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Population decline of brown teal (*Anas chlorotis*) on Great Barrier Island

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Abstract The brown teal (*Anas chlorotis*) is a threatened duck endemic to New Zealand, whose single remaining stronghold is on Great Barrier Island. During a study at Awana from 1985 to 1987 it was concluded that the population was stable. We evaluated this proposition by analysing counts made at flocking sites between 1985 and 2001, examining their demography, and by developing an age-specific demographic model to predict the likely persistence time of the population. Numbers of teal at flocking sites declined between 1985 and 2001 though demographic variables did not change except for duckling survival rate, which increased from 26% during 1996 to 54% during 1999. Previous predictions of stability were based on an incorrect model and our model suggests that the brown teal population will halve every 4.1 years. The decline observed since 1987 could be halted by improving adult survival rate.

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Keywords brown teal; *Anas chlorotis*; population decline; demography; population model; Great Barrier Island

INTRODUCTION

The brown teal (*Anas chlorotis*) is a threatened endemic duck, which was once widespread in New Zealand (Buller 1882; Hayes & Williams 1982; Dumbell 1986). The species is now largely confined to parts of Northland (Parrish & Williams 2001) and has 1 remaining stronghold on Great Barrier Is (Hayes & Williams 1982; Dumbell 1986, 1987; Williams & Dumbell 1996; Barker 1998, 1999). Brown teal have been declining steadily since the late 19th century as a result of predation, habitat loss, over-exploitation, and disease (Williams 1962; McKenzie 1971; Hayes & Williams 1982). The total population was estimated to number no more than 2500 wild birds in 1996 (Williams & Dumbell 1996). Close to 70% of the total brown teal population now occurs on Great Barrier Is.

Unlike mainland New Zealand, there are no possums (*Trichosurus vulpecula*), mustelids (Mustelidae), or Norway rats (*Rattus norvegicus*) on Great Barrier Is. A large part of the island including several wetland habitats important to brown teal (Anon 1995), is under the stewardship of the Department of Conservation (DoC), though some significant brown teal roosting and breeding sites are on private land.

Dumbell (1987) undertook an intensive study from 1985 to 1987 at Awana on Great Barrier Island, and concluded that the population was stable and should persist indefinitely. He estimated that the Great Barrier Is population consisted of *c.* 1500 individuals, and identified functionally discrete populations confined to major valleys. Migration between valleys was infrequent, adult survival rate was high and duckling survival rate low. Dumbell's (1987) recommendations focussed on managing mainland populations and regarded the Great Barrier Is population as requiring minimal conservation management.

In this study we re-evaluated Dumbell's (1987) prediction of population persistence. First, we revisited survey sites and counted individuals to assess long-term changes in the brown teal population of Great Barrier Is. Secondly, we examined demographic variables collated from a study at Okiwi Station (Barker 1998, 1999) and compared these with those recorded by Dumbell (1987) at Awana. Finally we developed an age-spe-

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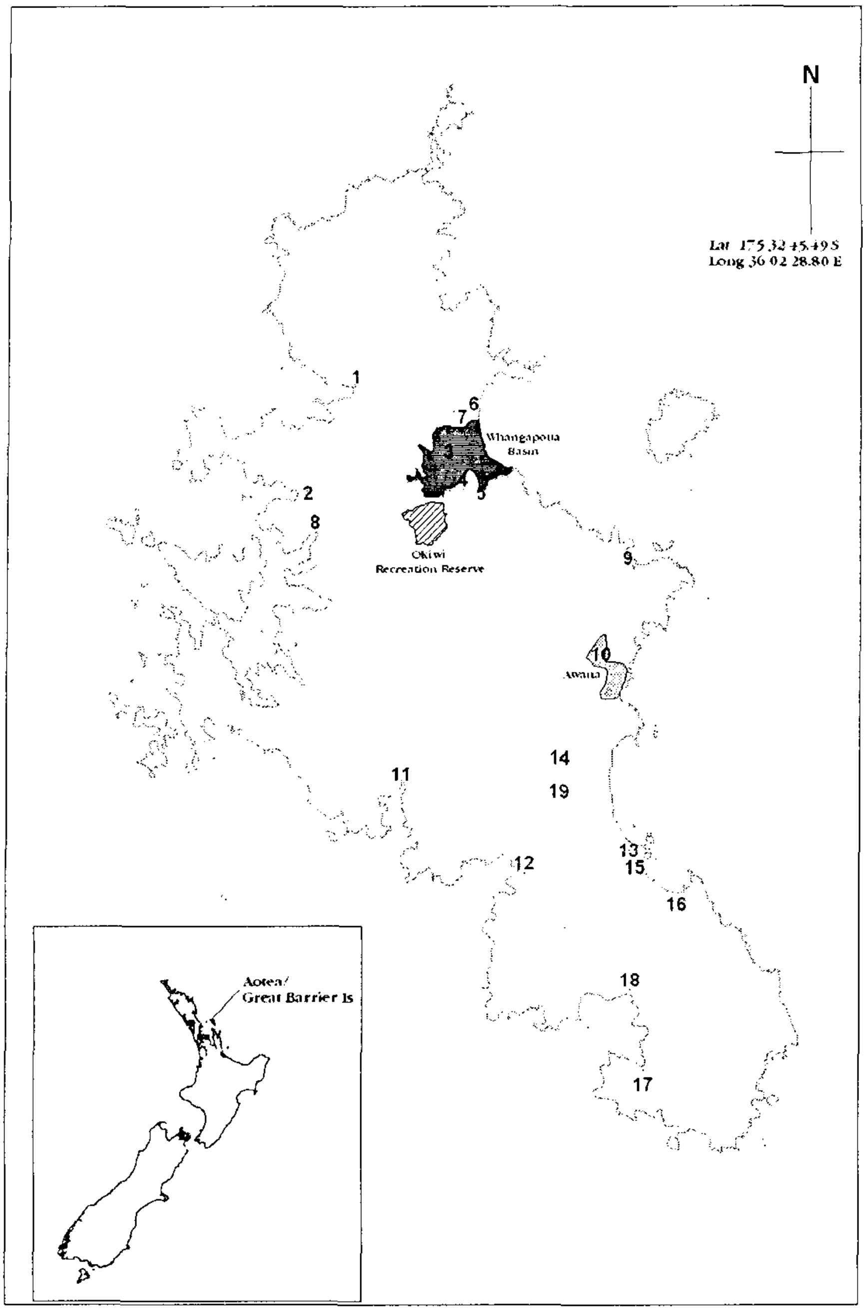

Fig. 1 Locations of flock survey sites for brown teal (*Anas chlorotis*) on Great Barrier Is. The study sites at Okiwi (present study) and Awana (Dumbell 1987) are also indicated. The numbers represent flock sites as indicated in Table 1.

cific demographic model, evaluated Dumbell's (1987) model predictions with it, made new predictions and assessed factors likely to affect the persistence of brown teal. From our results we recommend some possible management strategies.

METHODS

Flock counts and population change 1987-2000

Brown teal were counted at 19 roost sites around Great Barrier Is over 3 days each during Mar from 1994 to 1997, and in 2000 and 2001. Sites (site-specific descriptions and procedures are obtainable from the Great Barrier Is Area Office of DoC) were chosen to correspond with previous data collection (Dumbell 1987; Barker 1998, 1999). Several sub-population groups are known to exist on the island (Dumbell 1987) (Fig. 1). We calculated the annual exponential rate of change for each site as well as the total population as

$$r_a = (\ln N_{a,t+x} - \ln N_{a,t})/x \quad (1)$$

following Caughley (1977), where $N_{a,t}$ is the number at site a at time t and $N_{a,t+x}$ is the number at site a at time $t+x$. Because rates of change were not expected to be constant, we could use each annual estimate to calculate a mean estimate of rate of change for each flock and the total population over the study period from 1985 to 2001.

Demography 1987-2000

We analysed demographic variables for brown teal on Great Barrier Island from Barker (1998, 1999)

Table 1 Brown teal (*Anas chlorotis*) counts during Mar from 1985 to 1987 and 1994 to 2001 at 19 roost survey sites on Great Barrier Is.

Roost survey site	1985	1986	1987	1994	1995	1996	1997	1998	1999	2000	2001	Rate of change
1. Matairehe	24	22	26	18	10	8	9	8	20	12	9	-0.04±0.17
2. Karaka Bay (Orama)	52	56	59	36	20	22	19	30	33	20	26	-0.06±0.12
3. Whangapoa	136	170	150	130	146	16	43	12	23	9	7	-0.32±0.38
4. Okiwi Airport	-	150	155	6	0	2	0	0	0	0	0	0.03
5. Okiwi Stream	286	178	167	88	64	58	25	18	30	0	15	-0.23±0.16
6. Mabey's farm	165	162	198	117	93	122	140	110	95	76	110	-0.03±0.07
7. Burrel's drain (Okiwi Station)	-	100	240	198	195	172	150	246	177	123	145	0.06±0.17
8. Port Fitzroy	30	16	17	8	7	11	11	13	11	13	8	-0.01±0.11
9. Haratoanga	44	37	40	41	32	30	25	38	32	23	22	-0.08±0.08
10. Awana	208	255	208	171	89	29	34	70	36	53	54	-0.15±0.22
11. Whangaparapara	18	11	9	17	18	19	17	17	13	5	8	-0.24±0.12
12. Okupu and Okupu Sth	13	11	11	1	3	17	22	12	15	4	6	0.15±0.36
13. Blackwell's	75	72	74	25	30	57	67	71	56	80	68	0.14±0.09
14. Kaitoke	56	56	31	33	37	51	12	20	0	0	17	-0.03±0.36
15. Sugarloaf (quarry)	32	46	13	86	9	23	46	33	60	45	19	-0.19±0.39
16. Saltwater (Mitchener's)	86	120	73	2	18	22	21	16	11	20	25	0.27±0.31
17. Tryphena (Shoal Bay)	15	8	13	11	6	0	25	11	23	33	15	-0.08±0.27
18. Parr Beach	25	18	10	14	33	39	26	0	0	5	5	-0.06±0.26
19. Sanderson's Pond	-	26	0	-	-	-	-	-	-	-	-	-
Total Count	1265	1514	1494	982	810	698	692	725	635	521	559	-0.06±0.05

Table 2 Life-history variables recorded for brown teal (*Anas chlorotis*) at the Okiwi Station, Great Barrier Is: **A**, variables measured at the focal study area, from Barker (1998, 1999) for 1997 and 1998, respectively, and field observations by Barker during 1999; **B**, Survival estimates from banding records since 1994.

Breeding season			
A	1997	1998	1999
Clutch size	5.19 ± 0.29 (n = 17)	5.39 ± 0.26 (n = 18)	5.31 ± 0.33 (n = 14)
Eggs hatched	2.85 ± 0.61 (n = 13)	4.13 ± 0.52 (n = 15)	4.44 ± 0.56 (n = 9)
Duckling survival to fledgling	0.25 ± 0.11 (n = 16)	0.43 ± 0.07 (n = 44)	0.54 ± 0.07 (n = 55)
B	Males (n = 174)	Females (n = 202)	
Fledgling survival to adult	0.41 ± 0.26 (n = 29)	0.38 ± 0.21 (n = 43)	
Adult survival	0.50 ± 0.12 (n = 119)	0.65 ± 0.13 (n = 139)	

and Barker & Williams (2002). These studies focussed on the Okiwi Recreation Reserve and the Whangapoua Reserve (Fig. 1) and were considered to be representative of the population. Barker (1998, 1999) selected a focal study area of 195.5 ha on the south-western part of the Okiwi Recreation Reserve to determine most of the life-history variables and used individually-marked birds, birds with radio-transmitters, and a trained dog to collect his information. We also analysed data on the demographic variables at Awana during 1985 and 1986 (Dumbell 1987).

Survival

Brown teal have been banded since 1994 at Okiwi (D. Barker & M. Williams pers. comm.) and we used re-sightings since then to estimate adult and juvenile survival rates by assigning each individual annually, as present or absent, and expressing survival rate as

$$n_{t+1}/n_t \qquad (2)$$

where n_{t+1} is the number of age- and sex-specific individuals alive at time t+1 and n_t at time t (see Lebreton *et al.* 1992). We estimated adult and juvenile survival rate for males and females separately. Our survival estimates represent the worst case as we took no account of emigration or the possible failure to detect resident birds.

Population model

We used a simple matrix description to develop an

Table 3 Comparison of life-history variables (mean ± $SE_{\bar{x}}$, sample size in parentheses) for brown teal (*Anas chlorotis*) recorded at Okiwi Station during the present study (1999) with that during 1986 at Awana (Dumbell 1987). Note that duckling survival was the only significant increase*; t_s approximate t-test evaluating ratios; NE, not estimated.

	Eggs		Survival			
Breeding year, site	Clutch	Hatched	Duckling	Fledgling	Adult female	Adult male
1986, Awana	5.50 ± 0.20 (22)	3.50 ± 0.50 (22)	0.26 ± 0.05 (76)	NE	0.67 ± 0.10 (21)	0.61 ± 0.09 (29)
1999, Okiwi	5.31 ± 0.33 (14)	4.44 ± 0.56 (9)	0.54 ± 0.07 (55)	0.39 ± 0.06 (72)	0.65 ± 0.13 (139)	0.50 ± 0.12 (119)
Statistic	t_{35} = 0.49	t_{30} = 1.25	t_s = 3.28*	-	t_s = 0.18	t_s = 1.07

Table 4 Model sensitivity to changes in demographic variables. We illustrate the change required in a variable if all other variables are kept constant to achieve an exponential growth rate (r) of zero i.e. a stable population. Feasibility reflects on the likelihood of management actions achieving change required to achieve population stability.

	Variable					
	Proportion of		Survival to adult		Adult survival	
	Adults attempting breeding	Eggs hatching	Duckling	Fledgling	Male	Female
Model input	1.0	0.75	0.54	0.39	0.50	0.65
Input needed for r = 0	Cannot increase input	1.0 (r = -0.06)	0.85	0.61	0.80	0.82
Change		0.25	0.31	0.22	0.30	0.17
% change		50	57	56	60	26
Feasibility		No	Unlikely	Likely	Likely	Yes

age-structured population model that was transcribed as follows to represent number of adults as

$$N_{a,t+1} = N_{a,t} f_a \, s_a \, s_d \, s_{sa} + N_{a,t} \, s_a \quad (3)$$

where $N_{a,t+1}$ is the adult population at time $t+1$, $N_{a,t}$ the adult population at time t, f_a age-specific productivity of adult females, s_d age-specific survival rate of ducklings during the first seven weeks following hatching, s_{sa} age-specific survival of sub-adults to adults over ten months, and s_a age-specific survival of adults annually. Productivity of adult females was calculated as

$$f_a = l \, f \, p \, b \quad (4)$$

where l is clutch size, f adult sex ratio expressed as proportion females, p proportion of eggs hatching, and b proportion of adult females attempting to breed. f was set as 0.5 and b as 0.75 (Barker & Williams 2002). We evaluated sensitivity of the model by recording the change required in a specific demographic variable while all other variables were kept constant to achieve an exponential growth rate (r) of zero, i.e. a stable population (Akçakaya et al. 1999). We used data collected during 1999 for the model, as the most recent demographic variables will be most representative of the current demography of the population. Data collected at Awana during 1985 and 1986 were used to evaluate predictions for the period 1988 to 1999.

RESULTS

Flock counts

Brown teal on Great Barrier Island have been declining at an exponential rate of –0.06 ± 0.05 (n = 8) annually since 1985 (Table 1). Brown teal numbers have declined substantially at all but 2 sites and the total count during 2001 was *c.* 1/3rd of that 15 years earlier.

Demography

No significant differences in clutch size ($F_{2,46}$ = 0.13, P = 0.88) and number of eggs hatched ($F_{2,34}$ = 2.12, P = 0.14) nest^{-1} were found between the 3 breeding seasons (Table 2). Survival from hatching to fledging has increased since 1997 and was significantly higher during 1999 than the other 2 years (t_s = 2.13, P = 0.03, approximate t-test to evaluate differences between proportions, Sokal & Rohlf 1983). No significant differences were found between male and female fledgling survival to adult (t_s = 0.26, P = 0.80), but significant sex-specific differences were recorded for adults (t_s = 2.44, P = 0.02) with only 50% of the males surviving annually as against 65% of the females.

Life-history variables recorded during 1986 by Dumbell (1987) were similar to those recorded during this study, with the exception of duckling survival, which was significantly higher ($P < 0.01$) during the later study (Table 3).

Modelling the population
Our model predicts that the population will decline at an exponential rate of –0.17 annually, which is substantially faster than the observed rate of –0.06 per annum. Our model was most sensitive to female survival rate (Table 4).

Our predictions for brown teal at Awana during the period 1988 to 1999 approximated the observed decline, but our model consistently underestimated the actual counts ($t_7 = 3.58$, $P = 0.01$). This was in stark contrast to the model predictions of Dumbell (1987) which predicted a stable population (Fig. 2).

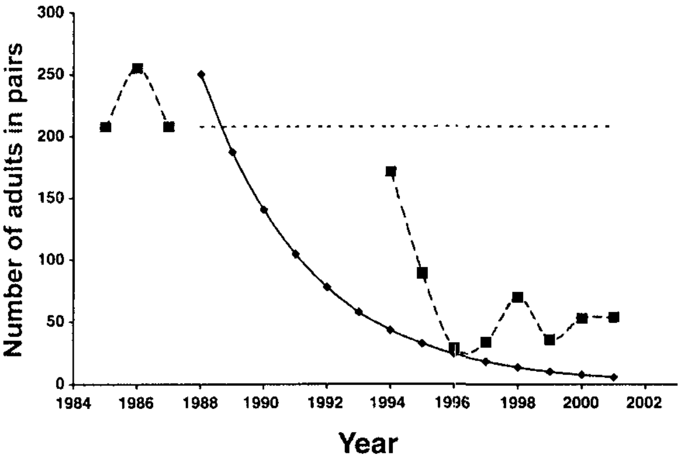

Fig. 2 Comparative outcomes of predictions for numbers of brown teal (*Anas chlorotis*) since 1987 at Awana using the life-equation model of Dumbell (1987) (broken line) and the demographic model constructed during the present study (solid line, diamonds) with the actual flock counts (dashed line, squares).

DISCUSSION

The data in Table 1 show that the stable population predicted by Dumbell's (1987) model was wrong: brown teal populations have decreased by *c.* 2/3rds since 1987, with 13 of the 19 surveyed flocks recording average annual declines since 1985. Rates of decline on Great Barrier Is between 1987 and 2001 were slower than the -0.14 ± 0.11 ($n = 10$) recorded for mainland populations at Mimiwhangata in Northland from 1988 to 1999 (Parrish & Williams 2001). The difference between Dumbell's (1987) prediction of stability and the actual population reduction needed explanation, and the implications for the persistence of brown teal on Great Barrier Is needed to be clarified.

Firstly, the results may highlight an inappropriate counting technique. Barker (pers. comm.) recorded many teal away from flocking sites while flocks were counted. Parrish & Williams (2001) recorded birds in 1/3rd of known breeding territories along streams and swamps during Feb 1995. They also noted that 25 – 30% of known adults at Clendon Cove and Tutaematai in Northland, were still at breeding territories during Feb 1994. Clearly, a large proportion of the population is not present at a particular time at a flock site. Populations may have been underestimated using the flock counting technique. However, the population could only have stayed stable if the proportion of non-flock individuals increased to compensate for the observed decrease in flock counts. This is highly unlikely given the social dynamics of the population (Dumbell 1987). In our view the trends observed in flock counts are a true reflection of trends in the total population.

Secondly, the demography of the population may have changed since Dumbell's (1987) study. We recorded no significant changes between 1986 and 1999 in clutch size, number of eggs hatched, nor in female or male adult survival rates. Duckling survival to fledging was actually significantly higher during the 1999 breeding season. On the basis of these similar demographic variables, the population during 1999 should also have been stable.

Third, using demographic varables, Dumbell (1987) estimated the average lifetime productivity of a bird (fledglings produced during an individual's life) using Burkitt's estimate of life expectancy:

$$l_a = (2-q_a)/2q_a \quad (5)$$

where $q_a=1-s_a$ and s_a = adult survival rate (Seber 1973). He calculated mean life expectancy to be 2.2 years and estimated lifetime productivity as 1.0 from $(l\ s_d\ l_a)/2$ (Dumbell 1987). As a result, the population would replace itself and therefore was stable.

Inherently, the life-equation model assumed that each adult breeds within its 1st year and age-specific survival is constant after fledging. However, both these assumptions were probably violated. In the 1st instance, captive brown teal can breed in their 1st year (Reid & Roderick 1973), but wild populations have a significant non-breeding component in the population. For instance, broods are observed during most months of the year (Marchant & Higgins' 1990), while Barker (1998, 1999) recorded a large proportion of females present at 2 flock sites during peak breeding around Whangapoua estuary (never less than 32% of total known number of females). In the 2nd instance, we found lower fledging survival to adulthood than adult survival. In addition, considering the number of fledglings as a measure of replacing adults is incorrect: fledglings will only have the potential to breed once they have reached adulthood and only then has an adult been replaced. If Dumbell (1987) considered this, life-time productivity would have been estimated as 0.39, which would predict the observed decline since 1987.

In contrast to Dumbell's life-equation model, our matrix model, which incorporates age-specific survival rates, predicts dramatic declines in the brown teal population on Great Barrier Is. The demographic variables estimated during 1999 predict a halving of the population every 4.1 years (doubling time = $0.6931/r$, r rate of change, if r negative the equation reflects halving time: Caughley 1977). Brown teal will go extinct on Great Barrier Is by 2025, given 1999 conditions and demographic parameters.

Note that our matrix model predicted the observed decline at Awana since 1986 using input demographic variables estimated by Dumbell (1987), but consistently underestimated population size as a result of underestimation of survival rate (by including individuals that may have emigrated rather than died – see Lebreton et al. 1992). Our model should therefore be seen as a worst-case scenario.

A prediction of population stability during 1985/86 (Dumbell 1987) was based on an inappropriate model of brown teal population dynamics. The consequences were severe because the recommendation of continued monitoring — even though the population was thought to be stable at the time, see Dumbell (1987) — was ignored and flock counts were only re-instated 7 years later. By 1994 total flock counts had declined by 1/3rd, which resulted in a research project from 1996 to 1999 (Barker 1998, 1999; Barker & Williams 2001) that generated the present estimates of demographic variables. The history and subsequent data on the demography of brown teal should enable management that would halt the decline in the brown teal population on Great Barrier Is.

The population is most sensitive to changes in the survival rate of adult females, with an increase of 17% in survival rate likely to result in stabilisation of the population. Note that in the 1st instance, survival rate is underestimated (see Lebreton *et al.* 1992), hence the population should increase at much lower rates than the 0.82 survival rate suggested by the present study. Secondly, our analysis kept all other variables constant while evaluating changes in female survival rate. In practice, managing for increased female survival rate will have positive consequences for other age-specific parameters in the population and is likely to increase the survival rate of fledglings as well as adult males. Designing a management programme to enhance female survival rate is therefore likely to result in rapid responses in the population.

The most important factors affecting productivity are number of breeding females, clutch size, nest and egg success, and duckling survival (Johnson *et al.* 1992; Barker & Willliams 2002). However, these factors are not the key variables for the total population. Maximising productivity through improving hatching rate and duckling survival was unlikely to stabilise the population, primarily because of low adult survival rates. Improving productivity, by whatever mechanisms would benefit the population as a whole, but its benefit would be less than that obtained by improving adult survival.

The obvious question is what are factors are limiting adult survival. The most likely factor is predation as has been surmised for mainland populations (Hayes & Williams 1982). Although Great Barrier Is has fewer pest species than most of New Zealand (Anon 1995), a significant suite of species is still present, including rodents (Muridae: *Rattus norvegicus*, *R. rattus*, *Mus musculus*), cats (*Felis catus*), and dogs (*Canis familiaris*). Anecdotal observations (D. Barker, pers. comm.) and reports (Barker 1999) suggest that adults are killed by cats, dogs, and pukeko (*Porphyrio melanotus*). The current management practice of implementing an intensive pest-management program directed at controlling all 3 pest species (David Agnew, Great Barrier Island Area Office, DoC, pers. comm.) should allow a higher adult survival rate that could lead to recovery of this population. Predator control would also enhance the survival rates of fledglings and ducklings, which in turn could result in more rapid recovery of the population.

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