Effect of an isolated bore on birds in the complex arid landscape of Faure Island, Shark Bay, Western Australia

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Abstract

Artificial water points in Australian rangelands have had various adverse effects on native biota. In this study, the terrestrial avifauna of an isolated bore on Faure Island, Shark Bay, Western Australia, was evaluated for drinking and geographical abundance patterns. The bore is in a unique environment close to three major biological boundaries: biogeographical, vegetational, and climatic. The island is also of interest because marsupial species extinct on the mainland (e.g. boodie *Bettongia lesueur*) have been re-introduced there. During a four-day survey, 1626 individuals from 20 bird species were observed. Of the species, 80% showed a gradient in relative concentration across the whole island, in the 100 ha around the bore and within the bore's piosphere. Patterns of drinking and attendance at the bore are also reported. Some birds (e.g. Crested Pigeon *Ocyphaps lophotes* and Little Crow *Corvus bennetti*) increased their relative concentration near the watering point while others (e.g. Silvereye *Zosterops lateralis* and Australasian Pipit *Anthus novaeseelandiae*) decreased. The null hypothesis that the bore had no impact on the distribution of birds was rejected.

Keywords: artificial watering point, rangelands, piosphere, faunal concentration gradient, relative analysis

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INTRODUCTION

The impact of artificial watering points along with the spread of pasture grasses has exacerbated the impact of selective grazing by exotic mammals (Landsberg *et al*. 2003). Through these changes, such watering points potentially pose threats to the persistence of endemic biodiversity in Australia, specifically through facilitating changes in the abundance and range of many species of plants, animals and other organisms (Saunders & Curry 1990; Landsberg *et al*. 1997; James *et al*. 1999). Exotic predators, for example the red fox *Vulpes vulpes*, have moved into arid and semi-arid rangelands through the availability of artificial watering points (Burbidge & McKenzie 1989; James *et al*. 1999). Introduced watering points have proliferated in Australian rangelands with most (outside of the driest deserts) substantially less than 10 km apart (Landsberg & Gillieson 1996).

In Australia's rangelands, some species have increased in abundance while others have been introduced, for example, kangaroos *Macropus* spp., cattle, sheep and goats (Bovidae), Buffel Grass *Cenchrus ciliaris*, Crested Pigeon *Ocyphaps lophotes* and Zebra Finch *Taeniopygia guttata* (Landsberg *et al*. 1997; James *et al*. 1999; Barrett *et al*. 2003; Van Dyck & Strahan 2008). Notable declines include the Paradise Parrot *Psephotus pulcherrimus* (a species that has become extinct) and critical weight range marsupials, which are thought to be indirectly affected from grazing competition and directly threatened by foxes and cats *Felis catus* (Shortridge 1909; Burbidge & McKenzie 1989; Jerrard 2008). Birds that feed and nest on the ground have been one of the most adversely affected groups: examples include Australian Bustard *Ardeotis australis*, Plains-wanderer *Pedionomus torquatus*, and Malleefowl *Leipoa ocellata* (Reid & Flemming 1992; Garnett & Crowley 2000; Olsen 2008). Despite the extreme proliferation of artificial watering points, relatively few studies show how they affect birds (Davies 1977a, 1977b; Landsberg *et al*. 1997; James *et al*. 1999; Howes & McAlpine 2008). Only two studies in Australia systematically recorded the bird species, which came to watering points over the course of a day (Davies 1972; Fisher *et al*. 1972). This type of study can identify what species use the artificial watering points and how they use this resource.

The bore on Faure Island in Shark Bay, Western Australia, presented a unique opportunity to investigate a more isolated bore in the absence of foxes and cats, and where the recolonization by native mammals has begun (Algar *et al*. 2010). The bore is of special interest because it is the only artesian bore on the island (June Gronow in Landgate's Geonoma Database). The island is positioned near the convergence of three significant boundaries: biogeographical, vegetational, and climatic (see detailed descriptions below). Thus, the island supports a diverse terrestrial avifauna (Dell & Cherriman 2008). It is situated within the Shark Bay World Heritage Area and surrounded by the Shark Bay Marine Park.

Aims

The watering point was surveyed to identify:

(1) the bird species using the watering point and their relative abundance;

(2) the drinking patterns of each species; and

(3) the geographical patterns of abundance, within the piosphere and at the bore, compared with the 100-ha zone around the bore and the whole island.

STUDY SITE

Physical and biological positioning

Faure Island (pronounced 'Four' according to Fulton 2011), is isolated from the mainland by ~8 km at the closest point, north of Petit Point, and ~14 km east of Francois Peron National Park on Peron Peninsula (Fig. 1). The island is 5148 ha with a perimeter of ~45 km (Abbott & Burbidge 1995; Burbidge & Morris 2002). The island has been a pastoral property since 1876 (June Gronow in Landgate's Geonoma Database) but is now

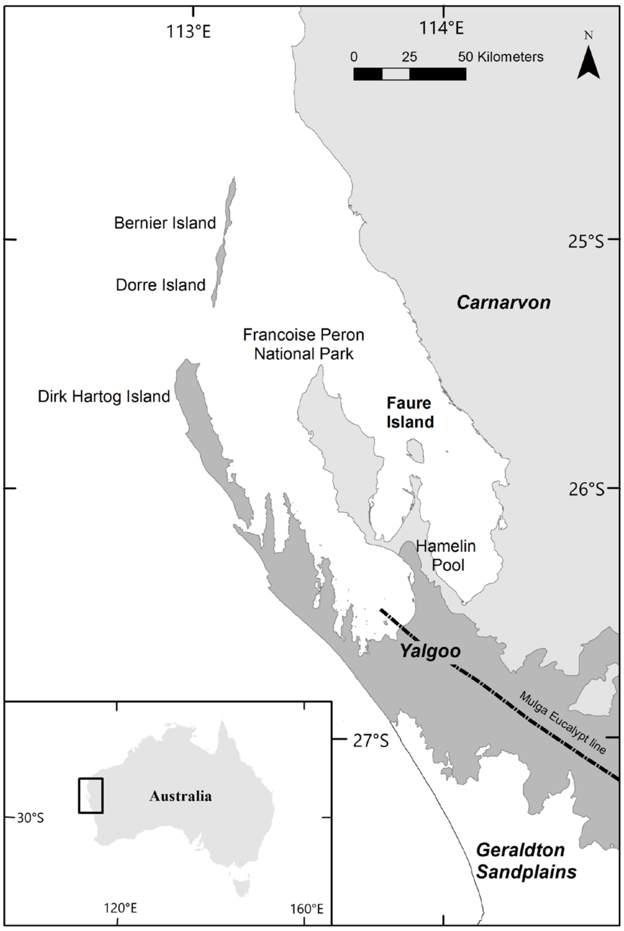

Figure 1. The location of Faure Island, in Shark Bay, in relation to the Mulga/Eucalypt Line approximating Beard (1969; Mulga on the eastern and Eucalypt on the western side). The shaded areas on the map indicate the Geraldton Sandplains, Yalgoo Bioregion and Carnarvon Bioregion (Department of Environment and Energy 2018).

Figure 2. Faure Island showing extensive sand flats, which are exposed at low tide, the position of mangroves and the position of the bore.

managed as a private nature reserve by the Australian Wildlife Conservancy. The bore site ID is 2000076 and was drilled on 30 June 1928 to 95.7 m at 25°53'20.8458"S, 113°54'39.2688"E (Joanne Gregory, Department of Water, Western Australia, pers. comm. May 2009); however, Google Maps shows its correct location at 25°53'11.1"S 113°54'32.4"E (Fig. 2).

As of 2008, feral predators and domestic grazers were removed, except for a small number of sheep *Ovis aries*, one horse *Equus caballus* and the house mouse *Mus musculus* (McCluskey 2008; Algar *et al*. 2010). There are no large kangaroos (*Macropus* spp.). Critically endangered marsupial species, such as the boodie *Bettongia lesueur*, have been re-introduced (McCluskey 2008).

The bore, which draws water from the Carnarvon Artesian Basin, is now partly saline. It is positioned above the northern and western extremity of the Mulga/Eucalypt Line (Mulga *Acacia aneura;* Fig. 1). Ground water on the Mulga side of this line is generally fresh—which has aided the development of the pastoral rangelands—whereas ground water on the Eucalypt side is generally saline (Serventy & Whittell 1976). Storr (1985, 1990) highlighted that the line provides a demarcation in range for many bird species, whereas Johnstone *et al*. (2000) point out that much of the avian diversity in the region stems from the intermixing of the avifaunas from either side.

The Mulga/Eucalypt Line is a natural ecotone that demarcates the acacia-dominated Eyrean vegetation of the north and inland from the eucalypt-dominated vegetation of the south-west (Taylor 1926; Serventy & Whittell 1976; Johnstone *et al*. 2000). Faure Island is situated marginally on the drier Eyrean side, as well as being positioned at the overlap zone of the summer and winter rainfall convergence zone (see *Climate* below) and in the Carnarvon Bioregion ~36 km above the boundary with the Yalgoo Bioregion (Fig. 1).

The Mulga/Eucalypt Line bisects Shark Bay whereas the Carnarvon and Yalgoo bioregions both bisect the southern Peron Peninsula, in Nanga, to the southwest of Faure Island. The Australian bioregions are defined by their climate, lithology/geology, landform, vegetation, fauna, and land use (Department of Environment and Energy 2018).

Ecotones in general show greater species richness and allele divergence than their immediate surrounding areas (Odum 1953; Smith *et al*. 1997; Kark & Van Rensberg 2006). In contrast to large land areas, islands in general show diminished species richness and harbour morphological variants diverged from adjacent mainland communities, although the extent of species richness depends on the island's size (MacArthur & Wilson 1967; Ford 1989). Thus, the positioning of Faure Island within a large and significant ecotone and its isolation as an island may synergistically interact to provide unique outcomes in relation to genetic variations and ecological associations in its assemblage of terrestrial bird species.

Climate

The climate is semi-arid to arid, with hot summers and mild winters. Precipitation is erratic falling mainly in winter with an annual average of 224.5 mm, recorded at Denham (~35 km to the west) over 1883–2009 (Bureau of Meteorology 2009). Cyclones can bring significant precipitation in summer and autumn (Hancock *et al*. 2000). Most of the year Faure Island receives modest rainfall and is thus more arid than the average suggests. Faure Island is also situated in the summer/winter rainfall convergence zone (Johnstone *et al*. 2000). Many northern birds have their ranges limited by the southern extent of summer rain. Conversely, the northern range of many southern birds is limited by the extent of the northern reach of winter rains (Blakers *et al*. 1984; Storr 1990; Johnstone *et al*. 2000; Barrett *et al*. 2003). Just prior to the current study, precipitation at Denham was measured at 6.8 mm for October and November 2008, including 2.0 mm that fell on 6 November 2008 (Bureau of Meteorology 2009). No ephemeral ground water was detected during the study and all birridas (seasonally inundated gypsum saltpans) observed from the ground and air were dry.

Vegetation

The vegetation surrounding the watering point has been severely modified by a long history of heavy and sustained grazing pressure of sheep, and the introduced Buffel Grass has established as a dense permanent ground layer replacing much of the former understorey. Formerly, the community would have been an *Acacia* shrubland, dominated by Kurara *Acacia tetragonophylla* and Horse Mulga *A. ramulosa* with a seasonal understorey dominated by short-lived perennial and annual species from the Poaceae, Asteraceae and Chenopodiaceae families. Isolated individuals of non-indigenous tree species established around the watering point include Athel Tree *Tamarix aphylla*, Moort *Eucalyptus platypus* and Date Palm *Phoenix dactylifera*.

On the western side of the island are two large regions of Grey Mangroves *Avicennia marina* with many smaller stands around the Island's perimeter, from significant clumps to single trees (pers. obs). Grey Mangroves are also present at the northern end of Peron Peninsula (Johnstone 1990; Storr 1990; Johnstone *et al.* 2000). The Carnarvon and Shark Bay regions represent the most southern extent of mangroves that support mangrove-specific birds (Johnstone 1990).

Piosphere

A piosphere is the zone around a watering point that shows the greatest damage from grazing and the trampling of hoofed mammals (Osborn *et al*. 1932; Lange *et al*. 1969). Although typically circular, it can be any shape especially if fences or buildings restrict access. It is clearly visible from aerial photographs, but the damage becomes more subtle and harder to detect farther from the watering point where the effects are then more related to selective grazing rather than general overgrazing and physical damage (Landsberg *et al*. 1997; James *et al*. 1999).

The piosphere surrounding the Faure Island bore measured ~275 m radius, from 355° clockwise to 245° (a total 250°; ~16.5 ha) owing to fencing that restricted grazing. The extent of the piosphere was measured using Google Earth images from an 'eye-altitude' of 900 m.

METHODS

Taxonomic procedure

Taxonomy of birds follows Christidis & Boles (2008). Scientific names of bird species are given in Tables 1 and 3 and at their first mention in the text. Plant names follow FloraBase (2009). This study was undertaken in November 2008.

Surveying and monitoring

The bore was monitored from 15:30–18:30 on 14 November 2008, and from 07:30–11:00 and 15:30–18:00 on 15 November 2008. In addition, ~15 km of the island's perimeter was surveyed for birds and 11 inland crossings of the island were made over four days on the 11–13 and 16 November 2008.

A natural hide formed by a small *Eucalyptus* sp. ~30 m from the bore was used to monitor birds coming and going from the bore and to view birds perching in the larger trees within a 200 × 200 m (2 ha) quadrat, centred on the bore. All birds here were counted and recorded as they entered the piosphere or in the case of the Zebra Finch as they approached the water.

Birds were categorised as either extending across the island, in the immediate ~100-ha zone around the bore, or birds that foraged within the piosphere, which includes birds that drank at the bore. Birds were determined to be foraging or drinking by their actions. Observations of birds within 100 ha of the bore were made daily, by driving, at ~10–15 km/hr, through the area (n = 11) or by searching ~10 ha around the homestead for two hours at a time (n = 6) and walking transects (~1.3 km) to the bore (n = 6) and recording the birds seen. Birds were observed during inland crossings of the island (n = 11) while standing in the back of a 4WD utility enabling 360° observations. The vehicle was stopped when necessary to identify birds. Birds detected across the whole island and from within the 100-ha zone were recorded in relative abundance categories at the end of each day. Thus there are no absolute abundance counts for these data. Only birds seen at the bore and in the piosphere were recorded as absolute counts. Where absolute and relative data are compared they are all reported as categories of abundance.

Analyses

Geographical distribution for each terrestrial species was categorised using relative abundances at the bore and piosphere, the 100-ha zone around the bore and the whole island. Therefore, it was possible to detect gradients or patterns of abundance and determine if species abundances were either higher or lower with regard to the proximity of the piosphere. The nullifiable (H_0) hypothesis was that the bore has no effect on the geographical distribution of each bird species on Faure Island. However, the probability of incurring Type I or Type II errors in these analyses was high, because sample sizes for some species were low.

RESULTS

In total, 1625 birds from 11 species were recorded in the 2-ha quadrat around the bore (Table 1). Only four of these drank at the bore: the Crested Pigeon, Welcome Swallow *Hirundo neoxena*, Tree Martin *Petrochelidon nigricans* and Zebra Finch. Zebra Finches attended the bore, in the greatest numbers, each day. Zebra Finch abundance increased during the day as the temperature rose and decreased in the late afternoon as the temperature fell (Fig. 3a). The Zebra Finch is a flocking bird detected over the entire island. It was frequently seen in flocks of 5–50 as they approached the bore. These smaller flocks accumulated into larger flocks, of up to 300 plus

Table 1
Counts of individuals observed in the 2-ha quadrat surrounding the artificial watering point; the asterisk (*) denotes species that drank at the bore. The Spiny-cheeked Honeyeater is omitted from this table, because its numeric count was not recorded; this was an oversight during fieldwork.

Common name	Scientific name	Totals
Crested Pigeon*	*Ocyphaps lophotes*	104
Brown Goshawk	*Accipiter fasciatus*	3
Wedge-tailed Eagle	*Aquila audax*	1
Brown Falcon	*Falco berigora*	3
Sacred Kingfisher	*Todiramphus sanctus*	1
Singing Honeyeater	*Lichenostomus virescens*	12
White-breasted Woodswallow	*Artamus leucorynchus*	3
Grey Butcherbird	*Cracticus torquatus*	1
Little Crow	*Corvus bennetti*	2
Welcome Swallow*	*Hirundo neoxena*	50
Tree Martin*	*Petrochelidon nigricans*	9
Zebra Finch*	*Taeniopygia guttata*	1437
Total		1626

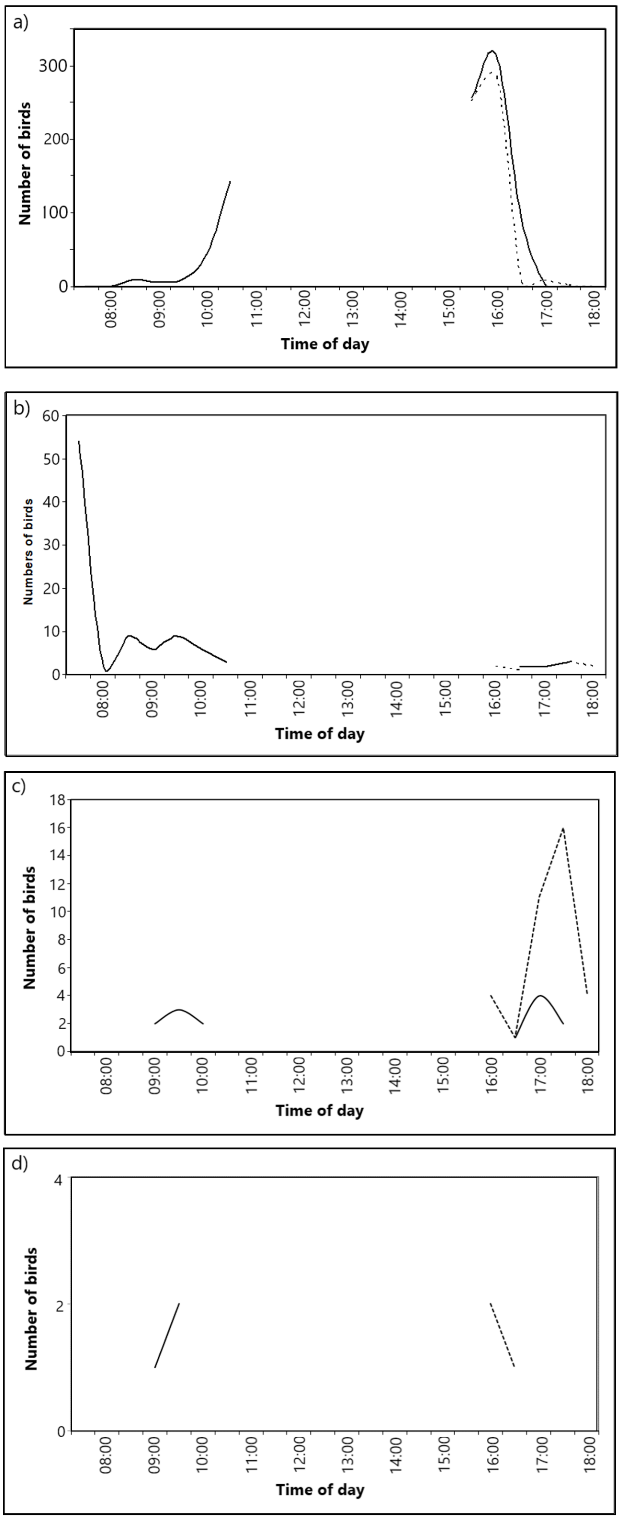

Figure 3. Abundances and temporal patterns of drinking recorded in this study: a) Zebra Finch; b) Crested Pigeon; c) Welcome Swallow; and d) Tree Martin. The dash line is the first day of monitoring (14/11/2008) and the solid line is the second (15/11/2008). The morning of the first day and the middle of both days over 10:30–14:30 were not monitored.

birds, near the bore, inside the piosphere, but in the cover of *Acacia* shrubs. Crested Pigeons were in greatest abundance early in the morning and showed no trend associated with increasing temperature throughout the day (Fig. 3b, Table 2). Welcome Swallows showed small peaks in abundance in the morning and afternoon, and a more abrupt peak on the afternoon of November 14 (Fig. 3c). Tree Martins were recorded at two of the three monitoring periods (Fig. 3d). In addition, the White-bellied Sea-Eagle *Haliaeetus leucogaster* has been reported drinking from the water troughs, in the early mornings of the survey period (Jo Williams, Australian Wildlife Conservancy, pers. comm. Nov. 2008).

Other birds were recorded in the 2-ha quadrat around the bore, although they were not observed drinking. These include a juvenile Brown Goshawk *Accipiter fasciatus*, Sacred Kingfisher *Todiramphus sanctus* and Singing Honeyeater *Lichenostomus virescens* perched in larger trees that are close to the bore. The Brown Goshawk may have used them as cover from which to ambush prey whereas the other two species used them as a high perch for calling. The Little Crow *Corvus bennetti* and Grey Butcherbird *Cracticus torquatus* were opportunistically recorded in the 2-ha quadrat while driving past. The Wedge-tailed Eagle *Aquila audax*, Brown Falcon *Falco berigora* and White-breasted Woodswallow *Artamus leucorynchus* were seen flying over the 2-ha quadrat, but they did not fly directly over or within 50 m of the water troughs.

There were 18 species detected in the 100-ha zone inclusive of the piosphere. Bird distribution patterns (including gradients) were identified when abundances in the piosphere were compared with the 100-ha zone and the whole island. Of the species recorded in the piosphere, 35% (n = 7 species) were detected in lower abundance than elsewhere on the island, 45% (n = 9 species) in higher abundance and 20% (n = 4 species) showed no change in abundance. Thus 80% of bird species showed a change in their distributive abundance at the piosphere and bore, compared with the surrounding 100-ha zone and the whole island (Table 3). Notably, only two species were common in the piosphere without going to drink water: the Singing Honeyeater and the Spiny-cheeked Honeyeater *Acanthagenys rufogularis*.

DISCUSSION

This survey provides a snapshot of how birds used this artificial habitat. The data do not demonstrate how birds might use the bore either seasonally or during migration, or how nocturnal birds use watering points (see Cameron 1938; Davies 1972). However, resident birds dependent on this water source for diurnal use would be detected in this short temporal survey. Possibly some birds may have been counted twice, though with diminishing probability when fewer birds were present.

Birds at the watering point: overview

Five bird species were recorded drinking at the bore. Four of these species are known to have increased in range and numbers throughout Australian rangelands with the addition of artificial watering points: White-bellied Sea-Eagle, Crested Pigeon, Welcome Swallow and Zebra Finch (Fisher *et al*. 1972; Davies & Chapman 1974; Davies 1977a; Blakers *et al*. 1984; Curry & Hacker 1990; Saunders & Curry 1990; Reid & Fleming 1992; Landsberg *et al*. 1997; Johnstone *et al*. 2000; Shephard *et al*. 2005; Olsen *et al*. 2006a). However, the fifth species, the Tree Martin has not been reported (by the same authors) demonstrating any range change associated with the spread of artificial watering points. It has been identified previously as a passage migrant at the island, sometimes in extensive flocks (Dell & Cherriman 2008). The provision of drinking water may dictate this section of its migration pathway.

Drinking patterns

The Crested Pigeon and Zebra Finch are granivorous birds and the Welcome Swallow and Tree Martin are aerial insectivores. Landsberg *et al*. (1997) found that granivores drink most frequently, because grain provides

Table 2
Bird species presence recorded hourly over two days (x = present). Times given are at the end of the hour. Sunrise = 06:28 and sunset = 19:50; temperature min 17.5°C (15 Nov.) and max 27.5°C (14 Nov.)

	14-Nov-08				15-Nov-08						
Species and time	**15:30**	**16:30**	**17:30**	**18:00**	**7:30**	**8:30**	**9:30**	**10:30**	**15:30**	**16:30**	**17:30**
Crested Pigeon	x	x	x	x	x	x	x	x		x	x
Brown Goshawk				x	x			x			
Wedge-tailed Eagle								x			
Brown Falcon								x			
Sacred Kingfisher				x							
Singing Honeyeater	x					x	x				
White-breasted Woodswallow							x				
Little Crow									x		
Welcome Swallow	x	x	x	x		x	x			x	x
Tree Martin	x	x	x			x	x	x			
Zebra Finch	x	x	x			x	x	x	x	x	

Table 3

The relative abundances of terrestrial bird species detected within the piosphere (includes birds coming to drink), the 100-ha zone around the watering point and across the whole island. The latter are not intended to be a complete list of terrestrial birds on the island. Birds flying over an area are included in that area.

Species	Island	100-ha	Piosphere	Pattern
Crested Pigeon *Ocyphaps lophotes*	C	A	C[1]	↑
White-bellied Sea-Eagle *Haliaeetus leucogaster*	U	R	U[1*]	↑
Brown Goshawk *Accipiter fasciatus*	U	U	U	↔
Wedge-tailed Eagle *Aquila audax*	U	U	R	↔[II] (↑)
Brown Falcon *Falco berigora*	U	U	R	↔[II] (↑)
Sacred Kingfisher *Todiramphus sanctus*	R	R	R	↔
White-browed Scrubwren *Sericornis frontalis*	U	U	A	↓
Redthroat *Pyrrholaemus brunneus*	C	C	A	↓
Pied Honeyeater *Certhionyx variegatus*	A	C	A	↓
Singing Honeyeater *Lichenostomus virescens*	C	C	C	↔
Spiny-cheeked Honeyeater *Acanthagenys rufogularis*	C	C	C	↔
White-breasted Woodswallow *Artamus leucorynchus*	C	U	R	↓
Grey Butcherbird *Cracticus torquatus*	A	A	R	↑
Little Crow *Corvus bennetti*	R	R	U	↑
Yellow White-eye *Zosterops luteus*	U	U	A	↓
Silvereye *Zosterops lateralis*	U	U	A	↓
Welcome Swallow *Hirundo neoxena*	C	U	U[1]	↔[II] (↑)
Tree Martin *Petrochelidon nigricans*	C	U	U[1]	↔[II] (↑)
Zebra Finch *Taeniopygia guttata*	C	C	C[1]	↑
Australasian Pipit *Anthus novaeseelandiae*	C	C	A	↓

Notes: C = common (seen in all surveys), U = uncommon (seen more than once, but not in all surveys), R = rare (seen once) and A = absent (not observed). [1] indicates the species entered the piosphere to drink; * is a pers. comm. from Jo Williams. ↑ = increasing and ↓ = decreasing relative abundance, closer to the piosphere. ↔ indicates that the species abundance may not be affected by the bore and piosphere. II indicates a Type II error. Corrected results after committing Type II errors are given as increasing (↑), and are probably artefacts due to small sample sizes.

little water content. In contrast, insectivorous birds are the least dependent, obtaining most of their water from insects (Fisher *et al*. 1972). This study also detected the predictable pattern of abundance with granivorous birds dominating counts at the bore: 1541:104 individuals (Table 1).

Davies (1972) found that Crested Pigeons preferentially drank early in the morning, more Zebra Finches drank in the hottest part of the day and Welcome Swallows drank in the morning and afternoon. Results that match with temporal drinking patterns observed in this study. However, Fisher *et al*. (1972) found Tree Martins drank throughout the day whereas this study detected them drinking only at either end of the day.

White-bellied Sea-Eagles are attracted to water in the inland, because this is where they get virtually all of their live prey, which consists primarily of fish, waterbirds and turtles (Fleay 1948; Olsen *et al*. 2006a, b; Debus 2008). On Faure Island, this species may only use the bore for drinking and bathing, because its main prey of fish and waterbirds are more abundant at beaches, tidal flats and lagoons (pers. obs).

Birds with greater abundances at the bore and piosphere

The bore and the piosphere influenced the geographical distribution of terrestrial birds on Faure Island. Eighty percent of the birds studied showed a change in relative abundance between the piosphere and bore compared with the 100-ha zone around the bore and the whole island. The availability of reliable drinking water had direct and indirect influences on the geographical abundance of terrestrial birds on the island.

Raptors are likely to be attracted to a bore (or other features) that concentrate prey animals (Olsen 1995; Aumann 2001; Shephard *et al*. 2005; Fulton 2006). At the time of this survey goats (*Capra hircus*) had been eradicated and sheep numbers had been significantly reduced on the island (Burbidge & Morris 2002). In the absence of the young of these mammals, raptors, particularly the Wedge-tailed Eagle, may preferentially hunt the re-introduced marsupials at the bore. Notably, Wedge-tailed Eagles adapted their diet to birds including the Plains Wanderer *Pedionomus torquatus* when rabbit (*Oryctolagus cuniculus*) numbers were reduced by the release of haemorrhagic disease Rabbit *Calicivirus* (Sharp *et al*. 2002; Fulton 2019a).

The Brown Goshawk was the most commonly detected raptor, recorded three times in the piosphere. This species is uncommon to rare in Shark Bay (Davies & Chapman 1974; Johnstone *et al*. 2000), although more common at watercourses and mangroves where it uses larger trees to perch (Johnstone *et al*. 2000). The bore may provide an important habitat component for the Brown Goshawk on Faure Island. A goshawk nest was detected within the 100-ha zone and a juvenile was observed moving from the area of the nest to the bore, indicating it may have fledged from that nest. Future research could involve searching the nests and surrounds near the bore for evidence of skeletal remains, to learn if the Brown Goshawk is depredating re-introduced marsupials.

Other predatory birds showed a response to the bore: Little Crows were detected in the quadrat three times, but were not seen drinking, although their proximity and behaviour at the water troughs indicated that they may drink and bathe there. The Grey Butcherbird is a known predator of smaller birds (Pizzey & Knight 1997; Fulton 2008, 2018, 2019b). It may attend the bore due to the concentration of prey. Small birds, particularly the Zebra Finch, were plentiful at the bore. Individual birds, particularly juveniles that bathe, can become waterlogged and incapacitated and thus easy prey for cracticids and corvids (Debus *et al*. 2006; Fulton 2006).

Birds that drank at the bore and did not stay within the piosphere

Crested Pigeons flew out of sight after drinking (>100 m outside the piosphere) and were never recorded in the 100-ha zone, unless perched near the bore before drinking. Presumably, they were prepared to travel substantial distances to obtain water. Zebra Finches flew outside the piosphere to *Acacia* spp. They only accumulated in large numbers at the bore and piosphere before dispersing into smaller flocks over the island. Granivorous species did not feed within the piosphere, which may be related to the higher chance of predation through less cover and/or the lack of seed through over-grazing. The White-bellied Sea-Eagle and other raptors did not stay in the area. They have large hunting territories, although they are generally linked to inland water sources that provide them with prey (Marchant & Higgins 1993; Debus 2008). Aerial insectivores presumably move over the whole island in response to their aerial feeding.

Birds that did not drink but were common near the bore and piosphere

Davies (1972) found that many of the same birds, as this study, approached the vicinity of watering points but did not drink (Table 1). However, the Spiny-cheeked and Singing Honeyeaters were the only birds commonly detected in the piosphere that did not attend the watering point. These two species were common in the 100-ha search zone around the bore and across the whole island; they are considered open-country birds and are common in arid lands (Blakers *et al*. 1984; Barrett *et al*. 2003). Schneider & Griesser (2009) reported that Singing and Spiny-cheeked Honeyeaters are found in moderate abundances (more so than the Pied Honeyeater *Certhionyx variegatus*) at watering points, but they failed to connect the need to drink and simply correlated the proximity of birds and species richness to watering points. Fisher *et al*. (1972), in contrast to my findings, found that large numbers of Spiny-cheeked Honeyeaters came to drink. Fisher *et al*. (1972) recorded 1500–2000 Spiny-cheeked Honeyeaters coming to drink, on one day, from all directions during a two-hour period. They also found that they drank at all periods of the day, but predominantly in the first two hours after sunrise.

Singing Honeyeaters have been reported at natural waterholes, and at equal frequencies at artificial lakes and control dry desert sites, indicating that they do not simply congregate at water (Schneider & Griesser 2009). This study did not detect them drinking at the bore, although they were common in the piosphere. The Singing Honeyeater is broadly distributed and abundant across Australia, including in the most arid regions (Barrett *et al*. 2003); however, there is little information as to its physiological adaptations to extreme arid environs. Notably, it was found abundant throughout the Great Victoria Desert when conditions were very dry—when rock holes and deep depressions were dry for months and the 'spinifex' had a dead appearance throughout the desert (Ford & Sedgwick 1967). Brooker *et al*. (1979) surveyed birds in the Nullarbor (1967–1978), which is climatically desert with no permanent natural surface water; yet they found the Singing Honeyeater abundant at all sites throughout their study. Physiologically, Skadhauge (1974) found that the Singing Honeyeater's renal concentrating ability compared favourably with other arid-adapted species such as the Zebra Finch. However, it has the added advantage over most granivores to gather its metabolic water requirements from invertebrates and nectar. The wide range of habitats occupied by the Singing Honeyeater suggests that further research into its physiology may provide interesting results with possible physiological adaptations, which may be evident clinally across Australia.

Birds more common away from the bore and piosphere

The Redthroat *Pyrrholaemus brunneus*, like the White-browed Scrubwren *Sericornis frontalis*, has most likely been excluded from the piosphere by overgrazing eliminating cover and its preferred invertebrate prey (Ambrose & Davies 1989; Rowley & Russell 1997; Higgins & Peter 2002). Australasian Pipits *Anthus novaeseelandiae* were frequently detected in the 100-ha zone and across the whole island, although they were absent from the piosphere. This species generally proliferates in grazed areas, feeding on invertebrates such as beetles (Coleoptera), grasshoppers (Orthoptera), ants (Hymenoptera) and springtails (Collembola; Garrick 1981; Fulton & Majer 2006; Higgins *et al*. 2006). James *et al*. (1999) suggested that some invertebrates (as above) have been replaced at bores by invertebrates that have aquatic instars. The absence of the Australasian Pipit in the piosphere, although common elsewhere on Faure Island, suggests that the invertebrates it feeds on were unavailable there, perhaps giving some support to the findings of James *et al*. (1999).

Future research might investigate what birds frequent the bore if it is shut down and monitor the recovery of vegetation and invertebrates in the absence of trampling at the bore by live stock.

CONCLUSION

The null hypothesis that the bore has no effect on the concentration of birds on the island is rejected. Because this study was limited in time and scope it is important to view the results in line with the limitations. Water was used by some species more than others. It is likely that there will be opportunistic predation on introduced marsupials and birds at the bore, particularly when they are more concentrated there.

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