

Productivity and survival within 2 declining populations of brown teal (*Anas chlorotis*)

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Abstract Brown teal (*Anas chlorotis*) populations at Clendon Cove and Tutaematai in Northland, New Zealand, declined catastrophically between 1993 and 1995, from 31 pairs to 1 and from 22 pairs to 8, respectively. Mean productivity was 1.8 fledglings pair⁻¹ in both populations. Fledgling survival was almost nil with only 1 of 51 identifiable fledglings surviving to recruit into 1 population. Almost all fledgling mortality occurred within 3 months of independence. Annual adult survival was 15% at Clendon Cove and 43% at Tutaematai and most deaths occurred in October-December, immediately after breeding. At Clendon Cove, significant mortality also occurred in autumn. Destruction of breeding and refuge habitat by cattle seeking moisture during periods of drought was identified as a significant cause of decline.

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INTRODUCTION

As an inhabitant of lake shores, occluded lowland wetlands, and damp forest floors in pre-human New Zealand (Atkinson & Millener 1991; Worthy & Holdaway 1994), the brown teal (*Anas chlorotis*) was a widespread and conspicuous member of New Zealand's endemic avifauna. Historically, it was resident throughout New Zealand's 3 main islands (Buller 1882) and had dispersed east to Chatham Islands (Fleming 1939). Other similar taxa occupy Campbell and Auckland Islands in the New Zealand subantarctic (Daugherty *et al.* 1999; Johnson & Sorenson 1999).

The history of the New Zealand species has been well chronicled (e.g., Buller 1888; Dumbell 1986) and pervading all modern writings (McKenzie 1971; Hayes & Williams 1982; Dumbell 1986; Williams & Dumbell 1996) are references to its rapid and extensive decline. The retreat of this species, from ubiquity to remnant, during the past 130 years, has been, arguably, more dramatic than for any other of New Zealand's endemic birds.

Northland has become the species' location of final retreat in North Island (Hayes & Williams 1982), but even there, extensive decline has been chronicled (Bell 1959; McKenzie 1971; Hayes & Williams 1982; Parrish & Williams 2001). Regional

populations appear to follow a similar pattern of slow decline and abrupt crash, as evidenced by the numbers of birds assembling annually in summer at traditional flock sites (Williams & Dumbell 1996; Parrish & Williams 2001). Once eliminated from a catchment, they seem not to reappear (Fleming 1982; author's unpubl. data).

Although predation and habitat destruction have been mooted as obvious causes of the brown teal's decline (Fleming 1982; Hayes 1994), just as they have for most declines of avian species in New Zealand (King 1984; Bell 1991; Holdaway 1999), the pathways and timing of their supposed impacts on brown teal populations have never been identified. For example, do predators impact mostly upon breeding females, as is evident for many hole-nesting passerines (O'Donnell 1996), or are fledglings and juveniles most affected? Does destruction of breeding sites have more impact than destruction of a refuge area or a feeding site?

In this paper, I report the outcomes of an investigation of timing and extent of adult and juvenile disappearance within 2 remnant populations of brown teal, and of each population's productivity. From these field data I attempt to interpret the mechanism of decline.

STUDY AREAS

The study areas on Northland's east coast, at Clendon Cove (35° 17'S, 174° 13'E) in southern Bay

of Islands, and Tutaematai (35° 20'S, 174° 18'E) at the head of Whangaruru Harbour, were lowland pastoral landscapes through which small streams draining scrub and forest-covered hills flowed to estuarine coastal margins. At the time of study (June 1993 – December 1995), the principal land use at both sites was cattle farming (meat and dairy), with sheep farming and some winter cropping being subsidiary activities.

Clendon Cove study area embraced 2 farms with differing patterns and histories of land use. On 1 (Gordons), all scrub and trees had been removed, the courses of streams straightened and their beds deepened. Most of the low-lying land was dissected by a network of drains and the coastal fringe of mangroves and other estuarine vegetation was grazed by cattle. On the other (Croydon), much of the principal waterway, the Whakawhiti Stream, retained a sparse riparian veneer of manuka (*Leptospermum scoparium*) and the stream banks, in places, remained untrampled by cattle. Several small farm ponds and areas of natural swamp, collectively termed "pastoral wetlands", added to the diversity of wetlands on the property. For the most part, areas of low-lying land were not dissected with drains. Stock on both properties relied mostly on the stream and drains for their water and trampling by stock in these watercourses was part of the farm management regime. No wetlands on these properties were fenced to prevent stock access.

Tutaematai study area was defined by the course of 2 streams which had their confluence at the estuarine margin of Whangaruru Harbour. Tutaematai Stream drained the southern face of Russell State Forest and its upper reaches were totally within forest. Where it emerged from the forest, its valley floor was narrow (0.5 km) and adjacent hills carried a mosaic of rough pasture and manuka scrub. A road running along the floor of the valley separated a number of seepages and swamps (pastoral wetlands) from the stream. For most of its length the stream was flanked by trees and its banks were covered by a curtain of mist flower (*Ageratina riparia*). The Kareawhau Stream, and its tributary Taratanui Stream drained forested hills to the west but flowed through a more extensive pastoral flat which was a dairy farm. For the most part these streams and associated pastoral wetlands were grazed to the water's edge and they lacked riparian forest.

During mid-summer (December-February), teal gathered at a traditional flocking site within each study area where they were counted annually prior to this study (Parrish & Williams 2001). The Clendon Cove flock site was at the estuarine margins of Whakawhiti Stream. At Tutaematai, the summer flock assembled on the margins of Kareawhau Stream, 100-150 m from its confluence with

Tutaematai Stream and at the upper limit of tidal influence.

METHODS

Banding

Central to the study was the compilation of sighting and activity histories of individual birds. A total of 124 teal (73 adults, 51 juveniles) was banded, caught either in August - September or January - March in streams, swamps, or on ponds. Birds were caught individually by hand, in hand nets, or in gill nets suspended across the stream or pond. All birds were fitted with a numbered metal band and most with 2 coloured plastic leg bands to permit individual recognition without recapture. Adults were aged and sexed by plumage. Juveniles were near-fledged or recently-fledged young and were sexed by cloacal examination.

Field observations and methods

When dispersed at their breeding sites, most teal were inactive during daylight. Most field observations were conducted at night during the first 4-5 h of darkness, but avoiding both full moon and new moon and periods of heavy rain. Spotlights and night viewing equipment were used to locate teal in the dark and identities of colour-banded birds were confirmed by viewing through 10 x 40 binoculars.

Initial surveys of breeding areas to determine teal presence were conducted during daytime by broadcasting taped female calls and awaiting a response. During May-July prior to nesting, this call would induce males either to appear or to call. Females sometimes responded with an inciting call (Johnsgard 1965). Males also responded to broadcast calls when attending broods but not while their females were nesting. Surveys were also conducted, to great effect, using a dog. The dog proved very adept at locating solo and cryptic males, nests, females and their broods, and at searching densely-vegetated wetlands.

Observations at flock sites were conducted during daylight from hides set in locations which provided views over most of the flock site and which permitted entry and egress without disturbance of the teal. Searches for banded individuals in attendance, and counts of numbers and ages of birds present were made at approximately fortnightly intervals December to February inclusive and were restricted to periods around high tide. All observations were conducted using 10 x 40 binoculars and 40x telescope.

Data management and analyses

From June to October inclusive I sought sightings of all banded teal at no more than 10-day intervals. Detailed case histories were then compiled for all

colour-banded individuals. From these case histories, individual and population productivity estimates were calculated (see Results for further details). Within each population, annual survival was calculated for adults as the percentage of banded individuals alive in June-October of 1 year observed again during these same months in the following year. For juveniles, annual survival was taken to be the percentage of banded individuals seen at breeding sites, or later at a flock site, in the year following fledging.

RESULTS

Dispersion and numbers of breeding pairs

Clendon Cove.

When dispersed for breeding (June-October), teal were encountered during daytime at sites along the streams, under bridges on drains, on farm dams, and amongst dense vegetation in swampy ground. Sites of encounter were holes in stream banks resulting from bank erosion around tree roots or from collapse of the bank edge, beneath a solid structure such as a bridge or hunting stand, and in dislodged drainage pipes. These sites all provided complete overhead cover. Sites in dense vegetation were generally deep within vegetation clumps where the bird could not be viewed from above. All daytime resting sites were used regularly throughout the breeding period, by both adults and their ducklings.

Thirty-one pairs and 5 unpaired males were dispersed throughout the Clendon Cove study area in 1993. Sixteen of these pairs were located on watercourses, 14 in swamps, and 1 on a farm pond. The unpaired males ranged along watercourses, each overlapping the daytime ranges of 2-4 pairs. Late in the breeding season, 3 of these males were encountered in nearby swamps.

In 1994, 5 pairs and 3 males were present in the same area; a pair on a farm pond, another in a wetland, and the remainder on the stream. None of the unpaired males were observed present after early September. In 1995, only a solitary pair remained, using a farm pond as their daytime refuge.

Tutaematai

A minimum of 22 pairs were present in 1993, all but 5 of which were dispersed along the streams. Four pairs remained in swamps and 1 pair inhabited a large dam. As at Clendon Cove, stream-dwelling pairs used holes in the banks as daytime refuges. However, dense swathes of mist flower along and hanging over the banks of Tutaematai Stream provided an abundance of cover, which was particularly favoured as refuges by pairs attending broods. The distribution and abundance of pairs at

Table 1 Productivity of brown teal (*Anas chlorotis*) pairs at Clendon Cove and Tutaematai 1993-5. ^a, 2 of these pairs raised 2nd broods; ^b, assumes no losses after C.III age).

Year	Clendon Cove			Tutaematai		
	1993	1994	1995	1993	1994	1995
No. pairs followed	24	5	1	-	15	7
No. pairs raising ducklings	18 ^a	2	1	12	13	6
No. ducklings fledged ^b	57	5	3	35	26	13

Tutaematai was determined from only 5 complete surveys of the study area and having individually banded birds in the population for the brood-rearing period only.

In 1994, 18 pairs were present, 15 of which were dispersed along Tutaematai Stream and in associated wetlands where, in the previous year, 13 pairs were encountered. On the more intensively grazed segment of the study area through which the Kareawhau Stream flowed, 3 pairs were present where 9 pairs had been found in the previous year. In 1995, 1 pair was located on Kareawhau Stream and 6 pairs along Tutaematai Stream.

Productivity

Nesting

Nine nests were located at Clendon Cove and 4 at Tutaematai. Clutch size ranged from 3 to 8 (mean = 6.5, SD=1.5). In all but 1 of these nests eggs hatched, and no unhatched eggs remained in the nests when inspected 1-5 days after hatching. The single nest failure was a consequence of my interference. Another nest was found after it had been abandoned.

Ducklings fledged

Estimates of numbers of ducklings fledged are presented in Table 1. The cryptic and furtive behaviour of adults and their ducklings ensured that only for 11 broods (7 from Clendon Cove, 4 from Tutaematai) were observations frequent and regular enough to determine survival throughout growth and final numbers at fledging. In none of these 11 broods did ducklings disappear after reaching plumage class III (C.III; Williams 1974), or about half-grown (\approx 30 days old). Table 1 lists "number of ducklings fledged" based on one or more sightings of broods at C.III or older and assumes no mortality after those sightings.

Not all pairs located in each study area during a breeding season were observed frequently enough to confirm a breeding attempt and its outcome. Data in Table 1 are from pairs whose breeding outcomes were known and in 3 instances at Clendon Cove (2

in 1993, 1 in 1994) included 2 breeding attempts in the 1 season. At Tutaematai in 1993, productivity measurement was limited to recording brood sizes of 12 successful pairs only.

Most pairs initially seen with ducklings successfully reared 1 or more. Six (25%) pairs at Clendon Cove in 1993 lost their entire brood, as did 3 (60%) pairs the following year. At Tutaematai, 3 (14%) of 22 pairs followed in 1994 and 1995 combined lost their entire broods. Overall, productivity successful pair⁻¹ (i.e. pairs raising 1 or more ducklings to C.III stage) was 2.7 (SD=1.4, $n=52$).

To estimate productivity across all pairs in each population requires the assumption that all 7 pairs obtained at Clendon Cove in 1993 for which breeding data were not obtained had an unproductive season. On that basis, productivity pair⁻¹ at Clendon Cove was 1.8 (SD=1.9) over the 3 years of study, the same as at Tutaematai (1.8, SD=1.3) in 1994 and 1995 combined.

Survival

Adults

Seven (19%) of 37 adults banded during the 1993 breeding season at Clendon Cove were located in the study area again during the 1994 breeding season. None of these 7, nor another 2 banded in 1994, was resighted in 1995. Combining data from both years, annual survival of adults at Clendon Cove was 15%. At Tutaematai, 12 (57%) of 21 adults banded at breeding sites in 1993 were present there again in 1994. Of these 12, and another 13 banded in 1994, 8 (32%) were resighted in 1995. Combining data from both years, annual adult survival at Tutaematai was 43%. This difference between study areas was statistically significant ($\chi^2=8.9$, $P<0.01$).

Determining survival from resightings of breeders at breeding sites assumes that adults did not emigrate from the population, and that they re-occupied the same, or nearby, breeding sites in consecutive years. Evidence of emigration is entirely lacking. Streams and wetlands in valleys immediately adjacent to both study populations were searched for teal in 1993 and 1994, even though there had been no reports of teal from areas near Clendon Cove for many years prior to this study (M. McGlynn pers. comm.). The absence of adjacent teal populations also precluded banding studies to determine possible immigration.

Re-occupation of previous breeding sites was confirmed by all paired banded birds ($n=25$) resighted in the study areas being at the very same breeding sites as in the previous year. Two banded but unpaired males present again at Clendon Cove (in 1994) were seen in the stream close to their former breeding sites but they were also sighted elsewhere on the stream adjacent, and in, areas oc-

cupied by remaining breeders. Similar data have been obtained on Great Barrier Island where 10 (83%) of 12 teal banded in 1994 while breeding were caught at precisely the same locations 1 year later; the other 2 were 100 m and 250 m distant but still on the same watercourse (MW unpubl. data).

Juveniles

None of 26 fledglings banded at Clendon Cove in 1993, and neither of 2 banded in 1994 was observed during a subsequent breeding period. At Tutaematai, 1 (a female) of 11 fledglings banded in 1993, but none of 12 banded in 1994, was found alive during a subsequent breeding period.

These data indicate that recruitment of locally-reared young into the breeding population was effectively nil (2%; 1 of 51). To interpret these data as indicating negligible survival of juveniles in their first year of life assumes that juveniles did not emigrate and that they all attempted to breed within their natal environs. Evidence supporting these assumptions was not obtained during this study. Although the solitary female juvenile found breeding on Tutaematai Stream was nesting about 200 m from her natal range, there are no other data from this, or the only other previous breeding study of brown teal, at Awana, Great Barrier Island (Dumbell (1987), to indicate patterns of juvenile dispersal and settlement.

Timing of mortality

Banded individuals were searched for during 2 periods each year: breeding season and mid-summer. Almost no adults disappeared during the breeding season (Jun-Oct). All but 1 of 41 banded adults (23 males, 18 females; both study areas combined) present at a breeding site with a partner at the commencement of a breeding season (June) were re-sighted at that breeding site, or at feeding sites nearby, during September and early October at the end of that season. All 51 breeding sites (both study areas combined) at which pairs were located in early June (1993,1994 combined), were still occupied by pairs at the end of September.

During mid-summer (Dec-Feb), flocks at the mouths of Whakawhiti Stream (Clendon Cove) and Kareawhau Stream (Tutaematai) contained both adults and juveniles and prolonged observations of the flocks allowed banded individuals to be identified. These observations were complemented by duplicated surveys in February of all breeding sites in each study area.

At Clendon Cove in mid-summer 1993/4, 5 different banded adults and 1 banded juvenile were identified in the small flock (max. flock size 16). Surveys of breeding sites in February located 11 banded adults (including 2 seen previously in the

flock), and no banded juveniles. In the following summer (1994/5), no teal assembled at the flock site but 3 banded adults were located during 2 surveys of breeding sites.

At Tutaematai, 9 banded adults were identified at the flock site during December - February 1993/4, and surveys of breeding sites located a further 3. Two banded juveniles were each observed once at the flock site in December and no banded teal were seen at both the flock site and at breeding sites. In the following year, 7 banded adults and 2 banded juveniles were observed at the flock site and 5 banded adults at breeding sites. One of these adults was seen at both localities.

Thus, juveniles were rarely observed during summer. Combining data for both years, only 1 (4%) of 26 banded juveniles was seen during December-February at Clendon Cove and 4 (17%) of 23 at Tutaematai. Assuming juveniles did not disperse beyond their natal catchment, these data indicate that most juveniles disappeared between fledging (September-October) and assembly at the summer flock site (December).

Resightings rates of banded adults during summer were significantly higher than for banded juveniles at both study areas (Clendon Cove: $\chi^2=10.5$, $P<0.01$; Tutaematai: $\chi^2=6.8$, $0.05>P>0.02$). Combining data for both years, at Clendon Cove 17 (37%) of 46 banded adults were seen during summer, and 23 (50%) of 46 at Tutaematai, a non-significant difference ($\chi^2=1.6$, $P=0.2$) between study areas. The inability to locate over half of the adults present at breeding sites 3-4 months previously suggests substantial mortality of adults in the immediate post-breeding period.

There was a major difference between study areas when summer resightings were compared with returns of breeders to their breeding sites of the previous year. At Tutaematai, 20 (87%) of 23 banded teal observed during summer returned to their breeding sites (data for both years combined). By contrast, at Clendon Cove only 5 (29%) of the 17 banded teal observed during summer returned to breed (another 2 banded breeders were not seen during summer). This difference is statistically significant ($\chi^2=13.8$, $P<0.001$), and highlights high mortality at Clendon Cove in the post-flocking period.

Changes in pair distribution in relation to breeding habitat

Breeding pairs disappeared more rapidly from breeding sites in pastoral wetlands (farm ponds, swamps and seepages in areas of pasture) than from those within streams. At Tutaematai, the decline in breeding pairs in 1994 occurred entirely within the confines of the intensively grazed dairy farm (4 from pastoral wetlands, 2 from stream sites), while numbers on Tutaematai Stream remained unaltered.

At Clendon Cove, pastoral wetlands were very heavily grazed during the dry autumn (Mar-May) of 1994 and most of the previous year's breeding sites there were severely denuded or obliterated. In addition, sections of stream banks were trampled by stock or modified by machinery destroying sites used the previous year by pairs and broods as daytime refuges. Thus, in 1994, only 7 of 18 pastoral wetland sites occupied the previous year by pairs or solitary males remained intact and 2 were re-occupied. Eight of 16 stream sites remained intact of which 3 were re-occupied.

Changes in the distribution of pairs in 1995 also appeared to be related to habitat destruction. Although much of the stream habitat occupied at Tutaematai in 1994 remained unmodified, pairs were conspicuously absent from all sections of stream to which cattle had ready access. At Clendon Cove, segments of stream occupied by 3 pairs in 1994 were unaltered in 1995 but no birds were present.

DISCUSSION

Two demographic processes explain the decline of the brown teal populations studied — recruitment failure and excessive adult mortality. They are processes that may have been operating for many years (Parrish & Williams 2001). Notwithstanding the productivity of breeding pairs, the apparent loss of all juveniles within months of independence resulted in both populations declining at the rate at which their breeders disappeared. And for both populations, that rate was extremely high, exceeding known natural mortality rates for more fecund continental dabbling ducks (Johnson *et al.* 1992) and hunted New Zealand waterfowl (Nichols *et al.* 1991; Barker *et al.* 1991).

Brown teal is a typical "island" waterfowl (*sensu* Lack 1970). In contrast to similar continental species such as grey teal *Anas gracilis* and chestnut teal *A. castanea* it has a low reproductive rate (Marchant & Higgins 1990; Williams *et al.* 1991), which is considered to be a response to the generally more predictable, and less widely dispersed, water and food resources of small land masses and a smaller guild of predators (Weller 1980). In addition to small clutch size (mean 5-6; Dumbell 1986; Marchant & Higgins 1990; this study), other adaptations to these ecological circumstances may include the year-round occupancy and defense of breeding and feeding sites (Williams *et al.* 1991), restricted dispersal (Dumbell 1987) and, presumably, lowered annual adult mortality. In response to an endemic suite of diurnally active, mostly aerial, avian predators (Holdaway *et al.* 2001) brown teal evolved a predominantly crepuscular-nocturnal activity cycle, spending daytime in hiding, and responded to the proximity of predators by "freezing".

Modern-day ecological circumstances are very different from those that shaped the behavioural repertoire of this species. Perhaps the most significant difference is the change in predator guild – from avian to mammal, from aerial hunting to ground hunting, from diurnally active to nocturnally active, and from sight-dependant to a reliance on hearing and scenting. Feral cats (*Felis catus*), 2 species of rat (*Rattus rattus*, *R. norvegicus*) and 3 species of mustelids (weasel *Mustela erminea*, stoat *M. nivalis*, ferret *M. furo*) are now widespread throughout most of New Zealand (King 1990), whereas the goshawk-like *Circus eylesi* has disappeared, the New Zealand falcon *Falco novaeseelandiae* is now restricted to the high country, and the Australasian harrier (*Circus approximans*), present only for the past 1000 years (Holdaway *et al.* 2001) is the only significant avian predator in lowland wetlands. In addition, dogs (*Canis domesticus*) of many varieties associated with human settlement and pastoral activity, and brushtail possums (*Trichosurus vulpecula*) (Brown *et al.* 1993; Sadleir 2000), have both been identified as significant predators of birds.

Profound though these changes have been, their combination with widespread landscape change, especially since European settlement (1840), has been catastrophic for brown teal. Despite having occurred in small alpine valleys in Fiordland (Williams & Dumbell 1996), and being retrieved as fossils from elevated cave deposits in Waitomo (Atkinson & Millener 1991) and north-west Nelson (Worthy & Holdaway 1994), brown teal was probably most common in lowland wetlands of pre-human New Zealand where, on lakes and the lower reaches of feeding streams, it was still found in great numbers late in the 19th century (Buller 1882, 1888; Potts 1882). In the conversion of New Zealand's landscape from forest to pasture, freshwater wetlands have suffered greater degradation than any other terrestrial ecosystem (Cromarty & Scott 1995). And the impact on brown teal of that conversion to pastoral farming can be glimpsed from the comments of Guthrie Smith (1927) when describing habits and status of birds on his Hawke's Bay sheep run, *Tutira*:

"...No other duck has been so adversely affected by the increase on a great scale of cattle. These iniquitous beasts, now a necessary evil on every sheep run, trample in the banks of the slow flowing shallow watercourses peculiarly the haunts of the Brown Duck, their great marauding mouths break away the friendly shade of sedges, shrubs, and grass, they tread down the Raupo beds growing tall and green from their moist beds of sud and mud. Cattle on *Tutira* have been fatal to the Brown Duck"

There was evidence of similar effect during this study. While the numbers and distribution of pairs

in stream, wetland and grazed habitats of both study areas were reduced, the initial and catastrophic reductions occurred in areas where grazing of cattle was concentrated. At *Tutaematai*, in particular, the initial decline of pairs (1993 to 1994) occurred solely in the heavily grazed landscape, and breeding sites still occupied in 1995 were those in sections of *Tutaematai* Stream to which stock did not have ready access and riparian cover remained luxuriant.

Of equal significance was where teal were found during surveys of the breeding sites during mid-summer. At *Clendon Cove* in February 1994, 3 pairs and 1 male were found along the stream, 4 pairs and 1 male in swampy wetlands and 1 pair on a stock pond. Yet, 5 months later, at breeding time, 3 pairs and 2 males were located on the stream, and only 1 pair each in the grazed wetlands and on the stock pond. At *Tutaematai* in February 1994, equal numbers (7 birds) were located at 5 sites each on *Tutaematai* Stream and on *Kareawhau* Stream within the dairy farm. Five months later, at breeding time, only 3 sites were occupied within the dairy farm, each being where cattle could not reach the stream-side grass whereas on *Tutaematai* Stream, 15 sites were occupied where the stream banks remained untrampled and the riparian curtain of mist flower remained intact. At both study areas, the grazing and trampling of cattle, especially during late summer and autumn, destroyed breeding habitat.

The mechanism of breeding site destruction in these years appears to have been an interplay between climate and the requirement of cattle for water. This study coincided with the most protracted El Niño event recorded in the 20th century (NIWA 2000). El Niño causes cold springs, summer-autumn droughts, and subsequent low water tables in Northland (Brenstrum 1999). Consequently, cattle activity is concentrated in remaining wet and swampy ground and in watercourses during summer and autumn dry spells. The potential impact of concentrated cattle grazing on brown teal was demonstrated at *Clendon Cove*, where, in spring of 1993, wet areas of luxuriant growth then used by teal as breeding sites, were, by May 1994, almost totally denuded. Two years later, those sites remained as rough pasture. Therefore, it is possible to view the "crashes" of the *Clendon Cove* and *Tutaematai* populations as an outcome of a prolonged drought and the habitat changes it induced.

However, direct destruction of breeding habitat was not the only negative interaction observed between cattle and teal. Brood-rearing and feeding habitats were also altered when farmers sought fresh grazing for breeding cows and their calves in spring. At *Clendon Cove* in 1993, for example, 5 teal pairs and their ducklings fed amongst tall veg-

etation (mostly *Juncus* spp.) in small pastoral wetlands in a single field. Within 2 weeks of cows and calves being introduced into this field, wetland vegetation had been denuded and 4 of the teal pairs had lost all of their ducklings. In 1994 at Clendon Cove, 2 pairs lost all of their ducklings under similar circumstances.

While destruction of breeding habitat has a significant role in brown teal population declines, it is not the only cause. An explanation for the demise of juvenile teal and the catastrophically high adult mortality is required.

There are no published data describing behaviour and movements of brown teal juveniles upon fledging. At Clendon Cove, I observed adult males deliberately searching hiding places within their daytime stream habitat and evicting any fledglings they encountered. Early evening observations in October included many fights and chases between adults and juveniles in streams, and vigorous fights and persistent chases by adults of juveniles at pastoral feeding sites during dark. In October and November, I encountered fledglings floating conspicuously on farm ponds during daylight, and found them hiding in rushes (*Juncus* sp.) in the middle of pasture, in piles of branches at a forest edge, amongst bales in a hay shed, deep inside drainage culverts, and sitting beneath farm bridges and hunting stands. Significantly, I did not find them either in sections of streams unoccupied by adults, or in estuarine areas at this time. It was not until late November that I first identified juveniles at the Tutaematai flock site, and then it was only after the first adults had assembled there.

These observations indicate that: (a) fledglings are actively evicted from their natal ranges; (b) fledglings are not tolerated by adults in breeding areas during the immediate post-breeding period; and (c) formation of a flock at the traditional summer flock site may require the initial presence of adults. But perhaps the most significant observations were of the locations where juveniles at Clendon Cove were found in October and November. Almost all were away from the safety of open water or occluded wetland edges. Most were in locations that mammalian predators were likely to choose as dens or daytime lairs (King 1990). Both study areas lacked large water bodies on which juvenile teal could aggregate without harassment, both contained streams along which breeding pairs were dispersed wherever riparian vegetation provided cover and refuge, and in both, potential islands of wetland refuge in pasture were being destroyed by grazing of cattle. Secure daytime refuges for juvenile teal appeared lacking at both sites and the outcome for juveniles the same at both—their almost total disappearance.

It is difficult to explain the demise of adults, es-

pecially during the post-breeding period when most were still at their breeding sites. Based upon resightings of birds at flock sites later in summer, between 50% (Tutaematai) and 63% (Clendon Cove) of adults disappeared in this interval, thus comprising 70% (Clendon Cove) and 88% (Tutaematai) of all adult losses between breeding seasons. Given that no disappearances of adults were detected at either study site during the 3-4 months of breeding, the sudden change is particularly perplexing.

The most significant post-breeding event for adult teal is their annual moult. At both study sites, moulting and flightless adults were located at the same stream or pastoral wetland sites they occupied while breeding. Flightlessness undoubtedly confers a special vulnerability and escape from fleet-footed predators such as mustelids, cats, and dogs, while feeding at night in damp pastoral sites distant from the safety of ponds or streams would be especially difficult.

Early summer is the main breeding time of cats and mustelids (King 1990), and the period during which dispersal of a cohort of newly independent and naive young mammals from their natal dens commences. It is also a time of peak activity on the farms which comprised the study sites, a period during which stock numbers and density were highest, stock movement about the farm was most frequent, and human and farm dog presence and activity extended to all parts of the farms.

Whether any, or all, of these mammals contributed to the high death rates of adults and juveniles in early summer remains conjectural because no bodies of adult teal and only 2 of juveniles (both scavenged by harriers) were encountered. Teal have been reported as being killed by cats, dogs or mustelids on Great Barrier Island (D. Barker pers. comm.), at Mimiwhangata in Northland (J. Fraser pers. comm.), during population establishment attempts (B. Green, N. Miller pers. comm.) and in anecdotal accounts (Ogle 1982; Williams & Dumbell 1996). Repetitive and persistent hunting of teal by 1 dog eliminated most of the Parekura Bay brown teal population in Bay of Islands (Parrish & Williams 2001; author's unpubl. data), and dogs are implicated in the decline of teal attending the Okiwi summer flock site on Great Barrier Island (D. Barker pers. comm.). Despite the lack of on-the-ground evidence, mammalian predators cannot be excluded as the likely agents of death of Clendon Cove and Tutaematai brown teal while they attempted to persist in their increasingly degraded habitat.

While an experimental test of the single, or combined, impacts on teal of cattle grazing and mammalian predation would provide clarity for any immediate conservation management response, causes of the demise of teal in Northland may also be rooted in historical changes of the local landscape and of its biota.

Clendon Cove and Tutaematai are typical of locations at which brown teal have lingered in Northland during the past 50 years, and from which they have now almost completely disappeared (Parrish & Williams 2001). They are both small coastal flats through which slow-flowing stream(s) meander after emerging from steep-sided hinterland valleys. The plethora of such sites throughout Northland had in common, 50-80 years ago, no possums or ferrets (Wodzicki 1950), low human population densities, mostly subsistence agriculture or small scale dairy farming (Franklin 1966), and extensive areas of scrub and regenerating forest on the hills, flats, and stream margins. The significant landscape change has been pastoralism, a consequence of extensive government investment during the 1950s and 1960s in land clearance and the application of fertilizers appropriate to region's soils, especially the podzolised yellow-brown earths (Franklin 1966). The subsequent changes converted much of coastal Northland to resemble many other parts of rural New Zealand. More intensive dairy farming on the moist flats, and an expansion of sheep and cattle farming, including a trebling of beef cattle numbers between 1960 and 1978 (Department of Statistics 1963, 1980) followed. So too did changes in the intensity of land use and human settlement (Department of Statistics 1963, 1980), changes in landscape and the distribution of lowland forest, and changes in the biota (Ogle 1982). Additions to the region's biota since 1950 that could have impacted, directly or indirectly, singly or collectively, upon brown teal include brushtail possums (Pracy 1980; Clout & Erikson 2000), ferrets (Miller & Pierce 1995), and paradise shelducks (*Tadorna variegata*) (Williams 1971). The 2 mammals have already been implicated in the declines of kiwi (Miller & Pierce 1995) and forest birds (Pierce *et al.* 1993) in Northland while the shelducks occupy and exclude teal from farm ponds within the teal's present range (author's unpubl. data). In addition, mallards (*Anas platyrhynchos*) expanded rapidly during this period, from comprising less than 10% of waterfowl hunters' bags in 1968 to over 50% by 1980 (Ogle 1982), and are now the most common and ubiquitous waterfowl in the region. Mallard have invaded most of the lowland streams to occupy space, which, until recently, brown teal had all to themselves. Perhaps, in the face of all of these changes, the persistence of brown teal in agricultural Northland was always going to be precarious, and what this study may have recorded is detail of the very same process that Herbert Guthrie-Smith (1927) observed on his *Tutira* almost 100 years before.

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