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Changes in bird abundance following Common Myna control on a New Zealand island

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We censused landbird populations on a small island during a year of intense trapping of the Common Myna *Acridotheres tristis*. We successfully removed mynas on Moturoa Island, Bay of Islands, with populations on the island decreasing in most areas, while holding steady on other, nearby islands where no trapping was conducted. The populations of many other bird species increased coincidently with the removal of mynas. This was most notable in the Tui *Prosthemadera novaeseelandiae*, Grey Warbler *Gerygone igata*, and Blackbird *Turdus merula*. Of 60 species-route comparisons, we found that 23 (38%) increased, 33 (55%) had no change, and only four (7%) decreased. The relative role of rats *Rattus* spp. and succession is also discussed. The historical decline of many species in the North Island of New Zealand may have been related to the concomitant increase of the myna, and control of this species may be warranted in some cases, especially where restoration of the native fauna is the objective.

Key words: Invasive species, Common Myna, New Zealand, Island, Population census.

INTRODUCTION

HUMAN introduction of birds to New Zealand and throughout the Pacific is one of many factors which have likely exacerbated the decline and eventual extinction of much of the native avifauna. There is, however, little evidence of the actual role that introduced birds have had in native bird declines. In this study, we examine the possible effects on an island's bird assemblage of removing an introduced bird.

The Common (or Indian) Myna was introduced into New Zealand in the 1870s (Bull *et al.* 1985). While initially found in both the North and South Islands, since 1890 it has been found only on the North Island. Now it is only common in the northern half of that island. The myna appears to have spread only slowly up the North Island (Long 1981). It reached the Bay of Islands about 1960 (Heather and Robertson 1996). Although most abundant in modified environments, the myna is sympatric with native and other introduced birds throughout most habitats in northern New Zealand, including native forests (Pierce *et al.* 1993).

Although the effects of mynas on other species have not been supported by quantitative studies, negative interactions have been often cited in the literature from many areas from throughout the Pacific, as well as in its native range (e.g., Mason and Maxwell-Lefroy 1912; Manson 1921; Cunningham 1950; MacDonald 1951; Stoddart 1956; Wright 1962; Wilson 1973; Moeed 1975; Watling 1975; Wilson 1975; Moon and Lockley 1982; Hay and McCormack 1984; Bull *et al.* 1985; Seitre and Seitre 1992; Simberloff 1992; Dhanda and Dhindsa 1993). There is some evidence from these sources that mynas interact as predators or competitors with other birds. This includes observations of destruction of eggs, chicks, and nests, and the chasing of adult birds attempting to rear young within myna territories. It is their alleged direct interference competition at food and nesting sites, however, which has earned the mynas almost universal dislike (e.g., Wilson 1975).

Observations of isolated acts of competition or predation do not validate any general conclusions about the impact of the myna on a variety of species. However, if predation and interference competition by mynas were important factors in limiting resident bird populations, the abundance of affected birds should increase following myna removal. We tested this hypothesis over one year by censusing the entire bird community on the island where mynas were being removed. We also demonstrated the possible importance of the removal by monitoring mynas on other islands where they were not controlled.

METHODS

Study design

Bird communities were censused at five sites in the Bay of Islands in northern New Zealand (Fig. 1), with similar habitats but varying histories of myna control. Primary work was on Moturoa Island, where mynas were controlled for the year of the study (1995). On this island, bird censuses had been conducted by Ralph (unpubl. data) for 15 years prior to the myna control, as summarized in Tindall (1996). At some additional sites censuses were also conducted in 1995: a mainland site (Crater or Wharengarere Bay), and at two island sites (Motu-rua and Urupukapuka) where mynas were uncontrolled. On Roberton Island they had been controlled to an extent for the five years previous to censusing (1987–1994).

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Bird census technique

Birds were censused by intensive point counts, a method used primarily for inventory (e.g., Ralph *et al.* 1993). Census stations (15 per census route) were 75 to 100 m apart, generally positioned to census fully an area of continuous habitat. A small proportion of individuals were detected from more than one station. These were a relatively small per cent of all observations, and for purposes of this study we considered each station an independent sample. Every attempt was made to avoid double counting individuals at a single station. Detections of all landbirds seen or heard at all distances were recorded for 10 minutes. Censuses were carried out on reasonably fine days; that is, no census was carried out in rain heavier than drizzle or in wind greater than 20 kph. Birds flying over but not landing within 100 m were not used in analyses. Censuses began within 20 minutes of sunrise and lasted approximately three hours. Each station was censused usually once per month.

The basic datum used for this study was the number of detections of each species recorded at each station each morning. As is usual with population data, we then used the natural logarithm of this datum to calculate the mean on each route on each day (the species-route mean) for further analyses, primarily *t*-tests (SAS 1996). For figures and tables we back-transformed the species-route means from logarithm to normal.

Effect of multiple *t*-tests

We chose to use a large numbers of *t*-tests to analyse the data, which effectively does not test species individually, and has been termed "pseudofactorialism" by Hurlbert and White (1993). The basis of their argument against this approach is that a correction for multiple tests might be useful to maintain an experiment-wide p-value of 0.05 (e.g., a Bonferroni or a modified Bonferroni correction). While widely used, this approach generates intense debate in the statistical, medical, and ecological literatures. To our knowledge, there is no widely accepted best practice, and to use the Bonferroni correction in these circumstances is, at the least, controversial (as suggested by Perneger 1998; Moran 2003; and Garcia 2004). We side with Moran (2003) and forgo the use of a correction.

Study areas and sampling

Bird censuses were conducted along five routes on Moturoa Island (148 ha), usually on a monthly basis, from January to December 1995.

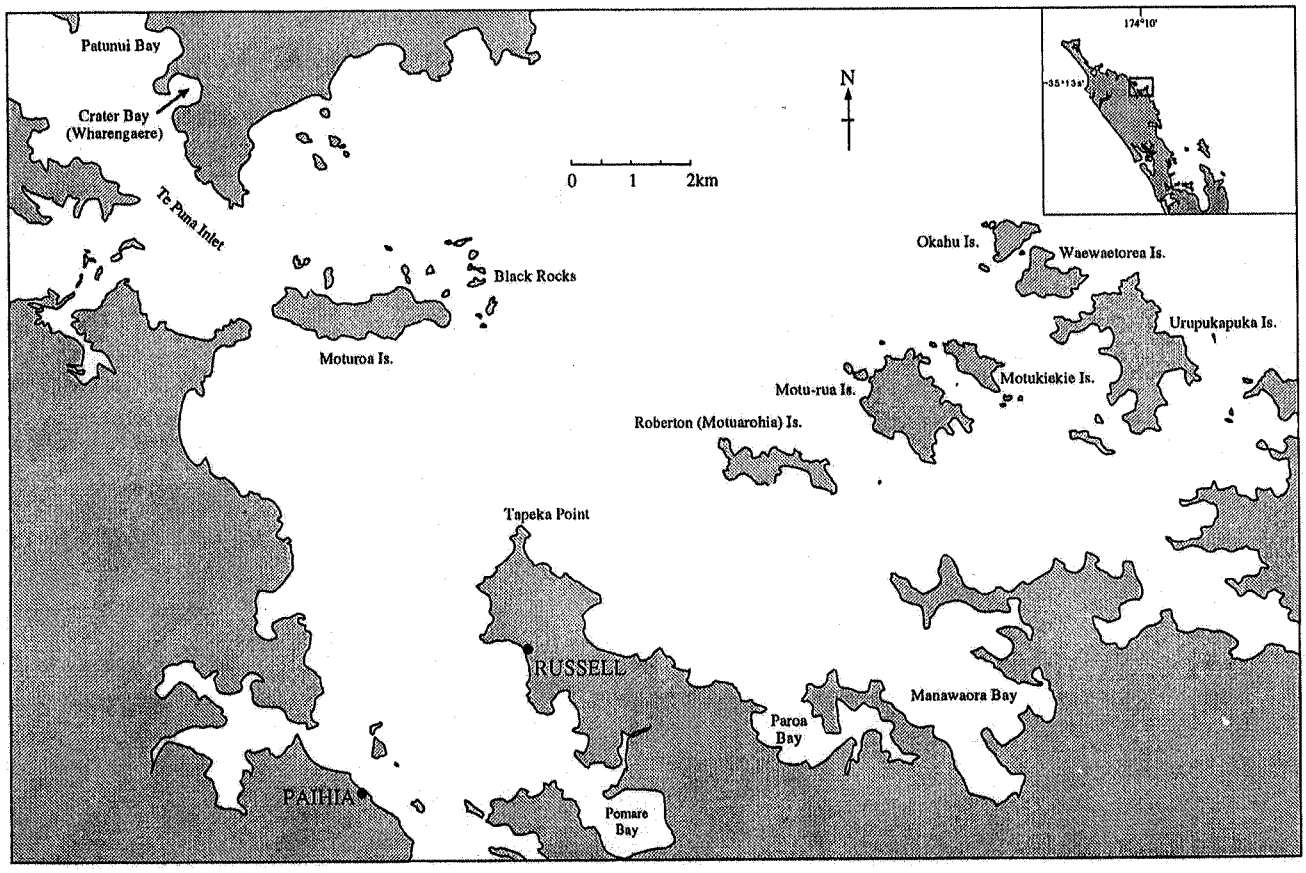

Fig. 1. Map of Bay of Islands showing locations of islands studied as well as location of Crater (Wharengarere) Bay.

The island is a privately owned, permanently inhabited farm which has been partly grazed since the 1860s (Spicer 1993). Beginning in 1980–82, a total of about 45 ha has been fenced and allowed to regenerate as native forest or bush. These bush areas and others (such as a number of small ponds and fence rows) were enhanced by the time of the study by the planting of more than 25 000 plants, largely of native species. The Norway Rat *Rattus norvegicus*, the Black Rat *R. rattus*, and the Stoat *Mustela erminea* were poisoned and trapped at a relatively low level annually over the previous ten years. At least the rats were apparently eradicated from Moturoa in 1993, through an extensive poisoning and trapping effort by the owners of the island.

On Moturoa, mynas were controlled beginning with pilot efforts in midsummer, January 1995, using various combinations of poisoned bait and decoy birds in traps in the island's grassland areas. By June we found that trapping was most effective, and intensified the effort (Fig. 2). The resident population of breeding birds was essentially removed by August 1995. Additional non-breeding or transient birds continued to be captured through mid-summer. Methods of control are detailed in Tindall (1996).

Bird censuses were also conducted from March to December 1995 on six other routes, five on nearby islands and one on the mainland. For this paper, we include primarily the results of myna surveys on these other routes; the many other species and their lack of change without concentrated myna removal are detailed in Tindall (1996). Two routes were on Moturua Island (162 ha), part of the Bay of Islands Maritime Park, which has not been grazed by stock for more than a decade. Both Norway and Polynesian rats *R. exulans* are apparently present (Moller and Tilley 1986) and are poisoned prior to peak visitor periods in summer (Mike McGlynn, pers. comm.). Mustelids have been trapped occasionally. Two routes were placed on Urupukapuka Island (208 ha), also part of the Park. Cattle were removed from much of this island in 1993. Formerly-grazed areas have been allowed to regenerate naturally, although some pohutukawa *Metrosideros excelsa* trees have been planted. Norway Rats are present (Moller and Tilley 1986) and are poisoned annually around designated camping areas (Mike McGlynn, pers. comm.). Mustelids have been trapped occasionally. The one route on Roberton (Motuarohia) Island (70 ha) was on the western (42 ha), private portion of the island. The owner has been revegetating the island for the past 25 years. Poisoning operations to control rodents (primarily Norway Rats) were carried out periodically, and mustelid traps are maintained year-round. Mynas were poisoned in this part of the island from 1989–1994, though none were removed during 1995 (Mike Alexander, pers. comm.). One route, "Lantana Coast", was at Crater (Wharengarere) Bay, the only mainland site. It comprises about 3 km of coast, with a combination of residential area, farm land, and regenerating forest. We made no attempt to control rodents and mustelids here.

Possible role of independence of stations

Given the 75–100 m distance between stations, some of the more vocal species, such as the Kingfisher, Song Thrush, Tui, and myna, were at times likely detected at more than one station (scientific names for bird species are below). This potential pseudoreplication would reduce variances within a route, increasing likelihood of a significant difference between months. In

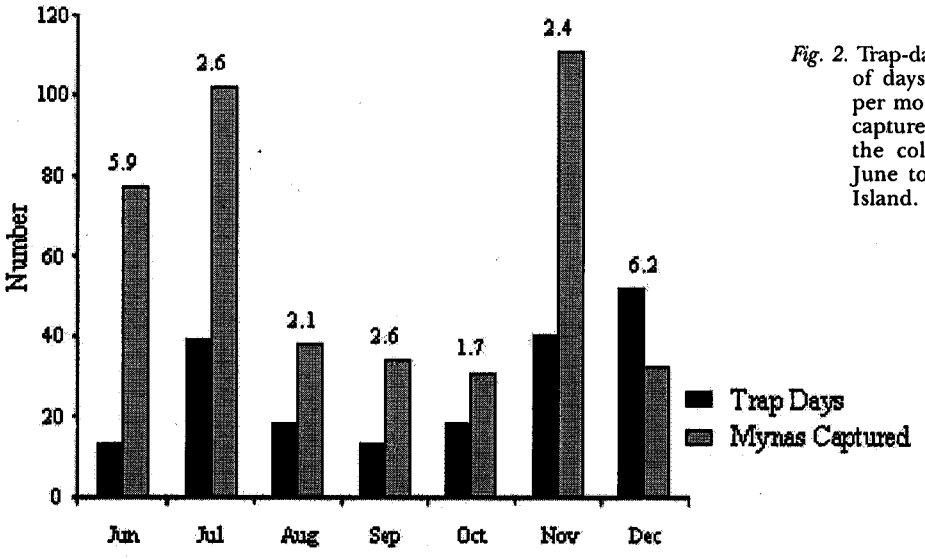

Fig. 2. Trap-days (number of traps × number of days), number of mynas captured per month, and the number of mynas captured per trap-day (shown above the columns for each month) from June to December 1995 on Moturoa Island.

general, background noise and undulations in terrain prevented double-counting. We estimate that less than 10 per cent of all observations could have overlapped between stations. To compensate for the reduction in independence for vocal species, we could raise the alpha level to $p < 0.01$ from the conventional $p < 0.05$. For these vocal species, this would reduce the significant changes only for the Kingfisher, from three to one, and in the Tui, from four to three. For all species, 16 of the 23 species-route significant increases during 1995 were at an alpha level of $p < 0.01$ or more. We (and Prof. Howard Stauffer, pers. comm.) feel that $p < 0.05$ is certainly adequate for the other nine less vocal, or even confiding, species.

Vegetation

Three routes on Moturoa (Old Bush, South Face Bush, and Stream Bush) were largely in regenerating native trees and shrubs, vegetation known as "bush", though they did traverse or border grassland as well. In the "bush routes", the Pohutukawa was an important emergent and flowering species, and the lower-growing Kanuka *Kunzea ericoides* and Manuka *Leptospermum scoparium* dominated the canopy. Kamahi *Weinmannia silvicola* and Mahoe *Melicytus ramiflorus* were also important canopy species. The sub-canopy was dominated by Hangehange *Geniostoma rupestre*, the tree fern Ponga *Cyathea dealbata*, the black tree fern Mamaku *Cyathea medullaris*, Karamu *Coprosma macrocarpa/robusta*, Mahoe, and *Coprosma rhamnoides*. Hangehange, Ponga, and Karamu appeared to be the most important shrub species, while grass species were unimportant in the ground layer.

The two "grassland routes", Homestead Paddock and Pine Paddock, were a mix of pasture for sheep and edges of large patches of established and corridors of regenerating bush. Here, the introduced Monterey Pine *Pinus radiata* was common. In both the adjacent bush and regenerating areas, Kanuka was the most prevalent canopy species, and Pohutukawa was fairly common. These routes mostly lacked the sub-canopy and shrub species of the bush routes. The habitats of the routes at the other locations were broadly similar to the Moturoa routes. All had a mix of regenerating bush and grasslands, with most trees and shrubs less than 50 years old. The biggest difference was at Crater Bay (Lantana Coast) that had extensive stands of the introduced shrubs Gorse *Ulex europaeus* and Lantana *Lantana* spp., and the Vine Moth Plant *Araujia sericifera*. The introduced Brush Wattle *Paraserianthes lophantha* was a common tree in most routes off Moturoa Island.

RESULTS

The effect of myna control on mynas

We removed 457 mynas from Moturoa during 1995 (Fig. 2), primarily from June to December. Mynas were trapped extensively along the margins of the bush areas. On Moturoa, in general, we found an increase in myna detections in late summer, followed by a decline in the winter (Fig. 3). Detections remained low in all Moturoa routes throughout the winter and continued low through early spring, as myna control was well underway and appeared to be effective (Fig. 3). Specifically, detections in December (by mid-summer) were significantly lower than the previous January ($p < 0.05$) in all three bush routes (Table 1). They were not different in the two grassland routes, Homestead and Pine Paddocks. Here, a continual influx of non-breeding birds might have maintained the numbers (see Discussion below).

Most of the routes off Moturoa Island (and thus without myna control in 1995), had fluctuations in myna populations similar to the Moturoa grassland routes: that is, an increase in detections in late summer, a decline over the winter, followed by an increase in spring and summer (Fig. 4). Routes with this pattern included Crater Bay, Urupukapuka Scrub, Urupukapuka Bush, and perhaps Motu-rua Stream. Censuses were not conducted in Roberton Bush or Motu-rua Bush in December, so the summer increase is less apparent.

Response of the 12 most common bird species to myna removal

Based upon the number of detections on Moturoa Island, averaged over the entire year, the 12 most common bird species (six native and six introduced) were selected to investigate the correlates with myna removal (Table 1).

Overall, we found that many species increased over the year, coincident with the myna control. Among the twelve species on the five Moturoa routes, for a total of 60 comparisons (Table 1), we found: an increase in 23 (38%) species-routes comparisons; no change in 33 (55%); and a decrease in only four (7%). We would have expected a significant change in only about three by chance alone, with the usual $p < 0.05$ criterion. Thus the decreases were at chance levels, whereas the increases were much more common than predicted by chance.

We found no consistent pattern of population changes on Moturoa that could be attributed to a species being either native or introduced, in relation to ecological niche, or between species in grassland (Homestead and Pine) and bush (Old, South-face, and Stream) routes.

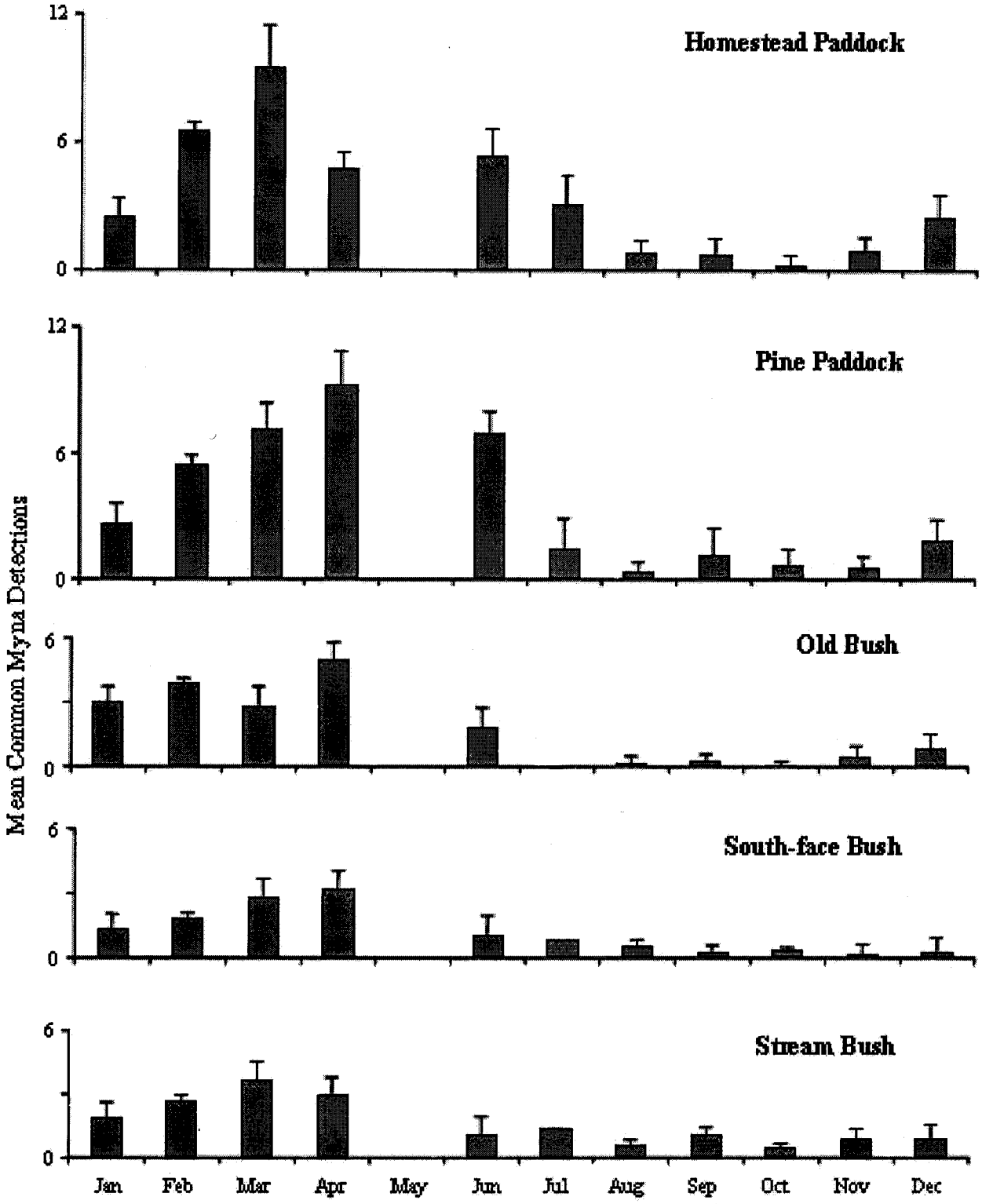

Fig. 3. Mean (and standard error) of Common Myna detections in the two grassland and three bush routes on Moturoa Island during 1995.

Table 1. Mean level of detections (and standard error) per 10-minute station count before and after control of the Common Myna for the myna and the 12 response species for January and December 1995 at the five Moturoa Island census routes, and *t*-test results.

Species		Homestead Paddock	Pine Paddock	Old Bush	South-face Bush	Stream Bush
Common Myna	Jan	1.25 (0.65)	1.29 (0.69)	1.38 (0.56)	0.83 (0.68)	1.05 (0.46)
	Dec	1.25 (0.73)	1.06 (0.69)	0.57 (0.56)	0.20 (0.46)	0.60 (0.52)
	t	0.035	0.920	3.943	2.929	2.526
	P	0.9722	0.3654	0.0005**	0.0076**	0.0176*
Native Species						
New Zealand Kingfisher	Jan	0.23 (0.34)	0.00 (0.00)	0.18 (0.32)	0.62 (0.29)	0.14 (0.29)
	Dec	0.00 (0.00)	0.35 (0.40)	0.12 (0.32)	0.32 (0.36)	0.40 (0.40)
	t	2.646	-3.388	0.558	2.501	-2.039
	P	0.0192*	0.0044**	0.5812	0.0189*	0.0519
Welcome Swallow	Jan	0.75 (0.69)	0.87 (0.53)	0.05 (0.18)	0.00 (0.00)	0.17 (0.35)
	Dec	0.45 (0.53)	1.09 (0.66)	0.29 (0.51)	0.82 (0.51)	0.30 (0.48)
	t	1.325	-0.991	-1.721	-5.955	-0.904
	P	0.1965	0.3306	0.0962	0.0001***	0.3743
Fantail	Jan	0.79 (0.51)	0.51 (0.55)	0.83 (0.59)	0.58 (0.50)	0.83 (0.54)
	Dec	0.65 (0.50)	1.03 (0.40)	0.96 (0.48)	1.24 (0.24)	1.05 (0.32)
	t	0.748	-2.959	-0.659	-4.557	-1.379
	P	0.4606	0.0062**	0.5154	0.0001***	0.1814
Grey Warbler	Jan	0.58 (0.67)	0.29 (0.43)	1.06 (0.45)	0.66 (0.40)	0.76 (0.49)
	Dec	0.84 (0.52)	0.84 (0.44)	0.97 (0.51)	1.43 (0.19)	1.18 (0.32)
	t	-1.220	-0.480	0.510	-6.740	-2.732
	P	0.2333	0.0017**	0.6141	0.0001***	0.0116*
Tui	Jan	0.28 (0.35)	0.09 (0.24)	0.26 (0.39)	0.20 (0.33)	0.62 (0.50)
	Dec	1.06 (0.40)	0.66 (0.39)	0.69 (0.48)	0.71 (0.50)	0.74 (0.43)
	t	-5.640	-4.838	-2.703	-3.271	-0.753
	P	0.0001***	0.0001***	0.0118*	0.0032**	0.4580
Silvereye	Jan	1.07 (0.77)	0.40 (0.63)	1.65 (0.57)	1.41 (0.33)	1.07 (0.59)
	Dec	0.78 (0.76)	1.12 (0.61)	1.49 (0.50)	1.50 (0.31)	1.51 (0.29)
	t	0.042	-3.160	0.836	-0.795	-2.587
	P	0.3063	0.0038**	0.4102	0.4338	0.0152*
Non-native Species						
Skylark	Jan	0.98 (0.73)	1.03 (0.64)	1.09 (0.54)	0.35 (0.45)	1.35 (0.27)
	Dec	1.12 (0.60)	0.92 (0.56)	0.87 (0.45)	0.54 (0.43)	1.06 (0.55)
	t	-0.570	0.498	1.192	-1.203	1.859
	P	0.5737	0.6223	0.2438	0.2395	0.0736
Song Thrush	Jan	0.18 (0.32)	0.40 (0.48)	0.92 (0.24)	0.00 (0.00)	0.05 (0.18)
	Dec	0.50 (0.52)	0.25 (0.47)	0.52 (0.47)	0.14 (0.29)	0.68 (0.42)
	t	-1.990	0.871	-3.149	-1.808	-5.445
	P	0.0586	0.3912	0.0039**	0.0824	0.0001***
Blackbird	Jan	0.42 (0.43)	0.14 (0.29)	0.61 (0.34)	0.21 (0.42)	0.33 (0.44)
	Dec	0.99 (0.66)	0.41 (0.57)	0.95 (0.49)	0.90 (0.36)	1.05 (0.33)
	t	-2.766	-1.646	-2.240	-4.787	-5.045
	P	0.0107*	0.1109	0.0342*	0.0001***	0.0001***
Chaffinch	Jan	0.23 (0.34)	1.33 (0.49)	0.67 (0.59)	0.40 (0.52)	0.50 (0.45)
	Dec	0.66 (0.54)	1.33 (0.36)	0.65 (0.48)	0.85 (0.51)	0.88 (0.43)
	t	-2.641	-0.019	0.102	-2.316	-2.418
	P	0.0144*	0.9847	0.9194	0.0285*	0.0224*
Starling	Jan	0.09 (0.24)	0.54 (0.80)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Dec	1.31 (0.96)	0.51 (0.74)	0.00 (0.00)	0.21 (0.63)	0.25 (0.69)
	t	-4.761	0.083	–	-1.263	-1.411
	P	0.0001***	0.9343	–	0.2273	0.1802
House Sparrow	Jan	1.51 (0.78)	1.48 (0.67)	0.60 (0.64)	0.62 (0.65)	0.34 (0.61)
	Dec	1.31 (0.63)	1.62 (0.82)	0.14 (0.29)	0.12 (0.32)	0.14 (0.39)
	t	0.804	-0.523	2.540	2.617	1.070
	P	0.4286	0.6052	0.0169*	0.0126*	0.295

* = P < 0.05; ** = P < 0.01; *** = P < 0.001

For comparison and perspective, we also mention below the population levels attained over the previous 15 years, as summarized in Tindall (1996), but due to their complexity, we do not present them in detail.

Native species on Moturoa Island

Kingfisher *Halcyon sancta vagans* — Detections in Pine Paddock were significantly higher (*t*-tests; SAS 1996; $p < 0.01$) in December than in the previous January, but significantly lower ($p < 0.05$) in Homestead Paddock and South-face Bush (Table 1). Among all species, only two other decreases during the year of myna removal were significant. Kingfisher detection levels during 1995 were very similar to levels recorded over the previous 15 years in all of the Moturoa routes (Ralph, unpubl. data, summarized in Tindall

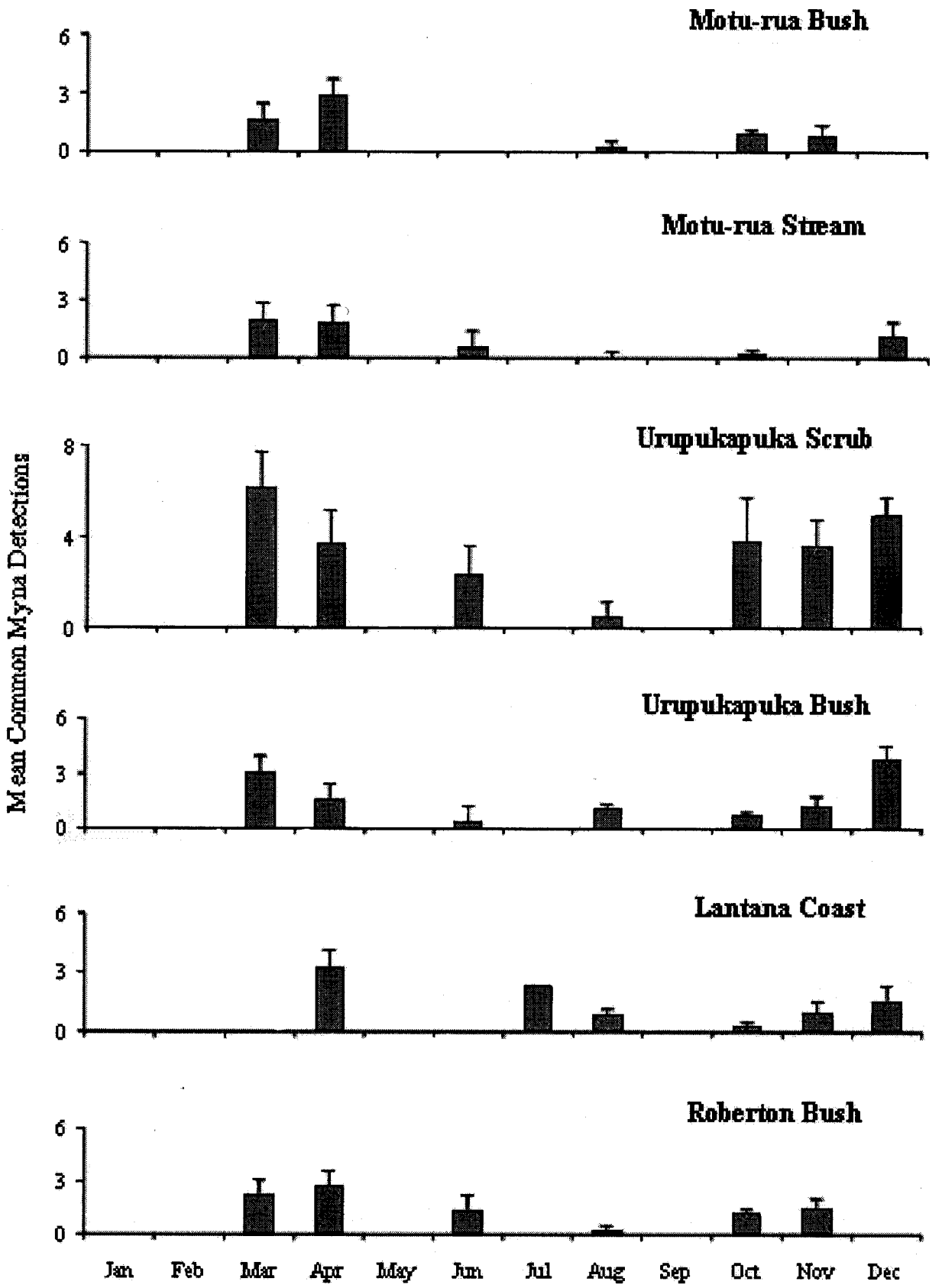

Fig. 4. Detections of Common Myna per ten-minute station count per month during 1995 at sites other than Moturoa Island.

1996), except Homestead Paddock, where detections in recent years have gradually increased to levels common in the 1980s.

Welcome Swallow *Hirundo tahitica* — Detections increased significantly ($p < 0.001$) only in South-face Bush during 1995. On most Moturoa routes, swallow detections over the previous 15 years had been stable. The level of detections in South-face Bush in late 1995 was the highest ever recorded for that species.

Fantail *Rhipidura fuliginosa* — During 1995, detections in the Moturoa routes significantly ($p < 0.01$) increased in Pine Paddock and South-face Bush, but not in the other three routes. During the previous 15 years, Fantail detections in most routes have been stable. The increases in Pine Paddock and South-face Bush during 1995 were exceptional, as they were the highest levels yet attained.

Grey Warbler *Gerygone igata* — Detections in December were significantly higher than in January in Pine Paddock, South-face Bush, and Stream Bush. Populations at the end of 1995 were the highest ever recorded in these three routes.

Tui *Prosthemadera novaeseelandiae* — Detections significantly increased between January and December 1995 in four routes: Old Bush ($p < 0.05$), South-face Bush ($p < 0.01$), Homestead Paddock ($p < 0.001$), and Pine Paddock ($p < 0.001$). Consistently low levels were detected over the past 15 years in most Moturoa routes, especially Homestead Paddock, Pine Paddock, and South-face Bush. The dramatic increase in all routes in 1995 involved a doubling or trebling of the island's population.

Silvereye *Zosterops lateralis* — December levels were not significantly different from January levels in Homestead Paddock, Old Bush, and South-face Bush, but were higher in Pine Paddock ($p < 0.01$) and Stream Bush ($p < 0.05$). Over the previous 15 years, detections were similar in most of the Moturoa routes, but the 1995 level in Stream Bush was the highest ever recorded.

Introduced species on Moturoa Island

Skylark *Alauda arvensis* — Detections of this strictly grass-dwelling species were not significantly different between December and the previous January on any route. Numbers of skylarks in all of the Moturoa routes have fluctuated over the previous 15 years but have shown no consistent trend.

Song Thrush *Turdus philomelos* — December detections were higher than the previous January in Old Bush ($p < 0.01$) and in Stream Bush ($p < 0.001$). The populations have been highly variable over the last 15 years, particularly in Old Bush. The increase in detections in Old Bush in 1995 was well within the normal range of variation. In Stream Bush, however, the 1995 detection levels were the highest of any previous year.

Blackbird *Turdus merula* — Detections in December were significantly higher than January levels in four of the five routes: Homestead Paddock and Old Bush ($p < 0.05$) and South-face Bush and Stream Bush ($p < 0.001$). As compared to the past 15 years, only South-face Bush appeared to be exceptional, with the highest levels recorded.

Chaffinch *Fringilla coelebs* — We found significantly more detections in December than January in Homestead Paddock, South-face Bush, and Stream Bush ($p < 0.05$). The significant increases during 1995 in Homestead Paddock and Stream Bush were well within normal annual variation of the past 15 years, but that in South-face Bush was the highest ever recorded.

House Sparrow *Passer domesticus* — Contrary to most species, populations in December were significantly lower than the previous January in two routes: Old Bush and South-face Bush, but in the other three routes, no changes were evident. Detection levels on all routes were within the normal range of variation over the past 15 years.

Starling *Sturnus vulgaris* — December detection levels were significantly different from January in only one route, a highly significant increase ($p < 0.001$) in Homestead Paddock. This increase resulted in the highest level of detections ever recorded.

Natural seasonal changes in detection rates and their possible roles

Changes in the rates of calling, singing, and other activities occur during the year, and result in changes in the ability of an observer to detect individuals. Our beginning and ending censuses in 1995, before and after myna control, were slightly less than a year apart, due to logistical constraints: in January 1995 we censused between the 5th and 9th; in the following December we censused between the 15th and 19th, a difference of 22 days for each route. Because of this 22-day interval, we wished to determine if normal December-January differences in populations (or detectability) could affect the numbers of birds that we recorded. To investigate this possibility, we compared data taken between 12 and 23 December 1997, with another set taken between 4 and 9 January 1998. These latter censuses were 17 to 19 days apart. Seven of the 12 response species were detected more often in December than in January, declining in detectability as the summer went on. These (and their change in detection)

were Blackbird (-47%), Welcome Swallow (-29%), Chaffinch (-28%), Fantail (-22%), Tui (-12%), House Sparrow (-11%), and Silvereye (-3%). In contrast, after myna control, five of the 12 response species were more commonly detected in January relative to December. The greatest change was in a less common bird, the Kingfisher (+88%), and in four other species Skylark (+25%), Song Thrush (+21%), Grey Warbler (+5%), and Starling (+3%). The Common Myna had only a 5% increase in detections in January 1998.

DISCUSSION

The effect of myna control on mynas

Relatively low detection levels of mynas on all Moturoa routes were maintained throughout the spring and into summer of 1995 (Fig. 3), as a reduced number of mynas are believed to have bred in all habitats on Moturoa in this year. Our data indeed indicated that myna numbers had been significantly reduced in the three bush routes during 1995. Detections in all routes, both bush and grassland, had been relatively consistent in recent years (Ralph *et al.*, unpubl. data), until the decrease in the bush routes in 1995. In two of the bush routes, Old Bush and South-face Bush, myna numbers were at the lowest levels ever recorded. Further evidence of the reduction of mynas on Moturoa is the relatively low populations on the island routes in the spring, as compared to the increases by November and December on some of the other off-island routes where mynas were not controlled (Fig. 4).

While after-control detection levels of mynas in the two grassland routes (Homestead and Pine Paddocks) were similar to levels in past years, apparently showing no (or minimal) effect of control, we noted that this was likely due to continual and temporary influx of small flocks of non-breeding mynas into the grassland areas. We often observed mynas in the grassland areas in flocks in the summer of 1995–96, a behaviour typical of non-breeders. These birds can easily reach the island, as it is only 0.5 km from the mainland. From our ageing of captured mynas (Tindall 1996), it appeared that most of these visiting mynas were younger, non-breeding birds. We also frequently saw these flocking birds quickly moving off the island to nearby mainland locations. These flocks did not frequent bush areas where older and established breeding birds were effectively removed by our control measures.

Bird species' responses to myna control

It appears likely that the differences in the population levels of various bird species between January and December of 1995 were not due to chance. Performing multiple *t*-tests increases the probability of Type I error, so that one difference in twenty (at the 5% level) is likely to be due to chance alone. Thus, of the 60 comparisons of mean detection levels in the Moturoa routes, we would have expected about three significant differences by chance. However, we found 27 significant differences (23 increases and 4 decreases) following myna control, many times more than predicted by chance. Additionally, ten of the 13 significant increases of native bird detections in 1995 resulted in the highest population levels recorded in the past 15 years.

Of the native species, the Tui seemed most changed, increasing in all five routes, and significantly so in four. Of the introduced species, the Blackbird had the most increases (four of five routes) following myna control. At least two of these increases were very large (428% and 1 480%). The marked increase in Starlings in one grassland route is consistent with results in Hawke's Bay, where Wilson (1973) found that Starling breeding success was very low in areas with many mynas, moderate where there were few mynas, and quite high with no mynas. A further suggestion of a marked change was that five of the detections of introduced species on Moturoa were very high, unequalled by levels recorded in past years (Ralph, unpubl. data). In comparing with other islands in the Bay, Tindall (1996) found that the populations of some species of native birds on Roberton Island were quite high, where long-term control of the myna (as well as some rodent and mustelid control) has been undertaken. He observed that Roberton Bush had the highest number of Tui and Fantail detections, averaged over the year, of the eleven routes surveyed. Additionally, Grey Warbler detections there were the third highest of all the routes anywhere in the Bay. The comparatively larger populations on Roberton could suggest that these native species have benefited, at least in part, from the long-term control of mynas.

We did not note any common intrinsic characteristics among the response species, or their ecological niches, which might have predisposed them to competition or predation by mynas. We might note that the two species most affected, the Blackbird and the Tui, are both large, dark-bodied birds, perhaps indicating some influence of interference competition.

Possible roles of rats, succession, and weather

Factors other than the myna undoubtedly have influenced changes in bird abundance in recent years on Moturoa, and we cannot separate our results from them. Rat eradication in 1993 quite probably favoured an increase in bird numbers

in subsequent years through the absence of predation. Furthermore, rat removal was likely to have accelerated vegetation regeneration, as rats are known to eat seeds, seedlings, and fruit. However, it is difficult to imagine a mechanism that would have had a sudden and marked effect after removal of rats only two years before. We are reasonably certain that rat control has had a role, but feel it more likely to be a cumulative effect over the years. Another factor is vegetation change. Over the past 20 years, planting and natural succession have increased the extent of bush habitat and the development of an understory on about a third of Moturoa. This accelerated succession has probably favoured bird populations. It too, is not likely to have caused the marked increase in a single year of so many species on various routes. The weather during 1995 was quite similar to most previous years (Tindall 1996), and so would also be unlikely to have been responsible for these changes.

Effect of seasonal changes in detection rates

We think it unlikely that the differences we documented could have been due to changes in detection rates between January and December of 1995. That is, our tests do not show that birds were merely more conspicuous in December, rather than more common. In fact, our test of seasonal changes in detection frequency in 1997–1998 showed five of the 12 response species had higher detection rates in January. These five species accounted for eleven of the 23 significant species-route differences over the year of myna control, indicating that a change in conspicuousness would not likely have played a role in these species. We did find that seven of the 12 species declined in detectability, and were, indeed, more commonly detected in December 1997 than in January 1998. However, the differences in detection rates were usually relatively small, as compared to the differences we noted during our year of myna control. The increases in detectability were highest in the Blackbird, with a +47% increase, while the other six species ranged from +12 to +29%, or less. This would have had some modest effect upon the remaining 12 species-route significant differences we found. For example, the Chaffinch increased significantly during myna control in three of the five routes, ranging from +76% to +186%, whereas the increase due to detectability was in the order of +30%. In the case of the Tui, for which detections changed over the month by +12%, the increases in detections during the 1995 study year were usually much larger. They ranged from a low of +21% (which could have been largely due to a change in detectability), but detections increased from +167% to +283% in the other four routes. Overall, we feel that perhaps two or three of the 23 increases we found during the year of myna control could have been due to detection changes, but the majority appear to be due to an actual increase in numbers of birds.

Future studies

This first attempt at experimental manipulation of myna numbers, and the assessment of its effect on bird communities, suggests procedures and directions for future research. The ideal study areas would have little immigration and no concomitant variables such as rat removal and succession. The populations of all potential response species would be censused both before and after myna removal, in both control and removal plots, because no two sites will be truly equal in bird populations at the start. Intensive study of some of the response species might allow more careful appraisal of the nature of the response by following nests, as well as assessing recruitment and survival by capture and observation. Understanding of myna movements, home range, and territory, both during breeding and non-breeding seasons by following colour-marked birds would help determine the adequate size of a study area for a removal experiment. Further, are feeding habits of flocking and of territorial mynas similar? We suspect that territorial birds in the bush areas have a bigger impact on other species than do the flocks in paddocks. It would be important to have studies centring on possible resources that are involved in competition between mynas and other species, such as food resources, roosts, or nest cavities.

Management implications

While our data are from only a single island where mynas were controlled, they support the widely-held belief that the myna can influence the numbers of various species of birds. High densities of mynas, like those in some areas of the north of New Zealand, might have been a factor in the decline of some native species in this region. The effective control of mynas, which we accomplished, is short term, local, and labour intensive. It is, therefore, a good use of conservation dollars only in certain situations, such as when a fragile naive species is being introduced and competition and nest predation must be minimal. We suggest that it is generally preferable to provide adequate habitat areas for the native species, and when deemed necessary, undertake control measures, such as those we conducted.

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