Foraging distances and habitat preferences of banded rail in the Ohiwa Harbour

Prepared by Annetjie Botha, Royal Society Teacher Fellowship

Bay of Plenty Regional Council
Environmental Publication 2010/06

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NEW ZEALAND

ISSN: 1175 9372 (Print)
ISSN: 1179 9471 (Online)

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April 2011

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Cover Photo:
Banded rail by Annetjie Botha

Acknowledgements

I would like to thank Trident High School, the Royal Society of New Zealand and my two host organisations Bay of Plenty Regional Council and the Department of Conservation (DoC) for making this year possible. Thank you to Matthew Bloxham (Bay of Plenty Regional Council) for his guidance, support and encouragement throughout the year and for reviewing the report. Thanks also to Graeme Elliot (DoC) for his guidance and statistical analysis of the data. I would also like to thank Keith Owen (DoC) for his interest in the project and assistance in finalising the methods and Willie Shaw (Wildland Consultants) for reviewing the report.

A final thank you to the following people for their interest and assistance throughout the year: Bay of Plenty Regional Council – Stephen Park, Rob Donald, Michelle Hosking, Victoria Ferguson, Tim Senior, Dianne Kimber, Braden Rowson, Adria Harper and Word Processing; Nukuhou Saltmarsh Care group – Stuart and Margaret Slade and Rainbow Springs (Rotorua).

The New Zealand Science, Mathematics and Technology Teacher Fellowship Scheme is funded by the New Zealand Government and administered by the Royal Society of New Zealand.

Executive summary

There is increasing pressure to restrict the spread of mangroves, but we have little knowledge of how mangrove control will affect wetland bird species. Banded rail are one of a number of bird species living in the saltmarshes and this study focused on their association with mangroves in Ōhiwa Harbour.

The objectives of the study were to establish:

- How far banded rail move from their primary rush roosting habitat into mangroves (under cover) or onto mudflats (where there is no cover).
- Which habitat type (mangroves or rushes) banded rail prefer.

Three saltmarshes were studied at the Ōhiwa Harbour. At Nukuhou Saltmarsh, mangroves covered an extensive area to seaward of a similarly large area of rushes, while at Burma Road Site 1, rail habitat consisted of rush habitat with only open mudflat without mangroves to seaward of the rushes. Burma Road Site 2 was a smaller marsh with sparse mangrove cover.

Banded rail foraging distances were compared between a saltmarsh with mangroves to seaward of rush habitat and a saltmarsh with no mangroves to seaward, only open mudflat. Where there were no mangroves, banded rail stayed in close proximity to their rush roosting habitat. Here banded rail, on average, stayed within one metre of rushes, never moving more than six metres away. However, where mangroves were present, rail foraged right to the seaward extend of the mangroves, up to 280 m from the nearest rush habitat.

To determine whether banded rail prefer to forage in rush or mangrove habitat, the number of footprints entering or exiting drains and channels in the two habitats were compared. Three times more banded rail footprints were found in the mangrove habitat than in the rush habitat. This implies that banded rail spend more time foraging in mangrove habitat.

Reasons for the foraging distances and habitat preferences were also investigated. The possibility that mangroves might provide cover for the birds while foraging, or that banded rail might be forced to forage further away from rushes because less of their preferred food exists under mangroves, was investigated.

To investigate the possible protection that mangroves provide to foraging banded rail, the study was carried out in a marsh with sparse mangrove cover. A higher proportion of banded rail footprints were found associated with mudflats with sparse mangrove cover than with open mudflats without mangroves. Banded rail were mostly absent from open mudflats. During the day, birds stayed close to shore, where denser mangroves provided greater cover. At night, banded rail foraged further away from rush habitat, they *still* made use of sparse mangroves as cover. That is, at night footprints were still significantly more likely to be correlated with scattered mangroves than with open ground.

The food available to banded rail in a marsh with mangroves was compared with food available to banded rail over open mudflat without mangroves. More *Potamopyrgus estuarinus* snails were found on open mudflats and more crabs (*Helice crassa*) were found in saltmarsh with mangroves. There was no difference in mud snail (*Amphibola crenata*) abundance, either inside or outside of mangrove cover. The study suggests that food isn't limiting under mangroves and that the primary reason banded rail move further away from rushes when under mangroves is that mangroves provide cover while foraging. The suggestion, therefore, is the species' fitness is improved by mangroves.

The main study conclusion is that mangroves are an important habitat for banded rail in Ōhiwa Harbour as they provide cover from aerial predators while foraging for *Helice crassa*, their preferred prey.

Contents

Part 1: Introduction

1.1 Banded rail distribution in New Zealand

Banded rail (*Rallus philippensis assimilis*) is an endemic New Zealand subspecies. Banded rail are also found throughout south-east Asia, south-west Pacific Islands and Australia (Marchant and Higgins, 1993). *Rallus philippensis assimilis* is naturally uncommon in New Zealand and listed as 'threat criteria qualifier: data poor' by Miskelly et al (2008).

Banded rail have an unusual distribution in New Zealand. They were once common throughout the North and South Island, but by the 1930's they had disappeared from many regions. According to Marchant and Higgins (1993) banded rail had disappeared from Parongahau before 1948 (Cunningham and Wodzicki, 1948); Wairarapa before 1931 (Stidolph, 1931); Wellington by 1925 (Stidolph, 1926); Canterbury by 1927 (Stead, 1927) and Westland by 1949 (CSN). Other areas from where banded rail were recorded before 1930, but have not been seen since include: Horowhenua (Buller, 1888); Stephens Island (Dawson and Dawson 1958; Buller, 1905); Napier (Hutchinson, 1900) and Otago (Specimens in the NMNZ).

Presently the distribution of banded rail is discontinuous in New Zealand. In the North Island banded rail are found from Northland to Waikato, Coromandel Peninsula and Bay of Plenty (including the Three Kings, Poor Knights Islands and Great Barrier Island). Banded rail are, however, absent south of Lake Taupo. In the South Island, banded rail occur in the coastal regions of Golden Bay, Nelson and the Marlborough Sounds, but are absent elsewhere. Banded rail do, however, occur on Stewart Island and a number of outlying islands (Big, Kaimohu, Tamaitemioko, Pohowaitai and Little Solander Islands) (Marchant and Higgins, 1993; Owen 1993).

1.2 Banded rail habitat

Banded rail occupy a range of different habitats throughout their distribution in south-east Asia, south-west Pacific Islands and Australia. They occur in permanent and ephemeral, fresh and saline, saltmarsh and littoral wetlands (Marchant and Higgins, 1993).[1] On the New Zealand mainland, banded rail are rarely found inland, except in freshwater wetlands in Northland and the Waikato (Elliott, 1987; Owen, 1993). Banded rail are mainly found along the coast associated with mangrove and saltmarsh wetlands within estuaries and harbours (Owen, 1994). On the northern group of outer islands, banded rail range freely through forested habitat as well as saltmarsh (M. Bloxham, Bay of Plenty Regional Council, pers. comm).

The only work that has focussed specifically on banded rail in New Zealand was by Elliott (1983) where he studied the distribution and habitat requirements of banded rail in Nelson and in Marlborough. Elliott (1989) found that in the South Island, which is free of mangroves, banded rail remained confined to saltmarsh habitats. However, in the northern North Island, Elliot found that banded rail frequently forage within mangroves (Elliott, 1987). Elliott found that generally banded rail prefer vegetation that provides cover but that also allows movement (Elliott, 1983, 1987)[2].

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[1] Examples include swamps, marshes, lakes, coastal lagoons, billabongs, rivers, creeks, pools, temporarily inundated depressions, tidal mudflats and artificial wetlands.

[2] As mentioned above, Elliott's cursory observations of banded rail in the northern North Island did suggest extensive use was made of mangroves.

Banded rail are most active in vegetation dominated by sea rushes (*Juncus maritimus*), whereas they roost and nest in stands of sedges (*Leptocarpus similis*) and marsh ribbonwood (Elliott, 1983). Banded rail will occasionally use marsh ribbonwood branches (*Plagianthus divaricatus*) as nest support (Elliott, 1983). According to Elliott (1989) banded rail need a regular supply of freshwater when living in saltmarshes in New Zealand.

There has been a considerable loss of banded rail habitat in New Zealand. Rushes, sedges and marsh ribbonwood occur at the upper margins of saltmarshes and, due to intensive coastal development, including the alteration and infilling of saltmarshes, these areas are under ongoing threat. In New Zealand available rail habitat has been reduced by infilling an drainage of wetlands for industrial, agricultural and urban development (Gilbert 1936; Stokes *et.al.* 1984; Owen and Sell, 1985) including roading. For example, since 1956, the upper margins of the Waimea inlet have been reclaimed for farmland, industry and roading. According to Elliott (1989), stock also trample or eat banded rail cover in and around wetlands.

Banded rail are locally common in northern coastal areas, but due to habitat modification and predation their numbers may be declining (Heather and Robertson, 1996). Banded rail nest- predation by stoats has also been recorded at the Omaha Saltmarsh by Parker and Brunton (2004). Elliott (1983) noted that banded rail suffer considerable losses during the nesting season from introduced predators, but that banded rail populations have survived this predation for at least 50 years in parts of Nelson and Marlborough.

No previous New Zealand studies have specifically focussed on the association between banded rail and mangroves.

1.3 Banded rail habitat in the Bay of Plenty

According to Owen (1994), the Ōhiwa Harbour supports one of the few long-term viable populations of banded rail in the Bay of Plenty Region. The size of the population in Ōhiwa Harbour makes it the second-largest population in the Bay of Plenty after Tauranga Harbour (Owen, 1993, 1994). According to Owen (1994), the fact that banded rail have such a discontinuous distribution in New Zealand, makes the Ōhiwa Harbour population nationally significant. The Nukuhou Saltmarsh provides the greatest area of continuous habitat in the Ōhiwa Harbour. After visiting the study site in August 2009, Elliott commented that he had not seen or heard anywhere near the same numbers of banded rail elsewhere in New Zealand as he had in the Nukuhou Saltmarsh. Using Elliott's (1989) estimations of 1.5 ha of saltmarsh rushland vegetation for a breeding pair of banded rail, Owen (1994) calculated that 150 birds could be living in the Ōhiwa Harbour region. Banded rail feed in mangrove areas but are unlikely to nest successfully as nests would probably be more vulnerable to rat predation in mangroves than those built in rush habitat.(M Bloxham, Bay of Plenty Regional Council pers. comm.). Furthermore, nests built in mangroves would, in many cases, be inundated during high tides (Owen, 1994). For this reason Owen did not consider mangroves in his calculation of the potential population size at Ōhiwa. However, by increasing their foraging area, mangroves may support a larger number of banded rails than if no mangroves were present.

With increasing pressure to control mangroves throughout their range, there is a need to quantify the value of mangroves for saltmarsh bird species, and specifically establish whether banded rail utilise mangroves.

1.4 Mangrove ecology and management

The expansion of mangroves and increasing pressure to control their spread is a controversial management and environmental issue in the upper North Island.

For many people using and living around estuaries and harbours, open water vistas are highly prized and the occupation of these areas by mangroves diminishes their enjoyment. It is also a general public perception that the spreading of mangroves reduces biodiversity and anecdotal evidence of lower bivalve numbers is often used to support this idea (Stokes, *et al.* 2009). Mangrove control has been one of the founding objectives for a number of 'estuary care groups' that have developed around Tauranga Harbour. In response to this community concern, the Bay of Plenty Regional Council has initiated mechanical mangrove removal in certain areas of the harbour.

Mangroves are native to New Zealand and perform various roles in the coastal environment. Mangroves create habitat for marine life (Beston, 2005) and play an important role in erosion control and shoreline protection as they slow the flow of water and break up and prevent waves and storm surges from reaching the shore (Morrisey *et al* 2007). A number of people in the Ōhiwa Harbour community believe that mangroves have some ecological value, but little research has been done to validate these claims (Bay of Plenty Regional Council, 2009).

In many estuaries and harbours in the upper North Island there has been a substantial expansion of mangrove cover over the last 50 years (Auckland Regional Council, n.d. a). Aerial photographs of the Ōhiwa Harbour show that mangroves covered an area of 20.6 canopy ha in 1945. By 2003 mangroves covered an area of about 90.8 canopy ha (Bay of Plenty Regional Council, 2009).

Increasing amounts of silt and mud (sediment) washed from surrounding catchments into shallow estuarine areas, provide more shallow silted areas suitable for mangrove colonisation (Environment of Waikato, n.d. and Auckland Regional Council, n.d. a). Mangroves alter the sediment type by promoting the concentration and accumulation of fine silts and mud, rather than coarser particulates. Mangroves generally first colonise the outer, shallower edges of estuaries close to stream mouths, a source of fine fluvial silts and sediment. It is here that mangroves collect and concentrate sediments, creating an environment more suitable to mangrove colonisation. Pre-existing habitats such as seagrass beds and the shellfish beds that occupy shallow estuarine areas are gradually displaced by mangroves. In this way mangroves may reduce the abundance and diversity of animals living in the sediments as they mature and spread (Environment Waikato, n.d.).

Tidal flats with shallow mud and silt provide a habitat for polychaetes, shellfish, crabs and shrimps that waders feed on (Battley and Brownell, 2007). The spread of mangroves may negatively affect wader roosting and possibly feeding grounds in the northern parts of the country by occupying and displacing estuarine foraging habitat by transforming open ground dominated by *Zosteria* and shellfish beds. Stokes *et.al.* (2009) compared the macro-invertebrate communities in mangrove habitat and un-vegetated intertidal flats. They found a significant difference in species richness between mangrove habitat and bare intertidal habitats. The bare flats had greater species abundance but no species were found to be exclusive to either habitat. Mangroves also reduce roosting sites for waders by restricting visibility; a critical element for waders is that they must have visibility in all directions for predator detection (Beston, 2005). This has caused thousands of birds in the Firth of Thames to leave roosting areas on the shore-side portion of the shellbank because mangroves are gradually colonising this area (Beston, 2005). The use of this site by waders has steadily decreased with no substantial use of the area since

1990. There has been a noticeable change in the distribution of wrybills, golden plovers, red knots and whimbrels in this area (Morrisey *et.al.* 2007; Auckland Regional Council, n.d. b).

However a number of other native bird species, such as banded rail, white-faced heron, harrier, kingfisher, welcome swallow, and pukeko occur regularly amongst mangroves. Grey warblers, silvereyes, fantails, shinning cuckoos, bitterns, and royal spoonbills, as well as roosting colonies of pied and little black shags, have also been observed in mangroves (Auckland Regional Council, n.d. b).

The spread of mangroves might be detrimental to waders; but rare saltmarsh bird species might benefit from mangroves as they provide new feeding and roosting habitat for these secretive birds.

1.5 Banded rail ecology

The secretive nature of most native wetland bird species has resulted in little information being amassed on their ecology, population status and breeding success (Anderson and Ogden, 2003). Few studies have been done on bird communities in New Zealand wetlands generally and there is little understanding of habitat use patterns by bird species within wetland systems (Anderson and Ogden, 2003). There is even less information on whether saltmarsh birds utilise mangrove habitat as, in some areas, such as my study site, mangroves are a relatively recent phenomena. Subsequently, it is difficult to predict how mangrove management will affect saltmarsh bird species. Research into the ecology and habitat requirements of these birds is essential to ensure that informed decisions are made when mangrove control is considered.

Banded rail have been observed in or near mangrove habitat by several authors:

- Marchant and Higgins (1993) suggested that banded rail are usually found amongst dense vegetation and occasionally in mangroves. Anderson and Odgen (2003) observed banded rail at the mangrove edge of inlets during their bird counts at the Kaitoke wetland on Great Barrier Island. The only work that has focussed specifically on banded rail in New Zealand was by Elliott (1983) where he studied the distribution and habitat requirements of banded rail in Nelson and in Marlborough. Elliott (1989) found, that in the South Island, which To investigate possible reasons for banded rail use of mangrove habitat. In particular, I investigated whether:

  (a) Mangroves provide cover and foraging opportunities for banded rail.

  (b) The value of mangrove cover varied between night and day.

I proposed doing this by assessing the relative value, abundance and diversity of organisms in substrate near mangroves compared with open mudflats without mangroves. Banded rail might be forced to forage further away from the rushes when mangroves are present to obtain suitable food in suitable quantities.

Part 2: Location and Methods

2.1 Location and habitat

Three saltmarshes in the Ōhiwa Harbour were studied (Figures 2.1 - 2.3).
At the Nukuhou Saltmarsh, mangroves cover an extensive area to the seaward of a large area of rushes, while at Burma Road Site 1, banded rail habitat consists of open mudflat withou

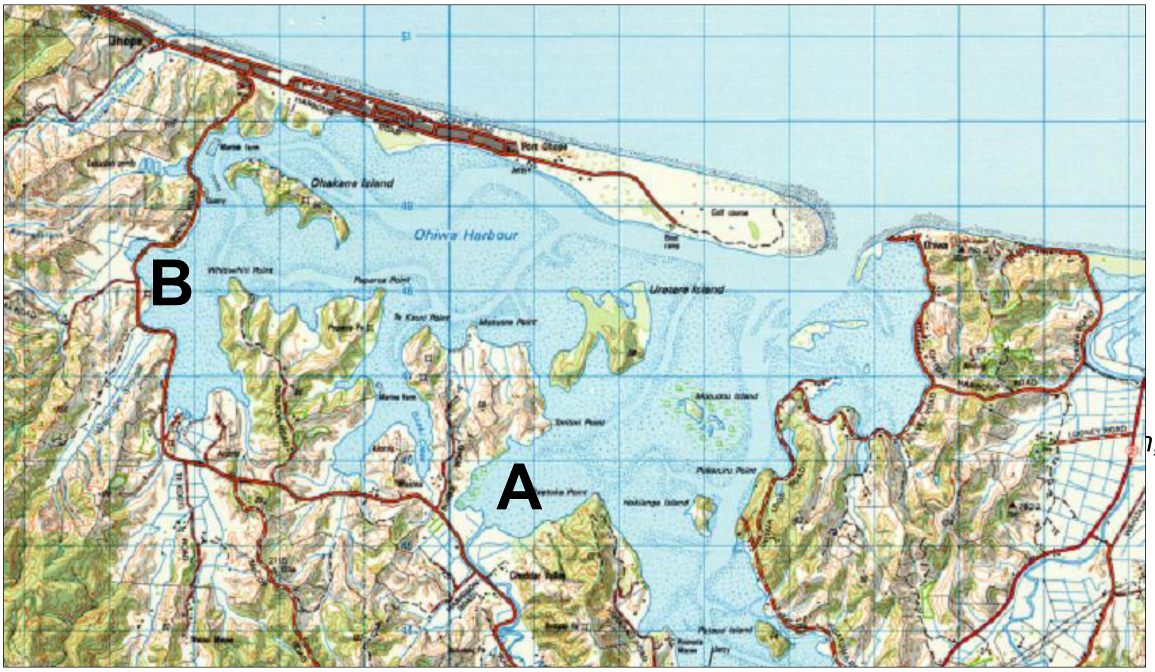


Figure 2.1 Location map for Ōhiwa Harbour, Whakatāne. A = Nukuhou Saltmarsh; B = Burma Road Saltmarsh (Site 1 and 2).

Figure 2.2 Burma Road Site 1 (open mudflats) and Site 2 (sparse mangroves).

Figure 2.3 Nukuhou saltmarsh site.

2.2 Detection of banded rail activity

According to Keith Owen (pers. comm.) and Elliott (1989), the most reliable method for detecting banded rail is footprints, as their responses to tape-recorded calls are unreliable. For this study, banded rail footprints were used to detect banded rail acFigure 2.4 Banded rail footprints.

2.3 Foraging distances

Transects were walked at both sites, across open mudflats (Burma Road Site 1) or amongst mangroves (Nukuhou Saltmarsh), to determine how far banded rail forage beyond their main rush roosting habitat.

- Burma Road Site 1 (open mudflat)

  Six visual transects were established, 50 m apart (Figure 2.5). The opposite ends of each transect were marked with a bamboo pole and flagging tape for the duration of the study. Transects were walked following a GPS bearing during the morning, about four to five hours after low tide. Each time a banded rail footprint crossed the transect, or if the print was within 50 centimetres on either side of the transect, the print was recorded using a GPS. The study was carried out during the months of February, March, April, and September. Each transect was walked eight times during the year.

- Nukuhou Saltmarsh (mangroves)

  Seven transects were placed 100 m apart with the opposite ends of each transect marked with a bamboo pole and flagging tape (Figure 2.6). Every 20 m, a mangrove tree was marked with flagging tape to ensure that the same transect track was walked during each visit. The flagging tape remained on the mangroves for the duration of the study. The same method was followed as at the Burma Road Site 1, but each transect was walked just six times.

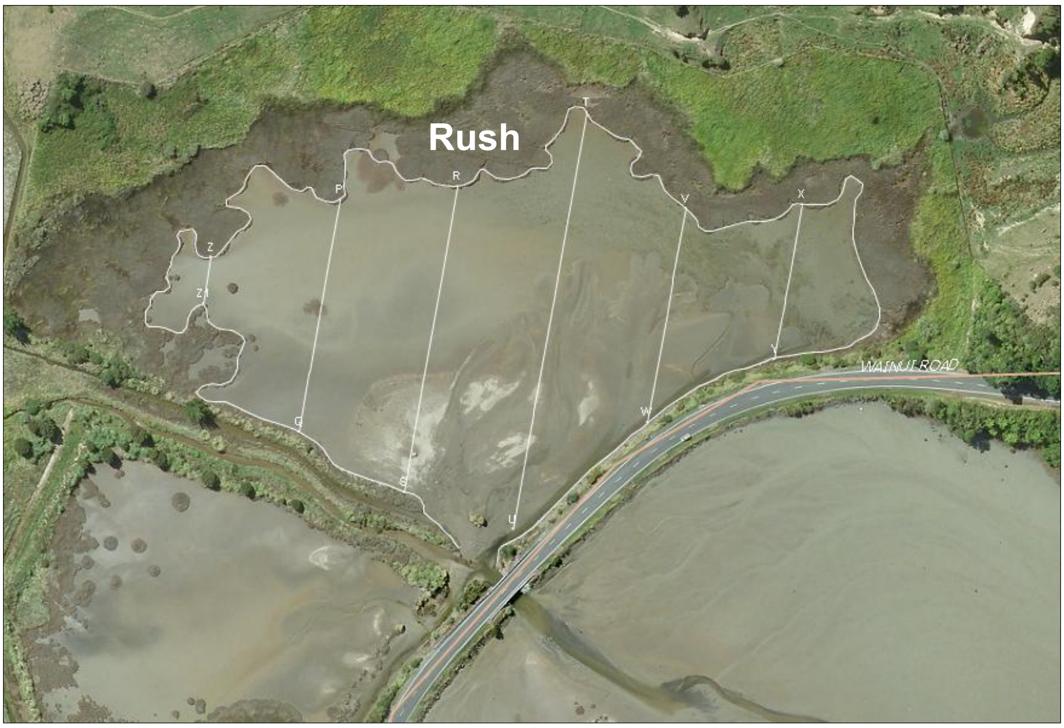


Figure 2.5 Transect lines used for the foraging distance study at Burma Road Site 1.

Figure 2.6 Transect lines used for the foraging distance study at Nukuhou Saltmarsh.

- Measuring the distance each footprint found from the closest rush/mangrove habitat.

The GPS data was accurately superimposed over Regional Digital Aerial Mosaic images (RDAM). Buffer lines were added to allow one to measure the distance that footprints were found extending away from rush into mangrove habitat or onto open mudflats.

At Burma Road Site 1, buffer lines were added at one metre intervals from the edge of the rush habitat (Figure 2.7).

At the Nukuhou Saltmarsh, rush habitat occurs on both the north-western and south-western side of the marsh. Buffer lines were added at 10 m intervals from the closest rushes (Figure 2.8). By using buffer lines, each footprint could also be entered into a distance class, for example 0-10 m, 10-20 m, 20-30 , and so on, from the closest rushes, irrespective of which side they occurred (Appendix 1 and 2). An account was kept of how many metres were walked in each distance class. A chi-squared test was used to compare the number of footprints found in each distance class with the length of transect in that distance class. Data was then adjusted for availability and effort in each of the distance classes.

At Nukuhou Saltmarsh three transect lines that ran through mangroves also extended onto the open mudflat. For these three transect lines, the area beyond the mangroves was also divided into distance classes, example 0-10 m, 10-20 m, 20-30 m, away from the closest mangroves (Appendix 1). This made it possible to measure the distance that footprints were found beyond the cover of mangroves. The number of footprints found in each distance class was analysed using a chi-squared test. As all footprints were found in the 0-10 m distance class, this class was then further divided into one metre sub-classes. A chi-squared test was used to compare the number of footprints found in each of these sub-classes.

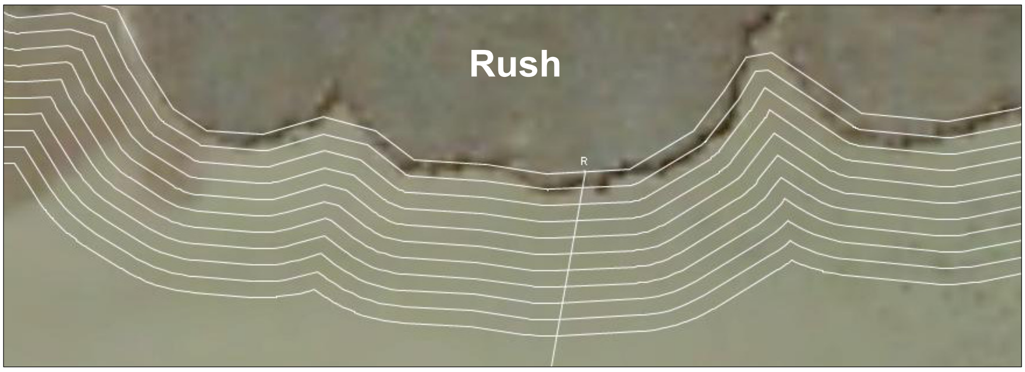


Figure 2.7 Buffer lines at one metre intervals from the edge of the rush habitat at Burma Road Site 1.

Figure 2.8 Buffer lines at 10 m intervals from the edge of rush habitat at Nukuhou Saltmarsh.

2.4 Habitat preferences

The study to determine whether banded rail prefer mangrove or rush habitat was undertaken at Nukuhou Saltmarsh, as significant areas of both habitat types occur there. A combination of natural flow paths (channels) and human-made drains were investigated for prints. For the purpose of this study, the watercourses walked were drains in rush habitat and channels in mangroves.

To prevent damage to the rush habitat, existing drains were used as surrogate transects and as a surrogate for rush foraging habitat. For mangrove habitat, naturally formed channels were used in the same way. Figure 2.9 shows the positions of the two 30 m transects that were walked in each habitat type. Every banded rail print entering or exiting the drain/channel was recorded as banded rail activity (Appendix 3). Any prints found inside the drain/channel and that extended out along the drain/channel towards the mangroves were not recorded as it was likely that the banded rails were using the drain/channel as a corridor to access the mangrove habitat beyond, rather than moving between blocks of rushes. Each transect was walked eight times.

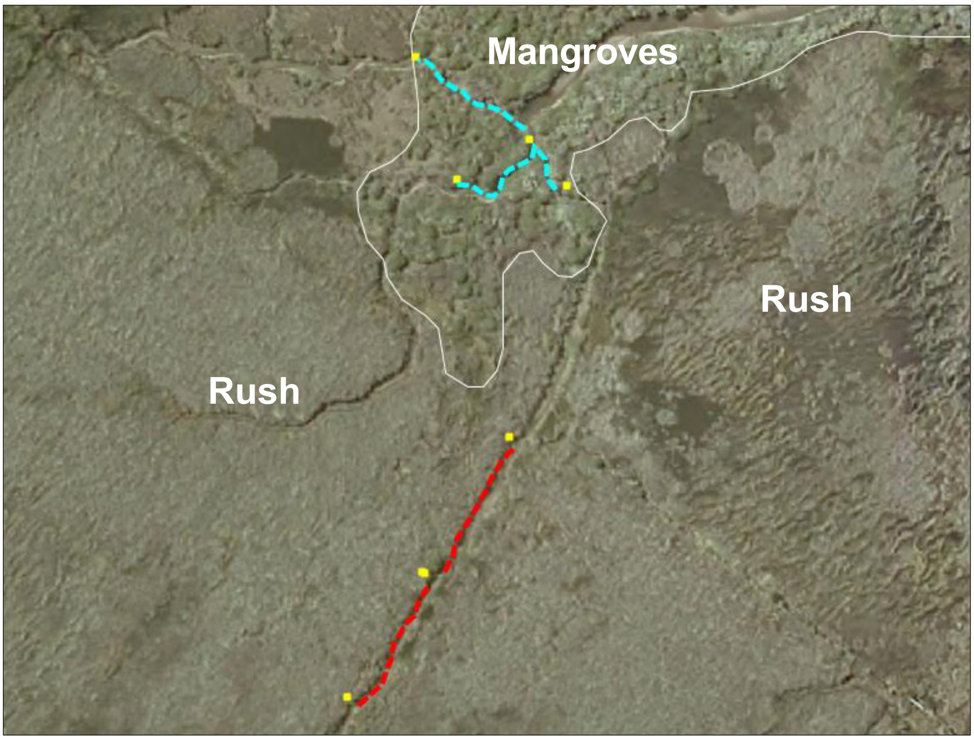


Figure 2.9 Banded rail habitat preference was studied at Nukuhou Saltmarsh using existing drains and channels as surrogate transects. Drains running through rush habitat are marked in red and channels running through mangrove habitat are marked in turquoise.

2.5 Foraging protection

Burma Road Site 2 (sparse mangroves) was studied to determine whether mangroves provide a level of protection for banded rail.

Ninety-one spatially isolated mangrove plants were numbered, marked with flagging tape and their positions recorded using a GPS (Figure 2.10). To be included in the study, each mangrove plant had to have a vegetated canopy at least fifty centimetres in diameter and to be at least three metres away from the next plant.

A one square metre quadrat was placed over each of the mangroves while the observer was facing directly east (Figure 2.10). East in this study was parallel to the shore. The presence or absence of banded rail footprints under each mangrove or on the perimeter of the plant was recorded. The quadrat was then placed one metre away from the mangrove, towards the shore (south) and one metre to seaward of the mangrove (north). Use of a magnetic bearing ensured that subsequent quadrats were placed reliably on both the inland and seaward quadrats of each plant. The presence or absence of footprints towards or away from the shore in relation to each mangrove plant was recorded in both of these open mudflat quadrats. The study was done twice. To study 'night time' banded rail foraging patterns, the data was collected at low tide at eight o'clock in the morning. To study banded rail foraging patterns during daylight hours, data was collected at four o'clock in the afternoon, after a morning high tide.

For each mangrove plant, information such as substrate type, distance from the densest continuous band of mangroves, distance from the rushes inland of the mangroves, and distance from the rushes adjacent to the road was also recorded (Appendix 4).

As only 72 plants had data for both the seaward and inland quadrats, data from these plants only were used to examine the proportion of quadrats that had footprints in them. A chi-squared test was used to determine whether this pattern was significant.

All 91 samples were used to examine the factors affecting banded rail distribution in and around spatially separated mangroves. Data were analyzed using logistic regression and stepwise variable.

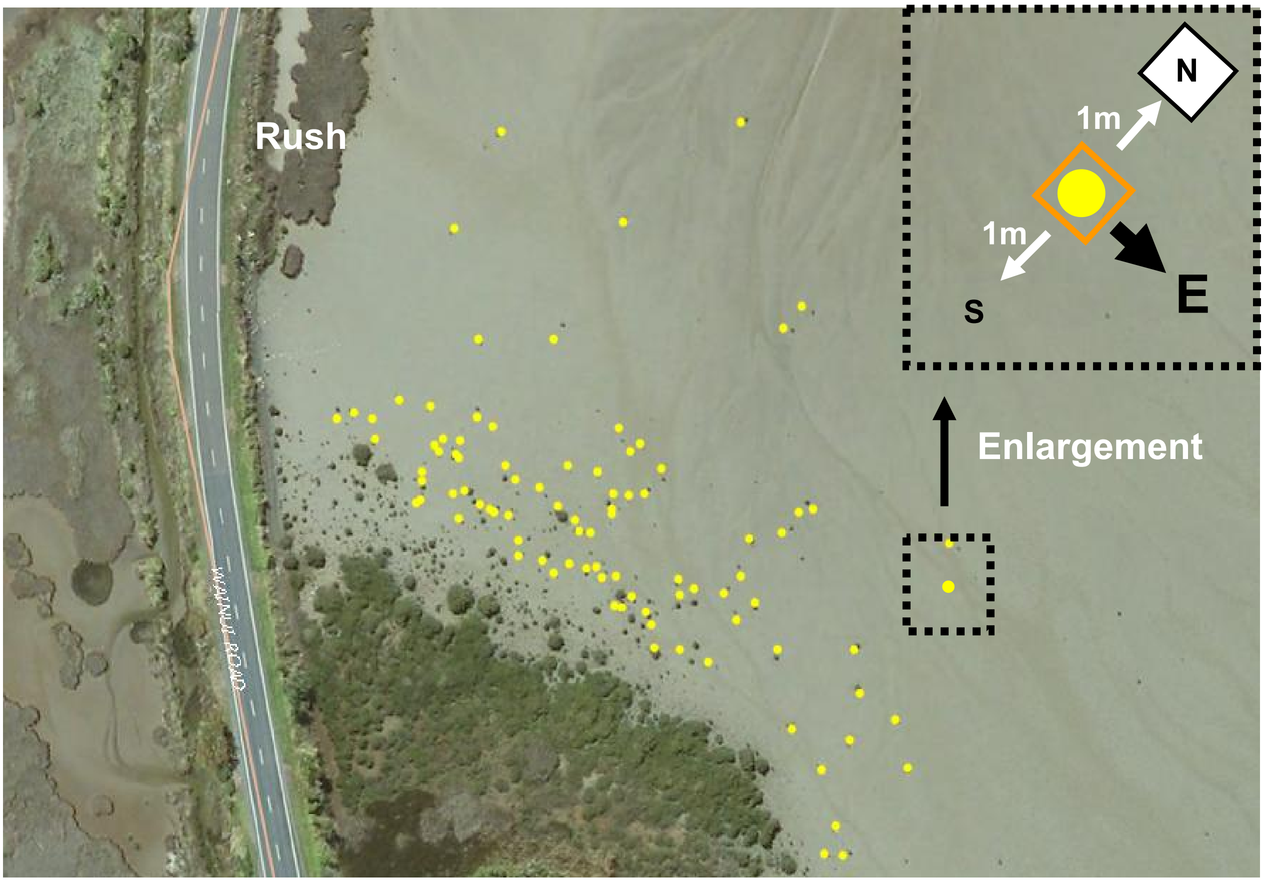


Figure 2.10 *Burma Road Site 2 (sparse mangroves). Each yellow dot indicates a mangrove plant that was checked for the presence or absence of footprints.* ***Enlargement:*** *The white squares show the positions of the open mudflat quadrats, seaward (north) and inland (south, in relation to the mangrove plant (Orange Square).*

2.6 Food availability

Elliott (1983) analysed the faeces of banded rail to determine their diet. He found that the crab *Helice crassa,* the mud snail *Potamopyrgus estuarinus,* and the two snails *Ophicardelus costellaris* and *Amphibola crenata* made up 50%, 30%, 20%, and 5% respectively of the greater than 0.3 mm portion of the faeces that he examined. Polychaete worms made up less than one percent of all food consumed. To compare differences in the food available to banded rail in a marsh without mangroves to a marsh with mangroves, Burma Road Site 1 (open mudflat) and Burma Road Site 2 (sparse mangroves) were studied. The number of *Helica crassa* holes, *Potamopyrgus estuarinus* snails, *Amphibola crenata* snails, and polychaete worm holes were compared between the two sites. Test digs were done in preparation for the dietary study, to predetermine the hole sizes for each of the burrowing species (i.e. infauna). Polychaetes occupied the smallest burrows (typically less than 2mm in diameter) and *Helice crassa* occupied burrows that were substantially larger.

Four visual transects were walked each site using a GPS bearing at. The transects at Burma Road Site 1 were placed 50 m apart and at Burma Road Site 2 the transects were placed 30 m apart (Figure 2.11). A one square metre quadrat was used and each quadrat sample position was recorded using a GPS (Figure 2.11).

For each sample, information including substrate type, distance from the densest continuous band of mangroves, distance from the rushes inland of the mangroves and distance from the rushes adjacent to the road were also recorded (Appendix 5). The method used in each habitat type is explained in greater detail below.

2.6.1 **Burma Road Site 1 (open mudflat)**

A 1 m^2 quadrat was placed at the edge of the rushes next to a bamboo pole used to mark the start of the transect. *Amphibola crenata* snails were counted in the top left hand corner of the quadrat, in a 50 cm^2 subdivision. *Helice crassa* holes, *Potamopyrgus estuarinus* snails, and polychaete holes were each counted in three separate 25 cm^2 subdivision (Figure 2.12).

The quadrat was then flipped repeatedly in a straight line until it was four metres away from the rushes and the count was repeated. Available food was counted in this manner up to 50 m away from the nearest rushes.

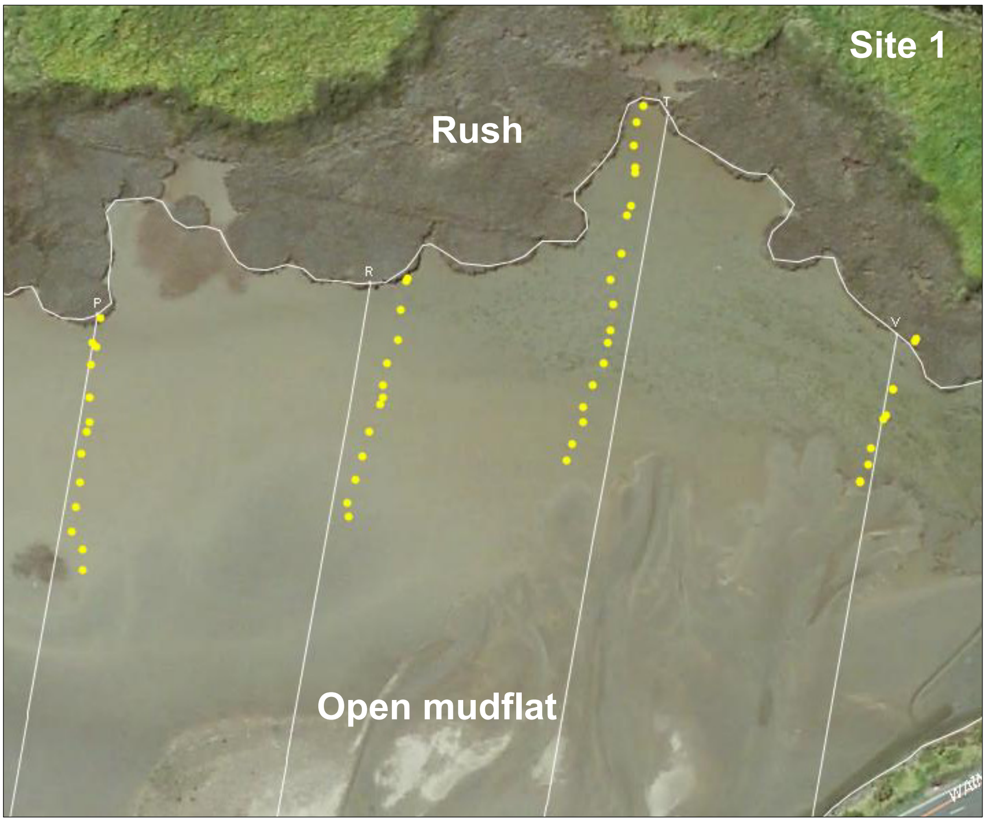
2.6.2 **Burma Road Site 2 (sparse mangroves)**

The same method was followed at the sparse mangrove site, but data collection started at the edge of the densest continuous band of mangroves, not at the edge of the rushes. Available food was assessed up to 50 m from the densest continuous band of mangroves.

If, once the quadrat had been flipped continuously in a straight line away from the continuous band of mangroves, it ended up next to another mangrove, the quadrat was moved one metre to the left or right of that plant for collection of a mudflat food sample. The quadrat was then returned to its original position, to ensure that the data sampling again continued in a straight line along the transect until its completion.

Generalised additive models were used to examine whether there was any relationship between the variables (such as substrate type, distance from the densest continuous band of mangroves, distance from the rushes inland of the mangroves, and distance from the rushes adjacent to the road) and the abundance of the four invertebrates studied,

A negative binomial generalised linear model was used to test whether a higher number of *Helice crassa* holes, *Potamopyrgus estuarinus* snails, *Amphibola crenata* snails and polychaete holes were counted at Burma Site 1 (open mudflat) or Burma Site 2 (sparse mangroves).



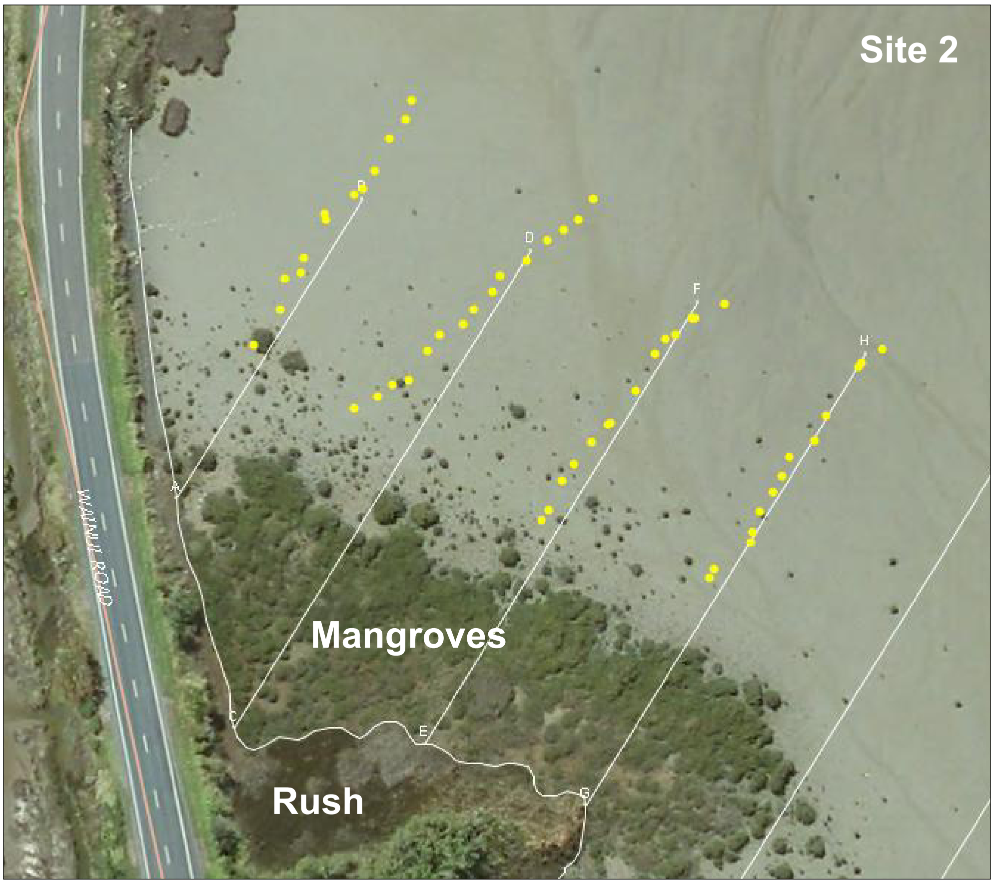


Figure 2.11 Mud food sampling sites at Burma Road Site 1 (open mudflat) and Burma Road Site 2 (sparse mangroves). Each yellow dot indicates a mud food sampling quadrat.

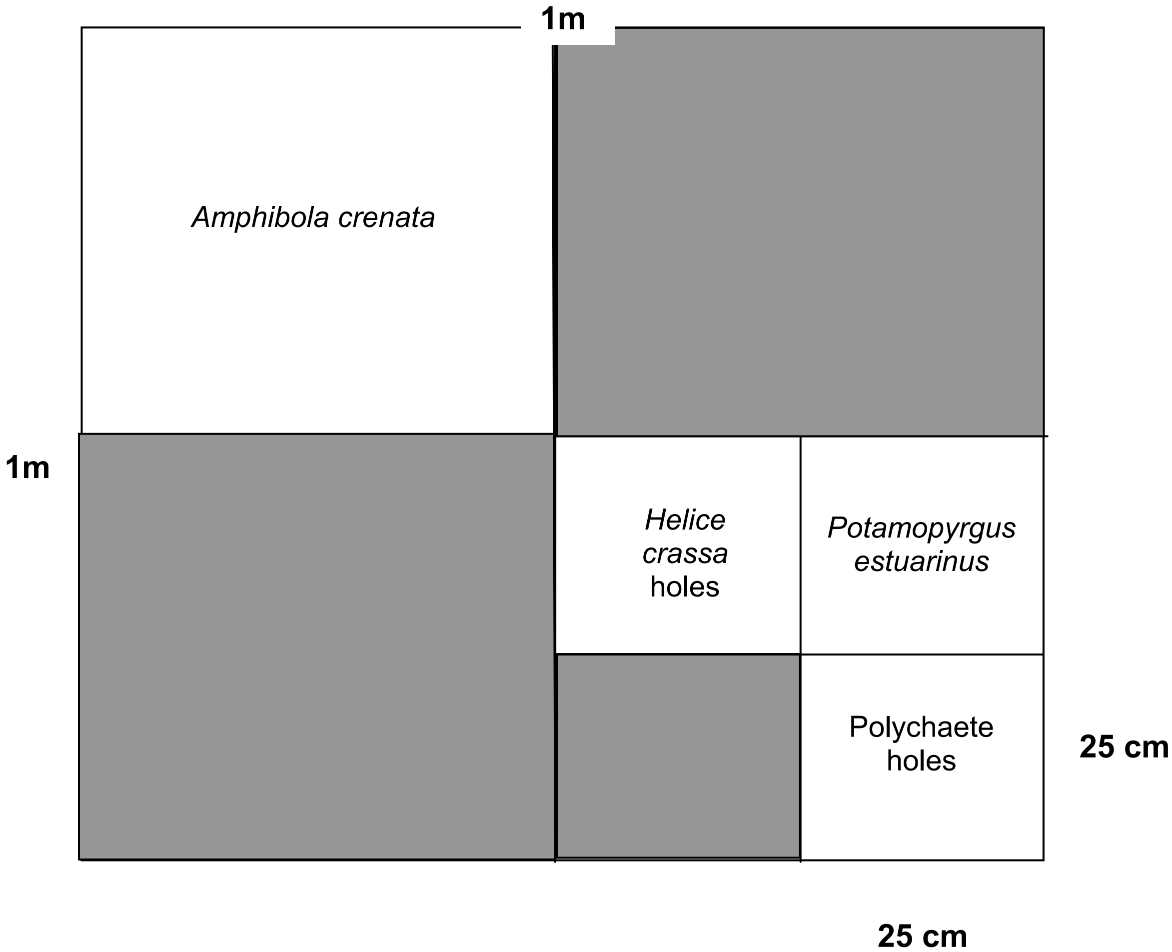


Figure 2.12 *Diagram of the 1 m^2 quadrat used to count Amphibola crenata snails, Helice crassa holes, Potamopyrgus estuarinus snails, and polychaete holes.*

Part 3: Results

3.1 Foraging distances

3.1.1 Burma Road Site 1 (open mudflat)

At Burma Road Site 1, banded rail foraged on average up to one metre away from rushes, but never more than six metres away from rushes. Figure 3.1 shows the mean number of footprints found up to six metres from rush cover.

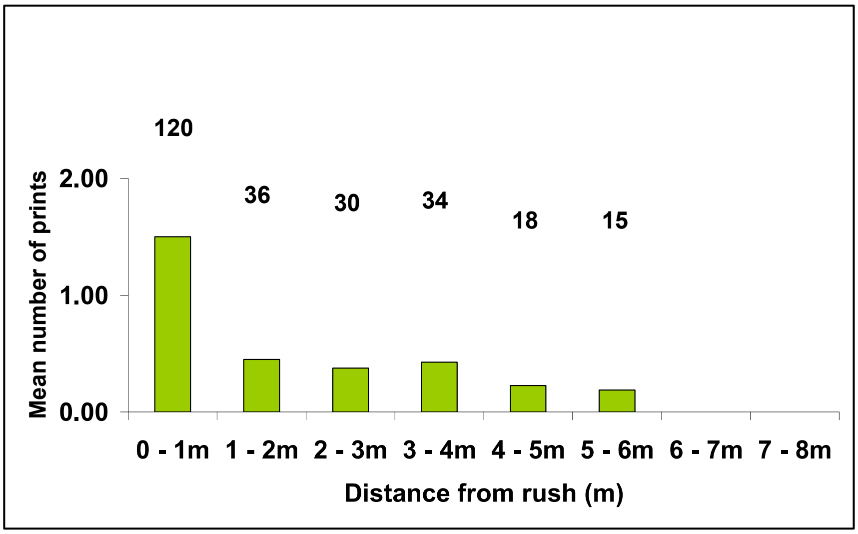


Figure 3.1 The mean number of banded rail prints found in each distance class on open mudflats at Burma Road Site 1 (transects were walked eight times).

The graph is based on a total of 253 prints sighted during the study.

3.1.2 Nukuhou Saltmarsh (mangroves)

Foraging distances into mangroves

At Nukuhou Saltmarsh, banded rail footprints were found throughout the mangrove habitat. The birds foraged right to the seaward extent of the mangroves, 280 m from the closest rushes (Figure 3.2).

Banded rail significantly aggregate towards certain areas within mangroves (chi-squared = 401.3105, df = 27, p-value < 0.001). A greater number of footprints were found in the 190-240 m distance class than anywhere else in the mangroves (Figure 3.3).

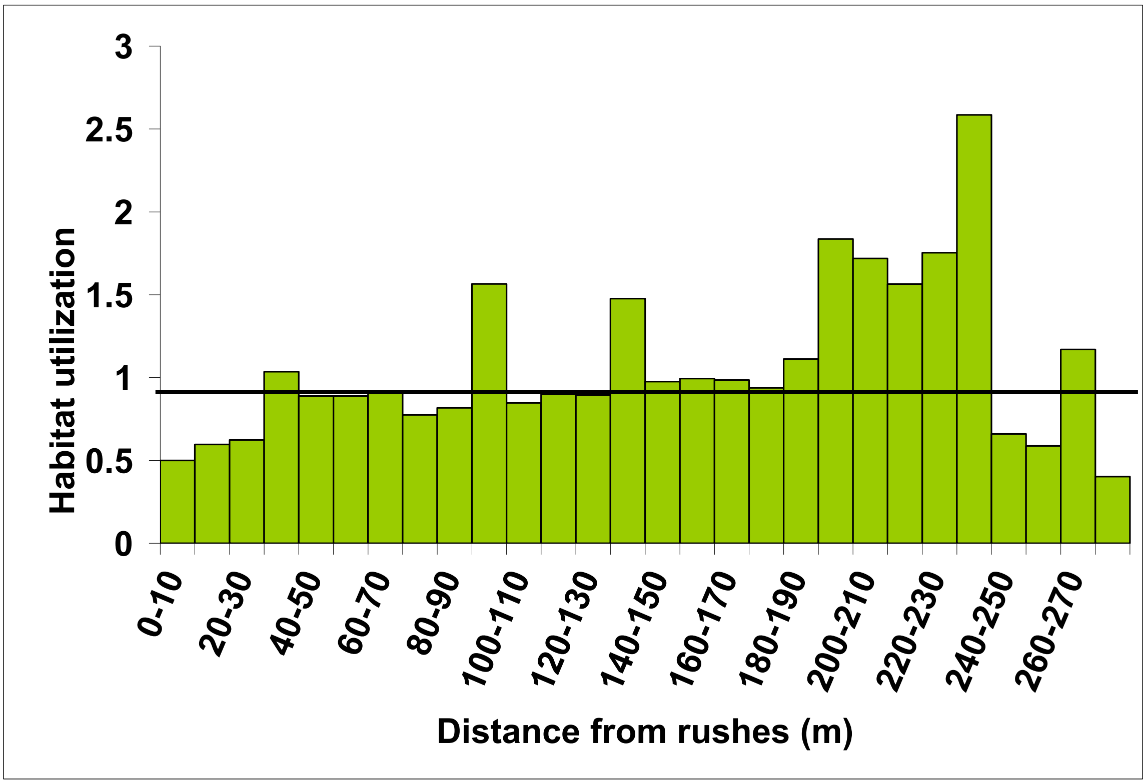


Figure 3.2 *Banded rail foraging distrances from rush habitat at Nukuhou Saltmarsh (transects were walked six times). The graph is based on a total of 2440 prints sighted during the study. Values above 1 indicate that banded rail aggregate towards those areas.*

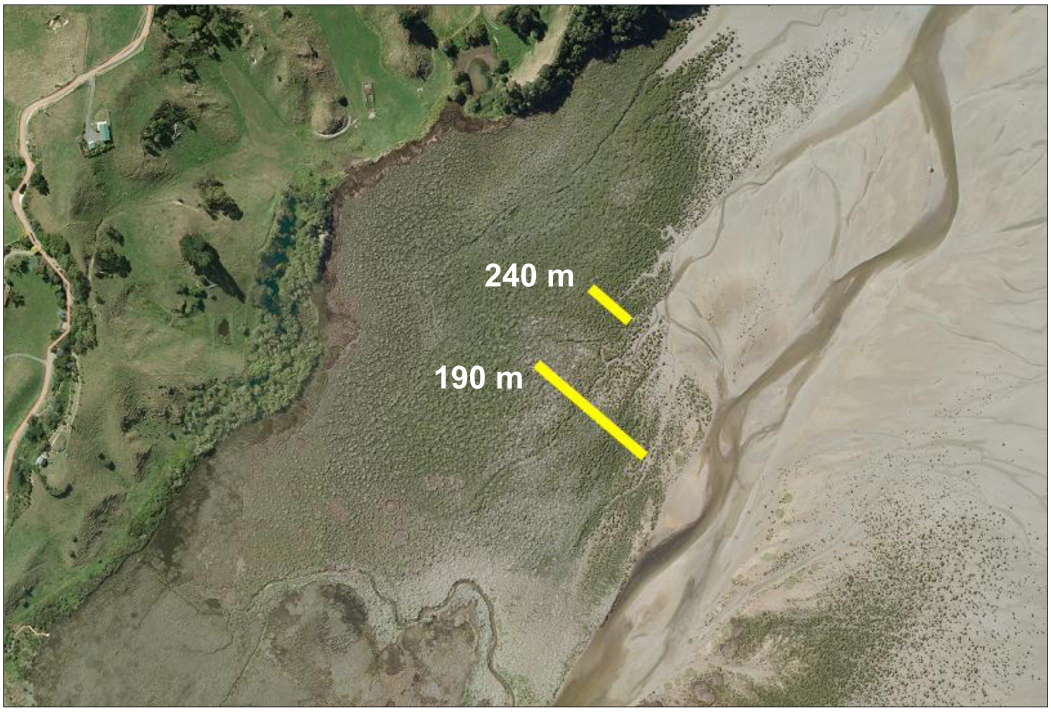


Figure 3.3 *Banded rail aggregate more towards certain areas within mangroves (yellow lines). The yellow lines indicate the zone 190-240 m away from the closest rushes.*

Foraging distances outside of mangroves onto open mudflat

Banded rail significantly selected a zone 0-10 m away from mangrove cover (chi-squared by simulation 110.9574, p= 0.0004998). No footprints were found further away than 10 m from mangrove cover (Appendix 1).

Furthermore, within the 10 m class, banded rail significantly selected areas closer to mangrove cover (chi-squared = 20.5, df = 6, p-value = 0.002255), with most footprints found within one metre of the mangroves.

3.2 Habitat preferences

A highly significant difference in habitat preference was found (paired t-test t=5.73, df=7, p=0.001). Three times more banded rail footprints were found along channels in the mangrove habitat (mean=0.7 footprints/m, sd=0.0275) than in drains in the rush habitat (mean=0.22 footprints/m, sd=0.091) (Figure 3.4).

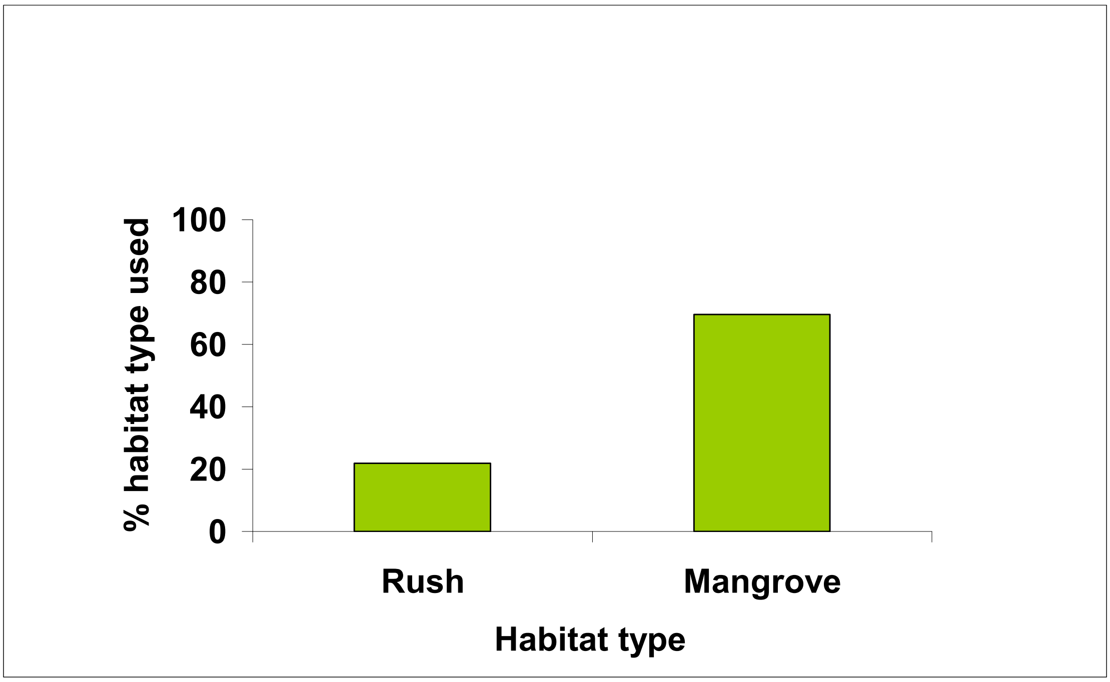


Figure 3.4 Banded rail use of rush and mangrove habitat (transects walked eight times along watercourses through rush and mangrove habitats).

3.3 Foraging protection

Data analysed for the proportion of footprints found under sparse mangroves compared to nearby open mudflat is summarised in Table 3.1.

For the morning data (reflecting night time foraging activity), quadrats with in mangroves had significantly more footprints than either of the mud flat quadrats (chi-squared=27.42, df=2, p-value<0.001).

For the afternoon data (reflecting day time foraging activity) quadrats with in mangroves had significantly more footprints than either of the mud flat quadrats (chi-squared=31.74, df=2, p-value<0.001).

- These results show that, in the morning and afternoon, a higher proportion of mangrove quadrats contained banded rail footprints than did the neighbouring seaward ('mudflat north') and inland ('mudflat south') quadrats.

- This effect is not as strong in the morning and implies that banded rail spend a higher proportion of their time away from cover during the night than they do during the day.

Of all the variables studied that could have an influence on the presence of footprints, only those with significant or nearly significant values are shown in Table 3.2.

In the morning banded rail footprints were significantly more likely to be aggregated under mangroves than over open ground. No other variable had a significant value for the number of footprints found in the morning.

In the afternoon, only distance to rushes had a nearly significant value, with banded rail footprints being more common under mangroves closer to the shore.

- During the night, banded rail forage far away from rushes, but they still make use of sparse mangroves for cover.

- During daylight hours, banded rail stay closer to shore, where denser mangroves and rushes provide more complete overhead cover.

Table 3.1 Proportion of quadrats containing banded rail footprints in the morning and afternoon. Percentages are in brackets.

		Mangrove Quadrats	**'Mud flat North' Quadrats**	**'Mud flat South' quadrats**
Morning data	No footprints	24 (33%)	54 (75%)	46 (64%)
	Footprints	48 (67%)	18 (25%)	26 (36%)
Afternoon data	No footprints	42 (58%)	86 (89%)	62 (86%)
	Footprints	30 (42%)	4 (11%)	10 (14%)

Table 3.2 Foraging protection value of mangroves. Only variables with a nearly significant relationship to the number of footprints found are included.

		Df	**Deviance**	**AIC**	**LRT**	**Pr (Chi)**
Morning data	Mangrove	2	92.013	98.013	10.941	0.004209
Afternoon data	Distance from rush adjacent to road	1	122.773	126.773	22.274	2.364e-06
	Distance from rush inland of mangroves	1	103.923	107.923	3.424	0.06427

3.4 Food availability

Availability of estuarine benthic invertebrate as food for banded rail was compared between the Burma Road Site 1 (open mudflat) and Burma Road Site 2 (sparse mangroves) (Table 3.3).

Significantly more *Helice crassa* were found at Burma Road Site 2, where sparse mangroves occur (Standard Deviance=17.589, df=1, p<0.001). *Helice crassa* were significantly more common on softer substrates where, fine, sediments were 5-15 cm deep.

- There was no significant difference in the relative abundance of *Amphibola crenata* snails at the two sites (Deviance=0.997, df=1, p<0.318).
- Significantly more polychaete worm holes were present at Burma Road Site 1, (open mudflat) than Burma Road Site 2 (sparse mangroves) (Standard Deviance=210.09, df1, p<0.001).
- Significantly more *Potamopyrgus estuarinus* were present at Burma Road Site 1, on open mudflats. No *Potamopyrgus estuarinus* were found at Burma Road Site 2 within the mangrove site (Standard Deviance=98.97, df=1, p<0.001).

Table 3.3 Relative abundance of Helice crassa, Amphibola crenata, polychetes, and Potamopyrgus estuarinus at Burma Road Site 1 (open mudflat) and Burma Road Site 2 (sparse mangroves).

		Mean	**Min**	**Max**	**SD**	**n**
Helice crassa	Open mudflat	27.77	0	79	17	53
	Mangroves	45.75	2	101	24	56
Amphibola crenata	Open mudflat	2.6	0	11	2.89	53
	Mangroves	3.13	0	8	2.22	56
Polychaete	Open mudflat	24.42	0	84	20.99	53
	Mangroves	12.58	0	64	14.89	56
Potamopyrgus estuarinus	Open mudflat	10	0	89	17.29	
	Mangroves	0	0	0	0	

Part 4: Discussion

4.1 Foraging distances

At Burma Road Site 1, where no mangroves were present, banded rail stayed in close proximity to their rush roosting habitat. On average, most footprints were found within one metre of rush cover and were never more than six metres away. Banded rail were seen foraging along narrow streams (in the saltmarsh without mangroves), but they quickly dashed into cover when it became apparent they were being observed.

At Nukuhou Saltmarsh, where mangroves were present, banded rail foraged right to the seaward extent of the mangroves, which extend up to 280 m to seaward of the rush/mangrove transition. The data analysis also showed that banded rail aggregated more around certain parts of the mangroves, 190-240 m away from rushes, but the reason for this is unknown. There are two channels in this area that link directly with the river, so it might be that this is one of the more productive areas of the mangroves, with a greater diversity of food yet still with abundant mangrove cover.

In assessing the relationship between vegetative cover and banded rail habitat use, Elliott (1987) established that banded rail rarely ventured far from rushes out onto open mudflats. Elliott's study was in the South Island, where no mangroves occur. Similar patterns of habitat use were found in this study in mangrove-free Ōhiwa Harbour habitat, where banded rails seldom ventured more than one metre from rush cover. Hence the distance that banded rail foraged away from rush habitat into mangrove habitat suggests that mangroves might provide extra foraging cover.

4.2 Habitat preference

Anderson and Ogden (2003) carried out a quantitative survey on the bird community of Kaitoke Wetland (Great Barrier Island) and linked bird distribution to the vegetation types present. Native wetland bird species, such as spotless crake, banded rail, Australasian bittern, Pūkeko and Australasian harrier, did not occur in sufficient numbers to allow exhaustive analysis by vegetation type in the study on Great Barrier Island. However, the authors did calculate an overall mean for birds counted in each vegetation type, to highlight trends. They found spotless crake throughout much of the swamp, but consistently in permanently shallow freshwater flax and sedge communities in the upper swamp area. They recorded banded rail in the estuarine saltmash (marsh ribbonwood and rush) and wet meadow vegetation (drained swamp communities bordering the saltmarsh, comprising exotic grasses and scattered manuka) of the lower wetland. They also observed banded rail outside the five minute counts sites at the mangrove edge. It is interesting that they found little overlap between spotless crake and banded rail distribution. In the present study, spotless crake were found to be restricted to a small area of raupo, a habitat type that was under-represented in the Nukuhou Saltmarsh and vulnerable to disturbance. Spotless crake were excluded from the experimental design for this reason.

In this study, banded rail habitat preference was compared within two habitat types: mangrove habitat and rush habitat. The results showed that, for foraging, banded rail preferred mangrove habitat to rush habitat. A highly significantly difference in habitat preference was found, with three times more banded rail footprints found in mangrove habitat than in rush habitat. This implies that banded rail spend more time in mangroves than in rush habitat. The reasons for this association were unclear, so was addressed in the next part of this research.

4.3 Possible reasons for the association between banded rail and mangroves

4.3.1 Foraging Protection

Banded rail roost and take shelter amongst thick, tall clumps of concealing vegetation such as grass, reeds, rushes or shrubs (Gilbert, 1936; Hodgkins 1948; Mason and Wolfe 1975; Elliott, 1987, 1989).

Banded rail are secretive and wary and are most often seen in the early morning or late afternoon foraging on mudflats near dense cover. Banded rail quickly retreat to cover when disturbed (Marchant and Higgins, 1993). During this study, banded rail were observed foraging between 12 – 2 pm on several occasions. However, banded rails always rushed for cover when disturbed, irrespective of the time of day.

Foraging banded rail appear to prefer plants with canopy structure that provides good cover from aerial predators at both high and low sun angles, but still allow movement (Elliott, 1987). *Juncus maritimus* forms a decent canopy yet still has space close to bed level, allowing free movement of small wading birds the size of banded rail (Elliott, 1987). In contrast, *Leptocarpus similis* and *Spartina* grow densely, yet provide arguably less cover from aerial predators and hinder movement. Grass, gorse and *Plagianthus* (marsh ribbonwood) provide good cover, but grow higher in the saltmarsh zone, where banded rails seldom venture (Elliott, 1987).

There is likely to be a metabolic cost for wetland birds and their predators while foraging amongst rush habitat, such is the density of rush cover at Nukuhou Saltmarsh. Yet this probably makes rushes effective refugia for otherwise vulnerable wetland birds when in their resting state (M. Bloxham, Bay of Plenty Regional Council pers. comm.). Mangroves, like other canopy forming species such as gorse and marsh ribbonwood, provide excellent cover for foraging banded rails. Nukuhou Saltmarsh is the southern limit for mangroves. Consequently, plants are quite stunted compared with forms in the northern districts, yet beneath the mangrove canopy, there is a clear area sufficient to allow the free movement of saltmarsh wading birds. This, together with the fact that crabs - one of banded rails preferred prey items - are abundant in mangrove habitat, might explain why banded rail forage extensively amongst mangroves.

Elliott (1987) found that banded rail were mainly diurnal but exhibit periods of elevated activity in the morning and evening, and that this was related to feeding. Elliott found that in the morning, banded rail forage near the mudflat edge of the saltmarsh vegetation and in the middle of the day they feed less and retreat into taller concealing vegetation away from the edge of the rushes and mudflat. Longmore (1978) recorded banded rail roosting at night but also noted that they have been observed foraging at night. It is not clear whether the night foraging was after a high tide, or otherwise.

In this study, the issue of whether mangroves provid cover for banded rail was investigated. At Burma Road Site 2, an area of open mudflat with sparse mangroves, a higher proportion of banded rail footprints were found associated with mudflats with sparse mangrove cover and specifically within the mangroves, rather than with open mudflats without mangroves. In open mudflats, banded rail footprints were mostly absent. During the day, birds were found to stay closer to the shore, where denser mangroves provide greater cover. At night, banded rail forage further away from rush habitat but they still make use of sparse mangroves as cover. That is, at night banded rail footprints were still significantly more likely to be correlated with scattered mangroves than with open ground. At the Nukuhou Saltmarsh, no banded rail foraged further than seven metres away from mangrove cover and most of the prints were found within one metre of the mangroves.

This study and Elliott (1987) showed that banded rail forage in or near vegetation that provides effective cover. Elliott (1987) found a higher level of banded rail activity lower down the shore, where the tide inundates vegetation more often and a greater abundance of food is available. This might explain why banded rail preferentially forage in mangroves, as compared with rush habitat higher up the shore, mangroves are subject to regular tidal inundation. By being lower down the shore, as mangroves are typically in an area where there are more crabs available, which banded rail can then forage for whilst using mangrove as cover.

4.3.2 Food availability

The issue of food availability was investigated in the second part of this study. Banded rail are known to mostly eat crustaceans, molluscs, worms, insects, sometimes young plants, seeds and other vegetable matter, fruits, frogs, eggs, carrion, and refuse (Marchant and Higgins, 1993).

Elliott (1983) investigated the diet of banded rail by analysing their faecal and gut contents. He found that plant material in salltmarshes made up only a small and insignificant component of banded rail's diet. Most of the plant material eaten by banded rail comprised rush (*Juncus martimus*), sedge (*Leptocarpus similus*), and algae. Elliott also found that insect remains and the polychaete *Nicon aestuarienis* made only a small contribution of the total volume of faeces. The crab *Helice crassa*, *Potamopyrgus estuarinus*, *Ophicardelus costellaris,* and the mud snail *Amphibola crenata* made up 50%, 30%, 20% and 5% respectively of the greater than 0.3mm portion of the faeces that he examined.

Elliott (1987) linked seasonal changes in banded rail diet with seasonal changes in the availability of small crabs and found that banded rail have to spend proportionately more time and energy predating snails than small crabs. Elliott's optimal foraging theory for banded rail predicted that the mudsnail *Amphibola crenata* would only be eaten when other preferred prey were unavailable. Despite being available year round, mudsnail were only eaten in large amounts in Elliott's (1987) study when small crabs were scarce. More crab remains were found in faeces between October to the end of February, with more mudsnail remains from March to August.

The crab *Helice crassa* feeds on organic matter it extracts from mud and flotsam left by the tide. According to Elliott (1987), the mud might be easier for the crab to handle immediately after a high tide and at such times there may be larger, edible flotsam available. The suggestion is that the increase in banded rail foraging activity after high tide coincides with an increase in crab activity and presumably, therefor, more crabs are available to banded rail at this time.

Potamopyrgus estuarinus is a small snail that is confined to brackish water (Winterbourn, 1970) and is an important element in the winter diet of banded rail (Elliott, 1989). Elliott (1989) observed, on occasions, snails scattered widely after being washed from cover during high tides and at such times banded rail can feed easily on the snails. Elliott (1989) found banded rail only in saltmarshes where freshwater is present. Whether this is because banded rail need the snail *Potamopyrgus estuarinus* in their diet or that banded rail have a metabolic requirement for (and therefore require access to) freshwater, is not entirely clear.

In investigating the value of mangroves as cover for banded rail, it was important to discount the possibility that banded rail might forage more extensively throughout mangrove habitat than over open mudflat simply because there was less of their preferred food available under mangroves. To investigate this, the quantity and type of invertebrate food available to banded rail under sparse mangrove cover was compared with that over open mudflats. More *Potamopyrgus estuarinus* snails were found over open mudflats, but more *Helice crassa* crabs were found in substrate near mangroves. There was no difference in the distribution and abundance of the mudsnail *Amphibola crenata.* Stokes *et.al.* (2009) also found that *Helice crassa* is more abundant in mangrove habitat than in un-vegetated sites. The suggestion is that banded rail are *not* being forced to forage more widely because their preferred prey item is more scarce under mangroves. Results from this study suggest the opposite may be correct.

4.3.3 Further studies

Anderson and Ogden (2003) suggested that the collection of more seasonal data on the breeding success of fernbird, banded rail, Spotless crake, and bittern as well as information on predator numbers and their impacts on wetland bird species would allow better management of wetland bird populations.

Specifically, for Bay of Plenty banded rail populations, data on the following aspects would be useful:

- An accurate estimate of banded rail numbers within Ōhiwa Harbour and Tauranga Harbour saltmarsh habitat.

- Investigations of the influence that mangroves have on the reproductive success of banded rail. Although there are no records of banded rail resting in mangrove habitat, the increased foraging area (under mangrove cover) and availability of *Helice crassa* their preferred prey item there might result in a higher breeding success. The only New Zealand study done on the breeding success of banded rail was by Elliott (1983) who found that in eight clutches, totalling 38 eggs, only 13 eggs hatched and left the nest. This is an average of 1.6 young per nest, with survival to young independence probably lower. This study was completed where no mangroves occur. It would be interesting to investigate whether mangroves improve juvenile survival through to independence. It may be that ground-based predators (for example stoats and rats), take a larger toll on juveniles than aerial predators.

- Satellite or radio-tracking of individual birds could be used to determine the extent of their foraging ranges. There is no information available on the distances that banded rail cover when foraging in a marsh, or when moving between marshes. Even within each of the study sites, it was not possible to determine the foraging patterns and distances of individual birds, nor whether banded rail maintain territories. Birds that *do* might be expected to require larger areas for foraging and so the provision of larger areas of mangrove would presumably be an advantage to the population as a whole.

- Evaluating the value of narrow strips of mangroves as ecological corridors for banded rail around harbour edges. When considering mangrove control, the retention of narrow corridors of mangrove may help to increase the range and dispersal of banded rail and other secretive wetland birds, by allowing them to travel to unexploited wetland habitat.

Part 5: Conclusions

The main conclusions from the study are:

- Banded rail use mangroves in preference to rushes for foraging.

- Banded rail forage right to the seaward extent of mangroves (i.e. they make full use of the whole area occupied by mangroves).

- Banded rail were not compelled to forage over larger distances under mangroves than they might over open mudflat just to sustain themselves. In fact, areas in and around mangroves contain more of banded rail's preferred prey item, *Helice crassa,* than areas without mangroves.

- Mangroves provide foraging rail protection from aerial predators.

Banded rail, along with a handful of other wetland bird species feed, roost, and breed in marshes in the Ōhiwa Harbour. This study indicated that banded rail make extensive use of mangroves in the harbour as they allow easy movement of banded rail and cover from aerial predators when feeding on their preferred prey, *Helice crassa*.

Any mangrove management plan in New Zealand should consider that the retention of existing cover or indeed the expansion of mangroves may, in some instances significantly, increase the fitness of banded rail as a species. Banded rail can forage for longer and over greater distances under mangroves, including during daylight hours, while enjoying protection from aerial predators.

In assessing the appropriateness of mangrove removal a mangrove management plan, or indeed a resource consent application to remove mangroves, should first assess whether banded rail and other saltmarsh bird species occupy these areas and whether there is any value in retaining mangroves to sustain existing banded rail populations or extending their habitat.

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Appendices

Appendix 1 – Foraging distances recorded at Nukuhou Saltmarsh

Transects were walked through the mangroves at the Nukuhou Saltmarsh. The position of any footprints that crossed the transect (or 50 cm on either side of the transect) was recorded using a GPS. GPS data was downloaded and the distance that each print was found from the rush habitat was measured. This table lists the transect and the number of prints found in each distance class.

		Number of footprints found in each distance class (m) from rush habitat								
Transect	Date	0-10m	.10-20m	20-30m	30-40m	40-50m	50-60m	60-70m	70-80m	80-90m
A	17-Feb	0	1	8	6	9	3			
A	2-Mar	1	7	8	12	9	0			
A	16-Mar	0	1	1	7	10	2			
A	1-Apr	3	4	3	13	8	5			
A	16-Apr	3	3	6	13	16	13			
A	31-Aug	0	4	3	1	1	1			
C	17-Feb	2	0	1	4	2	8	3	1	2
C	2-Mar	0	0	0	8	4	4	14	4	6
C	16-Mar	2	3	0	10	19	3	5	5	5
C	1-Apr	2	0	6	13	9	7	5	4	8
C	16-Apr	4	4	7	19	17	20	8	13	18
C	31-Aug	0	1	1	3	2	1	0	1	1
E	17-Feb	3	1	3	0	1	6	4	2	2
E	2-Mar	0	0	0	0	1	2	0	0	0
E	16-Mar	0	0	0	0	0	0	0	1	1
E	1-Apr	4	1	1	0	1	0	1	1	7
E	16-Apr	4	5	6	5	5	4	10	7	2
E	31-Aug	0	0	0	0	0	0	0	0	0
G	17-Feb	1	0	0	1	0	2	0	0	0
G	2-Mar	0	0	0	0	1	0	0	0	1
G	16-Mar	0	1	1	0	0	1	4	0	2
G	1-Apr	2	3	4	7	2	1	2	5	0
G	16-Apr	8	6	5	5	6	1	9	3	4
G	31-Aug	0	0	0	0	2	2	0	2	1
I	17-Feb	0	1	0	2	0	0	0	2	4
I	2-Mar	0	0	0	0	1	1	0	1	0
I	16-Mar	0	0	0	2	0	0	0	1	4
I	1-Apr	1	1	0	0	0	0	4	2	7
I	16-Apr	0	7	4	5	7	10	4	1	5
I	31-Aug	0	0	1	2	4	0	2	4	1
L	17-Feb	0	0	0	2	0	0	0	1	0
L	2-Mar	0	1	0	3	0	0	3	1	0
L	16-Mar	0	0	0	0	0	1	0	0	0
L	1-Apr	1	0	0	2	1	0	0	0	0
L	16-Apr	1	0	1	0	2	2	0	0	0
L	31-Aug	0	0	0	0	1	2	1	1	0
N	17-Feb	0	0	0	0	1	1	1	3	6
N	2-Mar	0	0	1	0	1	0	11	10	3
N	16-Mar	0	0	1	0	1	10	1	9	0
N	1-Apr	0	0	1	0	1	3	4	10	0
N	16-Apr	1	3	0	1	0	1	7	5	6

N	31-Aug	0	0	1	0	0	1	3	0	1

		Number of footprints found in each distance class (m) from rush habitat								
Transect	Date	90-100m	100-110m	110-120m	120-130m	130-140m	140-150m	150-160m	160-170m	170-180m
A	17-Feb									
A	2-Mar									
A	16-Mar									
A	1-Apr									
A	16-Apr									
A	31-Aug									
C	17-Feb	2	5	5						
C	2-Mar	5	3	5						
C	16-Mar	5	6	10						
C	1-Apr	5	3	1						
C	16-Apr	6	10	11						
C	31-Aug	3	0	3						
E	17-Feb	6	7	2	3	33	16	11	4	
E	2-Mar	2	0	2	1	19	7	14	2	
E	16-Mar	3	0	1	0	23	12	6	6	
E	1-Apr	2	0	1	3	17	13	18	4	
E	16-Apr	9	6	2	4	27	19	17	18	
E	31-Aug	0	0	0	1	7	4	1	1	
G	17-Feb	10	0	4	1	0	0	1	4	4
G	2-Mar	12	1	2	1	0	1	0	0	2
G	16-Mar	15	0	0	0	0	0	0	0	0
G	1-Apr	17	4	0	1	1	2	1	5	1
G	16-Apr	15	7	4	4	4	2	2	9	4
G	31-Aug	7	1	0	1	0	0	2	1	2
I	17-Feb	1	2	0	0	0	0	0	0	0
I	2-Mar	4	2	5	4	1	0	0	0	2
I	16-Mar	10	5	1	4	2	0	0	1	1
I	1-Apr	0	5	0	0	1	0	0	0	3
I	16-Apr	4	6	5	2	3	0	2	2	5
I	31-Aug	0	3	2	0	0	0	4	0	2
L	17-Feb	0	4	3	1	0	2	0	4	6
L	2-Mar	0	0	0	0	0	0	6	0	8
L	16-Mar	0	1	3	0	1	4	0	11	5
L	1-Apr	0	0	0	0	3	14	4	1	1
L	16-Apr	0	2	0	2	2	16	3	8	7
L	31-Aug	0	0	1	1	0	2	1	1	4
N	17-Feb	7	2	1	9	5	7	0	1	0
N	2-Mar	4	0	6	1	9	6	1	5	3
N	16-Mar	11	1	13	5	5	9	9	9	1
N	1-Apr	7	2	5	6	5	6	9	0	0
N	16-Apr	1	12	6	6	2	6	7	5	4
N	31-Aug	1	2	1	2	0	2	0	2	0

		Number of footprints found in each distance class (m) from rush habitat									
Transect	**Date**	**180-190m**	**190-200m**	**200-210m**	**210-220m**	**220-230m**	**230-240m**	**240-250m**	**250-260m**	**260-270m**	**270-280m**
A	**17-Feb**										
A	**2-Mar**										
A	**16-Mar**										
A	**1-Apr**										
A	**16-Apr**										
A	**31-Aug**										
C	**17-Feb**										
C	**2-Mar**										
C	**16-Mar**										
C	**1-Apr**										
C	**16-Apr**										
C	**31-Aug**										
E	**17-Feb**										
E	**2-Mar**										
E	**16-Mar**										
E	**1-Apr**										
E	**16-Apr**										
E	**31-Aug**										
G	**17-Feb**	4	6	3	9	10	40	3			
G	**2-Mar**	10	1	1	0	1	24	6			
G	**16-Mar**	0	0	0	2	2	28	0			
G	**1-Apr**	4	9	8	5	12	23	24			
G	**16-Apr**	2	9	2	4	4	42	15			
G	**31-Aug**	1	1	5	0	3	12	3			
I	**17-Feb**	0	4	5	10	4	2	5	4	0	1
I	**2-Mar**	1	7	0	1	2	2	1	3	4	0
I	**16-Mar**	2	0	5	4	2	7	1	4	1	1
I	**1-Apr**	2	3	3	3	1	10	3	1	0	0
I	**16-Apr**	2	5	11	1	3	6	4	2	9	3
I	**31-Aug**	1	2	1	1	0	0	2	0	1	0
L	**17-Feb**										
L	**2-Mar**										
L	**16-Mar**										
L	**1-Apr**										
L	**16-Apr**										
L	**31-Aug**										
N	**17-Feb**										
N	**2-Mar**										
N	**16-Mar**										
N	**1-Apr**										
N	**16-Apr**										
N	**31-Aug**										

At the Nukuhou Saltmarsh three of the transects extended onto open mudflats (see Figure 2.6). The mudflat beyond the mangroves was divided into 10 m distance classes, using buffer lines (See Figure 2.7). All footprints found on the mudflat beyond the mangroves were within 10m of mangrove cover. The first 10 m distance class was further divided into 1m buffer zones. The data below shows the distances (m) that each footprint was found beyond mangroves, onto open mudflat.

		The number of footprints found in each distance class (m) away from the cover of mangroves						
Transect	**Date**	**0-1m**	**1-2m**	**2-3m**	**3-4m**	**4-5m**	**5-6m**	**6-7m**
I	**17-Feb**	0	1	0	0	0	0	0
I	**2-Mar**	4	0	0	0	0	0	0
I	**16-Mar**	0	0	0	0	0	0	0
I	**1-Apr**	0	1	0	0	0	0	0
I	**16-Apr**	0	0	2	1	0	1	0
I	**31-Aug**	0	0	0	0	0	0	0
L	**17-Feb**	0	2	1	1	0	0	0
L	**2-Mar**	2	0	0	1	0	0	0
L	**16-Mar**	0	0	1	0	0	0	0
L	**1-Apr**	0	0	1	0	0	0	0
L	**16-Apr**	4	1	1	1	0	0	1
L	**31-Aug**	0	0	0	0	0	0	0
N	**17-Feb**	0	0	0	0	0	0	0
N	**2-Mar**	0	0	1	1	0	0	1
N	**16-Mar**	0	0	0	0	0	0	0
N	**1-Apr**	0	0	0	0	0	0	0
N	**16-Apr**	1	0	1	0	0	0	0
N	**31-Aug**	0	0	0	0	0	0	0
	TOTAL	11	5	8	5	0	1	2
	Total / 3	3.67	1.67	2.67	1.67	0.00	0.33	0.67
MEAN	**n=6**	0.61	0.28	0.44	0.28	0.00	0.06	0.11

Appendix 2 – Foraging distances recorded at Burma Road Site 1

Transects were walked at Burma Road Site 1 over open mudflat. The position of footprints that crossed the transect (or 50 cm on either side of the transect) was recorded using a GPS. GPS data was downloaded and the distance of each print from the rush habitat was measured. This table gives the transect start point and the number of prints found in each distance class.

		Number of footprints found in each distance class (m) from the rush habitat							
Transect starting points	Date	0 - 1m	1 - 2m	2 - 3m	3 - 4m	4 - 5m	5 - 6m	6 - 7m	7 - 8m
S	17-Feb	2	0	0	0	0	0	0	0
S	2-Mar	0	0	0	0	0	0	0	0
S	16-Mar	0	0	0	0	0	0	0	0
S	1-Apr	0	0	2	0	0	0	0	0
S	16-Apr	0	0	0	0	0	0	0	0
S	4-May	0	0	0	1	0	0	0	0
S	18-May	1	0	0	0	0	0	0	0
S	31-Aug	0	0	0	3	0	0	0	0
Q	17-Feb	1	0	0	0	0	0	0	0
Q	2-Mar	0	0	0	0	0	0	0	0
Q	16-Mar	0	0	0	0	0	0	0	0
Q	1-Apr	0	0	0	0	0	0	0	0
Q	16-Apr	0	0	0	0	0	0	0	0
Q	4-May	0	0	1	0	0	0	0	0
Q	18-May	0	0	0	0	0	0	0	0
Q	31-Aug	0	0	0	1	0	0	0	0
Z'	17-Feb	0	0	0	0	0	0	0	0
Z'	2-Mar	0	0	0	0	0	0	0	0
Z'	16-Mar	0	0	2	0	0	0	0	0
Z'	1-Apr	0	0	0	0	0	1	0	0
Z'	16-Apr	0	0	3	0	0	0	0	0
Z'	4-May	0	4	0	0	0	0	0	0
Z'	18-May	0	2	0	0	0	0	0	0
Z'	31-Aug	0	2	0	0	0	0	0	0
Z	17-Feb	3	0	1	0	0	0	0	0
Z	2-Mar	0	0	0	1	1	2	0	0
Z	16-Mar	0	0	1	3	0	0	0	0
Z	1-Apr	0	3	0	0	0	0	0	0
Z	16-Apr	0	0	0	6	1	0	0	0
Z	4-May	4	0	0	0	0	0	0	0
Z	18-May	0	0	1	1	3	1	0	0
Z	31-Aug	1	0	0	0	0	0	0	0
P	17-Feb	0	0	0	0	1	1	0	0
P	2-Mar	0	0	0	0	0	3	0	0
P	16-Mar	2	0	0	0	0	0	0	0
P	1-Apr	3	0	0	0	0	0	0	0
P	16-Apr	4	0	0	0	0	0	0	0
P	4-May	0	0	1	0	0	0	0	0
P	18-May	0	3	0	0	0	0	0	0
P	31-Aug	4	0	0	0	0	0	0	0

		The distance class that each footprint was found from the rush habitat							
Transect starting points	**Date**	**0 - 1m**	**1 - 2m**	**2 - 3m**	**3 - 4m**	**4 - 5m**	**5 - 6m**	**6 - 7m**	**7 - 8m**
R	17-Feb	0	0	0	0	3	0	0	0
R	2-Mar	2	0	0	0	0	0	0	0
R	16-Mar	2	3	0	0	0	0	0	0
R	1-Apr	3	0	0	0	0	0	0	0
R	16-Apr	2	0	0	0	0	0	0	0
R	4-May	0	0	3	0	0	0	0	0
R	18-May	0	0	3	0	0	0	0	0
R	31-Aug	0	0	0	0	0	0	0	0
T	17-Feb	0	0	0	8	5	0	0	0
T	2-Mar	6	0	1	1	0	0	0	0
T	16-Mar	9	3	0	1	0	0	0	0
T	1-Apr	1	1	3	0	0	0	0	0
T	16-Apr	10	0	0	0	0	0	0	0
T	4-May	4	0	0	0	0	0	0	0
T	18-May	4	0	0	0	0	0	0	0
T	31-Aug	2	0	1	0	0	0	0	0
V	17-Feb	0	0	0	6	0	0	0	0
V	2-Mar	2	5	0	0	0	0	0	0
V	16-Mar	4	0	0	0	0	0	0	0
V	1-Apr	3	0	0	0	0	0	0	0
V	16-Apr	0	0	0	0	4	4	0	0
V	4-May	3	0	0	0	0	0	0	0
V	18-May	4	0	0	0	0	0	0	0
V	31-Aug	2	1	0	0	0	0	0	0
X	17-Feb	0	0	4	2	0	0	0	0
X	2-Mar	4	0	0	0	0	0	0	0
X	16-Mar	4	0	0	0	0	0	0	0
X	1-Apr	3	0	0	0	0	0	0	0
X	16-Apr	5	0	0	0	0	0	0	0
X	4-May	1	0	0	0	0	0	0	0
X	18-May	4	0	0	0	0	0	0	0
X	31-Aug	2	0	0	0	0	0	0	0
Y	17-Feb	0	2	0	0	0	0	0	0
Y	2-Mar	4	0	0	0	0	0	0	0
Y	16-Mar	0	0	3	0	0	0	0	0
Y	1-Apr	0	3	0	0	0	0	0	0
Y	16-Apr	0	4	0	0	0	0	0	0
Y	4-May	2	0	0	0	0	0	0	0
Y	18-May	3	0	0	0	0	0	0	0
Y	31-Aug	0	0	0	0	0	3	0	0
[redacted]									
	Total	120	36	30	34	18	15	0	0
	Total/10	12.00	3.60	3.00	3.40	1.80	1.50	0.00	0.00
MEAN	**n = 8 visits**	1.50	0.45	0.38	0.43	0.23	0.19	0.00	0.00

Appendix 3 – Habitat types used by banded rail at Nukuhou Saltmarsh (mangroves versus rushes)

The study to determine whether banded rail prefer mangrove or rush habitat was undertaken at Nukuhou Saltmarsh. Every banded rail print entering or exiting the drain/channel was recorded. Two 30m transects were walked in mangrove and rush habitat.

MT = mangrove transect

RT = rush transect

Entry = footprints entering the drain/channel

Exit = footprints exiting the drain/channel

Date	**MT = 1 Entry**	**MT = 2 Entry**	**MT = 1 Exit**	**MT = 2 Exit**	**Total number of footprints entering *mangrove* channels**	**Total number of footprints exiting *mangrove* channels**	**Total / 60 m**	**Average / m**
17-Feb	13	8	13	12	21	25	46.00	0.77
2-Mar	8	5	4	3	13	7	20.00	0.33
5-Mar	7	10	11	11	17	22	39.00	0.65
17-Mar	21	17	23	8	38	31	69.00	1.15
1-Apr	14	8	18	15	22	33	55.00	0.92
16-Apr	8	11	16	15	19	31	50.00	0.83
18-May	7	7	6	5	14	11	25.00	0.42
19-Aug	9	5	8	8	14	16	30.00	0.50

Date	**RT = 1 Entry**	**RT = 2 Entry**	**RT = 1 Exit**	**RT = 2 Exit**	**Total number of footprints entering *rush* drains**	**Total number of footprints exiting *rush* drains**	**Total / 60 m**	**Average / m**
17-Feb	1	2	2	4	3	6	9.00	0.15
2-Mar	1	4	0	3	5	3	8.00	0.13
5-Mar	0	3	7	9	3	16	19.00	0.32
17-Mar	5	7	2	6	12	8	20.00	0.33
1-Apr	0	2	2	5	2	7	9.00	0.15
16-Apr	3	5	6	6	8	12	20.00	0.33
18-May	4	1	1	4	5	5	10	0.17
19-Aug	4	1	4	1	5	5	10	0.17

Appendix 4 – Foraging protection

To study the protective value that mangroves provide to banded rail, the position of 91 mangrove plants was recorded using a GPS. Each mangrove plant and the two adjacent mudflat quadrats were observed in the morning and evening for the presence of footprints. For each mangrove, the following information were also collected: substrate type (ST), mangrove density rating (MR), distance from the rushes inland of the mangroves (DR), distance from dense mangroves (DDM), and distance from rushes adjacent to the road.ST = Substrate type (1=firm; 2= foot sinks into mud; 3= foot and calf/leg sinks into mud).

MR = Mangrove density rating (1=Dense; 2=sparse; 3=very sparse; 4=open mudflat).

DR = Distance from rushes inland of the mangroves (m).

DDM = Distance from dense mangroves (m).

DRR = Distance from rushes adjacent to the road (m).

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
1	Mangrove	1	1	2	2	31.7	75.31	26.72
1	Mud S (twrds shre)	0	0	2	2	31.7	74.31	25.72
1	Mud N (awy frm shre)	0	0	2	2	31.7	76.31	27.72
2	Mangrove	0	0	2	2	30.4	76.68	29.16
2	Mud S (twrds shre)							
2	Mud N (awy frm shre)	0	0	2	2	30.4	77.68	30.16
3	Mangrove	1	1	3	2	34.3	75.11	28.38
3	Mud S (twrds shre)	0	1	3	2	34.3	74.11	27.38
3	Mud N (awy frm shre)	1	0	3	2	34.3	76.11	29.38
4	Mangrove	1	1	3	2	35.12	80.15	31.76
4	Mud S (twrds shre)	1	0	3	2	35.12	79.15	30.76
4	Mud N (awy frm shre)	1	0	3	2	35.12	81.15	32.76
5	Mangrove	0	1	4	2	28.18	113.1	68.87
5	Mud S (twrds shre)	0	0	4	2	28.18	112.1	67.87
5	Mud N (awy frm shre)	0	0	4	2	28.18	114.1	69.87
6	Mangrove	1	1	4	2	31.63	132.97	91.45
6	Mud S (twrds shre)	0	0	4	2	31.63	131.97	90.45
6	Mud N (awy frm shre)	1	0	4	2	31.63	133.97	92.45
7	Mangrove	1	0	4	1	85	164.1	112.23
7	Mud S (twrds shre)	0	0	4	1	85	163.1	111.23
7	Mud N (awy frm shre)	0	0	4	1	85	165.1	113.23
8	Mangrove	1	0	4	2	63.95	132.24	81.61
8	Mud S (twrds shre)	0	0	4	2	63.95	131.24	80.61
8	Mud N (awy frm shre)	1	0	4	2	63.95	133.24	82.61
9	Mangrove	1	1	4	2	57.49	96.29	57.52
9	Mud S (twrds shre)	1	0	4	2	57.95	95.29	56.52
9	Mud N (awy frm shre)	0	0	4	2	57.95	97.29	58.52
10	Mangrove	1	0	3	2	42.61	89.57	48.39
10	Mud S (twrds shre)	1	0	3	2	42.61	88.57	47.39
10	Mud N (awy frm shre)	0	0	3	2	42.61	90.57	49.39
11	Mangrove	1	0	3	2	41.04	76.63	32.69
11	Mud S (twrds shre)	1	0	3	2	41.04	75.63	31.69
11	Mud N (awy frm shre)	0	0	3	2	41.04	77.63	33.69

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)

12	Mangrove	1	1	2	3	46.87	70.42	27.83
12	Mud S (twrds shre)	0	0	2	3	46.87	69.42	26.83
12	Mud N (awy frm shre)	0	0	2	3	46.87	71.42	28.83
13	Mangrove	1	0	2	3	76.78	69.02	25.99
13	Mud S (twrds shre)	0	1	2	3	76.78	68.02	24.99
13	Mud N (awy frm shre)	0	0	2	3	76.78	70.02	26.99
14	Mangrove	1	1	2	3	48.48	64.33	19.52
14	Mud S (twrds shre)	1	0	2	3	48.48	63.33	18.52
14	Mud N (awy frm shre)	1	0	2	3	48.48	65.33	20.52
15	Mangrove	1	1	2	3	51.81	61.26	17.04
15	Mud S (twrds shre)	0	0	2	3	51.81	60.26	16.04
15	Mud N (awy frm shre)	0	0	2	3	51.81	62.26	18.04
16	Mangrove	1	1	2	3	47.84	68.36	24.85
16	Mud S (twrds shre)	0	0	2	3	47.84	67.36	23.85
16	Mud N (awy frm shre)	0	0	2	3	47.84	69.36	25.85
17	Mangrove	1	1	2	3	51.21	67.23	26.22
17	Mud S (twrds shre)	0	0	2	3	51.21	66.23	25.22
17	Mud N (awy frm shre)							
18	Mangrove	1	0	2	3	51.86	66.14	24.7
18	Mud S (twrds shre)							
18	Mud N (awy frm shre)	0	0	2	3	51.86	67.14	25.7
19	Mangrove	0	0	2	3	50.11	70.18	28.29
19	Mud S (twrds shre)	0	0	2	3	50.11	69.18	27.26
19	Mud N (awy frm shre)	0	0	2	3	50.11	71.18	29.29
20	Mangrove	0	1	3	3	49.23	76.94	35.62
20	Mud S (twrds shre)	0	0	3	3	49.23	75.94	34.62
20	Mud N (awy frm shre)	0	0	3	3	49.23	77.94	36.62
21	Mangrove	1	1	3	3	54	82.14	39.75
21	Mud S (twrds shre)	0	0	3	3	54	81.14	38.75
21	Mud N (awy frm shre)	0	0	3	3	54	83.14	40.75
22	Mangrove	1	1	2	3	61.64	65.72	26.31
22	Mud S (twrds shre)	0	0	2	3	61.64	64.72	25.31
22	Mud N (awy frm shre)	0	1	2	3	61.64	66.72	27.31
23	Mangrove	0	1	2	3	63.92	62.89	23.78
23	Mud S (twrds shre)	0	1	2	3	63.92	61.89	22.78
23	Mud N (awy frm shre)	0	0	2	3	63.92	63.89	24.78
24	Mangrove	1	1	2	3	69.76	62.46	24
24	Mud S (twrds shre)	1	0	2	3	69.76	61.46	23
24	Mud N (awy frm shre)	0	0	2	3	69.76	63.46	25
25	Mangrove	1	0	3	3	71.75	68.69	31.68
25	Mud S (twrds shre)	0	0	3	3	71.75	67.69	30.68
25	Mud N (awy frm shre)	0	0	3	3	71.75	69.69	32.68
26	Mangrove	0	0	3	3	79.03	70.18	39.12
26	Mud S (twrds shre)	0	0	3	3	79.03	69.18	38.12
26	Mud N (awy frm shre)	0	0	3	3	79.03	71.18	40.12
27	Mangrove	1	1	3	3	84.35	68	35.1
27	Mud S (twrds shre)	0	0	3	3	84.35	67	34.1
27	Mud N (awy frm shre)	0	0	3	3	84.35	69	36.1

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
28	Mangrove	0	0	3	3	85.93	65.34	32.4
28	Mud S (twrds shre)	1	0	3	3	85.93	64.34	31.4
28	Mud N (awy frm shre)	0	0	3	3	85.93	66.34	33.4
29	Mangrove	0	1	3	3	85.55	63.5	30.35
29	Mud S (twrds shre)	0	0	3	3	85.55	62.5	29.35
29	Mud N (awy frm shre)	0	0	3	3	85.55	64.5	31.35
30	Mangrove	1	0	3	2	87.28	69.59	35.71
30	Mud S (twrds shre)	0	0	3	2	87.28	68.59	34.71
30	Mud N (awy frm shre)	0	0	3	2	87.28	70.59	36.71
31	Mangrove	0	1	3	1	90.04	69.53	37.37
31	Mud S (twrds shre)	0	0	3	1	90.04	68.53	36.37
31	Mud N (awy frm shre)	0	0	3	1	90.04	70.53	38.37
32	Mangrove	0	0	3	1	90.4	77.26	43.45
32	Mud S (twrds shre)	1	0	3	1	90.4	76.26	42.45
32	Mud N (awy frm shre)	0	0	3	1	90.4	78.26	44.45
33	Mangrove	0	0	3	1	82.95	77.63	44.24
33	Mud S (twrds shre)	0	0	3	1	82.95	76.63	43.24
33	Mud N (awy frm shre)	0	0	3	1	82.95	78.63	45.24
34	Mangrove	0	0	3	1	85.01	79.04	46.7
34	Mud S (twrds shre)	1	0	3	1	85.01	78.04	45.7
34	Mud N (awy frm shre)	0	0	3	1	85.01	80.04	47.7
35	Mangrove	1	0	3	1	78.94	80.82	48.51
35	Mud S (twrds shre)	1	0	3	1	78.94	79.82	47.51
35	Mud N (awy frm shre)	0	0	3	1	78.94	81.82	49.51
36	Mangrove	1	0	4	1	103.98	112.06	79.53
36	Mud S (twrds shre)	0	0	4	1	103.78	111.06	78.53
36	Mud N (awy frm shre)	0	0	4	1	103.78	113.06	80.53
37	Mangrove	1	0	4	1	107.53	118.39	85.62
37	Mud S (twrds shre)	0	0	4	1	107.53	117.39	84.62
37	Mud N (awy frm shre)	0	0	4	1	107.53	119.39	86.62
38	Mangrove	1	1	2	3	84.7	59.08	26.18
38	Mud S (twrds shre)	1	1	2	3	84.7	58.08	25.18
38	Mud N (awy frm shre)	1	0	2	3	84.7	60.08	27.18
39	Mangrove	1	1	2	3	83.04	57.43	23.64
39	Mud S (twrds shre)	1	1	2	3	83.04	56.43	22.64
39	Mud N (awy frm shre)	1	0	2	3	83.04	58.43	24.64
40	Mangrove	1	1	2	3	79.33	60.4	24.5
40	Mud S (twrds shre)	0	1	2	3	79.33	59.4	23.5
40	Mud N (awy frm shre)	0	0	2	3	79.33	61.4	25.5
41	Mangrove	1	1	2	3	75.68	60.43	23.23
41	Mud S (twrds shre)	1	1	2	3	75.68	59.43	22.23
41	Mud N (awy frm shre)	1	0	2	3	75.68	61.43	24.23
42	Mangrove	1	1	2	3	37.99	71.85	23.7
42	Mud S (twrds shre)							
42	Mud N (awy frm shre)	1	0	2	3	37.99	72.85	24.7
43	Mangrove	1	0	2	3	54.5	60.66	13.1
43	Mud S (twrds shre)							
43	Mud N (awy frm shre)	1	0	2	3	54.5	61.66	14.1

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
44	Mangrove	1	1	2	3	53.37	61.91	14.24
44	Mud S (twrds shre)	0	0	2	3	53.37	60.91	13.24
44	Mud N (awy frm shre)							
45	Mangrove	1	0	2	3	56.35	59.71	18.7
45	Mud S (twrds shre)	0	0	2	3	56.35	58.71	17.7
45	Mud N (awy frm shre)	0	0	2	3	56.35	60.71	19.7
46	Mangrove	1	0	2	3	58.06	59.68	19.62
46	Mud S (twrds shre)	1	0	2	3	58.06	58.68	18.62
46	Mud N (awy frm shre)	0	0	2	3	58.06	60.68	20.62
47	Mangrove	1	0	2	3	61.9	57.4	17.22
47	Mud S (twrds shre)	1	0	2	3	61.9	56.4	16.22
47	Mud N (awy frm shre)							
48	Mangrove	1	1	2	3	61.99	54.31	13.95
48	Mud S (twrds shre)							
48	Mud N (awy frm shre)	0	0	2	3	61.99	55.31	14.95
49	Mangrove	1	0	2	3	54.05	56.59	17.9
49	Mud S (twrds shre)							
49	Mud N (awy frm shre)	0	0	2	3	54.05	57.59	19.9
50	Mangrove	1	1	2	3	65.46	56.41	17.16
50	Mud S (twrds shre)							
50	Mud N (awy frm shre)	0	0	2	3	65.46	57.41	18.16
51	Mangrove	1	0	2	3	67.94	56.15	51
51	Mud S (twrds shre)							
51	Mud N (awy frm shre)	1	1	2	3	67.94	57.15	53
52	Mangrove	1	0	2	3	73.76	51.05	12.19
52	Mud S (twrds shre)	1	0	2	3	73.76	50.05	11.19
52	Mud N (awy frm shre)							
53	Mangrove	1	1	2	3	75.97	48.73	10.48
53	Mud S (twrds shre)	1	0	2	3	75.97	47.73	9.48
53	Mud N (awy frm shre)	0	1	2	3	75.97	49.73	11.48
54	Mangrove	1	0	2	3	80.61	48.76	13.46
54	Mud S (twrds shre)							
54	Mud N (awy frm shre)	0	1	2	3	80.61	49.76	12.46
55	Mangrove	1	0	2	3	84.41	47.61	17.19
55	Mud S (twrds shre)							
55	Mud N (awy frm shre)	0	0	2	3	84.41	48.61	18.19
56	Mangrove	1	1	2	3	84.27	50.27	19.95
56	Mud S (twrds shre)	0	0	2	3	84.27	49.27	18.95
56	Mud N (awy frm shre)	0	0	2	3	84.27	51.27	20.95
57	Mangrove	1	1	2	3	87.72	52.36	19.54
57	Mud S (twrds shre)							
57	Mud N (awy frm shre)	1	1	2	3	87.72	53.36	20.54

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
58	Mangrove	1	0	2	3	89.09	52.86	20.13
58	Mud S (twrds shre)							
58	Mud N (awy frm shre)	0	0	2	3	89.09	53.86	21.13
59	Mangrove	1	1	2	3	71.71	50.3	18.25
59	Mud S (twrds shre)							
59	Mud N (awy frm shre)	0	0	2	3	71.71	51.3	19.25
60	Mangrove	1	1	2	3	97.38	45.01	13.74
60	Mud S (twrds shre)	1	0	2	3	97.38	44.01	12.74
60	Mud N (awy frm shre)	1	0	2	3	97.38	46.01	14.74
61	Mangrove	1	0	2	3	98.95	45.66	14.04
61	Mud S (twrds shre)	1	0	2	3	98.95	44.66	13.03
61	Mud N (awy frm shre)	1	0	2	3	98.95	46.66	15.04
62	Mangrove	1	0	2	3	99.29	48.12	16.54
62	Mud S (twrds shre)	1	0	2	3	99.29	47.12	15.54
62	Mud N (awy frm shre)	1	0	2	3	99.29	49.12	17.54
63	Mangrove	1	0	2	3	103.35	46.95	15.78
63	Mud S (twrds shre)							
63	Mud N (awy frm shre)	0	0	2	3	103.35	47.95	16.78
64	Mangrove	1	0	2	3	106.38	44.6	13.19
64	Mud S (twrds shre)							
64	Mud N (awy frm shre)	0	0	2	3	106.38	45.6	14.19
65	Mangrove	1	1	2	3	110.03	40.51	9.07
65	Mud S (twrds shre)	0	0	2	3	110.03	39.51	8.07
65	Mud N (awy frm shre)	1	1	2	3	110.03	41.51	10.07
66	Mangrove	1	0	2	1	114.29	43.54	13.13
66	Mud S (twrds shre)	0	0	2	1	114.29	42.54	12.13
66	Mud N (awy frm shre)	1	0	2	1	114.29	44.54	14.13
67	Mangrove	1	1	2	2	121.64	44.19	12.69
67	Mud S (twrds shre)	0	0	2	2	121.64	43.19	11.69
67	Mud N (awy frm shre)	0	0	2	2	121.64	45.19	13.69
68	Mangrove	0	0	3	1	120.59	55.2	23.69
68	Mud S (twrds shre)	0	0	3	1	120.59	54.2	22.69
68	Mud N (awy frm shre)	0	0	3	1	120.59	56.2	24.69
69	Mangrove	1	0	3	1	115.3	57.47	26.68
69	Mud S (twrds shre)	1	0	3	1	115.3	56.47	25.68
69	Mud N (awy frm shre)	0	0	3	1	115.3	58.47	27.88
70	Mangrove	0	0	3	1	116.88	61.9	31.2
70	Mud S (twrds shre)	0	0	3	1	116.88	60.9	30.2
70	Mud N (awy frm shre)	1	0	3	1	116.88	62.9	32.2
71	Mangrove	0	0	3	1	115.4	70.6	39.63
71	Mud S (twrds shre)	0	0	3	1	115.4	69.6	38.63
71	Mud N (awy frm shre)	0	0	3	1	115.4	71.6	40.63

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
72	Mangrove	0	0	3	1	120.83	75.05	43.15
72	Mud S (twrds shre)	0	0	3	1	120.83	74.05	42.15
72	Mud N (awy frm shre)	0	0	3	1	120.83	76.05	44.15
73	Mangrove	0	0	3	1	121.77	79.76	47.96
73	Mud S (twrds shre)	0	0	3	1	121.77	78.76	46.96
73	Mud N (awy frm shre)	0	0	3	1	121.77	80.76	48.96
74	Mangrove	1	0	4	2	124.4	83.03	50.97
74	Mud S (twrds shre)	0	0	4	2	124.4	82.03	49.97
74	Mud N (awy frm shre)	1	0	4	2	124.4	84.03	51.97
75	Mangrove	0	0	4	1	156.08	99.35	61.67
75	Mud S (twrds shre)	0	0	4	1	156.08	98.35	60.67
75	Mud N (awy frm shre)	0	0	4	1	156.08	100.35	62.67
76	Mangrove	1	0	3	2	146.24	69.4	31.41
76	Mud S (twrds shre)	1	0	3	2	146.24	68.4	30.41
76	Mud N (awy frm shre)	0	0	3	2	146.24	70.4	32.41
77	Mangrove	0	0	3	2	151.71	64.26	75.74
77	Mud S (twrds shre)	0	0	3	2	151.71	63.26	74.74
77	Mud N (awy frm shre)	0	0	3	2	151.71	65.26	76.74
78	Mangrove	1	0	3	2	161.86	68.85	29.3
78	Mud S (twrds shre)	1	0	3	2	161.86	67.85	28.3
78	Mud N (awy frm shre)	0	0	3	2	161.86	69.85	30.3
79	Mangrove	0	0	3	3	170.29	68.69	31.01
79	Mud S (twrds shre)	0	0	3	3	170.29	67.69	30.01
79	Mud N (awy frm shre)	0	0	3	3	170.29	69.69	32.01
80	Mangrove	0	0	2	3	170.76	51.62	15.86
80	Mud S (twrds shre)	1	1	2	3	170.76	50.62	14.86
80	Mud N (awy frm shre)	1	0	2	3	170.76	52.62	16.86
81	Mangrove	1	0	2	3	166.26	46.22	11.01
81	Mud S (twrds shre)	1	0	2	3	166.26	45.22	10.01
81	Mud N (awy frm shre)	0	1	2	3	166.26	47.22	12.01
82	Mangrove	1	0	2	3	164.62	49.72	12.43
82	Mud S (twrds shre)	1	0	2	3	164.62	48.72	11.43
82	Mud N (awy frm shre)	0	0	2	3	164.62	50.72	13.43
83	Mangrove	1	0	2	3	153.96	49.95	11.96
83	Mud S (twrds shre)	0	1	2	3	153.96	48.95	10.96
83	Mud N (awy frm shre)	0	0	2	3	153.96	50.95	12.96
84	Mangrove	1	0	3	3	115.43	57.93	18.89
84	Mud S (twrds shre)	0	0	3	3	115.43	56.93	17.89
84	Mud N (awy frm shre)	1	0	3	3	115.43	58.93	19.89

	Sample type	Footprints AM	Footprints PM	MR	ST	DRR (m)	DR (m)	DDM (m)
85	Mangrove	1	0	3	3	114.25	47.52	9.02
85	Mud S (twrds shre)	0	0	3	3	114.25	46.52	8.02
85	Mud N (awy frm shre)	0	0	3	3	114.25	48.52	10.02
86	Mangrove	1	0	2	1	131.55	54.95	21.17
86	Mud S (twrds shre)	1	0	2	1	131.55	53.95	20.17
86	Mud N (awy frm shre)	0	0	2	1	131.55	55.95	22.17
87	Mangrove	0	1	3	1	122.37	60.5	28.16
87	Mud S (twrds shre)	0	0	3	1	122.37	59.5	27.16
87	Mud N (awy frm shre)	0	0	3	1	122.37	61.5	29.16
88	Mangrove	0	0	3	1	108.84	56.02	24.45
88	Mud S (twrds shre)	0	0	3	1	108.84	55.02	23.45
88	Mud N (awy frm shre)	0	0	3	1	108.84	57.02	25.45
89	Mangrove	0	0	2	1	108.41	52.88	21.95
89	Mud S (twrds shre)	0	0	2	1	108.41	51.88	20.95
89	Mud N (awy frm shre)	1	0	2	1	108.41	53.88	22.95
90	Mangrove	1	1	2	1	105.09	56.37	25.11
90	Mud S (twrds shre)	0	0	2	1	105.09	55.37	24.11
90	Mud N (awy frm shre)	0	0	2	1	105.09	57.37	26.11
91	Mangrove	0	1	2	3	93.57	54.1	20.17
91	Mud S (twrds shre)	1	1	2	3	93.57	53.1	19.17
91	Mud N (awy frm shre)	0	0	2	3	93.57	55.1	21.17

Appendix 5 – Food availability

To compare differences in food available to banded rail in a marsh with no mangroves and a marsh with mangroves, Burma Road Site 1 (open mudflat) and Burma Road Site 2 (sparse mangroves) were studied. The food sources counted were *Helice crassa* holes*, Pot*ST = Substrate type (1=firm; 2= foot sinks into mud; 3= foot and calf/leg sinks into mud)

DR = Distance from rushes inland of the mangroves (m)

DDM = Distance from dense mangroves (m)

DRR = Distance from rushes adjacent to the road (m)

Food data collected at Burma Road Site 1 (open mudflats)

Transect	ST	DRR	DR	DDM	*Amphibola crenata*	*Helice crassa*	*Potamopyrgus estuarinus*	Polychaete holes
PQ	2	[redacted]	0	[redacted]	3	16	0	84
PQ	2	[redacted]	3.73	[redacted]	2	28	2	76
PQ	2	[redacted]	4.46	[redacted]	3	17	20	52
PQ	2	[redacted]	8.19	[redacted]	4	23	16	52
PQ	2	[redacted]	14.1	[redacted]	11	21	30	60
PQ	2	[redacted]	18.9	[redacted]	10	21	13	56
PQ	2	[redacted]	20.9	[redacted]	2	25	9	24
PQ	2	[redacted]	24.5	[redacted]	6	29	7	12
PQ	2	[redacted]	30.4	[redacted]	6	23	13	24
PQ	2	[redacted]	35.2	[redacted]	11	23	9	12
PQ	2	[redacted]	40.2	[redacted]	5	25	3	12
PQ	2	[redacted]	42.8	[redacted]	3	18	5	12
PQ	2	[redacted]	46.9	[redacted]	5	25	4	4
RS	2	[redacted]	0	[redacted]	2	41	3	32
RS	2	[redacted]	4	[redacted]	1	55	3	32
RS	2	[redacted]	5.46	[redacted]	5	48	0	48
RS	2	[redacted]	10.8	[redacted]	4	41	3	49
RS	2	[redacted]	15.4	[redacted]	8	8	40	33
RS	2	[redacted]	18.9	[redacted]	6	26	23	44
RS	2	[redacted]	20.9	[redacted]	2	29	38	6
RS	1	[redacted]	22.5	[redacted]	2	12	0	0
RS	1	[redacted]	27.8	[redacted]	0	8	0	0
RS	1	[redacted]	32.3	[redacted]	0	11	0	0
RS	1	[redacted]	36.7	[redacted]	0	12	0	0
RS	1	[redacted]	41.5	[redacted]	0	7	0	0
RS	1	[redacted]	43.5	[redacted]	0	8	0	0

Transect	ST	DRR	DR	DDM	*Amphibola crenata*	*Helice crassa*	*Potamopyrgus estuarinus*	Polychaete holes
TU	2	[redacted]	0	[redacted]	0	11	0	0
TU	2	[redacted]	2.4	[redacted]	0	22	0	12

TU	2	[redacted]	3.07	[redacted]	1	40	1	19
TU	3	[redacted]	4.97	[redacted]	0	32	8	23
TU	3	[redacted]	5.06	[redacted]	5	29	54	24
TU	3	[redacted]	8.85	[redacted]	3	18	89	40
TU	3	[redacted]	7.76	[redacted]	6	47	9	41
TU	3	[redacted]	7.64	[redacted]	3	20	15	36
TU	3	[redacted]	9.62	[redacted]	2	39	1	30
TU	3	[redacted]	13.7	[redacted]	1	41	0	28
TU	3	[redacted]	17.5	[redacted]	1	49	0	32
TU	3	[redacted]	19.6	[redacted]	0	79	0	36
TU	3	[redacted]	23.5	[redacted]	4	63	7	40
TU	2	[redacted]	27.1	[redacted]	0	56	4	15
TU	2	[redacted]	29.3	[redacted]	2	30	39	20
TU	2	[redacted]	32.4	[redacted]	3	16	10	15
TU	2	[redacted]	35.5	[redacted]	1	10	47	44
TU	1	[redacted]	38.5	[redacted]	0	0	0	0
VW	3	[redacted]	0	[redacted]	0	14	0	36
VW	3	[redacted]	4	[redacted]	0	21	0	0
VW					No data			
VW	3	[redacted]	6.95	[redacted]	0	26	0	0
VW	3	[redacted]	9.98	[redacted]	1	49	5	31
VW	3	[redacted]	10.7	[redacted]	3	62	2	24
VW	2	[redacted]	16.9	[redacted]	1	52	0	24
VW	2	[redacted]	19.6	[redacted]	0	29	0	0
VW	1	[redacted]	23	[redacted]	0	7	0	0
VW	1	[redacted]	23.7	[redacted]	0	10	0	0

Food data collected at Burma Road Site 2 (sparse mudflats)

Transect	ST	DRR	DR	DDM	*Amphibola crenata*	*Helice crassa*	*Potamopyrgus estuarinus*	Polychaete holes
AB	2	43.2	67.4	20	3	26	0	52
AB	2	35.6	74.8	27.7	3	72	0	44
AB	2	32.4	79.3	32.3	4	51	0	21
AB	2	33	81.5	33	3	61	0	12
AB	2	31	83.8	35.9	8	64	0	14
AB	2	29.8	89.3	42.9	4	54	0	13
AB	2	29.1	90.1	44.1	6	67	0	14
AB	2	31.3	94.3	48.3	5	50	0	15
AB	2	32.9	95.3	50.2	4	70	0	13
AB	2	32.5	99.1	83.9	6	69	0	12
AB	3	31.5	105	59.9	2	54	0	16
AB	3	33.2	108	64.1	6	52	0	6

Transect	ST	DRR	DR	DDM	*Amphibola crenata*	*Helice crassa*	*Potamopyrgus estuarinus*	Polychaete holes
AB	3	34	112	66.7	7	51	0	11
CD	3	58	59.4	14.3	2	64	0	25

CD	3	58.8	57	15.8	0	37	0	21
CD	3	58.3	59.4	18.1	5	24	0	16
CD	3	58.9	60.4	19.5	2	49	0	17
CD	3	57.8	65.7	25.4	2	39	0	20
CD	3	59.7	68.6	28.2	3	53	0	33
CD	3	61	71.1	31.8	1	64	0	28
CD	2	61	74	35.9	0	65	0	14
CD	2	61.7	77	39.1	6	48	0	24
CD	2	60.6	81	42.9	6	43	0	37
CD	2	63.4	84.7	46.7	3	17	0	25
CD	2	65.6	89	51.2	2	51	0	15
CD	2	66.9	92	54.4	1	45	0	27
CD	2	68.2	95	56.2	5	26	0	16
CD	2	69.4	98.6	61.3	1	24	0	6
EF	2	94.3	43.4	11	3	10	0	7
EF	3	92.9	45.7	13.5	5	52	0	39
EF	3	90.7	51.4	18.1	3	36	0	28
EF	3	90.8	55.2	21	1	74	0	64
EF	2	91.1	60.1	25.8	1	48	0	0
EF	2	91.5	64	29.4	2	81	0	0
EF	2	91.2	65	30.3	1	31	0	0
EF	2	92.6	69.8	36.9	1	97	0	0
EF	1	91.3	76.3	44.2	1	101	0	0
EF	1	90.9	79.9	47.7	2	9	0	0
EF	1	92.8	80.8	48.9	0	94	0	0
EF	1	94	84.9	53	1	26	0	0
EF	1	94.6	85	53.5	0	62	0	0
EF	1	98.1	88.9	57.2	1	33	0	0
GH	1	122	44.7	13.2	0	51	0	0
GH	1	122	46.8	14.7	1	94	0	0
GH	1	123	53.9	21.2	0	54	0	0
GH	1	122	55.8	23	5	2	0	0
GH	1	122	59	26.7	7	8	0	0
GH	1	122	63.2	31	3	12	0	0
GH	1	122	66.2	33.9	7	7	0	0
GH	1	121	70.2	38.8	4	20	0	0
GH	1	124	74.8	42.3	5	41	0	0
GH	1	123	79.5	47.1	5	15	0	0
GH	1	123	85.7	52.6	5	26	0	0
GH	1	124	90	57	1	29	0	0
GH	1	124	91.4	58.5	5	35	0	0
GH	1	127	94.9	62.4	5	24	0	0