the Bay of Plenty, the Masterton Oxidation Ponds and the Henley Lake near Wellington, Lake Lyndon and Marlborough Ridge wetlands in Marlborough, Waikanae estuary north of Wellington, the Ashburton Lakes, various sites around Christchurch (Avon River, Groynes, Travis Wetland, Charlesworth Reserve, Bromley Oxidation ponds, Lake Forsythe and Lake Ellesmere/Te Waihora, Lake McKenzie, Lake McGregor in Canterbury, Lake Hayes, the Sinclair Wetlands and Lake Dunston in Otago and the Rakatu Wetlands and Mirror Lakes in Southland (eBird).

Population status
Of the systematic counts, the largest numbers of birds recorded over the longest period were the Rotorua Lakes in the Bay of Plenty (n = 18 lakes), Bromley Oxidation Ponds in Christchurch, the Ashburton Lakes (n = 12 lakes), Lake Alexandrina, Lake McGregor and Lake Grasmere in Canterbury (1956–2018). Counts appear to peak during 1991, 2001, 2006, 2011 (Fig. 6); however this is due to the inclusion of juveniles during the summer counts of the Rotorua Lakes (Fig. 7).

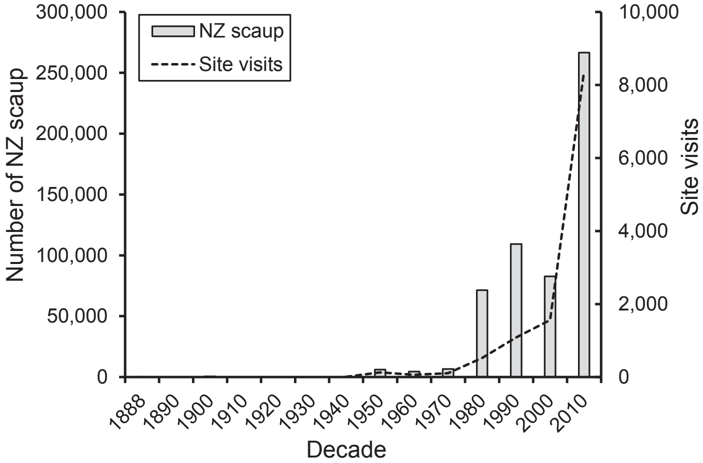

Figure 1. Number of New Zealand scaup and site visits, per decade, 1888–2018.

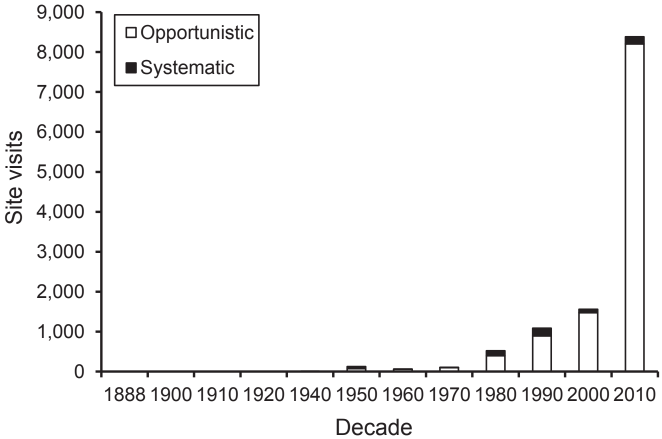

Figure 2. Number of opportunistic or systematic site visits of New Zealand scaup per decade, 1888–2018.

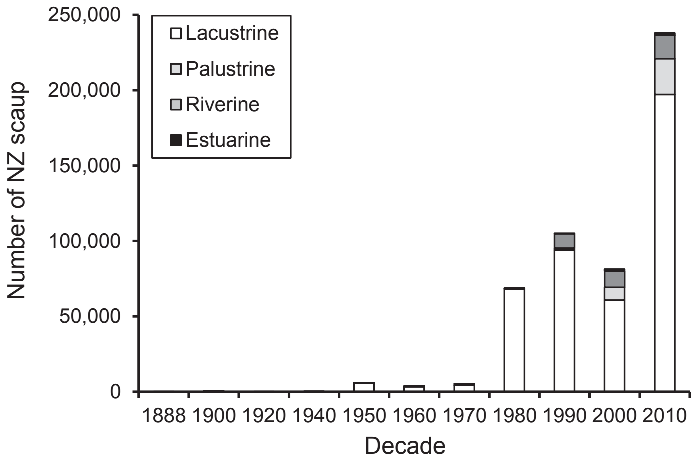

Figure 3. Number of New Zealand scaup per habitat per decade, 1985–2018 (n = 8,657).

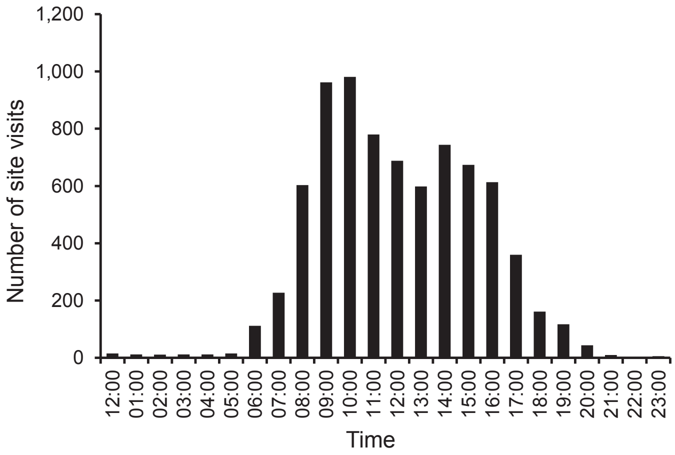

Figure 4. Number of New Zealand scaup per site visits and time of day, 1985–2018 (eBird, n = 7,758)

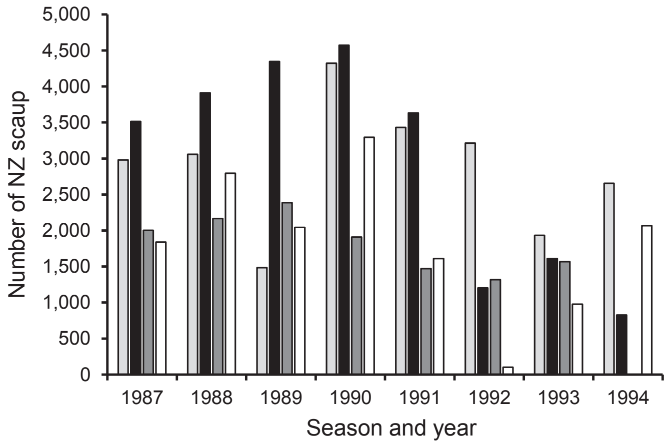

Figure 5. Number of New Zealand scaup by season and year at Lake Alexander, Lake McGregor and Lake Grasmere, 1987–1994. Black = winter, light grey = autumn, dark grey = spring, white = summer.

Based on systematic counts at these strongholds during 1984–2018, there are about 11,000 New Zealand scaup nationally with an unknown error. This estimate is based on the approximate 5,000 adult birds on the Rotorua Lakes (1984–2018) (n = 18 locations, range 0–5,121), up to 965 birds (1987–1998) on the Bromley Oxidation ponds in Christchurch (O'Donnell & West 1990–1996, 1998), about 2,000 birds on the Ashburton Lakes (1984–2018) (n = 12 locations, range 0–4,142) and about 3,000 birds on Lakes Alexandrina, MacGregor and Grasmere (1987–1993) (n = 3 locations, range 4–4,453).

As summer counts were sometimes tallied, this is likely to be an overestimate and must be interpreted with caution. Furthermore, if birds move within or between sites between counts, the risk of double counts may be high (e.g. Pollock & Kendall 1987; Frederick *et al*. 2003) and the population overestimated.

Population trends

Trends in water quality are correlated with trends in systematic counts (where known) by region from north to south below.

Far North and Northland

The Poutu Lakes (n = 14) comprise Lake Humuhumu, Lake Mokeno, Lake Waingata, Lake Whakaneke, Lake Rototuna (upper and lower), Lake Kanono, Lake Karaka, Lake Kuparere, Lake Rotopouua, Lake Wairere, Lake Rotootuauru, Lake Opuiti, Phoebes Lake and Rotopouri. A total of 700 birds were counted during the 1990s, 2000s and 2010s. The water quality of the 14 Poutu dune lakes is poor due to faecal runoff from farms in the surrounding catchment (Land, Air, Water Aotearoa 2018). Counts of 45 shallow coastal lakes showed that lakes in disturbed catchments had lower littoral zone area, reduced light and higher pH (Drake *et al*. 2010).

Auckland

Kaipara Dune Lakes – The Kaipara Dune Lakes were systematically counted each summer by OSNZ. The 22 lakes comprise Shag Lake, Lake Waikare, Lake Taharoa, Lake Kai Iwi, Walters Lake, Lake Kapoai (north and south), Lake Parawanui, Lake Rototuna (upper and lower), Northwest Lake, Main Lake (north and south), Large Southern Lake, Next South Lake, Last South Lake, Lake Humuhumu, Lake Roto-Otuauru (Swan), Back of Farm Lake, Lake Rotokawau, Lake Waingata, Lake Kanono, Twin Lake (east and west), Lake Kahuparere, Lake Mokeno. During summer (1969–2018) bird counts ranged from 0–70 birds, including juveniles. The water quality was good in Lake Kai Iwi, Lake Waikare and Lake Taharoa, average in Lake Humuhumu, poor in Lake Kanono, Lake Mokeno, Lake Kahuparere, Lake Rototuna and Lake Rotokawau and very poor in Lake Rotootuauru (Land, Air, Water Aotearoa 2018).

Western Springs Reserve – During 1978–2003 Western Springs Reserve bird counts ranged from 1–20 (Sibson 1979; Howell & Gaze 1986, 1987, 1988; Taylor 1990; Taylor & Parrish 1994 a,b; Parrish & Lock 1995; Parrish & Lock 1996; Gill & West 2016). During the mid-1990's to early 2000's, there were about 20 birds, and between 2010–2016, about 40 birds. During 2017–2018, there were over 140 birds which are likely to have increased due to supplementary feeding (Gill & West 2018). The water quality of Western Springs was poor, with high concentrations of *Enteroccocci* and *Escherichia coli* bacteria (Auckland Council 2020).

Waikato

Lake Taupo – Lake Taupo is New Zealand's largest lake and an UNESCO World Heritage site. One count by one observer during one week in summer recorded 383 adults (J. Innes, *unpubl*. *data*. 1986). Water quality was poor and continues to decline due to 60 years of pastoral development (Chapman 1996; Quinn *et al*. 2009).

Bay of Plenty

Rotorua Lakes – The Rotorua Lakes comprise 18 lakes: Lake Rotorua, Lake Tarawera. Lake Rotoiti, Lake Rotoma, Lake Okataina, Lake Rotomahana, Lake Rotoehu, Lake Rerewhakaaitu. Lake Rotokakahi, Lake Okareka, Lake Tikitapu, Lake Okaro, Lake Ngapouri, Lake Ngahewa, Lake Rotokawa, Lake Tutaeinanga. Waterbirds have been systematically counted once every five years or so during summer (Innes *et al*. 1999; Griffiths & Owen 2002; Evans 2006; Sachtleben *et al*. 2014; Graeme Young *unpubl*. *data* 2018). New Zealand scaup ranged from 0–5,121 birds (Fig. 5). The water quality of 12 of 15 lakes monitored was low to extremely low (Gibbons-Davies 2001; Carter *et al.* 2017; Land, Air, Water Aotearoa 2018).

Hawkes Bay

Lake Tūtira – During 1994, opportunistic counts recorded 121–190 New Zealand scaup on Lake Tūtira (Parrish & Lock 1995; Taylor & Parrish 1994a). Few or no birds were recorded as the lake became more eutrophic (McBride & Hamilton 2017).

Nelson

Lake Rotoroa – During 1888, there were 500 birds on Lake Rotoroa (Smith 1888). During the 1920s there were almost no birds. During 1944, 16 birds were recorded (Stidolph 1946). Counts from the southern end and west side of Lake Rotoroa by the Wildlife Service staff (now DOC) recorded 22 birds during 1965, 30 birds during 1970 and 17 birds during 1978–1990 (Butler 1991). Water quality was monitored during 1972–1978 and the lake classified as mesotrophic (Gillepsie & Spencer 1980) or of average water quality.

Lake Rotoiti – Lake Rotoiti (Kerr Bay) was systematically counted during 1969–1972 and 1978 and 1–3 birds recorded (eBird 2011, 2014). In 1981–1982, 47 birds were recorded (Booth 1983). During winter, 2–37 birds were recorded (eBird 2016, 2017, 2018).

Canterbury

Christchurch – During 1984–2016, the Groynes, Horseshoe Lake, Linwood Ave, and Lake Forsythe were semi-systematically counted by the same one or two observers following several methods outlined in Howes & Bakewell (1989). During the 1990s, the original four sites were counted along with the addition of Bexley wetland, Janet Stuart Reserve, Avon River and Charlesworth Reserve. During the 1990s, an additional two sites: Brooklyn's Lagoon and Travis wetland were also counted (Carran 2016, 2017). Notwithstanding differences in detectability between different habitats, there was a strong count effort bias (Carran 2016, 2017).

Bromley Oxidation ponds – Semi-systematic counts of the Bromley Oxidation ponds recorded 200 birds during 1989, 3,770 birds during winter 2008 and 7,403 birds during winter 2010 (Crossland 1999, 2013). These counts were orders of magnitude higher than independent opportunistic counts by other observers during the same period: 241–965 birds during winter 1987–1998 (O'Donnell & West 1990–1996, 1998) and 1–335 birds during winter 2008, 2014 and 2018 (eBird). The Bromley Oxidation ponds discharge toxic water into the Avon Heathcote estuary. The estuary is the largest in Canterbury and internationally important for migratory birds (Bolton-Ritchie & Main 2005).

Lake Forsythe – Up to 4,062 New Zealand scaup were semi-systematically counted on Lake Forsythe (Carran 2016, 2017), a highly polluted lake (Burns *et al*. 1999).

Lake Ellesmere/Te Waihora – Semi-systematic counts recorded fewer than 10 New Zealand scaup in Harts Creek, a spring that flows into Lake Ellesmere/Te Waihora (A. Grant, *pers. comm*. 1985–1990). During 2000, 235 birds were counted on the lake (Hughey 2012). During 2000–2018, up to 367 birds were seen (Crossland *et al*. 2015, Waihora Ellesmere Trust 2015 and *unpubl. data* 2017). Lake Ellesmere/Te Waihora is one of the New Zealand's largest lakes and severely polluted (Schallenberg & Crawshaw 2017).

Ashburton Lakes – The Ashburton Lakes comprise 12 lakes: Lake Heron, Lake Emily, Maori Lakes (eastern and western), Lake Trinity, Lake Denny, Lake Emma, Lake Roundabout, Spider/Donn lakes, Lake Nursery, and Lake Camp. The lakes have been systematically counted annually during winter since 1984, except for 1995 when ice precluded birds. New Zealand scaup ranged from 953–4,142 birds (Fig. 5). Water quality was poor-average for Lake Emma and the Maori Lakes, average for Lakes Clearwater, Emily and Camp and not recorded for other lakes (Land, Air, Water Aotearoa 2018).

McKenzie Basin – Systematic counts of the Tasman River, Godley River, Hopkins River, Ahuriri River, Tekapo River, Cass River, Ōhau River (upper and lower), and Pukaki River in the McKenzie Basin were undertaken by the NZ Wildlife Service, OSNZ and Acclimatisation Society during the 1960s and 1970s then by DOC during October and December 1991–1994 (Maloney *et al*. 1997; Maloney 1999). Counts followed O'Donnell & Moore (1983). Few birds were recorded on the Godley, Tasman, Tekapo, and Ahuriri Rivers during the 1960s (1962, 1965, and 1968) (Maloney 1999). No New Zealand scaup were noted on the Godley, Tasman, Tekapo, and Ahuriri Rivers during the 1990s (Maloney 1999), however, a check of original records showed that there were 15 birds on the Godley River during 1993, 105 during 1994 and 51 during 1995 (DOC *unpubl. data*). There was a total of 268 New Zealand scaup on five rivers during 1993, a total of 312 birds on four rivers during 1995 and a total of 519 birds on seven rivers during 1995.

Fish and Game New Zealand

As part of national monitoring of Australasian shoveler (*Anas rhynchotis*), the same observers from Taranaki Fish and Game New Zealand counted 30 locations throughout New Zealand and recorded a total of about 120 (0–221) New Zealand scaup (McDougall 2017, Taranaki Fish and Game Council of New Zealand 2018). Sometimes birds were seen on nearby lakes that were not counted and birds tended to avoid lakes with algal blooms (M. McDougall, *pers. comm.*)

Table 1. The location, date, number of sites, water quality, data type and accuracy of major New Zealand scaup data sources. O = Opportunistic, S = Systematic, C = Count, Su = Surveillance, G = General, A = Accurate.

Location	Region	Dates	Sites	Water quality	Data type	1980s	Site visits	Count 1990s	Site visits	Count 2000s	Site visits	Count 2010s	Site visits	References
Various	Various	1888–2018			O, Su, A	-		-	-	-	-	-	-	iNaturalist
Various	Various	1969–1979, 1999–2004			O, S, Su, G									OSNZ Atlas - Bell *et al*. 1985; Robertson *et al*. 2007.
Various	Various	1952–2003			O, C, A	4,294	47	10,843	449	3,661	75	-	-	OSNZ Classified summarised notes – see references.
Various	Various	1931, 1965, 1967, 1970, 1971, 1974–2018			O, C, A	7,1481	523	109,233	1,085	82,745	1,558	266,596	8,384	eBird Basic Dataset.
Poutu lakes	Northland	1994, 2008, 2009, 2010, 2012, 2014	14	poor	S, C, G	1	1	791	16	729	40	670	20	Keely & Gaze 1988; Parrish & Locke 1995.
Kaipara dune Lakes	Northland	1969–2018	22	3 poor, 1 fair, 5 poor, 1 very poor	S, C, G	0	18	13	18	83	18	180	18	OSNZ *unpubl. data*.
Western Springs	Auckland	1978–2003, 2010–2016	1	poor	S, C, A	20	1	20	1	20	1	40	1	Sibson 1979; Howell & Gaze 1986, 1987, 1988; Taylor 1990; Taylor & Parrish 1994 a,b; Parrish & Lock 1995; Parrish & Lock 1996; Gill & West 2016, 2018.
Various	Various	2003–2018			S, C, A	-	-	-	-	577	6	826	6	McDougall 2017; Taranaki Fish and Game Council of New Zealand 2018.
Lake Taupo	Bay of Plenty	1986	1	poor	S, C, G	136	13	-	-	-	-	-	-	J. Innes, *unpubl. data*.
Rotorua Lakes	Bay of Plenty	1985–2011	18	12 poor, 3 fair	S, C, G	4,638	18	6,349	36	8,007	36	-	-	Innes *et al*. 1999; Griffiths & Owen 2002; Evans 2006; Sachtleben *et al*. 2014; Graeme Young *unpubl. data* 2018.
Lake Tūtira	Hawkes Bay	1953–2018	1	very poor	S, C, A	191	4	575	7	190	-	95	13	Parrish & Lock 1995; Taylor & Parrish 1994a.

Table 1. *continued*

Location	Region	Dates	Sites	Water quality	Data type	1980s	Site visits	Count 1990s	Site visits	Count 2000s	Site visits	Count 2010s	Site visits	References
Nelson Lakes	Nelson	1888–2016	2	fair	S, C, A	47	2	-	-	-	-	29	2	Smith 1888; Stidolph 1946; Butler 1991; Booth 1983.
Christchurch	Canterbury	1984–2018			S/O, C, G	90	95	4,419	330	28,204	626	24,941	467	Carran 2016, 2017.
Bromley Oxidation ponds	Canterbury	1982–2018	1	very poor	S/O, C, A	256	3	11,369	14	26,425	8	23,982	26	Crossland 1999, 2013; O'Donnell & West 1990–1996, 1998.
Lake Ellesmere/ Te Waihora	Canterbury	1985–1990, 2000–2018	1	very poor	S/O, C, G	-	-	-	-	235	1	-	-	A. Grant, *pers. comm.;* Hughey 2012, Crossland *et al*. 2015; Waihora Ellesmere Trust 2015.
Ashburton Lakes	Canterbury	1984–2018	12	5 fair	S, C, A	2,100	72	3,813	108	4,097	108	-	-	DOC *unpubl. data.*
Lake Grasmere	Canterbury	1987–1993	1	fair	S, C, A	2,419	22	1,361	15	-	-	-	-	DOC *unpubl. data.*
Lakes Alexandrina and McGregor	Canterbury	1987–1994	2	good	S, C, A	30,110	33	40,349	37	-	-	-	-	DOC *unpubl. data.*

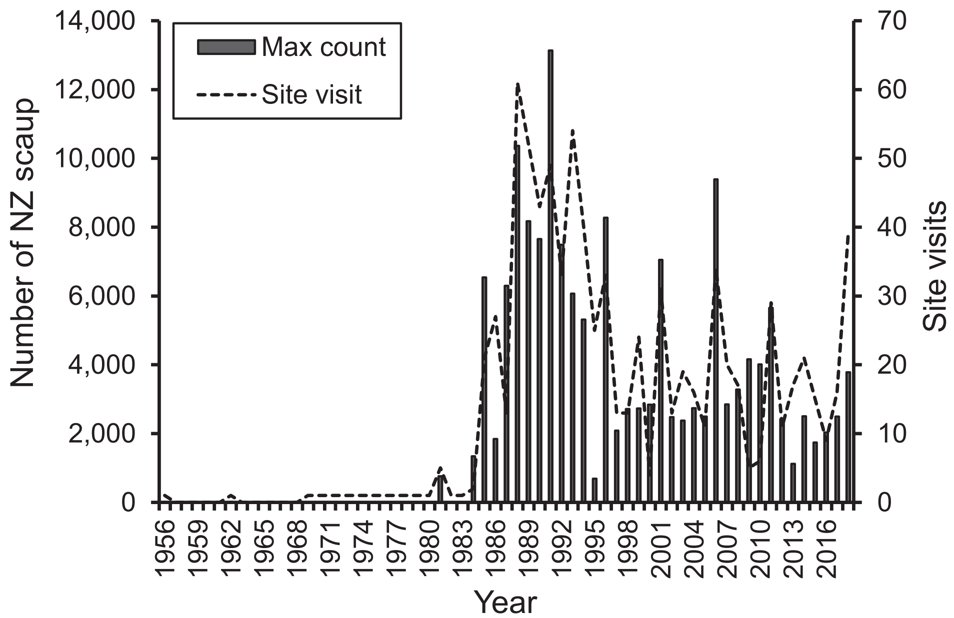

Figure 6. Number of New Zealand scaup vs number of site visits at the Rotorua Lakes, Bromley Oxidation ponds, Ashburton Lakes, Lake Alexandrina, Lake MacGregor and Lake Grasmere, 1956–2018.

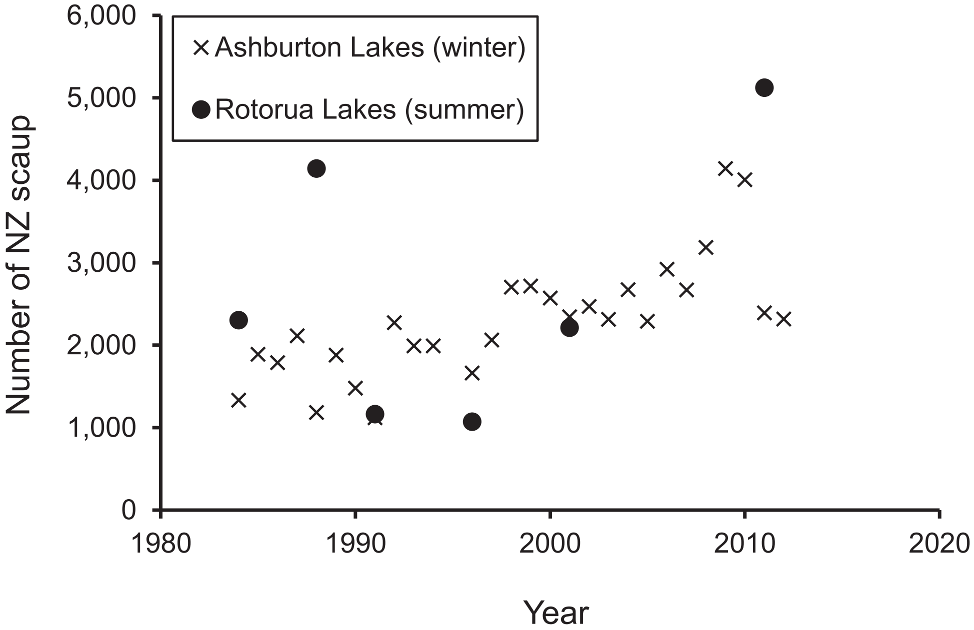

Figure 7. Number of New Zealand scaup during summer at the Rotorua Lakes (North Island) and during winter at the Ashburton Lakes (South Island). x = Ashburton Lakes 1984–2018 per annum. Closed circles = Rotorua Lakes every 5 years, 1984–2018.

DISCUSSION

Standard statistical analyses can be limited by data accuracy due to variation in count methods and count biases (Geldmann *et al*. 2016; Brown & Williams 2019; Callaghan *et al*. 2019). The main biases affecting New Zealand scaup counts were spatial, observer elevation, count effort, habitat, time of day, weather, season, and possibly gender, littoral zone area and bird movement.

Spatial and count effort bias will overestimate or underestimate the number of New Zealand scaup, counts during winter and on lakes will give the most accurate estimates, spring counts will underestimate the population and if gender is not recorded, summer counts will overestimate the population. Time of day bias will underestimate the population. Counts of wetlands or during windy days where birds may be hiding in vegetation will underestimate the population. If birds move within or between counts, counts will overestimate the population. These count biases are discussed in more detail below.

Spatial

During 2008–2018, the proportionally low opportunistic count effort in Northland, Westland and parts of Southland may reflect the lower population base and inaccessibility of sites. Systematic counts had high spatial bias towards Auckland, the Bay of Plenty and Canterbury regions which are close to large populations and accessible large lake systems. Overall, systematic count spatial bias was high and may over estimate or under estimate the number of birds.

Observer elevation

Aerial counts are commonly used for waterbird population estimates and trends (Hodges *et al*. 1996; Frederick *et al*. 2003; McEvoy *et al*. 2016; Brown & Williams 2019). The accuracy and precision of aerial waterbird counts increased with observer elevation and was more cost effective than ground surveys when the survey area and bird numbers was high (Kingsford 1999; Kingsford & Porter 2009). Low observation elevation of New Zealand scaup counts will underestimate the population."More New Zealand scaup were counted a the same site by the same observer at higher elevations (Kissling 2004)".

Count effort

The number of strongholds, the number of different habitats and the number of New Zealand scaup recorded by opportunistic and semi-systematic counts increased nationally between decades, but due to count effort bias this cannot be interpreted as a population increase. As systematic counts have a stable count effort, they have a lower count effort bias than observational counts, however as the number of observers and time spent counting was seldom recorded, there is an unknown count effort bias.

Habitat

The broad habitat classification used in this paper was limited in its scope. Wetlands, estuarine and coastal habitats may be as important for New Zealand scaup as they are for other *Aythya* species (Perry & Deller 1996), but relatively few sites were counted. Detection bias is likely to be lower on the open water and higher in vegetated areas so that overall, habitat bias will be variable.

Time of day

Many counts took place between 0600 h and 2000 h. While time of day bias can be accounted for by recording the start time and duration of counts, New Zealand scaup are semi-nocturnal and daylight counts are likely to underestimate the number of birds.

New Zealand scaup were counted at three sites during the same week of each month at the Sinclair wetlands, south of Dunedin (Kissling 2004). Counts were undertaken by the same observer during each of four sampling periods of 2–4 hours duration from 0600 h to 2200 h, during December 2001–2002. There was a seasonal bias, but no time of day bias.

In another study, New Zealand scaup were counted at five sites for three hours after dawn and three hours before sunset at Lake Grasmere and Lake Pearson in Canterbury twice a month for almost an entire year from March 1995 – January 1996 (McClymont 1997). There were no significant differences in counts by time of day during August to May, but significant differences during May and June (July was not counted). Maximum counts were recorded following dawn during winter mornings.

Weather

A wide range of weather conditions were recorded during counts. Wind speed (>5–10 knots) is a major factor as it influences bird detectability. Unless recorded, weather is likely to underestimate the population.

Season

Seasonal bias was high, with the highest number of New Zealand scaup and the least variable counts recorded during autumn and winter. Summer/spring counts were highly variable due to the interannual fluctuations in numbers of juveniles or absence of nesting females.

Bird movement

New Zealand scaup are thought to be largely sedentary (Heather & Robertson 2015). Their presence on lakes appears to be influenced by whether wetlands occur within an approximate 5 km radius (Stewart & Ward 1990). Home range estimates were inferred from a captive breeding programme at the Mount Bruce Wildlife Centre managed by the New Zealand Wildlife Service (Kear & Williams 1978). About ten birds were translocated to Lake Mangamahoe and Pukekura Lagoon (near New Plymouth, North Island) (Miskelly & Powlesland 2013). Observations during the 1970's suggested that these same birds moved about 16 km over the period of a year (Williams *et al*. 2006). After about a decade there were about 150 New Zealand scaup on Lake Mangamahoe and Rotokare/Barrett Lagoon — presumably the offspring of the original birds, about 8 km away (M. Williams *pers. comm.*; Reid & Roderick 1973).

Distribution, population status and trends

The distribution, population status and trends of New Zealand scaup is influenced by count biases and a complex relationship between physical, chemical and biological factors of which sex ratio, mammalian predation, littoral zone area, water quality and quantity appear to be the most important.

Sex ratio

A significantly skewed sex ratio is often observed for *Aythya* species (Munro 1941; Nilsson 1970) and waterbirds where the female is the sole incubator and therefore more susceptible to predation than the male (O'Donnell *et al*. 2014). There was a slight sex ratio bias in the New Zealand scaup population; however, the sample size was low, and very few counts were recorded during autumn/winter. During winter, the sex ratio of New Zealand scaup on lakes appears to be 3:1 (*pers. obs.*); however, it is possible that males displace females during this period and/or on this habitat.

Water quality and quantity

In New Zealand, agriculture, forestry, and urban development intensified between 1967 and 1991, nutrient loads and sediment increased and the general health (e.g. biodiversity, dissolved oxygen, chlorophyll-*a*, water clarity.) of over 800 lakes declined (Burns 1991).

As land continues to intensify, the quality and quantity of freshwater continues to decline (Erwin 1996; Burns *et al*. 1999; Ausseil *et al*. 2008; Drake *et al*. 2010; Marsh 2012; Belliss *et al*. 2017; Pringle & Burton 2017; Land, Air, Water Aotearoa 2018; Mueller *et al*. 2019) and the frequency and extent of bacterial disease and algal blooms continues to increase (McDowell *et al*. 2009; Ministry for the Environment and Statistics NZ 2017).

The water quantity and quality of many New Zealand scaup feeding and roosting areas is low, severely eutrophied and/or in decline. As lakes become more eutrophic over time, the birds move and populations decline. During 2005–2009, 54% of 112 New Zealand lakes were eutrophic or worse (Verburg *et al*. 2010; Ministry for the Environment and Statistics NZ 2017, 2020).

Littoral zone area

There was no relationship between the total lake area counted and number of New Zealand scaup, which supported a prior study of the Rotorua Lakes (Sachtleben *et al*. 2014). There may, however, be a relationship at a finer scale, between the littoral zone area within the diving depth range of New Zealand scaup (<10 m) and their population status.

As the lake area of the Kaipara Lakes in Auckland increased following the harvest of surrounding pine forest the number of New Zealand scaup increased (Mel Galbraith, *unpubl. data* 2014). After the pine forest was planted again, the lake area decreased and the number of New Zealand scaup decreased. The discrepancy between the national and local relationship between New Zealand scaup numbers and lake area is likely due to water depth. Most of the Kaipara Lakes are small and shallow (<10 m deep) and within the diving range of New Zealand scaup. In contrast, large (e.g. glacial lakes) have proportionally less littoral area (e.g. Lake Poteriteri, Lake Hauroko).

The relationship between the area of littoral zone and New Zealand scaup could be tested by correlating factors such as catchment area, water quality, lake bathymetry and New Zealand scaup counts. Lake bathymetry data were available from Horizon's Regional Council for Lakes Dudding, Horowhenua, Pauri, Poroa, Waipu, and Wiritoa (Elizabeth Daly *pers. comm.*). Low resolution images are available for dune lakes (Cunningham *et al*. 1953). Bathymetry and other environmental parameters are available for the Poutu Lakes from the Northland Regional Council.

Distribution and population status and trends

Observational counts, while generally spatially representative of New Zealand waterways, had variable count effort within and between locations and site visits and could not be used for population estimates. During 1956–2018, systematic counts at strongholds indicate a national population estimate of 11,000 New Zealand scaup. This suggests that the prior estimate 5,000–10,000 birds (Marchant &

Higgins 1990; IUCN 2016) is more accurate than the estimate of 20,000 birds (Heather & Robertson 2015). To improve accuracy and precision, it is recommended that a sampling design is developed and that count effort is recorded during systematic counts at existing strongholds in the Auckland, Bay of Plenty and Canterbury regions.

Based on national declines in water quality as well as declines in water birds that occupy similar habitats, the New Zealand scaup population is likely to be in decline. The Australasian crested grebe (*Podiceps cristatus*), for example, has a conservation status of nationally vulnerable and an estimated population of 600 birds (Heather & Robertson 2015). Historically common on Lake Rotoroa (Nelson), it is no longer present due to habitat loss, sedimentation, and pollution caused by farmed cattle (*Bos taurus*) and wild deer (*Cervus* spp.), impacts of introduced fish, and predation by introduced mammals as well as possible human disturbance, particularly on Lake Rotoiti, where powerboat, water-ski, and yacht races are held (Butler 1991).

The Australasian bittern (*Botaurus poiciloptilis*) has a conservation status of nationally critical, and an estimated population of fewer than 1,000 individuals (O'Donnell & Robertson 2016). Prior to the 1900s, Australasian bittern appeared to be common within (now drained) wetlands of New Zealand's major cities, but by the mid 1900s rapidly declined (O'Donnell & Robertson 2016). Wetland loss (*c.* 90% nationally) and hunting were historically major causes of declines, which, since about the 1970s, has been exacerbated by declines in water quality and predation by introduced mammals (O'Donnell & Robertson 2016).

The New Zealand dabchick (*Poliocephalus rufopectus*) has a conservation status of vulnerable and an estimated population of 2,000 birds (Heather & Robertson 2015). Historically very abundant (Buller 1888), by 1979 the New Zealand dabchick was locally extinct in the South Island (Heather 1988).

The New Zealand shoveler (*Anas rhynchotis*) is a partially protected game bird, of which an estimated 6,500 are shot annually. Birds banded at two southern South Island and two North Island sites between 1972 and 1986 had a home range the length and breadth of New Zealand (201–400 km) (Caithness *et al*. 2002). The population has been monitored annually by Fish and Game New Zealand on about 250 lakes nationwide and has a declining population of 15,000–30,000 birds (McDougall 2017).

To improve New Zealand scaup population estimates, it is recommended that 1) count effort be recorded during systematic counts, 2) wind speed (either knots or km/hr) be recorded during counts 3) observer error is quantified, e.g. by complementary ground and aerial surveys on large lakes, 4) systematic counts follow a standard count method on 20–50 lakes annually during autumn/winter, over as short a time as possible.

To interpret trends, it is recommended that 1) a more accurate habitat analysis be undertaken, e.g. by merging New Zealand scaup counts with the Freshwater Environments of New Zealand (FENZ) geo-data base (e.g. Ausseil *et al*. 2008; Lyons *et al*. 2012; Chadderton *et al.* 2014), 2) satellite, telemetry and/or banding research be undertaken to determine the home range and territory of New Zealand scaup and 3) a spatial model be developed (e.g. Kahara 2007). Priorities for research are New Zealand scaup ecology, particularly bird movement, gender, diet, predation and littoral zone quantity and quality (<10 m deep).

The ecological factors (e.g. rapid breeding rate, short life span) that make New Zealand scaup a good indicator species, also mean that it has high potential for recovery. Conservation management needs to focus on restoring the hydrology, water quality and littoral zone of freshwater habitats, alongside mammalian predator control at an appropriate (e.g. catchment) scale. Planning tools such as a seasonal register of important waterbird sites at a catchment scale (Innes *et al*. 1999) are also required. A national waterbird management and monitoring plan which includes a sampling design and standard count method on 20–50 lakes during autumn/winter would be an important first step towards achieving these aims.

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