REPRODUCTIVE TIMING AND HABITAT PREFERENCE IN THE STUBBLE QUAIL (*Coturnix pectoralis*) IN NORTHERN VICTORIA.

Honours Thesis submitted as part of the requirements for the Bachelor of Applied Science (Honours) Degree, University of Ballarat.

By
SIMON DENNIS TOOP

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DECLARATION

I hereby declare that this Honours thesis is of original work.

The work presented in this thesis does not contain any:

i. material that has been accepted for the award of any other degree at any University;

ii. material previously published; or

iii. material written by any other person which has not been acknowledged.

Signed:

Simon Toop

(August 12, 1994)

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ABSTRACT

The timing of breeding and habitat preference in the Stubble Quail (*Coturnix pectoralis*) were assessed at two study sites, Dookie and Mitiamo, in the north of Victoria. Surveying was over an eight month period between September 1993 - April 1994.

Reproductive timing was determined by monitoring changes in the gonad size of shot birds. Breeding events were verified by disproportionate increases in the number of young birds shot. Population density was measured as an indicator of habitat preference. Site characteristics known to affect habitat selection were monitored.

Breeding was in spring and autumn. Spring breeding coincided with the period of maximum plant growth. Autumn breeding was stimulated by above average late summer rainfall. Male Stubble Quail were shot in greater numbers during a known breeding event. Stubble Quail preferred areas of lightly grazed pasture dominated by native grass species. Recently harvested wheat and barley stubble provided an abundant short-term food supply, however the ability of this habitat type to support resident Stubble Quail populations is questioned. Stubble Quail population density appeared to be strongly influenced by territorial behaviour during breeding.

Implications for the management of this game species are discussed and future lines of research recommended.

INTRODUCTION

The Stubble Quail, *Coturnix pectoralis*, is an important Australian gamebird actively hunted in Victoria, New South Wales, and South Australia. It is the most common Quail species occurring in Australia and is found over much of south-eastern and south-western Australia across a range of habitat types (Olsen *et al.* 1993). Despite the intrinsic and economic value of the species, little is known of its reproductive biology or its habitat requirements (Frith and Carpenter 1980). Such information is essential for the formation of a successful management program. Such a program depends on an understanding of what factors affect the timing, duration, and success of breeding and the relationship between population productivity and habitat quality (Murray and Frye 1957; Kingsford 1989).

With the exception of the work done by Frith *et al.* (1977), in relation to habitat requirements, and Frith and Carpenter (1980), on breeding cycles, there is little quantitative information available about the breeding seasons and habitat preferences of the Stubble Quail. Data relating to Victorian conditions are even more limited.

The timing of breeding in Australian bird species

The ultimate and proximate factors that control the breeding seasons of Australian birds are poorly understood (Ford 1989). Ultimate factors are those which directly affect the evolution of a particular characteristic, in this case the timing of breeding, and proximate factors are those which act as indicators of forthcoming events (Perrins and Birkhead 1983). Due to the variability in latitude and rainfall within Australia, breeding seasons and likely initiating factors, may vary from place to place (Ford 1989).

Nix (1976), in a comprehensive assessment of the environmental factors controlling bird breeding cycles in the Australian region, suggests that spring is the preferred breeding time for the majority of Australian bird species. This is also the period of highest plant growth (Nix 1976) and corresponds with the notion that birds breed during times of peak food availability (Lack 1954). Some Australian bird species which are also known to breed in autumn (Davies 1976; Ford 1989). Lofts and Murton (1968) suggest that autumn conditions often mimic those of spring with respect to both temperature and day length. These factors could be important in the initiating of breeding in birds (Davies 1976).

In Australia, avian gonad cycles appear to be primarily controlled by changes in photoperiod (Ford 1989), however, these cycles can be strongly modified by environmental conditions (Braithwaite 1976; Frith *et al.* 1976; Murton and Kear 1978). Ford (1989) suggests that daylength is the main factor that influences preparedness to breed, but it is rain that may initiate actual breeding. Serventy and Marshall (1957) state that spring breeding may be coincidental with increasing daylength. They further suggest that photoperiod may not be as crucial as food abundance and the effect that rainfall has on both the quality and quantity of this resource (Serventy and Marshall 1957).

Frith and Carpenter (1980) found that breeding in the Stubble Quail most commonly occurred in spring and early summer. A frequent second peak of gonadal recrudescence was also observed in late summer and autumn and was thought to be stimulated by abundant food supply produced by autumn rains (Frith and Carpenter 1980). It has been recognised that the periods in which the species breeds varies from time to time (Frith and Carpenter 1980) and is to some extent related to rainfall (Miller 1938, 1944; Masters and Milhinch 1974; Frith and Carpenter 1980).

Habitat quality

Habitat quality has been found to positively correlate with species density (Cody 1974 , 1981; Wiens 1974; Fox 1979; Rotenberry and Wiens 1980; Van Horne 1983; Rands 1988a). A strong relationship has been shown to exist between the population status of small game species and the quality of their habitat (Shaw 1985).

Frith *et al.* (1977) and Frith and Carpenter (1980) found that the availability of food resources and cover were two of the most significant habitat variables affecting the success of the Stubble Quail in a given area. Rainfall has been identified as a major factor in determining the quality and quantity of both cover and food availability by directly influencing plant growth and productivity (Hobbs 1961; Nix 1976; Frith *et al.* 1977; Brooker *et al.* 1979; Frith and Carpenter 1980; Rotenberry and Wiens 1980; Goldsmith 1991). Presumably, if vegetation structure changes as a result of variation in precipitation, the distribution and abundance of the Stubble Quail may also change (Rotenberry and Wiens 1980).

The impact of many farm management practices on the habitat quality of the Stubble Quail are presently unknown and poorly researched. Procedures associated with the pastoral and agricultural industries such as grazing, cultivation, burning, and the use of chemicals, can affect the vegetational composition, and in turn the habitat structure (Brown 1978; Rotenberry and Wiens 1980; Frawley and Best 1991). Whilst acknowledging that the Stubble Quail is well adapted to agricultural areas, Frith *et al.* (1977) warn that improvements in farming techniques may prove detrimental to the species by removing their food and cover for much of the year hence restricting their range.

Objectives

This research aims to:

- Examine the reproductive timing of the Stubble Quail and identify the influencing factors.
- Identify periods of residency through population indices and determine the preferred habitat type/s of Stubble Quail.
- Monitor habitat variables, identify any change, and assess the response as indicated by Stubble Quail density.
- Suggest possible management strategies to maintain Stubble Quail populations and future research direction.

Project hypotheses

The following hypotheses were tested for significance:

- Stubble Quail reproductive timing is influenced by photoperiod and temperature and the resultant increase in food availability. Any subsequent reproductive activity is stimulated by rainfall which encourages plant growth and provides adequate food and nesting cover to ensure successful clutch production.
- Habitat quality, as determined by a number of environmental variables, is positively correlated with Stubble Quail density.

LITERATURE REVIEW

Much of the literature reviewing the Stubble Quail is based on qualitative data. With the exception of the work done by McNally (1956), Disney (1976), Frith *et al.* (1977), Frith and Waterman (1977), Frith and Carpenter (1980), Crome *et al.* (1981), and Roberts and Baudinette (1984, 1986, 1988), all literature exploring the life history of the species is based on observation. With this in mind, it is still plausible to identify the basic ecology of the Stubble Quail.

This literature review has a number of objectives. Firstly, the physiological and behavioural characteristics of the species will be outlined. To understand the implications of land and game management practices on the Stubble Quail, a basic knowledge of its ecological relationships is required.

Secondly, the focus of this study is to identify the timing of breeding and habitat preference of the Stubble Quail. Factors affecting both of these phenomenon will be reviewed, paying particular attention to gamebirds, and the implications related to the Stubble Quail.

Finally, current Victorian management of the Stubble Quail will be reviewed and contrasted with the theory of game species harvesting.

ECOLOGY OF THE STUBBLE QUAIL, *Coturnix pectoralis*

Distribution

The Stubble Quail is common throughout the grasslands and shrublands of temperate Australia, in particular the well watered south-eastern and south-western regions (Refer Figure 1). The species' range can extend into the arid zone after rainfall or flooding (Readers Digest 1990; Frith *et al.* 1977; Frith and Waterman 1977).

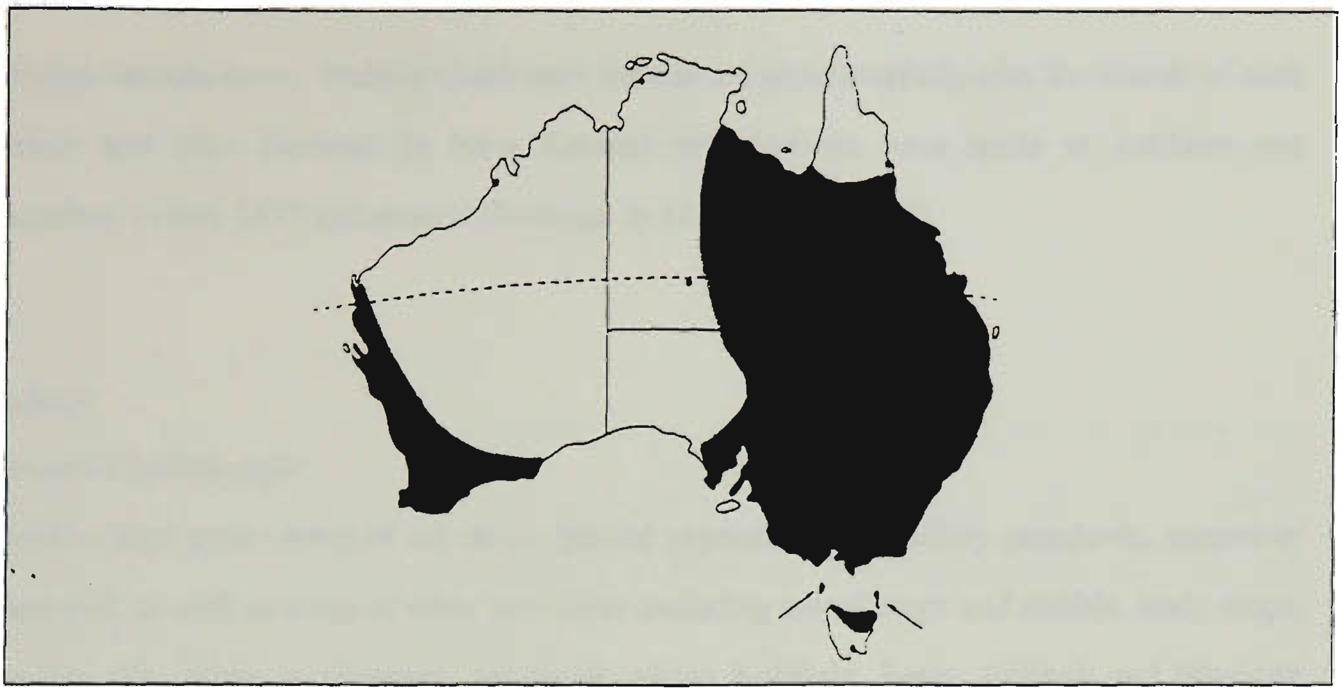

Figure 1: Distribution of the Stubble Quail throughout Australia (source: Olsen *et al.* 1993).

In the south-eastern region of Australia, the Stubble Quail has been recorded all year round (Miller 1938; Hobbs 1961; Frith 1969; Frith and Carpenter 1980; Blakers *et al.* 1984; Emison *et al.* 1987). During winter months the species becomes scarce in the south-east of South Australia, the south of Victoria, and the east of New South Wales (McEvey 1965; Frith and Waterman 1977; Gosper 1981; Ashton 1985; Taylor 1987; Emison *et al.* 1987).

Stubble Quail are generally more common in areas which receive high summer rains (Miller 1938; Hobbs 1961; Frith and Waterman 1977; Frith *et al.* 1977). Resident populations are often found in areas with high annual rainfall or perennial green growth (Miller 1938; Frith and Carpenter 1977). Large numbers sometimes appear in inland districts following good rains and plant growth (McGilp 1923; Hobbs 1961; Frith *et al.* 1977; Brooker *et al.* 1979) and disperse as plant growth dries out and food availability declines (Hobbs 1961; Frith and Waterman 1977).

Foreign Introductions: Stubble Quail were introduced unsuccessfully onto the islands of both Hawaii and New Zealand. In New Zealand introductions were made at Aukland and Cantebury before 1871 and around Hokianga in 1870's (Long 1981).

Habitat

Favoured habitat types

Stubble Quail prefer areas of tall dense ground vegetation, particularly grasslands, natural or improved, as well as areas of other low cover including cereal crops and stubble, leafy crops, bracken (*Pteridium esculentum*), saltmarsh, alpine herbfield, heath, saltbush and bluebush (White 1913; Miller 1938; Hobbs 1961; McEvey 1965; Quinn and Wade 1970; Cox and Pedler 1977; Wyndham 1978; Close and Jaensch 1984; Taylor 1987).

The species can also be found in open woodlands where the canopy is sufficiently open enough to allow the development of ground vegetation. Stubble Quail have been known to utilise grassy areas within young *Pinus radiata* plantations (Gepp and Fife 1975; Friend 1982)

Frith *et al.* (1977) and Frith and Carpenter (1980) examined habitat preference and found that favoured habitats are characterised by a well developed and varied ground layer of low growing herbs which are capable of providing seed for extended periods. Ideal habitats are those which provide tall grassy or leafy cover dense enough to shelter birds from aerial view but not so dense as to inhibit herb growth (Frith *et al.* 1977).

Weedy or thin cereal crops provide a perfect combination of food and cover capable of supporting many birds (Frith *et al.* 1977). After the harvesting of cereal crops, an abundant food source is available to the species and often large numbers of birds are found utilising stubble fields (Miller 1938; McNally 1956; Frith *et al.* 1977; Frith and Carpenter 1980). Open or low vegetation, even bare ground, will be tolerated if food is abundant (Miller 1938; Hyett 1967).

Unsuitable or avoided habitat types

Few Quail are found in areas heavily grazed by introduced stock or kangaroos (Neave and Tanton 1989) or where mice plagues have depleted food resources (Frith and Carpenter 1980). Disturbance by stock causes birds to leave paddocks before food resources are exhausted (Frith *et al.* 1977; Miller 1938).

Well grown crops are avoided as the dense canopy inhibits the growth of ground cover and provides little in the way of food before harvesting takes place (McNally 1956; Frith *et al.* 1977).

Densely forested areas are also avoided although birds may enter patches where clear felling has taken place (Loyn 1980). The species is uncommon in small patches of grass within woodland due to a reluctance to pass through intervening unsuitable habitat (Ashton 1985).

Social organisation and behaviour

Little is known of the species behavioural habits. Cruise (1966) chose to study captive birds due to the difficulty of observing this cryptic species in the wild. He made observations on the sexual behaviour, courtship, intrafamily and anti-predator behaviour. Miller (1938), Bourke (1948) and Frith and Waterman (1977) have all made observations on wild individuals. These are somewhat brief and general, merely highlighting basic behavioural traits. More specific behavioural and social peculiarities are yet to be recognised.

Social structure

Stubble Quail have been recorded as individuals, pairs, or small coveys of up to twenty individuals (Miller 1944; Frith 1969). Outside the breeding season, individuals generally congregate to form a small covey (Frith 1969).

In favourable conditions, large numbers have been seen to gather (Miller 1938, 1944; Pedler 1975). Numbers are likely to build up gradually in favourable areas as nomadic birds arrive. Stubble Quail are not known to travel in groups (Blakers *et al.* 1984).

Bonds

The species is believed to be monogamous, and possibly pairs for all of the year (Miller 1944; Pedler 1975). Cruise (1966) reported captive pairs appear unattached and rarely come into direct contact. They never allopreen (Cruise 1966). When courting the male offers food items to the female which are accepted (Cruise 1966).

In captivity, Cruise (1966) observed juveniles separating into male and female groups. Each of these groups would display territorial behaviour. Prior to the breeding season, courtship behaviour would commence and sexes would begin to intermingle as mates were being sought (Cruise 1966).

Sex ratio

The sex-ratio of males to females has been recorded at approximately 1:1 (Frith and Carpenter 1980). Miller (1938), however recorded a ratio biased in favour of males. He suggested that this reported imbalance was attributed to the observational bias that males tend to flush before females. This characteristic increases the chance of males being shot as hunters usually target the first bird to flush (Miller 1938). Leopold (1977) reports a similar marginal difference in the sex-ratio of some species of North American Quail and attributes this to differential mortality during the breeding season.

Parental care

Many authors suggested that only the female incubates the eggs (Bourke 1948; Cruise 1966; Pedler 1975; Ray 1982). Photographic evidence in Olsen *et al.* (1993) disproves this theory showing a male bird incubating a clutch. Both parents guard and brood the young until fully feathered and capable of strong flight at approximately six weeks of age (Pedler 1975).

Movement

The movements of the Stubble Quail are poorly understood particularly in the absence of any radio telemetry or ongoing banding studies. Hall (1907) and Cayley (1931) assumed the birds to be nomadic. Miller (1938) was inclined to accept the idea of a small-scale migration but was convinced that the birds were sedentary and moved only locally in response to the ploughing of stubble fields. He argued that numbers declined not because of random movement as a result of natural attrition caused by a depletion of food resources and other unspecified limiting factors. Further, an increase in bird numbers was not due to any migratory influx but rather as a result of the recuperative breeding ability of the species replenishing localised populations (Miller 1944).

MacDonald (1973) preferred to consider the bird as both sedentary and nomadic but failed to say whether this was at different times, places, or in different populations.

Nomadism

From 14 January 1969 to 4 April 1972, 12,970 Stubble Quail were banded in a large scale operation undertaken to determine the movements of the species (Frith and Waterman 1977).

Quail were banded in the grain growing districts of north Adelaide and their individual movements plotted. Of the 12,970 birds banded, the nominal recovery rate of 0.74% was recorded.

Frith and Waterman's (1977) results were consistent with the proposal that the Stubble Quail are not migratory but that their movements are nomadic and controlled by rainfall, plant growth and the availability of food (Miller 1938; Hobbs 1961; Pedler 1975; Frith and Waterman 1977; Frith *et al.* 1977). Agricultural and pastoral practices were also seen to cause localised movements as food supplies vary with crop development and grazing rotations (Miller 1938; Frith *et al.* 1977). Between 1969-1972 individuals dispersed in all directions and moved vast distances. One specimen was recorded as having travelled 1,143 km (Frith and Waterman 1977).

Dispersal

Dispersal occurs in any season in response to a deterioration of localised conditions (Miller 1938; Frith and Waterman 1977). Such a movement pattern is similar to those of several nomadic waterbirds of the Australian semi-arid region (Carrick 1962; Frith 1962; Matheson 1978; Burbidge and Fuller 1982). Both adults and juvenile waterbirds are known to disperse, however juveniles appear to be more dispersive (Mees 1964; Frith and Waterman 1977; Frith and Carpenter 1980) .

Large numbers of Quail are known to appear in inland districts after good rains and plant growth (McGilp 1923; Hobbs 1961; Frith *et al.* 1977; Brooker *et al.* 1979). Birds vacate these areas as plant growth dries and food disappears (Hobbs 1961; Frith and Waterman 1977). The drying-out of grasses and herbaceous plants results in the loss of food resources and can cause localised irruptions as birds gather in remaining patches of green feed or good cover (Miller 1938; Pedler 1975).

Observations made on Quail populations across the semi-arid inland plains of New South Wales emphasised the relationship between Quail distribution and resource availability (Frith *et al.* 1977). Normally, closely grazed, inland plains support few Quail. However, Frith *et al.* (1977) has shown that heavy summer rains stimulate rapid and vigorous plant growth which exceeds that lost to sheep and cattle grazing. During times of excessive food supply and cover, large numbers of Quail have been observed (Frith *et al.* 1977). As the vegetation dries and herbage is trampled and degraded by stock, the large populations of birds disperse being forced to seek areas capable of supporting nomadic individuals (Frith *et al.* 1977).

However not all populations are dispersive (Blakers *et al.* 1984; Green 1989). Where conditions are consistently productive, resident populations establish themselves.

Diet

The food habits of the Stubble Quail have been well identified. McNally (1956) and Frith *et al.* (1977) undertook comprehensive studies investigating the nutritional requirements and feeding habitat of the species.

Foraging habit

Stubble Quail have been found to be omnivorous but mainly granivorous (Russell 1921; Morse 1922; Kingthorn 1926; Lea and Gray 1934; Souter 1934; Miller 1938, 1944; McNally 1956; Hyett 1967; Rose 1973; Frith *et al.* 1977). The species is essentially a ground feeding bird (Frith *et al.* 1977; McNally 1956) however individuals have been observed climbing wheat stalks to feed on seed heads (Miller 1938). Food collection is by gleaning and scratching for seeds, grasses and foliage (Miller 1938; Frith *et al.* 1977). A range of food items will be accepted. The diet is determined by whatever is locally available. This emphasises the birds opportunistic feeding behaviour (Frith *et al.* 1977)

Food items taken

Food items range from cultivated cereals to pasture plants and weeds. Green leaf material such as clover is also seen as an important dietary source (Lea and Gray 1934; McNally 1956; Frith *et al.* 1977). In addition, animal material is consumed and consists mainly of insects. This food source is of secondary importance to the birds' staple intake of seeds (Morse 1922; McNally 1956; Frith *et al.* 1977).

Early studies investigating the dietary intake of the Stubble Quail were directed toward evaluating the species' impact upon agricultural practices. Russell (1921) and Morse (1922) found the bird played an important role in crop protection by acting as a major insect predator. Kingthorn (1926), Lea and Gray (1934), Miller (1938), and McNally (1956) in examining the crops of birds collected from throughout New South Wales and Victoria showed that the birds' diet consisted primarily of seeds and to a lesser extent insect material.

Frith *et al.* (1977) identified a total of 169 plant species in the crops of 6,568 specimens collected throughout New South Wales, South Australia and Victoria. Of those plant species identified by Frith *et al.* (1977), 32.5% were native plants and the remainder exotic crops, pasture plants and weeds. There were differences between the food items taken at various localities. This highlighted the opportunistic foraging behaviour of the species. The principal animal food was insects but many other classes such as crustacea and amphibia were eaten in small quantities (Frith *et al.* 1977). The most important insects taken were of the Lepidoptera and Orthoptera order. Both adult and larval stages were consumed.

Depletion of food resources is thought to be a motivating factor behind dispersal (McNally 1956; Frith *et al.* 1977; Frith and Waterman 1977). Frith and Waterman (1977) demonstrated that Stubble Quail undertake extensive movements influenced by agricultural practices and rainfall and the effect that these variables have on the availability of food and cover resources.

Breeding

The breeding season of the Stubble Quail has not been clarified in detail. It has been recognised that breeding season is related to rainfall, cover and the availability of food (Miller 1938, 1944; Masters and Milhinch 1974; Frith and Carpenter 1980).

Timing

Many authors have provided specific periods in which they observed the species' breeding: October-February (MacDonald 1973), October-December in south-east Queensland (Storr 1973) and in south-western Australia from September-December (Serventy and Whittell 1976). Other estimates in various districts are August-January (Masters and Milhinch 1974), September-January (Russell 1921), August-March (Morse 1922), October-December (Jenkins 1931) and November-January (Bravery 1970). Frith and Carpenter (1980) found evidence of a latitudinal trend in the date of the beginning of the annual gonad cycle.

In the most comprehensive review of the Stubble Quail's breeding patterns, Frith and Carpenter (1980) identified an annual spring/early summer peak in the gonad cycle. They also identified a frequent autumn peak which they believed to be controlled by rainfall.

Reproduction can be influenced by both food availability and the degree of cover available for nesting (Miller 1944; Frith and Carpenter 1980). If any of these essential characteristics is in limited supply, breeding can be delayed (Frith and Carpenter 1980). Frith and Carpenter (1980) demonstrated the importance of food supply on reproductive activity by recording restricted breeding periods during mice plagues when food stocks were dramatically depleted.

Nest site

Nests can be found under tussocks of many grassland species (Bourke 1948; RAOU Nest Record Scheme; Frith and Carpenter 1980), paddocks of lucerne, cereal crops (particularly those with moist undergrowth), wheat crops with a dense ground-cover of clover spp. (Bourke 1948; Masters and Milhinch 1974), under small shrubs and even the epicormic growth of eucalypts (Cheney 1915; RAOU Nest Record Scheme).

Nests

The nest is generally a scrape in the ground, lined with dried grass and material from surrounding vegetation (Serventy and Whittell 1976). The female excavates the scrape with her feet and adds material during whilst incubating until the nest is approximately 8 cm above ground level (Cruise 1966). Nest measurements have been recorded at 90-100 mm in diameter and 40 mm in depth (Cruise 1966).

Eggs

The eggs of the Stubble Quail are oval to pyriform in shape (North 1914; Readers Digest 1990; Beruldsen 1993). They have a lustrous, close-grained appearance and are yellowish white to pale yellowish brown in colour (Littler 1910; Cruise 1966; Beruldsen 1993). The eggs are uniformly covered with irregular freckles and rich umber-brown or olive-green blotches (Littler 1910; Shanks 1949; Cruise 1966; Beruldsen 1993). The eggs measure approximately 30 x 23 mm in size (Serventy and Whittel 1976; Readers Digest 1990).

Incubation

Cruise (1966) reported that incubation was undertaken only by the female. However, Olsen *et al.* (1993) includes photographic evidence proving that both the male and the female

Plate 1: Male Stubble Quail incubating eggs.

participate in the incubation process (Plate 1). Incubation begins when the clutch is complete (Bourke 1948; Cruise 1966). Incubation takes between 18 days (Bourke 1948) and 21 days (Cruise 1966).

The female pulls surrounding vegetation together over the nest for cover during the incubation period (Bourke 1948). Hatching is synchronic with the female possibly having the ability to retard hatching even after the eggs have been chipped during the hatching process (Bourke 1948).

Productivity

Clutch size has been quoted as varying between 7-14 eggs (Littler 1910; Morse 1922; Carnaby 1933; Miller 1938; Serventy and Whittell 1976; RAOU Nest Record Scheme). Eggs are laid on consecutive days (Cruise 1966) and as many as four clutches in a season have been recorded (Morse 1922; Miller 1938; Bourke 1948).

Pairs often lay two to three broods per season with juveniles recorded until April (Morse 1922; Miller 1944; Masters and Milhinch 1974; RAOU Nest Record Scheme). Breeding may continue into autumn and possibly winter, following summer rains (Fletcher 1903; Carter 1923; Jenkins 1931; Miller 1944; Frith and Carpenter 1980).

Nesting Success

Failure of eggs can occur through flooding (Bourke 1948; Frith and Carpenter 1980) or breakage during incubation (Bourke 1948). Predators such as foxes and goannas are responsible for heavy losses (Bedggood 1973) and many nests and adults are destroyed during crop harvesting and hay-making (Fletcher 1903; Shanks 1949; Frith *et al.* 1977).

Young

The young are precocial and nidifugous upon hatching (Shephard 1989). Both parents brood the juvenile until almost fully grown (approximately 6 weeks of age) (Pedler 1975). The female shows newly hatched chicks how to obtain food (Cruise 1966). The young are covered in a buff coloured down with black stripes running centrally from crown to tail and laterally on the sides of the back (Shephard 1989).

When approximately two-thirds grown (six weeks), the female attacks and repels the young, forcing them to become independent (Cruise 1966). These displaced juveniles then band together and fend for themselves as a group (Cruise 1966).

Growth

Full adult plumage is attained at 16 weeks of age (Cruise 1966; Crome *et al.* 1981) and young are capable of weak flight at 16 days (Cruise 1966). Sexual maturity is reached between 60 and 448 days (Frith and Carpenter 1980). Disney (1969, 1974) stated that under suitable conditions Stubble Quail may breed at the age of four months, but not before two months (Disney 1978), and further supported this with direct evidence investigating both the Stubble Quail and the related Japanese Quail, *Coturnix coturnix japonica* (Disney 1978).

Ageing

The role of ageing in wildlife management is clearly introduced in Alexander (1958). In other countries, considerable work has been done on ageing gamebirds, particularly Quail (Disney 1969). The ability to age individual Stubble Quail is an important aid to investigators when analysing the demographic structure of those specimens collected for reproductive assessment or from banding studies.

A method based on the moult of the juvenile primaries and primary coverts has been used to age specimens of many gallinaceous gamebirds species in North America (Leopold 1939; Thomson and Kabat 1950; Wallmo 1956; Leopold and McCabe 1957; Rait 1961; Lyon 1962; Watson 1963; Rait and Ohmart 1966; Ohmart 1967).

Disney (1969) confirms that the Stubble Quail moults in a similar fashion to North American Quail and suggested that this species can also be classified into age categories by examination of the plumage.

In the Stubble Quail, most immatures can be recognised by a combination of the state of the individuals primary moult, juvenile primary coverts and breast pattern (Disney 1969, 1974; Crome *et al.* 1980). In some cases this may be difficult to determine. Wear of primaries, replacement of juvenile primary coverts, an overlapping breast pattern in some adults, and similarity of the breast pattern to fully developed birds are all problems which can make the accurate ageing of birds difficult (Disney 1969; Crome *et al.* 1980).

Crome *et al.* (1980) modelled the growth of primaries in post-natal and post-juvenile moults for ageing in days up to day 90. The technique is accurate to a few days (average 1 day) in captivity however this has not been tested on wild populations.

AVIAN TIMING OF BREEDING

The vast majority of birds live in a nonuniform environment and posses a nonuniform temporal pattern of energy requirements (Immelmann 1971). Their survival therefore depends on the development of an efficient timing program that permits the adjustment of physiologically important functions to favourable times of the year (Immelmann 1971). Because of its heavy physiological demands, reproduction is the most critical among the recurrent events and must be timed to a period of minimum stress on the adults and maximum probability for the survival of parents and young (Immelmann 1971).

Reproduction is the part of the life cycle with the greatest environmental dependence (Immelmann 1971). In general, all species of birds breed at all those times of the year when, on average, young can be profitably raised (Lack 1954). Fledglings hatched at less advantageous times suffer a higher mortality and rarely survive to a reproductive age (Immelmann 1971). The gene complexes of those pairs producing young at inappropriate times will be reduced or eliminated by natural selection (Immelmann 1971).

The environmental factors that control species-specific breeding periodicities have been termed the "ultimate factors" (Thomson 1950). Ultimate factors, with regards to the timing of breeding, are those which directly affect the evolution of this particular characteristic (Perrins and Birkhead 1983).

By far the most important ultimate factor for the majority of bird species is the availability of an adequate food supply (Immelmann 1971; Murton and Westwood 1977; Perrins and Birkhead 1983). The most critical point in the sequence of annual events occurs immediately after the main nesting period, when population density is at its highest and there is a high percentage of inexperienced young which must become self supporting (Moreau 1950). It is therefore advantageous for birds to breed at such a time that their young are in the nest, or have recently fledged, when there is a peak in the abundance of food (Lack 1954).

Each bird species has come to rely on various means, both environmental and physiological (eg. hormone levels, photoperiod, temperature change, rainfall) (Nix 1976), to adjust breeding to the most propitious time (Lack 1954, 1966; Wolfson 1960; Marshall 1961; Farner 1967). However, for a bird to have young in the nest at the time of peak food availability, it must start breeding much earlier (Perrins and Birkhead 1983). This is to allow for gonadal development, courting, nest building, egg formation, the time required to complete clutch laying and, finally, incubation. To do so, birds rely on a series of environmental cues, or "proximate factors", to time their breeding cycles. Proximate factors have no immediate value in terms of the bird's physiological needs however they do act as indicators of forthcoming conditions (Perrins and Birkhead 1983).

In an attempt to identify the timing of breeding and the factors which stimulate gonadal recrudescence in birds, many techniques are used. Nest searches provide direct evidence of a breeding event whilst inspection of the sexual organs can give an accurate insight to exactly when and what possible influences may have affected stimulated sexual activity.

The increase in either testis length or oocyte diameter is regarded as an indicator of a bird populations' breeding status. Norman and Hurley (1984) showed that in the Chestnut Teal, *Anas castanea*, a strong correlation existed between an increase in gonad size and their respective viability. Whiting *et al.* (1985) and Roberts (1980), Davies (1977), and Braithwaite and Frith (1969) found that increase in the size of gonads of American Woodcock, Zebra Finch (*Poephila guttata*) and several species of Australian waterfowl respectively, indicated that individuals were in, or approaching, breeding condition.

Gonads need not necessarily be at the peak of their growth cycle to be viable (Frith *et al.* 1976; Frith and Carpenter 1980). Braithwaite and Frith (1968), Frith *et al.* (1976), and Frith and Carpenter (1980) used histological examinations of gonads to assess their relative viability and found that beyond a particular stage in the growth phase birds become capable of producing fertile sperm or oocytes (Frith *et al.* 1976; Frith and Carpenter 1980).

The timing and duration of bird breeding cycles is well understood in north temperate birds, particularly in Europe, however the proximate and ultimate factors that control the breeding seasons of Australian bird species are poorly researched (Ford 1989). In higher latitudes, climate, particularly the severe winter that affects both a bird's physiology and its food supply, often limits breeding to the warmer months (Braithwaite and Frith 1969). In the temperate parts of the Northern Hemisphere birds traditionally breed in spring and early summer (April to July) (Ford 1989). In these strongly seasonal climates, the abundance of food varies predictably with season, and photoperiod is the most reliable cue within the annual cycle for the control of reproductive activity (Breed 1982).

In lower latitudes, breeding tends to be limited indirectly through the effects of more immediate conditions, particularly rainfall (Braithwaite and Frith 1969). Thus, in lower latitudes many birds breed over an extended period (Keast and Marshall 1954; Serventy and Marshall 1957; Marshall 1961). The spread in latitude and rainfall within Australia means that breeding seasons and likely initiating factors probably vary from place to place (Ford 1989).

The breeding season of the Stubble Quail has not been well established (Frith and Carpenter 1980). Early authors recognised that the periods in which the species breeds is to some extent related to rainfall (Miller 1938, 1944; Masters and Milhinch 1974). Frith and Carpenter (1980) undertook extensive research which investigated the timing of breeding in the Stubble Quail across a wide variety of habitats and climates. They concluded that there was an annual spring/early summer cycle with a frequent second breeding event in late summer/autumn.

Frith and Carpenter (1980) found that rainfall had a significant effect on annual gonad cycles. Years of exceptionally high rainfall recorded prolonged sexual activity and the number of months in which eggs were known to have been laid increased. It was suggested that the reason for this sustained breeding was due to the extended availability of both food and cover resources.

Frith and Carpenter (1980) made no discussion of alternative stimulating factors such as photoperiod or increasing ambient temperature. Known to stimulate plant growth and consequently food availability, it would be reasonable to expect that these two environmental variables, together with rainfall, play an important role in the stimulation of gonadal development, particularly spring recrudescence.

The timing of breeding in Australian bird species

Many Australian bird species have variable breeding seasons (Frith 1959; Frith and Tilt 1959; Serventy and Whittell 1967; Braithwaite and Frith 1969; Nix 1976) however when studied over a period of years, many of these species display a regular breeding cycle (Frith *et al.* 1976). Taking this into account, spring and early summer appear to be the main breeding periods of the majority of Australian bird species (Davies 1976; Nix 1976; Ford 1989). The reason for this is different in the north of the continent than it is in the south. Low temperatures prevent breeding in winter in the southern and inland areas whereas low rainfall inhibits breeding in the north (Ford 1989).

Although most species show a marked seasonal breeding peak in spring to early summer, autumn breeding is shown to occur frequently in some species (Ford 1989). Serventy and Marshall (1957) provide examples from inland southwestern Australia of many species breeding after late summer cyclones distributed unseasonal rain throughout the area. Lofts and Murton (1968) point out that autumn often mimics spring in its temperature and daylength characteristics. Davies (1976) suggests that these two factors could be important in initiating breeding in autumn and may be distinctly separated from the effects of late summer or autumn rain. Autumn breeding is probably more common in Australia than in Europe and North America because, in Australia, autumn reared birds have a reasonable chance of surviving the relatively mild winter (Ford 1989).

The importance of food supply

Generally, the major ultimate factor in determining the breeding season of birds in Australia is food supply (Marshall 1961; Immelman 1971; Ford 1989). The nutritional requirements of the young is the most important factor for the ultimate timing of reproduction (Immelmann 1971). Food availability must be at its peak immediately after hatching to ensure the highest possible chick survival rate (Lack 1954; Immelmann 1971; Rands 1988a).

Great demands on the food supply are also made prior to the time when nestlings fledge. For many bird species, the energetic demands of egg production can be considerable (Perrins and Birkhead 1983). Moss (1968), when studying the effect of food quality available to the laying Ptarmigan hen, found that productivity is related to the quality of the feeding habitat of the female. Larger clutches were laid and chick survival rate was greater than at those sites with an inferior quality food supply. In a study of the breeding success of Red Grouse, Miller *et al.* (1966) found that the number of young raised was positively correlated with the amount of new heather growth in the summer of the previous year.

The food of birds depends either directly or indirectly on the primary productivity of plants and their seasonal patterns of growth and development (Nix 1976). These patterns are a function of ecophysical responses to the physical environment in general and climate and weather in particular (Nix 1976). Growth of plants, and hence food supply, can be limited by temperature, light, and moisture or a combination of these factors (Ford 1989). These climatic variables therefore may play an important part in dictating the breeding seasons of many Australian bird species. Each of these factors will be examined and their impact on the timing of breeding assessed. The environmental factors of greatest direct importance to the reproductive biology of Australian birds are daylength, temperature and precipitation (Davies 1976).

Temperature

Temperature can effect the timing of breeding in Australian bird species in two ways. Firstly, plant growth can be limited by temperature extremes (Ford 1989). Low temperatures retard germination and plant growth in winter and high temperatures are a restricting factor in the summer (Ford 1989). Limited plant growth generally means that food for most bird species is in short supply. Therefore, breeding during these times would prove unprofitable, giving chicks little chance of survival (Kikkawa 1980).

Secondly, ambient temperature is known to effect the sexual development of birds. Not only does temperature affect the development of the testes and egg production in spring, but cold may also terminate autumn breeding in some species (Rowley 1982). Cold weather inhibits spermatogenesis (Farner and Mewalt 1952; Marshall 1959) and, combined with a shortage of food, prohibits breeding in many species (Serventy and Marshall 1957; Ford and Sedgwick 1967; Maclean 1976; Davies 1976; Wyndham 1978). Carnaby (1954), Serventy and Marshall (1957), Frith and Tilt (1959), and Kikkawa (1980) have all demonstrated the arresting affects of low temperatures on the breeding of the Zebra Finch. Therefore, in Australia, breeding tends to take place at the end of the rainy season, as days become warmer (Immelmann 1971).

Rainfall

Moisture, generally received as rainfall, is the major limiting factor to plant growth in most areas of Australia (Ford 1989; Kingsford 1989). Plant growth is inhibited during summer months in the southwest and southern Australia (Mediterranean climates), and in the northern half of the continent in winter (monsoonal climates) (Ford 1989).

Early anecdotal evidence that good falls of rain stimulated nesting at any time (eg. McGilp 1923) later received some quantitative and experimental support from Keast and Marshall (1954), Serventy and Marshall (1957), Marshall and Serventy (1958) and Keast (1959).

Keast and Marshall (1954), Serventy and Marshall (1957), Keast (1959), and Immelmann (1963) have all emphasised a correlation between the breeding of arid zone birds and the occurrence of rain. Rain is of little value to birds, other than waterfowl, except to drink (Rowley 1982). It is the consequence of rain (the future promise of food) that is important (Rowley 1982). Rainfall is therefore considered to be a major proximate factor stimulating the onset of the reproductive season in many Australian birds species.

Keast and Marshall (1954) considered the effects of rain to be the main proximate factor, but Immelmann (1963) suggested that the mere sight of falling rain might act as the proximate factor that stimulates breeding. The influence of rain on vegetation and other environmental factors becomes apparent after the event, suggesting that the rainfall itself is the actual stimulating factor to initiate breeding (Immelmann 1971). Rainfall is the earliest possible environmental factor functionally connected with the oncoming increase in food supply.

That rain is the proximate factor stimulating breeding in the semi-arid and arid zone may be an oversimplification (Schodde 1982). Emphasis has shifted from regarding rain alone as the proximate factor to the quantity of rain (Ford and Sedgwick 1967) and the food that it produces (Maclean 1976; Davies 1976)

Photoperiod

The way in which photoperiod, or daylength, affects different bird species is complex and has been reviewed in detail by Lofts and Murton (1968), and Murton and Westwood (1977). Changes in daylength impose a regular seasonal rhythm on the environment of Australia (Davies 1976) and may be used by birds as an indicator of impending favourable conditions.

Photoperiod has been suggested by a number of authors (eg. MacLean 1976; Frith *et al.* 1976; Kikkawa 1980; Schodde 1982; Ford 1989) as being an important proximate factor in initiating reproduction in Australian bird species. Schodde (1982) and Ford (1989) suggest that increasing daylength, and possibly temperature, are the only consistent cues to trigger the physiological and behavioural changes that birds must under go before breeding. Recently, Halse and Jaensch (1989) demonstrated that a number of summer-breeding waterbirds responded positively to photoperiod when determining the time of laying. Alternatively, others have questioned the role of photoperiod in stimulating reproductive activity.

Marshall (1961) argued that the role of photoperiodism had been overemphasised in the control of Australian bird breeding seasons. Serventy and Marshall (1957) concluded that photoperiodicity is of little importance as a regulator of the sexual cycle. They suggested that plant growth and rising temperatures following rainfall were the most critical proximate factors that induce breeding. The fact that these conditions arise most commonly in spring, when photoperiod was lengthening, was regarded as coincidental. Braithwaite (1976) also stresses the difficulty in separating any effect of photoperiod from other possible proximate factors (eg. rainfall, increasing temperature) because in Australia they are likely to occur at the same time.

Photoperiod has been implicated in stimulating autumn recrudescence in some Australian bird species. Lofts and Murton (1968) point out that autumn often mimics spring in its day length characteristics and may act to stimulate a second breeding event (Davies 1976). Frith and Tilt (1959), Davies (1977), and Kikkawa (1980) found both spring and autumn peaks in Zebra Finch breeding and remarked that daylength is similar at these times. They suggested that this particular photoperiod regime may positively influence gonadal development.

THE IMPORTANCE OF HABITAT QUALITY IN AVIAN DISTRIBUTION

It is generally accepted that animal species density is positively correlated with habitat quality (Cody 1974 and 1981; Wiens 1974; Fox 1979; Rotenberry and Wiens 1980; Van Horne 1983; Rands 1988a). The availability and abundance of resources essential to the survival of a particular species will determine its success in a given area (Van Horne 1983). A greater habitat quality reduces competition for limiting resources allowing an increase in nett population productivity (Rands 1988a).

Density indexes are often used as a measure of habitat quality however high index values may be a misleading indicator of quality (Van Horne 1983). Habitat quality should be defined in terms of the ability of an area to sustain a breeding population that is capable of producing offspring which contribute towards maintaining future populations. This is preferred to simply the number of animals per unit area that the habitat can support at any one time or carrying capacity (Van Horne 1983).

For the majority of species, the production of young, emigration, recruitment and certain types of mortality are all influenced to varying degrees by habitat quality (Rands 1988a). The essential resources needed for survival include food, suitable nesting sites and some form of protection against predators and environmental elements. It is the variation in the quality and quantity of these specific resources which determines habitat quality (Rands 1988a).

The long term abundance of gamebird species is considered a function of the availability and quality of food, cover, and nesting and brood-rearing habitat (Roseberry and Klimstra 1984). Frith *et al.* (1977) and Frith and Carpenter (1980) found that the availability of food resources and cover were two of the most critical environmental variables effecting the distribution and abundance of the Stubble Quail. Areas displaying high values for both of these resources were found to contain higher Quail densities than areas with poor cover and/or limited food supplies (Frith *et al.* 1977). Both of these limiting resources will be examined in the literature in an attempt to highlight their importance as a major influence in determining habitat preference.

Importance of food in relation to habitat quality

The abundance and quality of food supplies is known to limit gamebird numbers (Rands 1988). Species with an adequate food supply generally grow larger, have a higher productivity, are more vigorous and healthy, and are more resistant to many forms of mortality than those affected by malnutrition (Nagy 1980).

Evidence that population levels are affected by habitat quality comes from the experimental manipulation of food supply. Miller *et al.* (1970) increased food quality on a heather moorland and observed increases in red grouse (*Lagopus lagopus scoticus*) populations. Newton (1980) also found correlations between bird densities and food supply. Food supply was identified by Leopold (1977) as a factor that may limit California Quail (*Callipepla californica*) populations. He stated that Quail numbers fluctuated with the abundance of food if adequate cover was available. Oates and Crawford (1983) also found that Californian Quail abundance and productivity was related to the availability of certain key foods.

Gamekeepers in the United Kingdom acknowledge the importance food availability and, in an attempt to increase the harvestable population of an area, plant crops which provide both a food source and suitable cover (Roseberry 1979; Hill 1985; Robertson and Rosenberg 1988). This serves to decrease emigration and encourage immigration of gamebird species.

Frith and Carpenter (1980) demonstrated the importance of food supply to the Stubble Quail during a mouse plague in 1970. During this period, cover was abundant and was not considered a limiting factor. Mice had depleted much of the available seed supply and Stubble Quail were forced to forage for less satisfactory sources of food (Frith *et al.* 1977). Quail dispersed from the study area and breeding was impaired as a result of the apparent lack of food (Frith and Carpenter 1980).

Frith and Waterman (1977), in a large scale banding operation, also highlighted the importance of food supply to the species. They demonstrated that Stubble Quail movements were determined by the availability of food supply. Frith *et al.* (1977) reported, in an intensive study into the food habits of the Stubble Quail, that the species secures most of its food from crops and exotic weeds of cultivation. Miller (1944) suggested that localised movements of the Stubble Quail was in response to harvesting regimes as abundant food supply became available.

Habitat structure

Habitat structure, commonly referred to as cover, can be any structural resource of the environment that enhances reproduction and/or survival (Bailey 1984). Cover fulfils a variety of habitat requirements for wildlife (Yoakum *et al.* 1980). For gamebirds, cover plays an important role in influencing breeding and its rate of success, foraging habits and food availability, predator avoidance, and thermoregulatory relations. The absence of cover, its sparseness, or its poor distribution can limit the use of an area by many ground-dwelling bird species (Yoakum *et al.* 1980).

That vegetation structure is associated with habitat selection has been known for a long time (Hilden 1965; Cody 1981). The role of vegetation structure in bird habitat selection has been focused on by MacArthur and MacArthur (1961), MacArthur *et al.* (1972), Kohn (1967), Rosenweig and Winakur (1969), and Cody (1985a). These authors correlated the structure of environments with some measure of biotic diversity. Structural aspects of habitat have been identified as good predictors in determining faunal diversity (Cody 1981).

Typically both species diversity and bird density increase with seral stage and with increasing habitat complexity, with more resource specialists in the later stages and more census variability in the earlier, successional stages (May 1982).

Black (1954) identified four different cover types commonly recognised for upland game birds. They include;

- *Concealing cover* - cover which exists in sufficiently large patches to confuse predators. Concealing cover provides the type of protection that any successful gamebird population must have if it is to survive in quantity.

- *Shelter or thermal cover* - the type of cover which provides protection from adverse weather conditions.
- *Nesting cover* - the quality and quantity of this cover type varies widely with species. At least a minimum of nesting cover must be provided for a species to reproduce successfully.
- *Emergency cover* - temporary shelter which birds utilise to escape from predator activity.

Those cover types of particular importance to the Stubble Quail will be further investigated.

Nesting cover

For the majority of gamebirds, the most crucial form of cover is that for nesting (Shaw 1985). Breeding habitats must ensure the best chance of securing mates, nesting and raising young (Cody 1985b). Hanson (1970) and Wolfe and Brotherson (1981) have shown that the Ring-necked Pheasant (*Phasianus colchicus*) nest site selection was directly related to cover.

The most important component of nesting cover is overhead and lateral nest concealment (Klimstra and Roseberry 1975; Gregg *et al.* 1994). Most species of upland game birds have a strong preference for nesting cover with an abundance of residual vegetation (Kirsch *et al.* 1978). Tall, dense cover may provide scent, visual, and physical barriers between predators and the nests of ground dwelling birds (Bowman and Harris 1980; Crabtree *et al.* 1989; Gregg *et al.* 1994).

Ground-nesting birds are particularly vulnerable to predation during egg laying and incubation, and the choice of where to nest may affect both the adults' chances of survival and their breeding success (Rands 1988a). Rands (1988b) demonstrated that nest site quality determines nesting success. He showed that birds choose to nest where their eggs are less likely to be lost to predation.

Rands (1988b) established that the Grey Partridge (*Perdix perdix*) chose to nest in sites where the amounts of residual dead grass were greatest and that the rate of nest predation was lower at these sites. Greg *et al.* (1994) similarly demonstrated that the quality and quantity of nesting cover can decrease nest predation and increase productivity in the Sage Grouse (*Centrocercus urophasianus*). With many introduced predator populations, good quality nesting habitats may become of more importance to the survival of many Australian ground-nesting bird species.

A shortage of suitable quality nest sites has been shown to reduce recruitment and consequently limit breeding densities (Rands 1987). Most examples come from species with easily recognisable nest requirements such as hollow-nesting tits, *Parus* spp., (Perrins 1979) and kestrels *Falco tinnunculus* (Cave 1968).

Thermal cover

Morphology is closely associated with habitat selection (Lundberg *et al.* 1981; Winkler and Leisler 1985). Being physically small animals, Quail often need thermal cover to guard against extreme weather conditions, heat but more particularly cold (Shaw 1985). Thermal cover serves as an aid for ameliorating the effects of ambient temperature, radiant heat loss, and insulation (Thomas *et al.* 1979; Nagy 1980). Vegetation structure, or cover, is known to affect microclimate factors such as air temperature, leaf temperature, atmospheric moisture, soil evaporation below the canopy, soil heat storage and soil temperature, precipitation interception and others (Norman and Campbell 1989)

Stubble Quail occur in some of the hottest and driest regions of Australia (Roberts and Baudinette 1984). Behaviour which enhances a bird's physiological capacity for temperature regulation by bringing the bird into cooler microclimates are of crucial importance during the heat of the day (Dawson and Bartholomew 1968). Stubble Quail escape the heat of the day by roosting in the shade at the base of grass tussocks (Olsen *et al.* 1993). In doing so, Stubble Quail are able to reduce radiational gains of heat and lessen evaporative water loss (Roberts and Baudinette 1984, 1986).

The semi-arid and arid regions of Australia can also be very cold places, particularly at night (Dawson 1984). Low atmospheric humidity and substantial radiational heat loss (Dawson 1984) in these semi-arid and arid regions mean that Stubble Quail must endure subzero temperatures at night (Roberts and Baudinette 1986). Unless microhabitat selection or other behaviour is adopted to reduce the impact of such low ambient temperatures, much energy is expended simply to maintain homeothermy (Roberts and Baudinette 1986, 1988). Stubble Quail may overcome the problem of heat loss by roosting communally in the lee of a grass tussock (Olsen *et al.* 1993).

The effect of pastoral and agricultural practices on gamebird habitats

Grazing by domestic livestock and crop production are two agricultural practices that have been widely used to manage plant communities in upland habitats (Kirsch *et al.* 1978). Grazing and crop production can drastically alter the amount and composition of vegetation available to birds. Relationships of grazing to wildlife populations are difficult to define because grazing varies so much in intensity, duration, and distribution (Kirsch *et al.* 1978). Even so, Shaw (1985) states that wildlife populations and diversity decline under prolonged and heavy grazing.

Much research into the impact of crop production and grazing on gamebird species has been undertaken in North America. Results show that some gamebird species, like the Stubble Quail, have actually expanded their ranges whilst others have suffered localised extinction (Brown 1978). Some of those species adversely effected include; the Greater and Lesser Prairie Chickens (*Tympanuchus cupido* and *T. c. pallidicinctus*, respectively), Motezuma Quail (*Cyrtonyx montezumae*), Bobwhite (*Colinus virginianus*) and Scaled Quails (*Callipepla squamata*) and the Sharp-tailed Grouse (*Pedioecetes phasianellus*). All of these species have experienced a marked reduction in distribution and abundance in the North American south-west (Brown 1978). In contrast to these, some game species have actually benefited and increased their range (eg. the California and Gambel's Quail - *Lophortyx californica* and *L. gambeli*) (Brown 1978).

Expanding pasture and cropland at the expense of nesting, brood-rearing and protective cover is thought to be detrimental to the success of gamebirds (Kabat and Thompson 1963; Exum *et al.* 1982). Frith *et al.* (1977) stated that grazing stock, particularly sheep, make habitat unsuitable for Stubble Quail almost immediately. Stock were observed to break down top cover which provided protection and destroy ground cover, a valuable food source, which resulted in birds dispersing.

Kirsch *et al.* (1978) found that higher densities of upland game and waterfowl nested in undisturbed vegetation than in adjacent habitats that were subject to annual grazing or harvesting. Residual vegetation of sufficient height and density were found to be the most influential habitat variables in determining the strong relationship between high nest densities and undisturbed cover.

The Stubble Quail is well adapted to agricultural districts (Frith *et al.* 1977; Olsen *et al.* 1993). However, the fact that grainfields may alleviate food shortages does not reduce the overall importance that pastoral and agricultural practices have on the birds' habitat and its potential to support quail populations. Frith *et al.* (1977) warn that an improvement in agricultural methods and the intensification of pasture management may restrict the range and success of the Stubble Quail by removing their food and cover source for much of the year.

MANAGEMENT OF VICTORIAN STUBBLE QUAIL POPULATIONS

The principles of gamebird management

The management program for any gamebird species must be based on accurate knowledge of the animal's life history strategies (Avery and Ridley 1988; Dobson *et al.* 1988; Rands *et al.* 1988). It is important to know the size of the population, breeding rate, juvenile mortality between birth and the age at which harvest is taken, the animals normal life span, death rate, sex ratio and the age structure of the population under investigation, so that informed management decisions can be made (Frith 1973; Beddington 1974; Shaw 1985).

Only when this basic biological information is known should any form of sustained harvest be attempted (Murray and Frye 1957; Frith 1973; Shaw 1985). Computers and sophisticated forms of statistical analysis make data gathered in the field a powerful tool to the manager (Tapper 1988). The knowledge of a species life's history, together with an understanding of its interaction with the environment, mean that simulation models can be used to predict the impact of varying harvest intensities or habitat manipulations. In Britain, several models have been developed to describe the fluctuations in the number of Red Grouse shot in northern England (eg. Potts *et al.* 1984). A number of population models have also been developed to rationalise the management and hunting practices of many wildfowl (eg. Walters *et al.* 1974; Anderson 1975).

Gamebird management has twin objectives: (1) to manipulate environmental characteristics so the habitat supports the optimum game breeding stock and; (2) to ensure the maximum production of young birds to maximise the harvestable yield (Caughley 1977; Holt and Talbot 1978; Rogers *et al.* 1979; Savidge and Ziesenis 1980; Shaw 1985; Tapper 1988).

Harvest strategies are primarily concerned with maximising the qualitative and quantitative aspects of the yield from a population (Rands 1988; Savidge and Ziesenis 1980). Since biological resources are renewable, the object is to determine the long-term level of harvesting which produces a yield that remains stable over a period of years - the sustainable yield (SY) (Caughley 1977; Roseberry 1979; Savidge and Ziesenis 1980; Robertson and Rosenberg 1988).

A sustained yield is not a single value for a given population. There will be a large number of SY values, each corresponding to a different management treatment. Efficient management aims to develop the treatment/s to provide the largest possible sustained yield (the maximum sustained yield or MSY) or more commonly to provide a sustained yield that maximises revenue or recreational values (the optimum sustained yield or OSY) (Caughley, 1977; Robertson and Rosenberg, 1988).

Harvesting in a fluctuating environment

Stubble Quail are often found inhabiting highly modified environments (Miller 1938; Bravery 1970; Serventy 1948; Frith *et al.* 1977; Frith and Carpenter 1980). These habitat types are highly dynamic, constantly fluctuating as management manipulates the environment to accommodate agricultural enterprise (Kirsch *et al.* 1978). The methods used for estimating MSY can cope with only a moderate degree of year-to-year fluctuation in a population's conditions of life (Caughley 1977). The simplifying assumption of a steady density is not applicable to Stubble Quail populations which exhibit a "boom and bust' growth pattern (Frith 1973; Caughley 1977; Frith and Carpenter 1980; Perrins and Birkhead 1983).

Victorian management of Stubble Quail

Considered a social species, Frith (1973) and Caughley (1977) recommend that Stubble Quail should not be harvested until its social organisation is fully understood. Predicting the effect of harvesting on covey social organisation and its effect on replacement potential is of critical importance in the management of this species (Caughley 1977).

Present Victorian management of the species is restricted to setting open season dates, bag limits and a small degree of policing (Frith *et al.* 1977). Currently, one percent of the Victorian Government's expenditure on hunting and habitat management is spent on Quail hunting (Victorian Government 1994).

The Stubble Quail is classified as both a protected native species and as a game species under the conditions of the Wildlife Act, 1975 (Victorian Government 1975) and is subject to legal hunting during those official periods outlined by the relevant regulating body, presently The Department of Conservation and Natural Resources (Victorian Government 1994). The Quail season is administered and policed by Department of Conservation and Natural Resources, who also supply and collect fees generated by the sale of game licences.

The legal Victorian hunting season for the Stubble Quail is variable, based on population levels and lead up weather conditions. In calculating the dates suitable for a hunting season, not only must human social factors be considered but it should also be ensured that hunting coincides with the birds' post-breeding period (Frith and Carpenter 1980). The population, then temporarily increased by replacement and recruitment (Frith 1973; Perrins and Birkhead 1983), is at its greatest and the activities of hunters may not damage breeding stocks (Shaw 1985; Nichols 1991; Robertson and Rosenberg 1988).

The impact that hunting mortality has on Stubble Quail populations is presently unknown. The degree to which hunting mortality is additive or compensatory to naturally occurring mortality levels is poorly understood.

Stubble Quail display many r-selected characteristics; reproducing rapidly under favourable conditions (Miller 1938; Frith *et al.* 1977; Frith and Carpenter 1980) and experiencing high rates of population turnover (Frith 1973). It is assumed that small game populations, such as the Stubble Quail, exhibit high rates of turnover with or without hunting pressure and that mortality inflicted by hunters must be compensatory (Shaw 1985). It is habitat conditions, rather than harvesting, that are assumed to be the most critical determinants of population size and productivity of small game species (Shaw 1985; Dobson *et al.* 1988; Rands 1988a).

Frith and Carpenter (1980) explored the breeding behaviour of the Stubble Quail relying on data derived from samples collected over a period of eight years spanning 1967 to 1975. They identified those times of the year in which a hunting season could be successfully established without intruding into periods of vulnerability such as incubation, brooding, and moult. The recommendations put forward by Frith and Carpenter (1980) were, to an extent, accepted by wildlife authorities; hence, Victoria, New South Wales and South Australia adjusted the season to the period of May-July.

The timing of the open season for Quail in the three south-eastern mainland states has varied more in the past thirty years than for any other game species (Cowling 1981). The periods outlined by Frith and Carpenter (1980) essentially avoid the breeding season, however complaints from hunters and ensuing discussions with the relevant authority have seen the season advance to the months of April-June in the State of Victoria (Cowling 1981; Victorian Government 1994).

In accordance with the Fourth Schedule, Wildlife (Game) Regulations 1990, a maximum of twenty birds may be taken on any one day during the period outlined as the open season period (Victorian Government 1990). There are currently no models used to calculate the bag limits set, however records obtained from hunter mail surveys since 1991 have been used to track and monitor the success of hunters (J. Holmes 1994 pers comm.).

SUMMARY

The Stubble Quail is a highly opportunistic species (Miller 1938; McNally 1956), capable of vast movements (Frith and Waterman 1977) and the ability to reproduce rapidly under favourable conditions (Frith and Carpenter 1980). Its reproductive capacity and the density-dependent responses of fecundity and mortality make the Stubble Quail a species capable of withstanding harvesting pressure (Frith 1973).

Wildlife managers require detailed knowledge of the life history and a clear set of management objectives, before deciding on harvest strategies and habitat manipulation techniques. This literature review identifies and highlights the lack of empirical evidence relating to the ecology of the species.

Native grasslands, which were originally inhabited by the Stubble Quail, are now restricted to small, isolated and fragmented remnants (Department of Conservation and Environment 1992). The Stubble Quail has adapted to the changes borne by agricultural development and now occurs widely in areas dominated by pastoral development and crop production (Blakers 1984; Emison *et al.* 1987). There is a need to integrate the aims of wildlife management with agricultural practices, particularly as agricultural enterprise impacts on the majority of the species' range.

METHODOLOGY

This chapter will outline the procedures employed to gather and analyse the data used in this report.

STUDY SITES

Site selection

Two separate study areas were surveyed to identify; (1) the timing of breeding, and (2) the habitat preference of the Stubble Quail. Geographically separate sites were required to avoid any bias that one survey method may impose on the other.

The study areas chosen were located at Mitiamo, in the north, and Dookie, in the north east of Victoria (Figure 2).

Figure 2: Victorian location of study sites.

Mitiamo

Situated in the Mitiamo-Patho District of North-central Victoria (36°15'S., 144°30'E.) an area of approximately 400 ha. of crop production and grazed rangelands was used as the specimen collection site. This site is located 22 km east of Mitiamo and 31 km west of Echuca.

Climate

The area has a warm temperate climate - warm to hot summer and a wet winter. Maximum rainfall occurs over the winter/early spring period. The annual average rainfall for the area is 436 mm. All climatic data used for this site was obtained from the Echuca Aerodrome weather station.

Vegetation

The principal cereal crop grown is wheat, however oats and barley are also grown under irrigation. The irrigated pastures are composed of exotic plants (*Bromus mollis, Avena fatua, Rumex* spp., *Trifolium* spp.) and grazed by both sheep and cattle. An area of approximately 80 ha. has received intermittent grazing over the past 10 years and provides an excellent habitat well suited to the Stubble Quail as described by Frith *et al.* (1977) and Frith and Carpenter (1980). Native grass species were dominant (*Stipa elegantissima, Danthonia caespitosa, Chloris truncata*) and were indispersed with many weeds of cultivation.

Prior to agricultural development, this region of the Northern Plains was dominated by Buloke Pine (*Allocasuarina luehmannii*), Yellow, Grey, and Black Box (*Eucalyptus melliodora, E. microcarpa* and *E. largiflorens*) woodlands. Remnants of these woodland species can be found scattered throughout the study region.

A vegetation corridor at the site was subject to inundation and served as a breeding area for many species of waterfowl (pers. obs.). In addition, it provided a refuge for Stubble Quail which are known to inhabit marginal swamp areas (MacDonald 1973).

Victorian College of Agriculture and Horticulture, Dookie Campus

Habitat preference of the Stubble Quail was investigated at the Victorian College of Agriculture and Horticulture, Dookie Campus (36°23'N, 145°42'E). Located 9 km south of the northern Victorian township of Dookie, the College grounds cover a total area of 2446 hectares.

Five paddocks were defined as five separate study sites (Figure 3). Four of these sites were grazed, each at different intensities for varying durations. The fifth site was used for crop production and contained both wheat and barley. The combined area of these sites was 127.9 hectares. A detailed description of each study site is included in Appendix 1.

Climate

The area has a warm, temperate (Mediterranean) climate - a dry, and warm to hot summer (December - February) and a wet winter (June - August) (Land Conservation Council 1991). The area has an annual average rainfall of 548mm (Bureau of Meteorology 1994) and maximum rainfall occurs throughout the winter months (Bureau of Meteorology 1994).

A Bureau of Meteorology weather station situated at the college recorded all climatic data for the Dookie area used in this study.

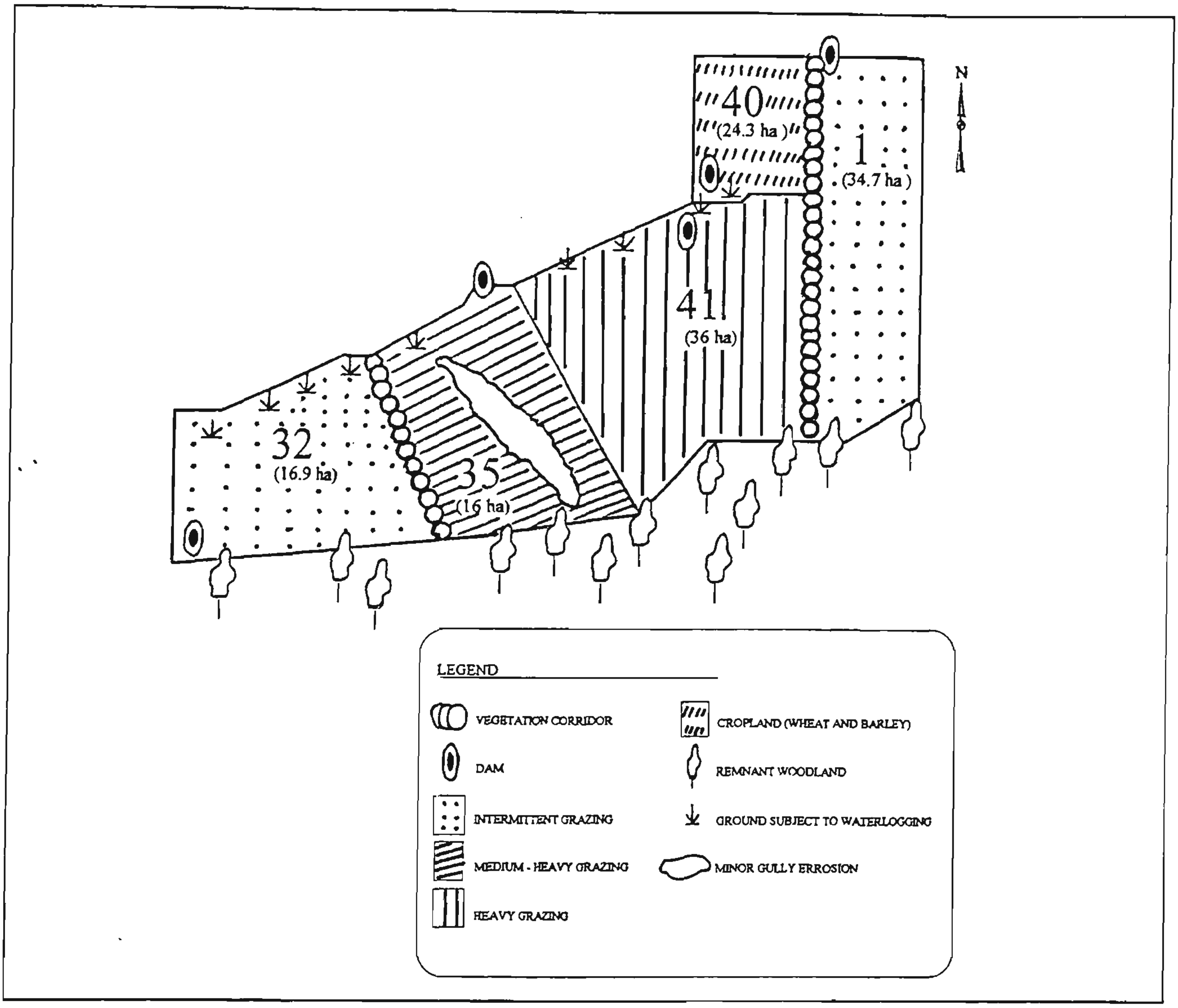

Figure 3: Distribution and land use of the Dookie study sites. A complete description of each site is included in Appendix 1.

Vegetation

Much of the dry sclerophyll forest which dominated the Dookie area has been cleared to make way for grazing and croplands (Rowley 1961). The area once supported vast areas of open forest, mainly grey box and yellow box (*Eucalyptus microcarpa* and *E. melliodora*) (Rowley 1961). Scattered individuals of both these species provide shelter for stock and can be found at all study sites with the exception of Paddock 35 (See Figure 3). Associated grasses included native *Danthonia* spp. and *Stipa* spp. although few of either species were to throughout the area as crop (various cereal and legume species), improved pasture (*Phalaris* spp., *Dactylis glomerata*, *Trifolium* spp.), and agricultural weed species (*Hypochoeris radicata*, *Avena fatua*, *Bromus mollis*, *Polygonum aviculare*, *Convolvulus arvensis*) now dominate.

SURVEY METHODS

Reproductive assessment of birds and habitat preference was undertaken from September 1993 to April 1994. The frequency of survey is outlined in the methodology of each technique.

Reproductive cycle

Specimens required for examination were shot using a 12 gauge shotgun, shot size No. 9. Individuals were shot haphazardly by walking random routes throughout the Mitiamo collection site. All collected specimens were free-ranging individuals.

The reproductive condition of Stubble Quail was evaluated in a post-mortem. The necropsy procedure followed was similar to that outlined by Jones and Gleiser (1954). Shot specimens were preserved on ice to prevent deterioration (Wobeser and Spraker, 1980) until examination of the reproductive organs took place. Each specimen was examined within two hours of being shot to prevent further atrophy (Frith *et al.* 1977).

The length (± 0.02 mm) of the left testis, for the male, and the diameter of the three largest ovarian follicles (± 0.02 mm), for the female, were recorded. These measurements were later used in statistical analysis. All measurements were taken with vernier callipers (precision ±0.02mm).

Specimen collection was attempted in each month for the duration of the study period. Sampling frequency was determined by the number of field trips necessary to obtain the requisite number of birds per month, ideally, a sample size of 20.

In order to harvest the species outside those legal dates stipulated by the open season, a research permit allowing the collection of Stubble Quail, a protected native species, was obtained. Pursuant to the provisions of Section 4 of the Wildlife Act 1975, this permit (Permit No. PR-93-130) was granted subject to a number of conditions. This project was also approved by the University of Ballarat Animal Ethics Experimentation Committee.

Ageing Stubble Quail

Guidelines listed in a key constructed by Crome *et al.* (1981) were followed in conjuction with diagrams found in Disney (1969, 1974) to age collected individuals. All shot specimens were examined and separated into three age classes;

- juvenile (0-60 days);
- immature (77-448 days);
- adult (515 days and over) (Crome *et al.* 1981).

Age classes were determined according to moult and plumage characteristics of the primaries and wing coverts. The data from which this key was formulated were extremely variable (Frith and Carpenter 1980) however no alternative ageing system is currently available.

Juvenile birds, as identified by plumage characteristics, were excluded from the statistical analysis of reproductive assessment as they are considered incapable of breeding and would bias any statistical procedure.

Habitat preference

All habitat preference measurements were conducted at the five Dookie study sites.

Physiognomy

One 30m permanent line transect was located at each of the five study sites. The starting point and direction of each transect was randomly selected using a grid overlay of each site and a random numbers table (Kent and Coker 1992). At 1m intervals along each transect, the vertical structure and height of the vegetation was recorded.

Average height and vertical plant structure were measured with a visual obstruction pole (Robel *et al.* 1970) 4cm wide, 140cm tall and graduated at 10cm intervals (Schultz and Guthery 1988). Each 10cm interval was alternately coloured with red and white tape. The percentage of each 10cm interval obscured by vegetation was visually estimated to a precision of 10%. Data were averaged to obtain a single reading per stratum for each transect (Shultz and Guthery 1988).

Samples were taken in the first and third week of each month for the duration of the study period. The frequency of sampling was necessary to measure the growth and decline phases displayed by vigorous annual and perennial pasture grasses and weed species. Regular monitoring intervals were required to quantify the effect of grazing on vertical plant structure and density (Brown 1978; Neave and Tanton 1989; Bock and Bock 1993).

It was considered unnecessary to identify the structure of each plant species present as Stubble Quail have been shown not to discriminate against those species offering cover, provided the appropriate structural characteristics are displayed (Frith *et al.* 1977; Frith and Carpenter 1980)

Vegetation percentage cover and species richness

At each site, randomly positioned, permanent quadrats were assessed visually and the percent coverage of bare ground, herbs, and grasses visually estimated. The precision was determined by the Daubenmire cover scale (Daubenmire 1959). Categorical measurements were converted to estimates of percent coverage by substituting class midpoints (Mundinger 1976; Burger *et al.* 1990)

The number and size of each quadrat was determined by the vegetative characteristics of each separate study site. The number of quadrats at each study site was decided independently of one another and considered against the amount of sampling necessary to attain a certain level of accuracy (Kershaw and Looney 1985). To ensure a true representation of species composition, the number of sample units required was calculated from the formula described by Wratten and Fry (1980, pg 6).

The number of sampling units used at each study site was determined by the initial estimation taken at the onset of the study period (Wratten and Fry, 1980). The size of each quadrat was determined using a species-area-curve (Kent and Coker 1992). All quadrats were positioned randomly and permanently marked (Goldsmith 1991).

Species richness and percentage cover field work was assessed in the first and third week of each month for the duration of the study period.

Population density estimation

The strip transect method (Burnham *et al.* 1980; Verner 1985) was employed to estimate Stubble Quail population density. Density estimation using strip transects require that a number of assumptions be satisfied:

- all birds within the strip are detected;
- all birds are correctly identified;
- no bird moves into or out of the strip in response to the moving observer;
- no bird is counted more than once;
- no errors are made in determining whether a bird is within the strip;
- detections are independent events (Verner 1985).

Birds seen outside the strip were not recorded. Under the assumption that all objects were detected and recorded, density (D) was estimated as;

$$D = \frac{n}{2Lw}$$

Where L is the length of the transect and w is one half the width of the strip transect and n is the number of objects detected (after Burnham and Anderson, 1984).

Using the principals outlined by Baker-Gabb *et al.* (1989), an 8 m long, square steel tube "boom" was constructed and fitted to the front of a four wheel drive to act as a flushing device. From this boom, chain link droppers were fitted at regular intervals to enhance the flushing ability of the apparatus, particularly to locate birds found in dense vegetation (Baker-Gabb *et al.* 1989). As each transect was traversed, it was assumed that all Quail encountered were flushed and detected, and that none were overlooked. This assumption, however, was only applicable to birds capable of flight. Juvenile birds unable to fly and mature birds in the advanced stages of moult, in all probability, remained undetected. This sampling bias may have resulted in an underestimation of Stubble Quail density.

The boom length served as the total transect strip width (2w = 8 m) and only birds flushed from within this eight metre spread were recorded in the census count. This eliminated the need to estimate the flushing angle and distance of the subject in relation to the observer (Burnham *et al.* 1985; Burnham and Anderson 1984; Burnham *et al.* 1980).

Strip transects were placed systematically throughout each study area. Each transect route was located parallel to the longest fenceline and progressively spaced at 75 m intervals. This allowed the optimal use of the limited available area yet minimised the chance of counting the same individual twice, insuring statistical independence (Daniel *et al.* 1993). Nocturnal flushing distances were generally observed not to exceed this distance. The length of each transect was dependent on the dimensions of the sample plot (paddock) under investigation.

Each study site was censused on a weekly basis for the duration of the study period. Censuses were generally conducted 2 hours after sunset (Labisky 1959, 1968). Surveying in darkness was observed to modify avoidance behaviour, reduce flushing distance and minimise repulsion.

Vehicle speed was kept constant at approximately 15km/hour. Any bird species flushed were identified with the aid of a roof mounted 12 Volt, 100 Watt spotlight. Bird species observed were identified by reference to standard field guides (Slater 1970, 1974; Pizzey 1980; Simpson and Day 1984).

STATISTICAL ANALYSIS

Data analysis was performed on the statistical software package Minitab. Confidence levels of $P<0.05$ were considered significant. The following statistical procedures were performed using Minitab:

Pearson Correlation Coefficient

To identify the relationship between variables, Minitab calculated the Pearson correlation coefficient. The test was used to determine any significant relationship between testis and ovary growth phases. Gonadal development was also correlated with the following environmental variables: photoperiod, temperature, rainfall.

Analysis of variance (ANOVA)

To determine any significant variation between sample means, ANOVA was used. ANOVA calculates the probability of a significant difference occurring by chance and calculates an F statistic to test this. If the calculated F statistic is significant at less than 0.05, the difference is considered to be significant. ANOVA was used to test for any significant difference between both mean monthly gonad sizes and mean monthly population densities.

If a significant F statistic was found, the Tukey test was employed to determine which of the sample means differed significantly from the rest of the population. Where there was an uneven number of observations in each sample set, the harmonic mean was substituted as the denominator in the Q equation.

Student's t-test

To establish whether there was a significant difference between the means of two sample groups, a Student's t-test was used. T-tests were used to determine if there was a significant difference between maximum and minimum gonad sizes.

Chi-square

The Chi-square test was used to explore the association between nominal observed and expected nominal frequencies. Chi-square was used to determine whether there was any significant bias in the sex ratio of shot birds. In addition, the distribution of individuals throughout each of the assigned age classes was tested for significance.

RESULTS

In this section, the results of statistical analysis performed on the data will be presented. Interpretation of the results will also be included.

Growth and decline phase of gonads

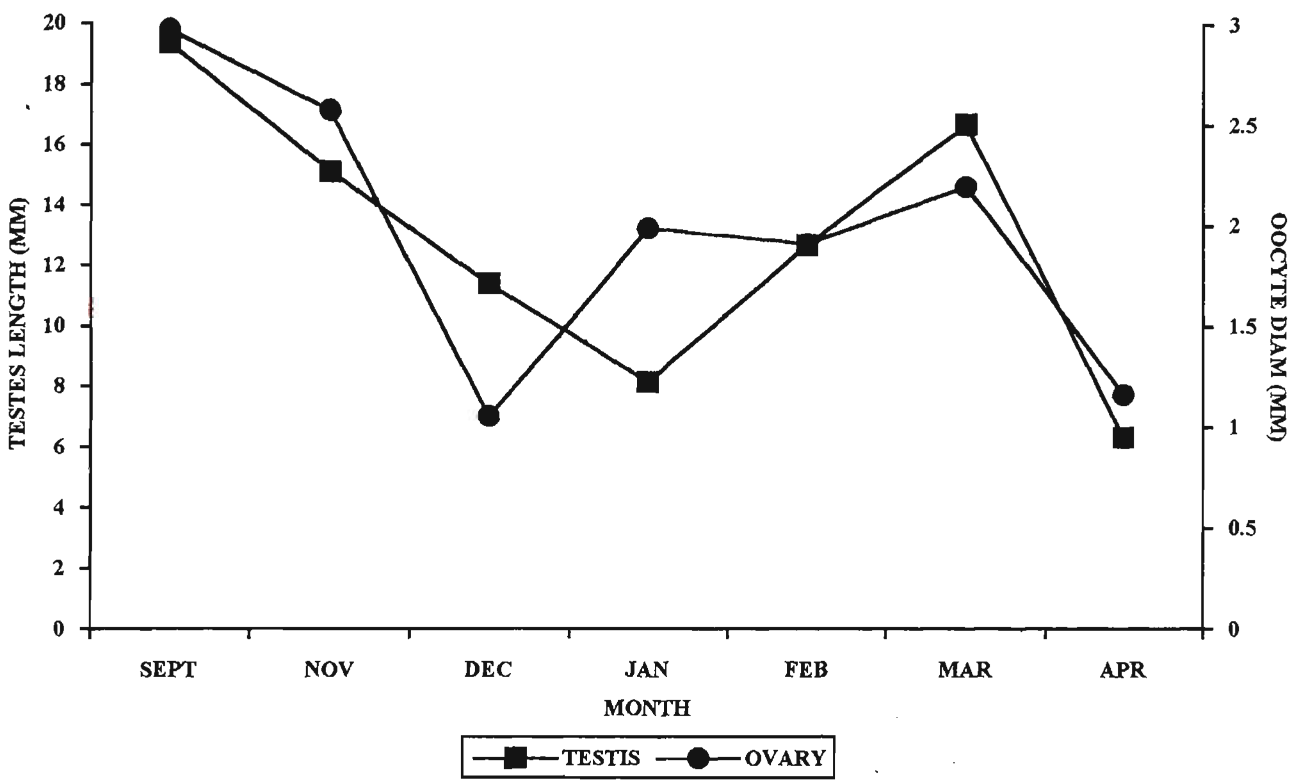

Figure 4: Relationship between growth phase of testis* and oocytes*, Mitiamo. September 1993 - April 1994 ($r = 0.789$, $P<0.05$).

*Age Class 2 & 3 only. No data available Oct. 1993.

A strong correlation ($r = 0.789$, $P<0.05$) was found between the growth phases of both testis and oocytes at the Mitiamo study site (Figure 4). This indicated that both male and female Stubble Quail responded to the same sets of environmental cues which stimulated gonadal recrudescence.

Analysis of variance revealed a significant difference in mean testis length between the eight individual sample months (Sept 1993 - Apr 1994) ($F = 11.08$, d.f. = 6, 32, $P<0.01$). ANOVA also revealed a significant difference between mean monthly oocyte diameter ($F = 13.65$, d.f. = 6, 74, $P<0.01$).

To determine which monthly group means differed significantly from one another, a multiple comparison procedure, the Tukey Test, was employed. Due to the uneven number of observations in each sample set, the harmonic mean was used as the denominator in the Q equation (Pagano 1986). The Tukey Test, whilst recognising a significant difference ($P<0.05$) between the peaks and troughs displayed in gonadal recrudesence, showed there was little variation amongst the interim values between the consecutive highest and lowest points on the graph. This highlighted a gradual, steady decline in gonad sizes.

A Student's t-test was used to determine whether there was a significant difference between the consecutive maximum and minimum values displayed by the graphed data (Figure 4). Mean testis length was significantly greater in September 1993 than January 1994 ($t = 9.13$; $P<0.001$) and also greater in March 1994 than April 1994 ($t = 4.02$; $P<0.05$). Mean oocyte diameter was found to be significantly greater in September 1993 than December 1993 ($t = 37.04$, $P<0.001$) and also greater in March 1994 than April 1994 ($t = 4.63$, $P<0.001$). The twin peaks displayed by the gonad growth phases indicated that an apparent double breeding event for both the male and female of the species was possible.

Effect of climatic variables on gonad growth phases

Photoperiod

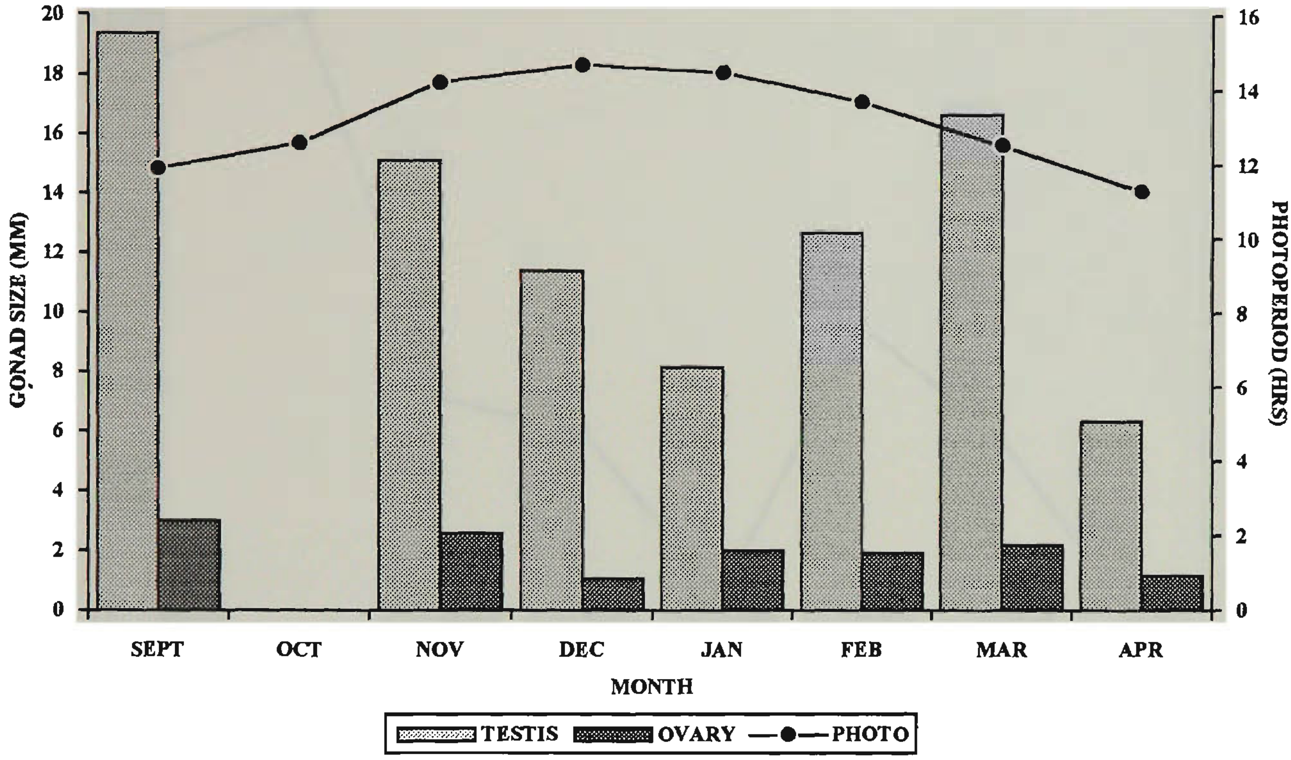

Figure 5: Relationship between mean monthly gonad growth phases and photoperiod*.

*No data available Oct. 1993.

There was found to be no correlation between either mean monthly testis length (r = -0.126) or mean monthly oocyte diameter (r = -0.125) with respect to photoperiod (Figure 5). Due to the timing of the study, monitoring began when gonad growth sizes were in a highly active state. It was therefore impossible to determine the key factor/s responsible for stimulating the initial breeding event. Photoperiod may have been an important factor in this process, even though the results do not reflect this assumption.

Rainfall

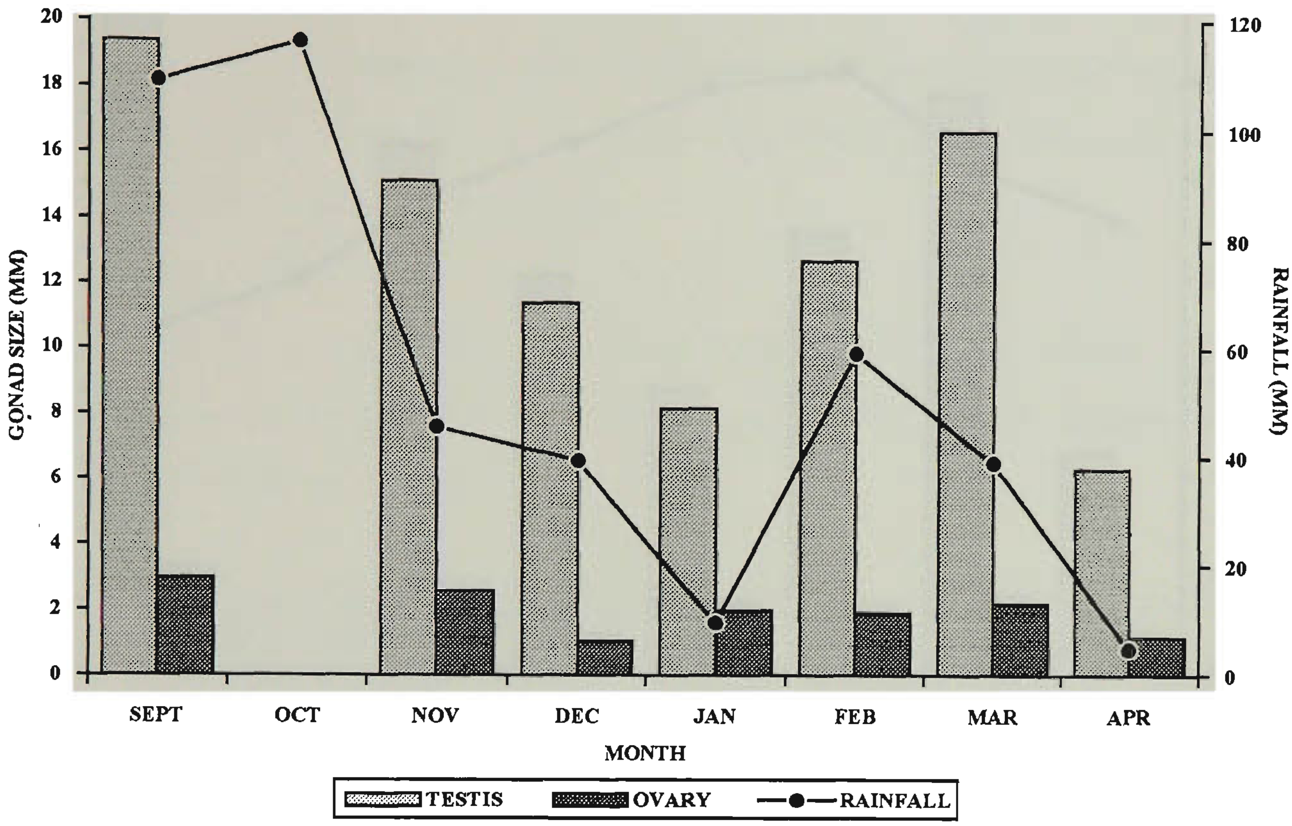

Figure 6: Relationship between mean monthly rainfall and mean monthly gonad size,* September 1993 - April 1994.

*No data available Oct 1993.

There was found to be a strong correlation (r = 0.860, P<0.05) between mean monthly testis growth patterns and mean monthly rainfall, and a moderate correlation (r = 0.684, P<0.05) between mean monthly oocyte growth patterns (Figure 6). This concurs with the results of many authors who have studied the reproductive timing of Australian semi-arid and arid zone bird species. Rainfall is an indicator of increased plant productivity and subsequent food availability. In this study, rainfall appears to be a significant proximate factor in stimulating the gonadal recrudescence of Stubble Quail.

Mean maximum temperature

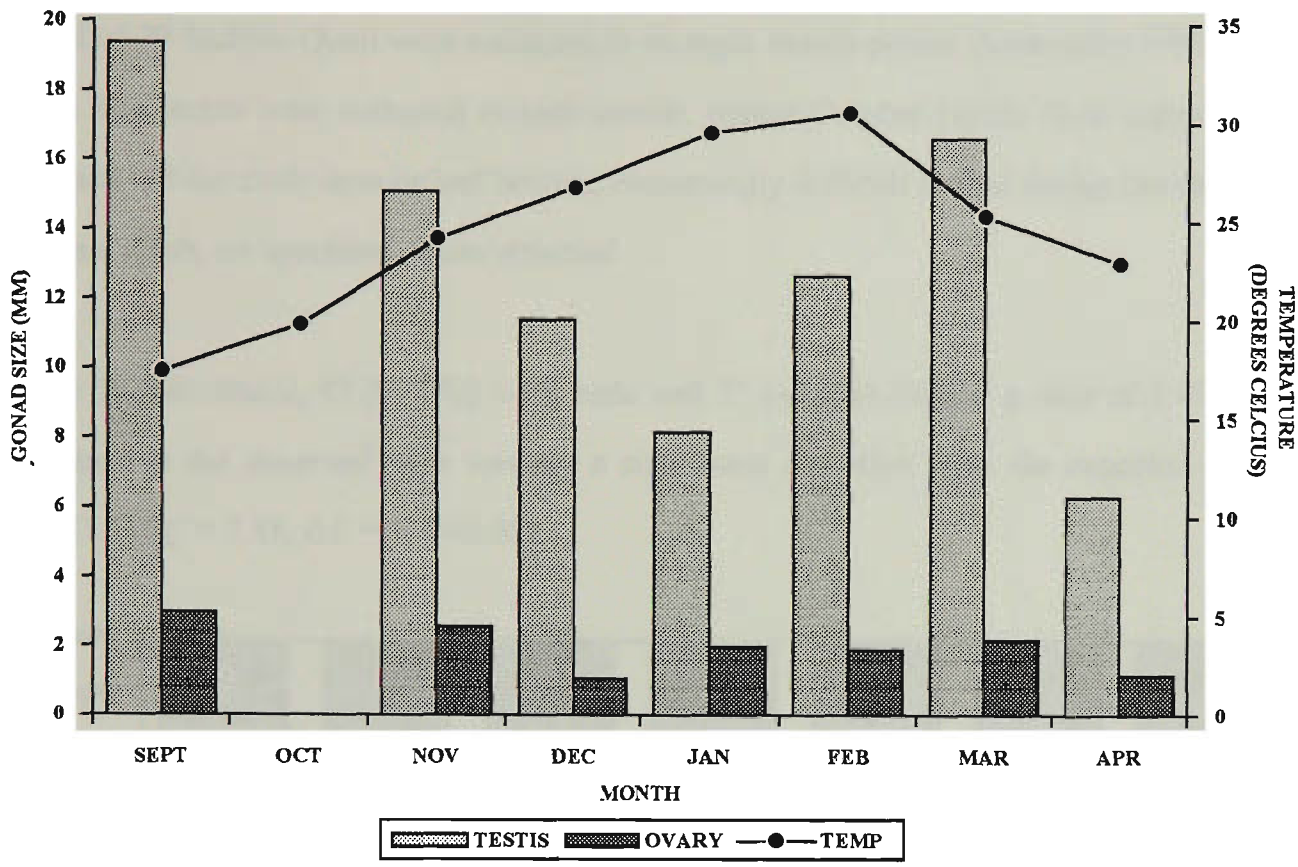

Figure 7: Relationship between mean maximum monthly temperature and gonad growth phase, September 1993 - April 1994*.

*No data available October 1993.

There was found to be a modest negative correlation between both mean monthly testis size and mean maximum temperature ($r = -0.501$) and mean monthly oocyte diameter ($r = -0.448$) (Figure 7). This suggested that an increase in ambient temperature may inhibit gonadal activity and stimulate the onset of a refractory period for both male and female Stubble Quail.

Sex and Age Class Ratios of Collected Specimens

A total of 79 Stubble Quail were collected in an eight month period (September 1993 - April 1994). Specimens were collected in each month, except October (Table 1). It appeared that birds had left the study area or had become increasingly difficult to find during October 1993 and, as a result, no specimens were obtained.

Of the 79 individuals, 47 (59.5%) were male and 32 (40.5%) female, a ratio of 1.47:1. The difference in the observed ratio was not a significant deviation from the expected ratio of unity (1:1) ($\chi^2 = 2.48$, d.f. = 1, $P<0.05$).

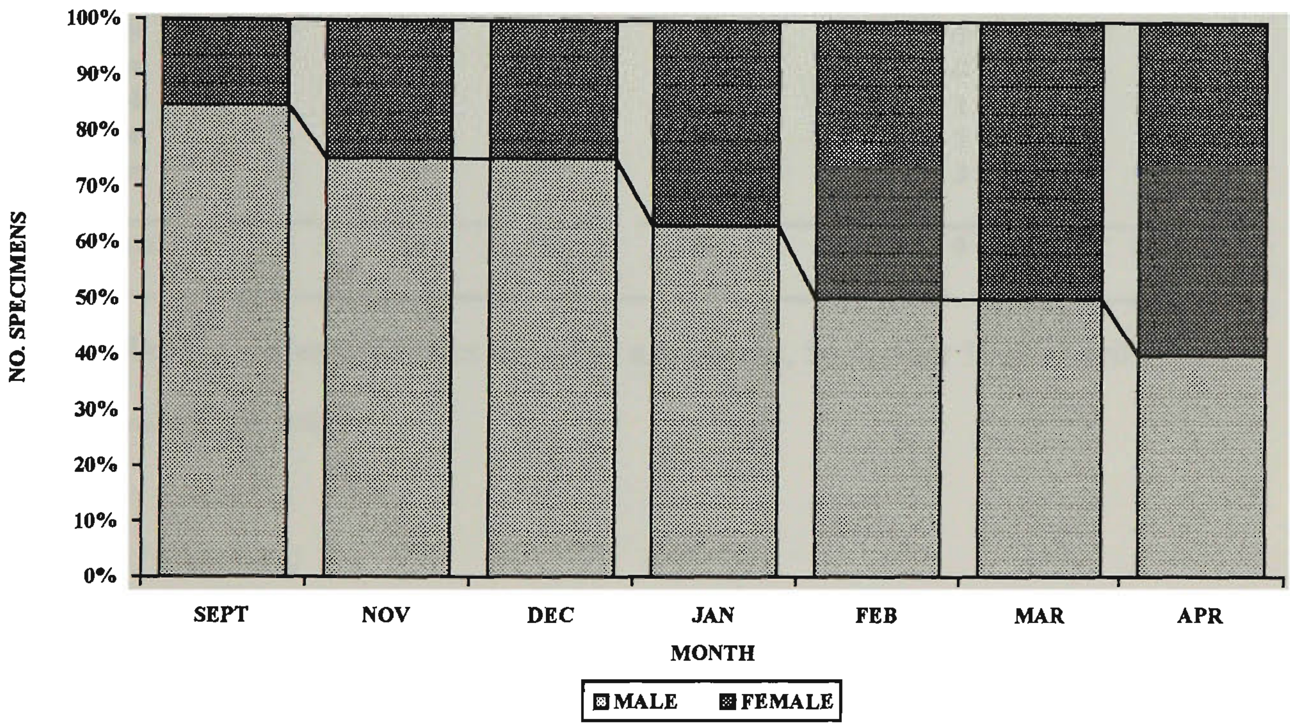

Figure 8: Ratio of male to female specimens collected, September 1993 - April 1994*

*No data available Oct. 1993.

On a monthly basis, the differences in the male to female sex ratio were found not to be significant ($P<0.05$) with the exception of September, 1993 (Figure 8). In September, the ratio of males to females was 5.5:1 (85% male, 15% female) which proved to be a significant departure from the expected ratio of unity ($\chi^2 = 4.92$, d.f. = 1, P<0.05). This suggested that there were more males present in the sample population at this time. Alternatively, shooting as a collection method may have been selectively biased towards males during this period.

Sex ratios of age classes

Month	Male (*n*) Age Class 1	Male (*n*) Age Class 2	Male (*n*) Age Class 3	Female (*n*) Age Class 1	Female (*n*) Age Class 2	Female (*n*) Age Class 3	Ratio Male:Female
Sept	1	7	3	0	1	1	5.5:1
Oct							
Nov	0	1	2	0	0	1	3:1
Dec	0	2	1	0	1	0	3:1
Jan	2	8	2	1	6	0	1.7:1
Feb	1	2	4	1	5	1	1:1
Mar	2	1	2	0	2	3	1:1
Apr	2	3	1	1	5	3	1:1.5
Total	8	24	15	3	20	9	1.47:1

Table 1: Ratio of males to females across all age classes, September 1993 - April 1994*

*No data available Oct. 1993.

Age class 1 (Juvenile)

The number of individuals collected from this age group was subject to strong bias. Specimens had to be able to fly in order to be subject to collection, therefore the numbers of birds collected may not be truly indicative of the actual numbers present in the population at the time of sampling (Table 1).

The ratio of males to females in the Juvenile age class (Class 1) was 2.67:1.00 (8 males - 73%, 3 females - 27%) and was not a significant deviation from the expected 1:1 ($\chi^2 = 1.42$, d.f. = 1, P<0.05) (Table 1).

Age class 2 (Immature)

The sex ratio of males to females in the Immature age class (Class 2) was 1.20:1.00 (24 males - 55%, 20 females - 45%), and was not significant ($\chi^2 = 2.05$, d.f. = 1, $P<0.05$).

Age class 3 (Adults)

In Adult birds (Class 3) the sex ratio of males to females was 1.67:1.00 (15 males - 63%, 9 females - 37%) which was not a significant deviation from parity ($\chi^2 = 1.04$, d.f. = 1, $P<0.05$).

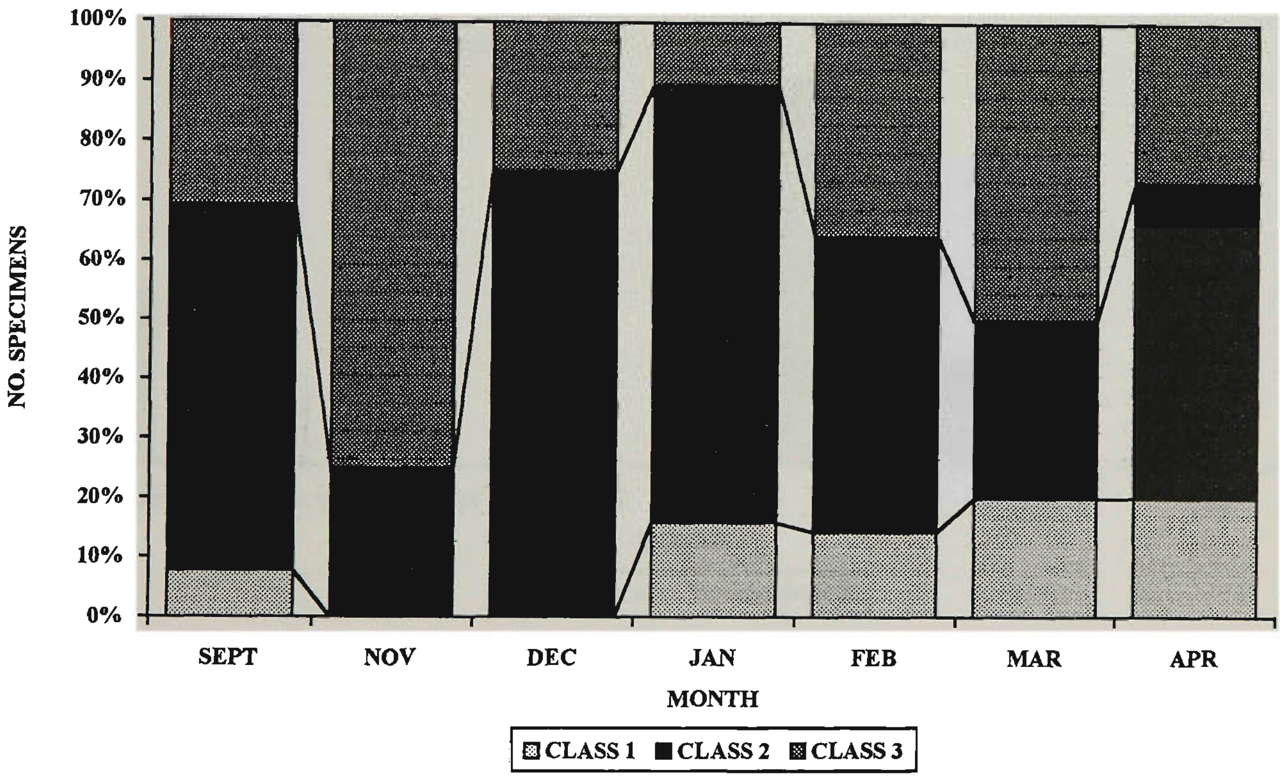

Figure 9: Distribution of individuals across all three age classes, September 1993 - April 1994*

*No data available October 1993.

In each month, the number of individuals found in each of the three age classes was not significantly different with the exception of January 1994 ($\chi^2 = 16.74$, d.f. = 2, $P<0.05$)

(Figure 9). In this month the distribution of individuals across each age class was - Class 1 n = 3, Class 2 n = 14, Class 3 n = 2. The number of immature birds collected from this age class differed significantly from the numbers found in the remaining two classes. This result suggested that the increase in the number of immature birds resulted from of a spring breeding event. Birds hatched during early to mid spring would have matured sufficiently to progress from the juvenile to immature age class.

Stubble Quail density

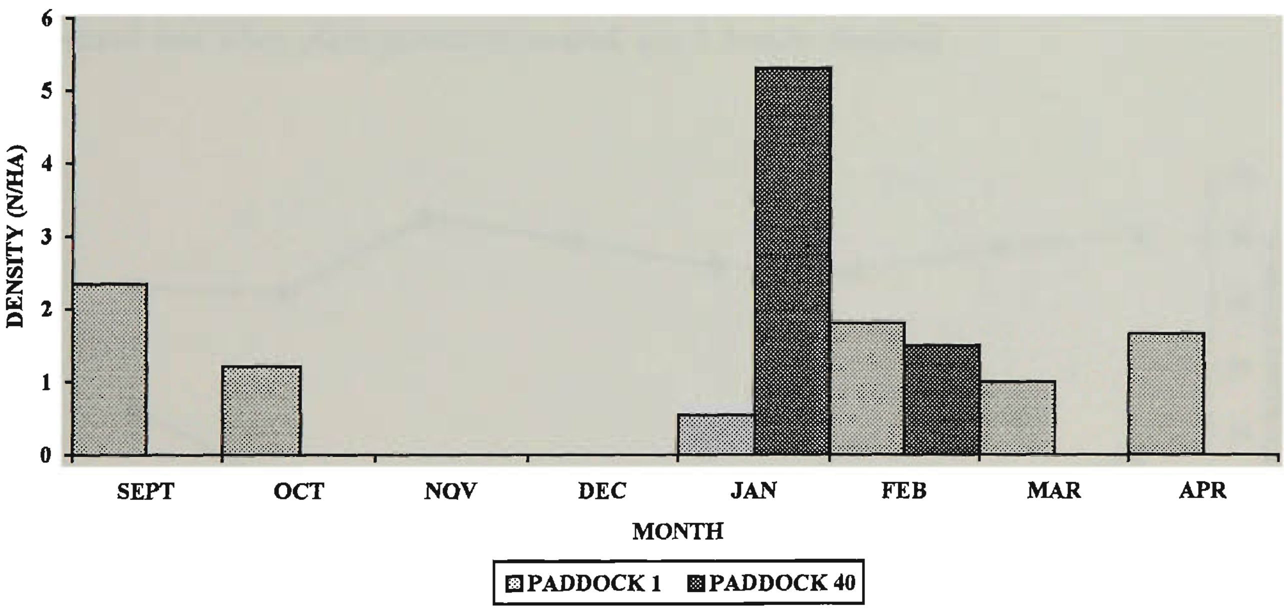

Figure 10: Stubble Quail density, Paddock 1 and 40. Sept 1993 - Apr 1994.

Paddock 1

Analysis of Variance (ANOVA) was used to test for any difference between the mean monthly bird densities observed for Paddock 1 (Figure 10). The results revealed a significant difference between the recorded densities (F = 4.27, d.f. = 5, 16, $P<0.05$). The Tukey Test was then used to determine which of these monthly densities differed from the other.

The only months to show any significant difference were the months with the highest (September) and lowest (January) values (Q = 5.413, d.f. = 5, 16, $P<0.05$). Those months where birds were absent, November and December, were considered different to those months where density figures were recorded.

The disappearance of birds from this site during November and December suggested that habitat conditions were not suitable to support a Stubble Quail population. This was not consistent with the observed increase in plant productivity at the site (Figure 11). Figure 11 visually demonstrates the relationship between Stubble Quail density and plant productivity. It appeared that when plant growth increased, quail density declined.

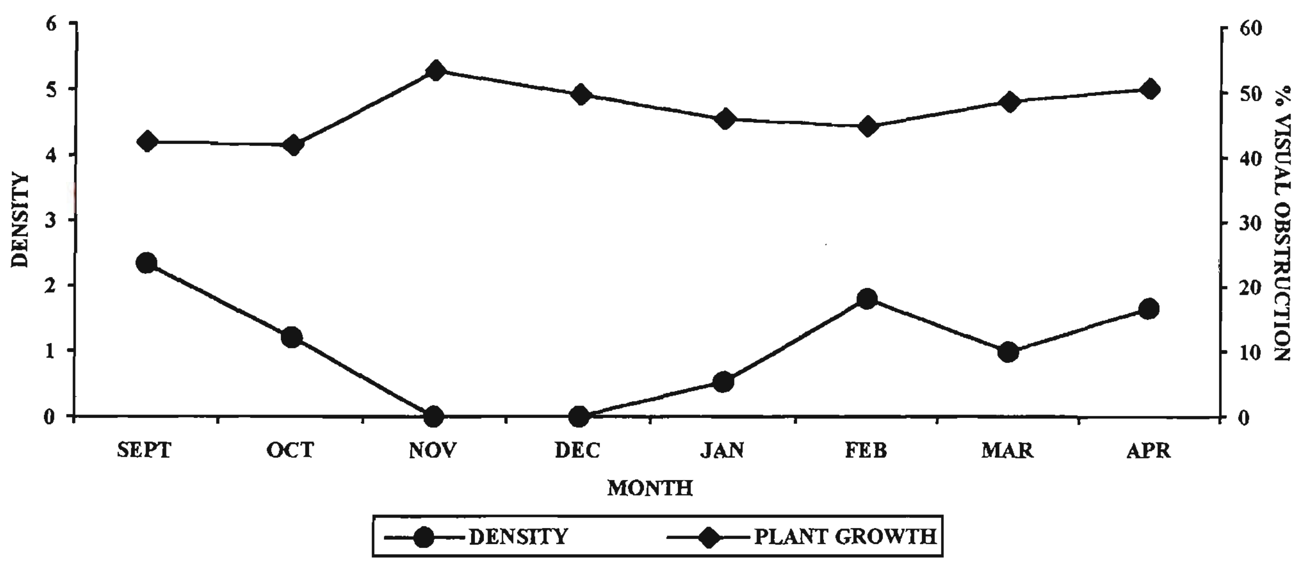

Figure 11: Quail density compared to percentage visual obstruction (0-10 cm), Paddock 1. September 1993-April 1994. An increase in obstruction is an indication of plant growth.

Alternatively, this period of emigration coincided with a known breeding event. Changes in social behaviour or structure may have influenced the observed reduction in quail density.

Paddock 40

This site was surveyed after crop harvesting took place (January - April). A Student's t-test was used to determine whether there was a significant difference between the density figures recorded for Paddock 40. The result revealed that there was a significant difference ($P<0.05$) between Stubble Quail densities for the months of January and February ($t = 3.21$; $P<0.05$). The significant reduction in quail numbers may have been caused by a reduction in habitat quality.

Plant productivity

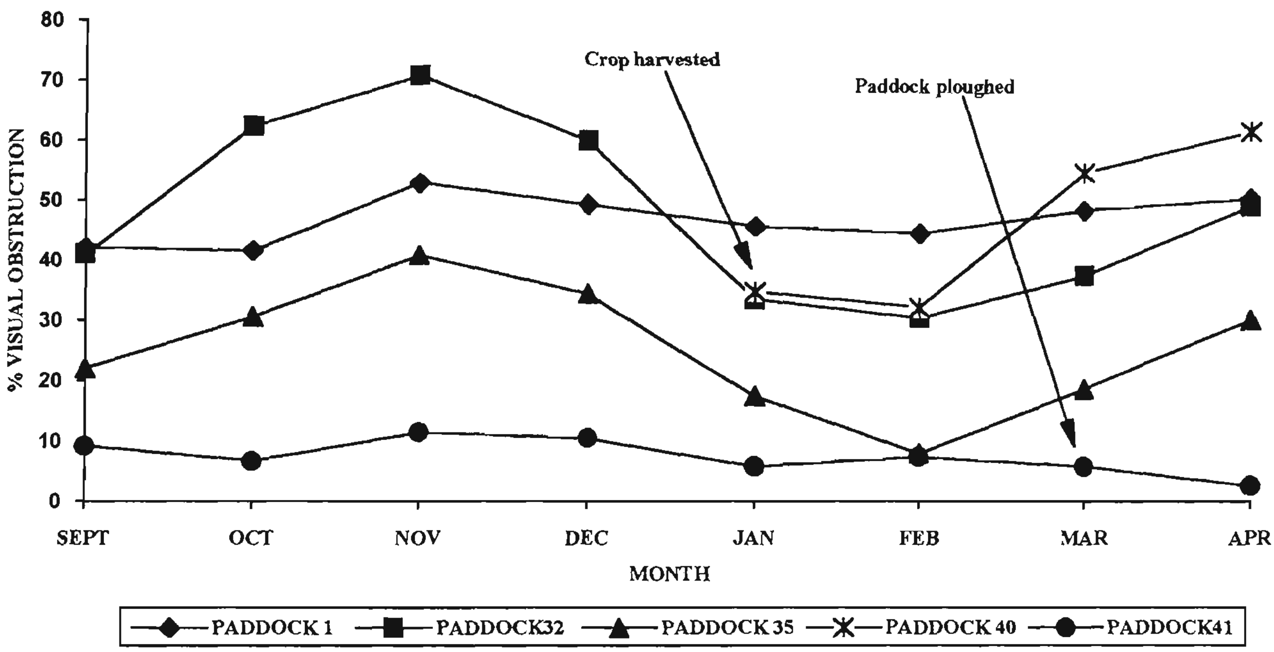

Figure 12: Plant productivity as represented by percentage visual obstruction (0 - 10 cm).

A visual interpretation of the graphed data indicates an increase in plant productivity during the early spring months (September - November). Plant growth was observed to peak in both November and again in March. This suggested an increase in both food availability and nest site quality available to Stubble Quail during these periods. Paddock 1, which supported birds throughout the study period was shown to display the least variation in plant productivity. Whilst periods of growth were recorded at similar times to other paddocks, there were no dramatic fluctuations. Paddock 1 appears to be a relatively uniform and stable environment.

DISCUSSION

Timing of breeding

Overview of gonadal cycles

The timing of gonadal development in both male and female Stubble Quail collected in this study was similar to that reported by Frith and Carpenter (1980) for the Werribee region of Victoria. Both male and female sexual development were strongly correlated, each developing and regressing at similar times. Data presented indicated that there were two distinct periods of gonadal recrudescence, each followed by a regressional phase. This suggested a bimodal pattern of reproduction.

Gonadal acceleration phases (Marshall 1961) peaked in September (Spring) and March (Autumn) for both sexes and regressed to their lowest points in January and April for the male and December and April for the female. Factors most likely responsible for the cessation in the reproductive activity of birds include; a continued increase in photoperiod and ambient temperature, and, a lack of rainfall (Immelmann 1971).

In an attempt to rationalise the observed pattern of gonadal activity, spring and autumn peaks will be examined separately and the possible causes for the recrudescence investigated.

Spring

Evidence of a successful spring breeding event was apparent from two measured indices: (1) physiological activity in the form of gonadal recrudescence; (2) population productivity as indicated by a disproportionate increase in the number of immature birds in the sample population.

Gonad development for both sexes was observed to be at its greatest in September. Plant productivity, stimulated by an increase in photoperiod and mean maximum temperature (Mott 1972; Nix 1976; Kingsford 1989), also peaked in spring. The resultant flush of seeds provided Stubble Quail with an abundant food supply. Insect populations are also known to respond rapidly to increased plant productivity (Nix 1976; Ford 1989) and their availability may have been an important factor in determining chick survival rates.

When investigating the food habits of the Stubble Quail at Werribee (Victoria), Frith *et al.* (1977) reported that insects contributed upward of 34% of the bird's dietary intake when breeding was known to occur (August and September). Insects may therefore play an important role as a source of nutrition during incubation and/or brooding. Evidence from British gamebirds supports this theory. Chick survivorship in both the Grey Partridge (Potts 1986) and Red Grouse (Hudson 1986) have been positively correlated with insect availability.

The increase in spring plant growth also improved nest cover quality. Dense cover provided a visual and physical barrier between predators and the nesting parent. The quality of nest cover to ground-nesting birds is critical in determining population productivity and survivorship as demonstrated by Rands (1988), for the Grey and Red-legged Partridge, and Gregg *et al.* (1994), for the Sage Grouse.

An increase in gonad size and favourable environmental conditions suggested that Stubble Quail bred in spring. This is consistent with the findings of Frith and Carpenter (1980) who also recorded a spring/early summer peak in gonad size for Stubble Quail in south-eastern Australia. Gonadal recrudescence alone, however, is not proof that a successful breeding event had taken place. Increased gonadal activity simply indicates that a population has received the appropriate stimuli to induce a physiological change. Whether nest building and insemination take place is dependent on a series of environmental cues and behavioural displays by the mate (Frith and Carpenter 1980).

Conformation of a successful breeding event came from a disproportionate increase in the number of immature birds (age class 2) collected during January 1994. Immature birds were considered to be a minimum of 77 days of age (approximately 2.5 months). This indicated a hatching date of at least mid November 1993. Furthermore, an incubation period of approximately 18 (Bourke 1948) to 21 days (Cruise 1966) suggested that nesting would have occurred in mid to late October.

Above average rainfall was recorded in September and, although gonad activity was at its peak and viable fertilisation was possible, nesting may have been delayed by high rainfall totals. Various environmental stimuli, including excessive rainfall, are known to inhibit gametogenetic activity in birds (Marshall 1959). Whilst this was not observed, the timing of nesting may have been impeded. Flooding is known to result in the failure of eggs (Bourke 1948) and to avoid unsuccessful nesting, breeding was suspended until October. Frith and Carpenter (1980), when examining Stubble Quail breeding seasons in Werribee (Victoria), also found that although the timing of the gonad cycles did not differ greatly between years, the duration of the reproductive season was very much shorter during periods of excessive rainfall than in normal seasons.

Determining the proximate factor/s responsible for stimulating spring breeding proved difficult. Spring recorded an increase in ambient temperature and photoperiod together with high rainfall. All are factors known to stimulate breeding in birds (Immelmann 1971; Murton and Westwood 1977). That these factors occurred at the same time would make it almost impossible to determine which might individually or in combination stimulate Stubble Quail breeding. Whatever the stimulating mechanism (proximate factor/s), the timing and availability of food resources appeared to be the ultimate factor governing the spring breeding period in Stubble Quail at this site.

Autumn recrudescence and possible stimuli

A second cycle of reproductive activity was recorded in Autumn. Male and female gonad sizes were seen to peak again in March. This finding is supported by Frith and Carpenter (1980) who identified a similar reproductive pattern in the Stubble Quail. Stubble Quail were observed to exhibit a frequent second peak in gonad size during the late summer and autumn months.

Although not demonstrated in the field, Stubble Quail are assumed to rear second broods (eg. Miller 1940, 1944; Frith and Carpenter 1980). The findings in this report suggest that if conditions are favourable for clutch production, multiple broods will be raised. Such a breeding strategy is similar to that adopted by many Australian bird species (eg. Grey Teal, Zebra Finch, Budgerigar *Melopsittacus undulatus*).

Between October and January the amount of rain that fell declined steadily. As a result, spring grasses and forbs began to dry out and their value as a food resource diminished. Conditions for breeding were unsuitable and, in response, gonad sizes regressed.

During January, light showers fell on five of the first seventeen days of the month. These light showers may have triggered a gonadal response which was further enhanced by the heavy falls recorded during February. February received more than twice the average monthly rainfall which resulted in a rapid flush of plant growth. Cover quality increased providing the necessary protection for safe incubation. This increase in rainfall was considered to be the stimulating factor which triggered the second gonadal recrudesence.

Both the quantity and temporal distribution of rainfall have been frequently noted to affect the reproductive rate of quail and other birds (Francis 1970). The improved conditions (increased food availability and improved nesting cover) which resulted from this unseasonal rainfall would not have become apparent for some time after the event, yet there was an immediate gonadal response. This suggested that the sight of rainfall stimulated sexual development in the Stubble Quail. This hypothesis is supported by Immelmann (1963) who observed immediate courtship and nesting activity after heavy rain in both the Zebra Finch and the Black-faced Wood Swallow (*Artamus melanops*). Braithwaite (1976) also reported a similar reaction in the Grey Teal (*Anas gibberifrons*) who began courtship displays after constant rainfall provided sufficient visual stimulus (Braithwaite 1976).

This gonadal response to rainfall might well be a secondary mechanism to ensure that as many birds as possible nest after rain so that advantage is taken of any unpredictable events and that the population is not therefore totally dependent on the survival of young from nests begun in a fixed annual period (Frith *et al.* 1976).

The age-specific reproductive patterns of this species are unknown. Typically, young birds are slow to begin nesting at the start of a breeding season (Reid 1987; Perdeck and Cave 1992). Birds attempting to breed for the first time have problems finding a mate or suitable habitat, for example, or may forego breeding altogether (Moser and Rusch 1989; Wheelwright and Schultz 1994). Breeding success is known increase with the parent bird's age (Perrins and McCleery 1985) so newly recruited Stubble Quail might be expected to display an inability to pair bond and successfully mate so shortly after hatching.

Exploring this further, examination of the data showed that 66% of the males and 50% of the females in breeding condition were adult birds (age class 3). The remainder of those birds capable of breeding were immatures (age class 2). This demonstrated that the second cycle of gonadal activity was not caused by new recruits maturing sufficiently to breed and that adult Stubble Quail are capable of producing more than one brood in a season.

Sex and age ratios

Sex and age ratios of gamebird populations are used in research and wildlife management to estimate recruitment, predict harvest success, and, in conjunction with measurements of density or abundance, to assess the status of populations (Crawford and Oates 1986). Whilst acknowledging that the collected sample sizes in this study were small, some general conclusions can be drawn about the demography and productivity of the sample Stubble Quail population. The samples were collected from a relatively discrete study area and therefore do not represent pooled data from large or different areas.

Pooled data

The sex ratio found in this study is in agreement with Fisher's (1930) argument for the evolutionary stability of equal investment in the sexes which results in sex ratios of unity. This suggested that causes of mortality act on Stubble Quail in a uniform fashion and do not discriminate between the sexes.

This result is supported by the findings of Frith and Carpenter (1980) who also found a small but insignificant preponderance of males to females. Leopold (1977) found similar results for some species of North American Quail and ascribed the apparent imbalance to differential mortality during the breeding season (Frith and Carpenter 1980).

Sex ratios within months

Sex ratios, when examined on a monthly basis, were shown not deviate significantly from parity. However there was one notable exception. In September, the numbers of male specimens collected were significantly greater than females.

This male bias occurred during a known breeding event. No data were available for October of that year, however, both November and December also recorded a male bias of 3:1. These results were proven to be statistically insignificant however.

During breeding, male birds appeared to be more susceptible to hunting as a collection method. Miller (1938) and Frith and Carpenter (1980) reported that males were more readily flushed than females. Incubating or brooding females are known to be difficult to flush (Pedler 1975; Frith and Carpenter 1980). Such behaviour may be an evolutionary safeguard to protect the incubating female. Males flush first in an attempt to attract danger away from the incubating or brooding female and, in doing so, increase the likelihood of those chicks maturing to further add to the possible breeding stock.

The impact on population dynamics of harvesting reproductive males is unknown. The Stubble Quail is thought to be monogamous in its mating system (Miller 1944; Pedler 1975; Olsen *et al.* 1993). Prejudicial harvesting of male Stubble Quail would result in a decrease in population productivity as females are left unable to contribute to replacement. The length of time that females are restricted from breeding after losing a mate would be dependent on whether the species paired for life and its reluctance to remate, as suggested by Cruise (1966), or if the hen remained unmated for that season only.

Sex ratios between age classes

There was found to be no significant differences between the male to female sex ratio in any of the noted age classes. This suggested no differential mortality between the sexes in either of the age groups. Sample sizes however were inadequate to make a definite judgement on this.

Recalculation of Frith and Carpenter's (1980) results

Frith and Carpenter (1980) published a report which investigated the breeding habits of the Stubble Quail in south-eastern Australia. Included in this report was an analysis of the sex ratio from a large sample population of 7384 shot birds.

Age class#	Sample population size	Male to female ratio	Male population size	Female population size	χ^2 value
Juvenile	**328**	**100:139***	**127**	**201**	**16.68†**
Immature	**5120**	**106:100**	**2635***	**2485***	**4.37†**
Adult	**1936**	**115:100**	**1036***	**900***	**9.40†**
Pooled data	**7384**	**108:100**	**3834***	**3550***	**10.85†**

Age classes as determined by Crome et al. 1981.
* *Result recalculated from Frith and Carpenter's (1980) data.*
† *Significant at P<0.01.*

Table 2: Sex ratio analysis of shot Stubble Quail samples taken from Frith and Carpenter's (1980) data set. * indicates generated or recalculated results.

In their analysis, Frith and Carpenter (1980) considered the observed male bias to be a "small preponderance of males over females" and ascribed this imbalance to differential mortality during the breeding season. On re-examination of Frith and Carpenter's (1980) data, the reported male bias was considered a significant deviation from parity in all three age classes.

The same was found for pooled sex ratios. A summary of Frith and Carpenter's (1980) data, together with the recalculated results, can be found in Table 2.

The recalculation of these results revealed a significant disparity in the susceptibility of different aged sexes to harvesting. Juvenile female Stubble Quail appear more vulnerable to shooting, yet immature and adult males are shot in higher proportions to females of the same age class. The pooled data for all age classes predicts that male Stubble Quail will be shot in significantly greater numbers than females.

Caughley (1977) warns that a social species, such the Stubble Quail, should not be harvested until its social organisation is fully understood. Any disruption to the social assemblage of Stubble Quail populations may negatively affect the potential rate of increase, or replacement ability, of the species (Caughley 1977). Harvesting monogamous males would reduce productivity, and as a result the potential size of the harvestable yield, by decreasing the breeding stock. Such a practice is in direct contradiction to the principles of game species management.

These recalculated results are contrary to those found in this study. The pooled sex ratio of samples collected here revealed a ratio of parity. It is possible that a large sample set collected over an extended period is necessary to expose any significant bias in Stubble Quail sex ratios.

Habitat preference

For some species of gamebird, population densities are influenced to varying degrees by changes in habitat quality (Rands 1988). Frith *et al.* (1977) and Frith and Carpenter (1980) identified both the availability of food and quality of cover as being two of the most significant habitat variables affecting the distribution and abundance of the Stubble Quail. Habitat quality can influence population processes (eg. production of young, recruitment, emigration, and mortality during nesting) in gamebirds and an understanding of these interactions can be used in the management of harvested populations (Rands 1988).

In this study, Stubble Quail population density was used as a direct measure of habitat preference. Habitat variables such as plant species richness, percentage cover, vertical plant structure and height were used to characterise habitat types at each separate study site. Increased population density values were seen to reflect preferred Stubble Quail habitats.

Stubble Quail were found to occur in two of the five sample sites. One of these (Paddock 1) was intermittently grazed and the other was cropped (Paddock 40). The remaining sample sites were found not to support any Stubble Quail populations at any time. Paddocks 1 and 40 will be investigated separately in an attempt to determine causation for the observed fluctuations in Stubble Quail densities.

Paddock 1

Paddock 1 was intermittently grazed by cattle, and to a lesser extent sheep, throughout the study period. Grazing had little effect on habitat structure and vegetation cover was observed to remain relatively constant.

Windmill grass (*Chloris truncata*) was the dominant plant species at the site. This native grass is tussocky in its growth character and its persistent seed heads provided excellent overhead cover for Stubble Quail. Ground cover (herbs and forbs) was permitted to develop as this grass species did not completely dominate at ground level and allowed light to penetrate. Ground cover species are an important food source of the Stubble Quail (Frith *et al.* 1977). Without this food supply, habitat quality for the Stubble Quail is greatly reduced and the area is unable to support resident populations (Frith *et al.* 1977).

The presence of bare ground at this site was also considered an important habitat characteristic as it provided a desirable surface for feeding and did not impede movement throughout the area (Frith *et al.* 1976; Frith and Carpenter 1980). Bare ground and the presence of overhead cover have also been identified as important characteristics in determining habitat use and the distribution of the Bobwhite Quail (*Colinus virginianus*) (Hammerquist-Wilson and Crawford 1981).

Even though habitat quality at this site was excellent (as described by Frith *et al.* 1977), Stubble Quail density was observed to fluctuate over the study period. Densities were highest during the first month of sampling (September) after which values were seen to decline significantly. November and December recorded zero densities. Birds returned to the site in January and numbers continued to increase until March. Density values again fell in March, however bird numbers were observed to increase in April. A reduction in population density implied that quail emigrated from the site in response to a decrease in the availability of limiting resources. Such a response was considered unlikely however as habitat variables remained relatively uniform throughout the study period.

The mating system of the Stubble Quail was thought to be responsible for the decrease in quail density at this site. Reductions in recorded density levels coincided with known breeding events. Density decreased in the period between October to December when breeding was known to occur. Density was again seen to decrease in March when a second gonad cycle peaked indicating that breeding had taken place.

Avery and Ridley (1988) contend that most species of gamebird show some form of territoriality at some stage throughout the year. Bird species establish breeding territories to dominate a particular resource or resources (Avery and Ridley 1988). Typically, these include food, breeding habitat, and nest sites. If Stubble Quail were to establish territories, these resources would be defended, excluding any competition for the laying female and impending brood. Observations by Cruise (1966) suggest that during the reproductive season, male Stubble Quail do establish a breeding territory. The size of these territories and the vigour with which they are defended is unknown, however North (1914) reported that in captivity a male Stubble Quail killed a pair of Little Button Quail (*Turnix velox*) whilst defending his territory.

Pair bonding occurs during the breeding season (Olsen *et al.* 1993) suggesting that territoriality is purely a seasonal pattern of behaviour. Olsen *et al.* (1993) states that outside the breeding season large coveys, often of one sex, are formed. This explains the observed increase in Stubble Quail densities when breeding events were not recorded. Territoriality may have been abandoned and nonbreeding birds returned to the site.

That reported densities decreased again during the autumn breeding event strengthens the argument for the establishment of territories. Although not as obvious, the reduction in quail density coincided with increased gonadal activity and an improvement in habitat conditions.

A reproductive event with fewer participants requiring and establishing territories may explain the nature of this small decrease.

A reduction in population density would also lessen the probability of detection. Enforced breeding territories increased the spacing between Stubble Quail pairs thereby reducing the population density (Perrins and Birkhead 1983). Antipredator behaviour associated with breeding activity may further reduce detectability, particularly during nesting and brooding periods.

Females, whether incubating or brooding, are known to be difficult to flush (Frith and Waterman 1977). Pedler (1975) observed females to stay on the nest whilst harvesting takes place or the nest is inspected. Also, newly recruited juveniles with insufficient plumage development are unable to fly and therefore remain undetected. Even though the population may have increased during breeding through direct recruitment, the underdeveloped juveniles would have escaped detection. Behaviour may also have been different between the adult birds and young (Frith and Carpenter 1980). Young birds are known to scatter or freeze when threatened (Cruise 1966) and may be reluctant to flush.

The accuracy of the population census method may also have affected the observed results. Strip transects are known to underestimate population densities (Tilgham and Rusch 1981; Bell and Ferrier 1985; Shaw 1985; Janvrin *et al.* 1991) and an increase in the spacing of individuals would further lessen the probability of detection.

Paddock 40

Paddock 40 contained both wheat and barley. The crop was in good condition and the application of herbicides kept the site relatively weed free. This habitat type is considered poor for supporting Stubble Quail populations (Frith *et al.* 1977), however breeding pairs are commonly found to nest in them (Frith *et al.* 1977). A dense, well grown cereal crop prevents the growth of ground cover and provides insufficient food to sustain Stubble Quail (Frith *et al.* 1977).

Monitoring at this site took place only after harvesting occurred in late December. This was to avoid damage to standing crops. As a result, censusing commenced in early January.

Stubble paddocks are known to provide high quality habitat to Stubble Quail (Frith *et al.* 1977), affording birds suitable top cover and an abundant supply of food in the form of spilled grain (McNally 1956; Frith *et al.* 1977). The species is known to be highly mobile and it is assumed that their movements are controlled by the availability of food (Frith and Waterman 1977). The observed influx of birds into this area supported this theory as waste grain attracted birds from areas where food supplies were limited. January population densities were the highest recorded at this 24 ha. site with an estimated population size in excess of 125 birds.

Quail numbers were reported to decrease significantly from January to February. Cattle were introduced to Paddock 40 shortly after harvesting. Their impact was immediate. Cattle were observed to trample stubble which resulted in a decrease in cover quality.

Both the quantity and quality of the food source available to Stubble Quail was presumed to decrease immediately after harvesting. Consumption and the effects of rainfall were thought to be major contributing factors. Seventeen millimetres of rain was recorded in the first seventeen days of January which may have stimulated waste grain to germinate. Rainfall is known to decrease both the availability and quality of food to ground feeding birds. Frith *et* *al.* (1976) and Frith and Carpenter (1980) have reported the adverse short term effects that rainfall has on food supply by causing seed to germinate and be replaced with less nutritive herbage.

With the exception of spilled grain, alternative food supplies at this site were limited. Food was provided in the form of sparsely distributed weed species and scattered tussocks of *Phalaris* spp. Frith *et al.* (1977) found that in excess of two thirds (67.5%) of the plant products consumed by Stubble Quail consisted of exotic crops, pasture plants and weeds. Herbicides used to protect the crop from weed infestation reduced the food supply available to the local Stubble Quail population. Grasses and ground cover species were prevented from growing, depriving Stubble Quail of an important source of food. Both the abundance and diversity of herb and forb plant species is known to limit the capacity of an area to support Stubble Quail (Frith *et al.* 1977). Areas of scattered or single species ground cover support few birds, however habitats containing well developed, species rich ground cover plants are able to sustain permanent Quail populations (Frith *et al.* 1977).

The reduction in cover quality together with a decrease in food availability were the most obvious reasons for the reported decrease in Stubble Quail density at this site.

These results raise serious doubts about the value of stubble as a productive Stubble Quail habitat. Grazing after harvesting and the use of herbicides to limit weed infestation are incompatible with the production of quality Stubble Quail habitat. Frith *et al.* (1977) warned that improved agricultural techniques may have a detrimental effect on the species and the data reported here strengthens this argument. The assumption that cereal crop production provides suitable Stubble Quail habitat and ensures the future success of the Stubble Quail is therefore questioned.

Avoided or unsuitable habitat types

Paddocks not containing Stubble Quail were characteristically heavily grazed and, for extended periods, provided little in the way of overhead screening. During periods of high plant productivity, these same sites showed prolific plant growth. The resultant dense grass overstorey restricted light penetration and inhibited the establishment of any ground cover species which limited the available food supply.

As plant growth dried and collapsed, it resulted in a dense carpet of dead plant material. This has been observed to restrict the movements of Bobwhite quail and exclude them from utilising particular areas (Scott and Klimstra 1954). The foraging habits of some seed-eating bird species have also been limited by dense ground cover (Frith *et al.* 1976; Hammerquist-Wilson 1981). Frith *et al.* (1977) recognised these environments as providing poor Stubble Quail habitat. As a result, no quail were observed to utilise these study sites at any time.

Summary of discussion

A double breeding cycle for Stubble Quail was observed in this study. Spring reproduction coincided with maximum food availability. The proximate factors stimulating breeding are difficult to determine. Those considered most likely to be responsible (increased photoperiod, temperature and rainfall) occurred simultaneously .

Autumn breeding appeared to be associated with rainfall. The beneficial effects of rainfall are not apparent for some time after the event yet Stubble Quail gonadal activity was immediate which suggested that the sight of falling rain was enough to trigger a reproductive response.

Habitat preference was strongly associated with the availability of cover and food supply. Birds were not found in areas of excessive bare ground or areas where vegetation was so dense that movement and foraging were impeded.

Stubble Quail density appeared to be closely associated with the timing of breeding. Territoriality during a breeding event was thought to limit density and displace subordinate birds.

In examining the hypotheses proposed:

1. Stubble Quail were observed to breed during times of maximum plant productivity and, consequently, abundant food supply. Spring reproduction appears to be an annual event and any subsequent activity is an opportunistic response to periods of abundant food and cover stimulated by sufficient rainfall.

2. Stubble Quail density appeared to be directly linked to habitat quality (food availability and cover quality). Behavioural characteristics during breeding may modify population density.

MANAGEMENT IMPLICATIONS

The primary goal of game species management is to optimise the utilisation of wildlife resources by humans. The management of gamebirds is directed towards maximising the harvestable yield whilst avoiding any direct impact on breeding stocks. To do so would reduce productivity and the size of the harvestable yield.

Data on game populations are generally limited to harvest success, density estimates and hunter effort. In Australia, this information is available on hunted waterfowl, however, quantitative data on Stubble Quail harvests is scarce. In addition, knowledge of the species' life history strategies and its relationship with the environment is generally poor.

Results from this study raise some important management issues. The most notable are;

- Autumn breeding coincides with the official hunting season and may disrupt pair bonding and successful clutch rearing.

- Prejudicial harvesting of males during breeding and courtship may impact negatively on the replacement ability of localised populations.

- The social system of the species may regulate density at particular times throughout the year.

- Habitat quality appears to determine the range of the species and its relative abundance and productivity.

Before any successful harvest strategy can be employed, the ecology of the species must be better understood. Extensive field research investigating the impacts of harvesting and, more importantly, land management practices are needed to ensure the species success.

Topics of critical importance which warrant investigation include:

- habitat utilisation in response to change;
- movement in response to the availability of limiting resources;
- the impact of agricultural practices (grazing and harvest rotations, stocking rates, herbicide and pesticide applications) on breeding, home range and habitat utilisation patterns;
- the social structure of coveys;
- recruitment and dispersal rates;
- mortality rates and response to harvesting pressure; and
- factors effecting productivity and chick survival.

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CHARACTERISTIC	PADDOCK NO.				
	1	32	35	40	41
LOCATION	Central	Central west	Central west	Central	Central
AREA (HA)	34.7 ha	16.9 ha	16 ha	24.3 ha	36 ha
DAM POSITION AND VOLUME	North west corner 1 megalitre	South west corner 1 megalitre	NA	South west corner 1 megalitre	North west 1.5 megalitre
ASPECT	West facing slope	North facing slope	North facing slope	East facing slope	North facing slope
COMMON PLANT SPP.	*Chloris truncata*, *Avena fatua*, *Trifolium* spp., *Phalaris* spp., *Medicago* spp. *Hypochoerus radicata*.	*Avena fatua*, *Phalaris* spp., *Convolvulus arvensis*, *Trifolium* spp.	*Bromus mollis*, *Avena fatua*, *Phalaris* spp., *Trifolium* spp., *Polygonum aviculare*.	Cotunga wheat, Coolabah oats, *Polygonum aviculare*, *Heliotropium europaemum*.	*Bromus mollis*, *Lolium perenne*, *Phalaris* spp., *Rumex* spp., *Hypochoerus radicata*.
TREATMENT	Intermittent grazing.	Intermittent grazing.	Med-heavy grazing.	Crop production. Stubble grazed.	Heavy grazing.
SOIL TYPES	Gowangardie, Caniambo and Nalinga loam.	Caniambo, Nalinga and Gowangardie loam.	Caniambo, Nalinga and Gowangardie loam.	Nalinga and Gowangardie loam.	Caniambo and Nalinga loam.
OTHER	Bordered by agricultural land and a reserve containing remnant savanna woodland. The only site dominated by a native grass species (*Chloris truncata*). Separated from paddock 41 and 40 by a wildlife corridor.	Northern end of paddock subject to waterlogging. Separated from paddock 32 by a wildlife corridor (eastern boundary). Unsealed road borders the southern boundary of the site.	Minor gully erosion. SEC power line tower in north east of the paddock. Separated from paddock 35 by a wildlife corridor (western boundary). Unsealed road borders the southern and eastern boundary of the site	Monitoring began only after harvesting due to the prospect of damage to growing crops. Surrounded by grazed rangelands. Southern boundary abuts paddock 41. Eastern boundary abuts paddock 1.	Two SEC power line towers placed in the south west and south central regions of the site. Bordered by an unsealed road to the west and woodland reserve to the south. Separated from paddock 1 by a wildlife corridor (western boundary).

APPENDIX 1: Dookie study site descriptions.